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

AMALi – the Airborne Mobile Aerosol Lidar for Arctic research

Response to Anonymous Referee #4

by Stachlewska et al. 2009-11-04

We would like to thank the Anonymous Referee # 4 for his comments.
In the following we give explanations to the issues raised.

Referee: The paper by I.S. Stachlewska et al., is an interesting paper describing the AMALI lidar system. I think the reviewers did a great work posting their comments and giving new ideas to be elaborated. To add to these comments, I would like to raise 2 points: 1) some interesting papers on depolarization calibration techniques are missing (e.g. Freudenthaler et al., in Tellus 2009).

Authors: We added the following sentence within the section 5.1 point no. 3: 'To obtain high accuracy of the depolarization ratio retrieval various calibration methods can be used (Biele et al., 2000, Reichardt et al., 2003, Alvarez et al., 2006, Gary G. Gimmestad, 2008, Freudenthaler et al., 2009).'

Biele, J., Beyerle, G., and Baumgarten, G., Polarization lidar: Corrections of instrumental effects, Optics Express, Vol. 7, No. 12, p427-435, 2000.
Reichardt, J., Baumgart, R. and McGee, T. J., Three–signal method for accurate measurements of depolarization ratio with lidar, Appl. Opt. 42, 4909–4913, 2003.
Alvarez, J. M., Vaughan, M. A., Hostetler, C. A., Hunt, W. H. and Winker, D. M., Calibration technique for polarization-sensitive lidars. J. Atmos. Ocean. Technol. 23, 683–699, 2006.
Gary G. Gimmestad, "Reexamination of depolarization in lidar measurements," Appl. Opt. 47, 3795-3802, 2008.
Freudenthaler, V., M. Esselborn, M. Wiegner, B. Heese, M. Tesche, A. Ansmann, D. Müller, D. Althausen, M. Wirth, A. Fix, G. Ehret, P. Knipperts, C. Toledano, J. Gasteiger, M. Garhammer, and M. Seefeldner, Depolarization-ratio profiling at several wavelengths in pure Saharan dust during SAMUM, Tellus 61 B, 2009.

Referee: 2) about the section 4.1..1. Some papers on horizontal calibration techniques are missing (e.g. P. Chazette et al.,: in Environ. Sci. Technol., 2007, 41 (24), pp 8335–8341).

Authors: Mentioned by the Referee publication of Chazette et al. 2007 is know to us, however our aim in section 4.1.1 was a description of the horizontally-aiming ground based inversion, as the AMALi lidar so far, did not performed any horizontally-aiming airborne measurements. Hence, we did not referenced this section with the airborne horizontal techniques. However, the Referee gave us a nice hint that, indeed, in the Arctic when the atmosphere is homogeneous and contains only air particles we could calculate the lidar constant as in Chazette et al., 2007. Unfortunately, we have a record of a single-shot signals during only 7 consecutive minutes, for which we could speculate, that the obligatory conditions mentioned above have occurred (i.e. the extinction value of the order of magnitude of the molecular extinction but unfortunately we lack in-situ measurements to confirm this). The spread of the lidar constant C values obtained for this measurements with Chazette et al., 2007 approach is < 3%.

NOTE: Actually, according to the request of the Referee #2 on giving in the introduction a short overview of the airborne backscatter lidars the LUAVA lidar and the reference to Chazette et al., 2007, Chazette et al., 2008 and Cuesta J. et al., 2009 are now added.

Chazette P., J. Sanak, and F. Dulac, New approach for aerosol profiling with a lidar onboard an ultralight aircraft: application to the African monsoon, Multidiscipl. Anal. Environ. Sci. Technol. 41, pp. 8335-8341, 2007.
Chazette P., Sanak J., Raut J.-C. and S. Berthier, Mini-lidar for balloon-borne and aircraft-borne measurements, 24st International Laser Radar Conference (ILRC24), 23-27 June 2008, Boulder, CA, USA, 2008.
Cuesta J., P. Chazette, J.Sanak, T.Allouis, S.Durrieu, P.Genau, C. Flamant, and P. H. Flamant, New airborne lidar observes forest canopies, SPIE Newsroom. DOI: 10.1117/2.1200909.1732, 2009.

Referee: In addition, I would like to know how the authors perform the calibration of their lidar system.

Authors: As the Referee did not specified which calibration he means we assume here that we should discuss the depolarization ratio calibration and the airborne lidar calibration.

