Answer to the interactive comment of Dr. P. Achtert

We thank Dr. Achtert for her interest in our manuscript and her contribution toward its improvement. We will address the comments pointwise as detailed below:

- *The observations on 25 January 2010 show only MIX2 and MIX2 enhanced but no STS in the lidar observations. The in-situ measurements show a size-distribution that is shifted towards larger particles compared to the other measurements of that year.*

This coincidence of enhanced presence of large particles in the measured size distribution and depolarization enhancement is a good point we have noted in our measurements, but neglected to point out in the final version of the manuscript. We thank the commentator for this highlight that will be underlined in the reviewed manuscript.

- *NAT rock is identified in the in-situ measurements of 11 December 2011. This particle type is rarely observed with lidar and your measurements could be useful to check the reliability of the lidar-based classification schemes. Is NAT rock also classified in the airborne lidar data of that day?*

No, unfortunately neither the lidar nor the backscattersonde were part of the payload for that flight. Actually, they have not been deployed in the ESSENCE campaign.

Lidar is a common source for long-term statistics on the occurrence frequencies of the different PSC types. These types were originally defined based on the optical properties as observed with lidar. I have several comments regarding the part of the manuscript that deals with the lidar observations aboard Geophysica:
1. More details on the instruments (lidar and backscatter sonde), their calibration, and the derived parameters should be provided. Lidar-based PSC classification crucially depends on the quality of the particle depolarization ratio measurements, i.e. the crosstalk in the polarization channels. Yet no information is provided on how this parameter has been determined. It is also of interest to know how the backscatter ratio has been calculated for the two optical instruments. What is plotted in Figure 11 and 13: the total backscatter ratio, the parallel backscatter ratio, or the perpendicular backscatter ratio? Figure 13 shows backscatter ratios between 2 and 5 only. This looks like an artifact to me.

As the two optical instruments are well proven ones, deployed on the M55 Geophysica since its first campaign 1996 and already described elsewhere in the peer reviewed literature, we did not dwell on their characteristics in the present paper, neither we think that would be worthwhile to do so in its revision, unless otherwise asked by the reviewers. However we take this chance of interactive comment to summarize their performances and characteristics.

The backscattersonde, in its present configuration, uses a Nd-YAG laser, actively Q-switched at 0.3 s^{-1} pulse repetition rate. The energy per pulse on its SHG emission (532 nm) is 5 mJ. The light polarization, specified 100:1 by the factory, is further cleaned by a cube polarizer (500:1 extinction ratio) that filters the light before its emission into the atmosphere. The backscattered light is divided into polarizations by a similar polarizing cube and then further cleaned by a second cube placed in front of the photomultipliers. The parallelism between the polarization of the laser and the axes of the polarizers has been designed, implemented and optically controlled to stay below 0.25°, and represent the main source of inaccuracy in the depolarization measurements. The induced cross-talk between channels is esteemed to stay below 0.5 %.
At this maximum value, and given the depolarization calibration procedure detailed below, this systematic effect can in principle depress the aerosol depolarization by as much as 20% in the range of values shown in fig. 13 (see as instance the simulations in Cairo et al. 1999). However aerosol depolarization encountered in cirrus clouds have been checked to stay in the range reported in the literature. In any case, even if a cross talk effect was present, it did not significantly

hamper neither the cloud classifications, nor the main message figure 13 wants to drive, i.e. the encounter of cloud scarcely depolarizing, with a progressive enhancement of the relative presence of aspherical scatteres in the observations from 17 to 20 to 25 Jan flights.

For what concerns the calibration scattering SR and volume depolarization ratio DR,

(1) $$SR(z) = \frac{\beta_{mol}(z) + \beta_{aer}(z)}{\beta_{mol}(z)}$$

(2) $$DR(z) = \frac{\beta_{S,mol}(z) + \beta_{S,aer}(z)}{\beta_{P,mol}(z) + \beta_{P,aer}(z)}$$

Where β are the volume backscatter coefficients as defined in Collis and Russell (1976), and the subscripts P and S relates to their polarized and depolarized contribution.

if P_P (t) and P_S (t) are the raw backscattered signals observed during the flight, this is performed by finding suitable constants CR and CD at a time t_0 when the airplane crossed a region supposed (and checked by inspecting the data from aerosol detectors) free of aerosol, to pose:

(3) $$P_P(t_0) = CR\frac{p(t_0)}{T(t_0)}$$

(4) $$\frac{P_S(t_0)}{P_P(t_0)}CD = DR_{\mathrm{mol}}$$

Where p and T are respectively pressure and temperature from other sensors on board, and DR_{mol} = 0.014 is the value of volume depolarization to be expected by a molecular atmosphere, given the 10 nm FWHM bandwidth of our interferential filter (all our measurements were performed in darkness) (Young 1980; Behrendt 2002).

