Response to Reviewer 1

We thank Reviewer 1 for the careful assessment of the manuscript and valuable suggestions.

The data have been reprocessed to take into account the remarks made in his/her review.

The main changes have been:

i. The data are now averaged over 10 minutes instead of 5 (line 253 now changed to "… data are from 10 min averages…"

ii. The BR threshold value to detect cirrus clouds (above 10 km) clouds has been increased from 1.15 to 1.2; moreover, an additional threshold on the SNR has been used, so that a cirrus cloud is now identified as (line 254 now changed: "… a cloud is defined as an altitude interval not thinner than 150 m where the condition BR>1.2, and SNR lower than 0.5 on the parallel channel is continuously met."

This reprocessing has brought some changes in the overall results of the study:

1. the number of data points with particle depolarization below 10% has been greatly reduced. Compare new fig. 7 to the old one, and note the virtual disappearance of data points with aerosol depolarization <10%, now basically restricted to a layer between 16 and 17 km. Depolarization values around 10% however still exist; they are associated with the lowest values of BR. We acknowledge that if low BR values resulted overestimated during an inaccurate calibration process, they can lead to an underestimation of the particle depolarization. We have no reason to suspect such inaccuracy in the determination of the BR at high altitude, however the possibility exists and – given the BR and volume depolarization values at play – an overestimation of 0.5 in the BR may induce a relative overestimation as high as 50% in the particle depolarization. This cannot be ruled out and we have stated it explicitly in line 276 that now reads (… low values of beta_a. In particular, particle depolarization values as low as 10%, which are atypically low for cirrus clouds, have been observed in association with lowest values of beta_a. These low values can be relatively more affected by an inaccurate signal calibration process which may in turn induce inaccuracies in the determination of particle depolarization. We have estimated such inaccuracies to be no greater than 50% on the particle depolarization value."

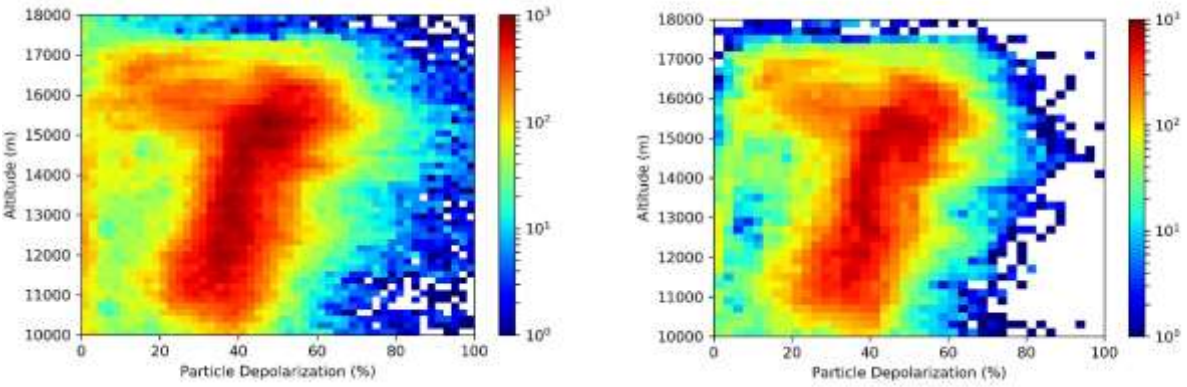


Fig.1: Left panel old fig. 7 in the manuscript, displaying right panel, new fig. 7.

2. A reduction of the number of clouds with low optical thickness. This is evident in new figure 4, the bidimensional (Optical Thickness, altitude) Probability Distribution Function. The reduction is more marked in the 11000-12000 m range, less in the 15000-17000 m range. However, the shape of the PDF is maintained. Similarly, in figure 5 (geometrical thickness, Optical Thickness), the peak of the PDF has shifted from very low thickness values to values close to the SVC threshold, maintaining

the overall shape of the function.

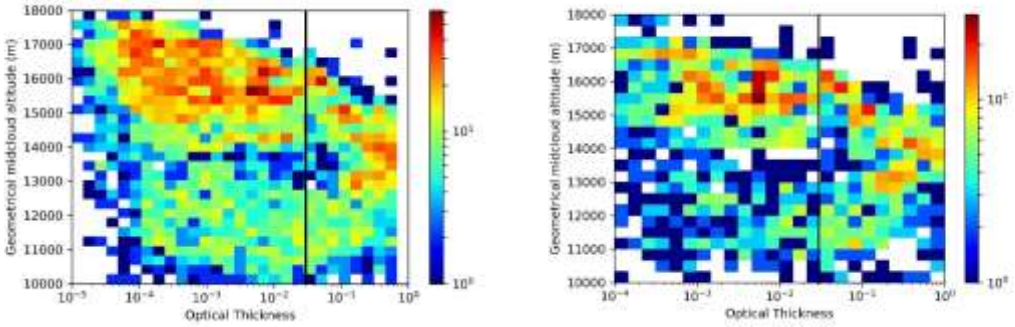
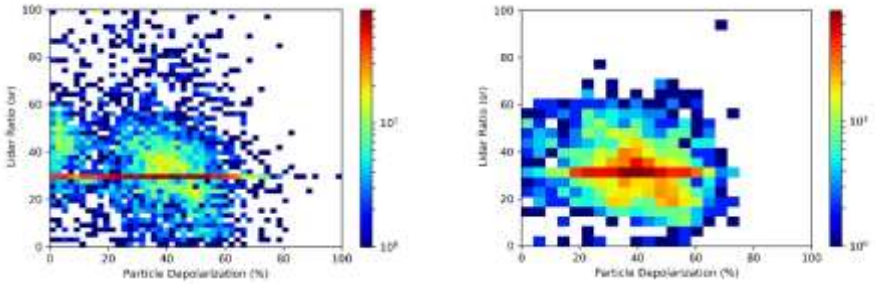


Fig.2 Left panel old fig 4 in the manuscript, displaying right panel nef figure 4.