Before we discuss this issues we would like to point out that the AMALi was designed for the nadir-aiming measurements performed in low troposphere onboard a non-pressurrised aircraft under a tough Arctic weather conditions. Hence, we made all efforts to design and build a system which have highly stable performance and can be optimized, adjusted and kept with these settings throughout the campaign.
We assessed the stability of the AMALi performance during several tests. The ground based pulse-to-pulse fluctuations of the lidar constant C have been investigated each time before using the AMALi in the Arctic. The laser power pulse-to-pulse variability is very low, i.e. for 80% energy (NF 8) at 15 Hz we measured laser power fluctuations between 10^{-2} to 10^{-3}. The optical assembly of the AMALI is entirely closed with shielding and after the laser is switched on its interior warms up to achieve the thermal stabilization at 35^{o}C, which is continuously measured using a temperature cube. The thermal stabilization is achieved over 30 min and measurements are either started after the required warm up time or the higher errors are considered for the data acquired when the stabilization is not achieved. We tested the variability of the lidar constant C by taking ground based quasi-horizontal measurements during clear air conditions (after the rain during the night). The single shots measurements were acquired using software especially designed by LICEL Ltd. for the AMALi airborne applications. Prior to the Arctic campaigns signals were measured at an inclination angle of 2.5^{o} aiming out from the laboratory window over about 6 h period (in total) obtained with two PMT settings (750V and 850V). The range and background corrected single-shot signals were plotted in a logarithmic scale and form the slope of the linear fit on these profiles the values of the lidar constant C were obtained. The spread of the lidar constant calculations was between 3% and 5% for the different PMT setting (the higher spread was obtained for the lower PMT setting). Similar was done during a period of about 30 min on one day of the single-shot horizontal ground-based measurements performed with AMALi in the Arctic. Here the spread of the lidar constant calculations over was < 2% for high (850V) PMT setting. Additionally, we calculated the lidar constant using a method in the Appendix C of the Stachlewska and Ritter 2009, this ACPD issue 'ASTAR'. Here the spread of the lidar constant calculations was from 2.3% to 6.9% at different PMT setting (again the highest spread was obtained for the lowest applied PMT voltage).

Bearing the above in mind we can comment on following:

<u>Depolarization calibration issue</u>

1) high polarization of the laser output

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 99.9%. 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 $5 \cdot 10^{-5}$ according to the manufacturer.

2) negligible parallel to perpendicular cross-talk

For the final installation the position of the polarizing cube was adjusted in the laboratory experiment and fixed in the optimal position to minimize the cross talk of the two 532 nm detection channels. Experiment was performed in dark conditions using the Nd:Yag laser itself. Energy of the laser beam was measured before it entered the detection block unit, then consecutively after the beamsplitter, after the interference filter, after the polarizing cube on the parallel and the perpendicular channels, and finally after the thin film polarising filter on the perpendicular channel. Each optical element was successively adjusted and fixed. This adjustment gave on perpendicular channel contribution of 10^{-3} % parallel cross talk, finally reduced to 10^{-6} % by polarizing filter.

3) particle depolarization

We retrive the linear particle depolarization ratio (Biele et al. 2000) by division of the perpendicular particle backscatter coefficient profile by the parallel particle backscatter coefficient profile. Both backscatter profiles being obtained with the Klett-Fermald-Sassano method with profiles calibrated in tropopause or the iterative airborne inversion described in this paper with profiles calibrated with the known backscatter coefficient value near the aircraft.

<u>Backscatter calibration issue</u>

We understand that the Referee asks for the calibration of the airborne lidar profiles during the nadir-aiming flight as the calibration of the zenith-aiming airborne AMALi is simply a calibration in aerosol free tropopause for the retrieval with the classical Klett-Fernald-Sassano (KFS) scheme. In the case of the AMALi operated in the nadir-aiming mode at a low altitude the largest insecurity in the applied classical KFS scheme would be due to the choice of the reference value near the ground and far off the system. To solve this calibration issue we applied the Newton-Raphson iterative, which is the classical numerical approach for finding zeros of real valued functions, to this classical KFS scheme. Two following assumptions were made: the KFS solution is applicable and the lidar constant C is known (calculated as described in this document in point no. 3 'high stability of lidar performance' or by other means). Then the iterative method works like this:

- 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 $2 \cdot 10^{-5}$ per meter and 235m overlap range the $\exp(-2 \cdot 2 \cdot 10^{-5} \cdot 235) = 0.99$, i.e. only 1% loss is due to extinction), and, hence, we assume the transmission term is equal unity.
- hence, the backscatter coefficient at the end of the overlap can be directly determined out of the lidar equation.
- the KFS approach is performed with an arbitrary boundary condition β(href)
- with knowledge of the partial derivative $\partial\beta$(hgc) / $\partial\beta$(href) the boundary condition β(href) is changed according to the Newton-Raphson scheme until the value of backscatter in the Klett β^{KFS}(hgc) matches to the value at the end of the overlap β(hgc).