The parallel backscatter and depolarization ratios are then derived as:

(5) $$SR_{\mathrm{P}}(t) = \frac{P_P(t)}{CR\frac{p(t)}{T(t)}}$$

(6) $$DR(t) = \frac{P_S(t)}{P_P(t)}CD$$

And the total backscatter ratio as:

(7) $$SR(t) = \frac{SR_P(t)[1+DR(t)]}{1+DR_{mol}}$$

This "0° calibration" (to use the nomenclature introduced in Freudenthaler et al., 2009), although commonly used, might induce inaccuracies in the depolarization values, when small amounts of aerosol are present in the calibration range. Results are thus checked in the laboratory after the field deployment with a method outlined in Snels et al. (2009), similar to what exposed in the already mentioned Freudenthaler et al. (2009).

Concerning the determination of the backscatter ratio from the lidars MALs:
The lidars and the procedure to determine the backscatter and depolarization ratios are described in Mitev et al. (2002). The explanation below follows it, with some differences in the notations.

The lidars are identical, backscatter – depolarization, at wavelength 532nm.

The method to determine the total scattering ratio is the traditional one, based on the comparison with the pure molecular backscatter. The equation for the received power for a lidar operating at short range from a high altitude aircraft, may be simplified by assuming that the atmospheric attenuation to the probed volume is negligible.

We may obtain for the value expressing the background and dark noise corrected signal, normalised to the laser energy transmitted during the integration time and to the range resolution, corrected for the range to the probed volume, the following:

(8) $$S_C(z)=\frac{N(z)-N_B}{E_L\Delta z}.z^2=C.\beta(z)=C.[\beta_{mol}(z)+\beta_{aer}(z)]=C.\beta_{mol}(z).SR(z)$$

The parameters in (8) are as follows:
N(z) is the detected signal from range Δz bin at range z in photon counts;
N_B is the number of photon counts due to optical background and dark noise of the photomultiplier;

The constant C is determined at ranges z0 (and time t0) where we may expect that the lidar(s) probe aerosol free atmosphere. At these ranges and time the value for is determined from the temperature and pressure profiles in the atmosphere, corrected with respect to the temperature and pressure measurements at the aircraft level, performed by its sensors.

i. e.,

(9) $$C=\frac{S_C(z0,t0)}{\beta_{mol}(z0,t0)}$$

After determination of the calibration constant C, SR(z) is determined from equation (8).

Concerning the determination of the volume depolarization ratio DR:

The laser light is linearly polarized with a ratio ~1:100. It pass a polarizer and is finally is transmitted as linearly polarized with a ratio ~1:500.

The interference filter in the receiver chain has FWHM=0.12nm. As may be seen in Behrendt and Nakamura, (2002), Figure 2, for such filter bandwidth there is only Cabannes line transmitted, while no pure rotational Raman spectrum is transmitted. Respectively, with such interference filter, the volume depolarization ratio of the molecular backscatter is 0.368%; where we do not need to take into account the temperature dependence in the volume depolarization ratio measurements (see Fig. 4 in Behrendt and Nakamura, (2002)).

The measurement:
$\beta_P(z)$ is the atmospheric backscatter at polarization parallel to the one of the transmitted laser light.

$\beta_S(z)$ is the atmospheric backscatter at polarization perpendicular to the one of the transmitted laser light.

The volume depolarization ratio DR(z) is then determined as in (6):

(10) $$DR(z)=\frac{\beta_S(z)}{\beta_P(z)}=\frac{S_{c,S}(z)}{R.S_{c,P}(z)}$$

Here R is the ratio of the efficiency constants in the lidar equation for the receiver and detection chains, respectively for the measurement channels for perpendicular and parallel signals. This is a calibration constant. It is determined in calibration measurements where the polarization of the transmitted light is set to 45 deg with respect to the one used in the measurement.

The measurements of the lidars MAL1 and MAL2 on Geophysica and of CALIPSO lidar (at 532nm) have been co-located during the Geophysica flight on 20 January 2010. The overlap between the M55 flight path and CALIPSO track took place for an approximately 12-minute period. The comparison was for the backscatter at parallel and perpendicular polarisations, instead of backscatter and depolarisation ratios. It is reported in Mitev et al (2012). It is also presented here in Figures 1-4. As we may see, there is excellent comparison at PSC altitudes, i.e., the differences are well into the standard deviation. The comparison at cirrus altitudes is also good, where the small differences may be explained by the not exact colocation between the respective probing tracks and by the different sampling points.

For both MAS and MAL(s), the passage from the volume depolarization to the aerosol depolarization

(11) $$DR_{aer}(z) = \frac{\beta_{S,aer}(z)}{\beta_{P,aer}(z)}$$

Is accomplished according to the formulae given in Cairo et al. (1999).

What is plotted in Figure 11 and 13: the total backscatter ratio, the parallel backscatter ratio, or the perpendicular backscatter ratio?

As common practice, total backscatter ratios are reported. This will be explicated in the captions.