3. The greatest change was in the LR values. The LR values greater than 29, previously reported mainly at high altitudes and low temperatures, which were associated with low depolarization and low values of optical thicknesses, are no longer so apparent (see new figures 9,10,11). This forces us to drop the discussion from line 281 to 294 which have been replaced with:" The analysis of the LR obtained with the Young procedure shows that in the majority of cases LR is distributed between 20 and 40 sr, with a peak around 30 sr and without showing particular dependencies on the mean depolarization, temperature or optical thickness of the cloud (see figs. S2, S3 and S4 in Supplementary material).". Moreover from line 348 onward there is no reference to LR and now reads : "It is worthwhile noting that the high level SVC with low optical thickness and depolarization have the highest potential temperature difference along…"

The old figures 9 ,10 and 11 have been moved to the supplement material as suggested by referee2.



Concerning the multiple scattering (MS) correction, line 179 has been modified as: "We have followed the procedure suggested in Chen et al. (2002) that assumes that the real τ values can be obtained by multiplying the observed ones by a factor η depending on the τ of the cloud layer itself. In our case, η was calculated iteratively by applying the correction to the observed τ multiple times, until the consistency between the real and observed τ and η was achieved. In our analysis, the η correction ranges from close to 1 in very thin clouds to 0.58 for the thickest ones, which is however a small portion of our data. This latter value can be taken as the order of magnitude of the possible bias on the largest optical depths due to multiple scattering effects."

We have not considered this effect on the depolarization. The MS effect should depend, among other factors, on the penetration depth inside the cloud. So, if MS plays a role on depolarization, observed depolarization should increase with increasing penetration within the cloud. We have checked if there was a systematic increase in depolarization as penetration into the cloud increased and we did not find any;

rather the depolarization remains constant even in the thickest clouds, throughout their thickness. So we thought we could overlook the effects of MS on depolarization. We have stated it in the new manuscript, where line 182 now reads “No corrections were made to the backscattering and depolarization coefficients. In fact, the effect of multiple scattering in depolarization is to increase the observed depolarization as the penetration of the lidar pulse into the cloud increases. We inspected the cloud depolarization profiles and found no systematic increase with altitude within the cloud. We therefore considered the effect of multiple scattering in our depolarization, and ever more so on backscattering, to be negligible.”

Concerning the LR retrieved with the Young technique and its effect on the data statistics, it is clear that the uncertainty of the lidar ratio is the single most important source of inaccuracies in elastic lidar retrievals.

We have changed line 174 to: “… a fixed value of LR=29 sr was assumed (Chen et al., 2002). The choice of LR has an effect on backscattering and extinction retrievals. The distribution of our retrieved LR is almost evenly disperse around the fixed value LR=29, ranging from 20 to 40 sr-1. If we consider such variability as an estimation of the LR uncertainty, and given the size of the optical thickness involved which is often low, the retrieval of the backscatter coefficient may be considered accurate and so for the particle depolarization, while the extinction, and hence the retrieved optical depths, are more affected as the relationship between the two and LR is linear, can be inaccurate up to a factor of 2.”

Sections 3.2 and 3.3 have been merged. All acronyms have been checked and reported explicitly on first use. The discussion was deepened and new references were added. See reply to Reviewer 2.

The Discussion part has been greatly reshaped, and more references have been added, namely: Massie et al., 2010; Sassen et al., 2008; Sassen et al, 2009; Nazaryan et al., 2008; Virts and Wallace, 2010; Vitrs and Wallace , 2014; Zou et al., 2020; Luo and Rossow 2004, Wang et al., 2020; Sunilkumar et al., 2005.

Specific Comments

1. 15 February, corrected.
2. Line 129 now reads: “An absolute calibration of the channels gain ratio was also performed before the deployment, following the procedure outlined in Snels et al. (2009).”
3. Different correction algorithms have been
4. Line 179 has been modified as: “… proposed (see for instance Eloranta et al. 1998, Hogan et al. 2006) although corrections or adaptations of single scattering retrieval algorithms to take into account multiple scattering effects are not straightforward.” We ae not experts of these topic, we had the impression of no univocal consensus on a particular correction method, reading the Bissonnette survey: “… models of multiple scattering but the main inputs to drive these models are actually the medium properties we wish to correct for. Iterations to derive true values from “effective" values are possible but there is almost always a missing input not available from the retrieval algorithms under study, e.g., the phase function.” so that “work is continuing at a steady pace to devise practical retrieval algorithms to account for or even exploit multiple scattering”.
5. Figure 2b and 6 have been improved
6. Line 357 now reads: “In our dataset depolarization increases with height and generally decrease with temperature, as has been reported in other observations (Wang et al., 2020; Sunilkumar et al., 2005)”
7. cirrus clouds with geometrical thickness less than 150m which were apparent in fig. 5 for a software error, are now not present.
8. The readability of the labels has been improved.
9. Figure 3 captions has been corrected
10. and following. All typos have been corrected.