Figure 13 shows backscatter ratios between 2 and 5 only. This looks like an artifact to me.

MAS aerosol depolarization data are reported only for SR greater than 2 (this will be specified in the caption of the figure, and in the accompanying text in the reviewed manuscript), as the computation of aerosol depolarization became instable for lower values of SR, due to unexpected random noise in the volume depolarization data. SR greater than approx. 5 were not observed.

2. Why do you not use the PSC classification scheme of Pitts et al. (2009) or a comparable one (see Achtert et al. 2014 for a review of lidar-based PSC classification schemes) to determine the PSC type from the lidar measurements?

This will be done in the review of the manuscript, by adding the dividing lines in the SR-DR plot of fig. 13 as in the Pitts at al. classification, and referencing to the two papers suggested by the commenter.

3. Also, why are the lidar-derived results on PSC only shown for selected days?

Unfortunately the instruments did not operate during all the flights, and we only showed the available results.

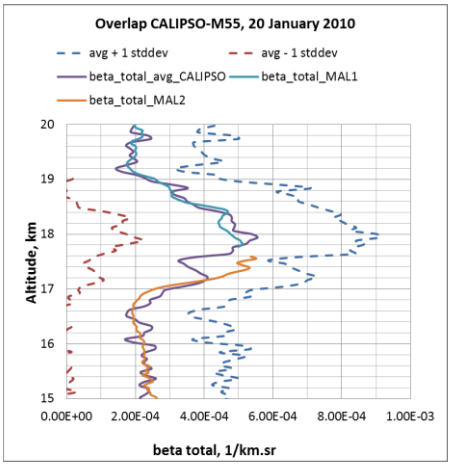

Fig. 1. Profiles of the total backscatter coefficient derived from the measurements of CALIPSO lidar, MAL1 and MAL2, averaged for 35800s – 36600s, flight on 20 January 2010: Comparison at PSC altitudes.

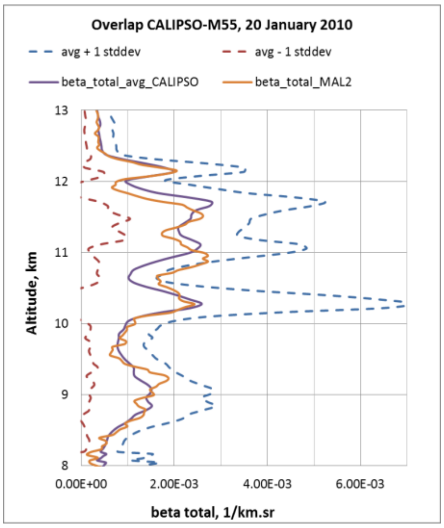

Fig. 2. Profiles of the total backscatter coefficient derived from the measurements of CALIPSO lidar, MAL1 and MAL2, averaged for 35800s – 36600s, flight on 20 January 2010: Comparison at cirrus cloud altitudes.

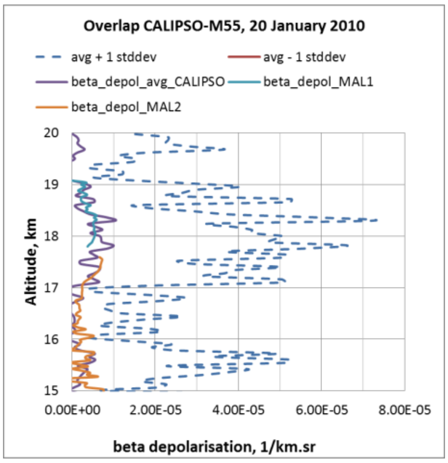

Fig. 3. Profiles of the cross-polarized component of the backscatter coefficient derived from the measurements of CALIPSO lidar, MAL1 and MAL2, averaged for 35800s – 36600s, flight 20 January 2010: Comparison at PSC altitudes.

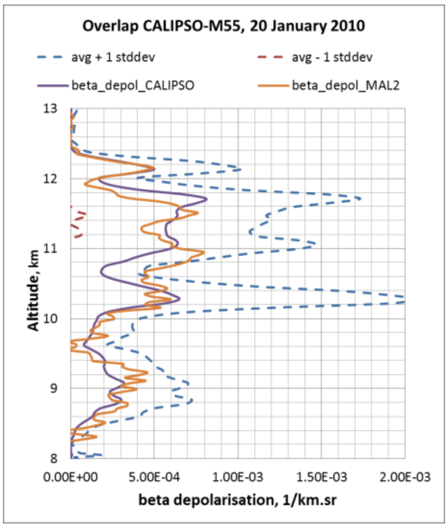

Fig. 4. Profiles of the cross-polarized component of the backscatter coefficient derived from the measurements of CALIPSO lidar, MAL1 and MAL2, averaged for 35800s – 36600s, flight 20 January 2010: Comparison at cirrus cloud altitudes.

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