A depolarisation lidar based method for the determination of liquid-cloud microphysical properties" by D. P. Donovan et al.

Response to anonymous reviewer 1.

We thank the reviewer for his thorough review. Our specific responses are detailed below.

1. It would be useful to comment somewhere about the applicability of something like this approach to spaceborne lidar. Obviously the receiver footprint on the cloud would be much larger and the cloud is viewed from above, but the global information obtained if it would work from space could be very valuable.

 Response: The following text has been added to the conclusion:

> The technique described in this work is specific to the case of upward looking terrestrial depolarization lidars. The larger footprints involved and the change from viewing cloud-top instead of cloud-bottom means that the specific technique used in this work is not applicable to spaceborne lidars. If a technique similar to the one presented in this work were applicable to spaceborne lidars then the global information so obtained could be very valuable, so the matter is worth considering.
> The characteristics of the depolarization return from water clouds has been successfully exploited using CALIPSO lidar observations as a means to determine cloud phase (Hu et al., 2007), but it is unclear at this point if the approach used here could be usefully adapted to the case of spaceborne lidars. In order for this to occur, a suitable model of cloud top conditions to serve the analogous role of the simple cloud-base model used in this work would have to be identified or formulated. Secondly, extensive simulations including, ultimately, the effects of expected noise levels, would have to be carried out to determine what, if any, cloud microphysical information may be recoverable. In particular, the larger footprints associated with space-based lidars lead to relationships between such quantities as the integrated backscatter and the integrated depolarization ratio (Hu et al., 2001,

> 2007) which seem to be weakly dependent on the cloud microphysics when compared to the case with ground-based observations. Nevertheless, CALIPSO lidar observations and related simulations do suggest that microphysical information may indeed be recoverable (See Fig. A3 and the related discussion) but further dedicated work would have to be carried out to establish this.

2. Line 4 of the abstract: I would regard "macrophysical" properties to be things like the overall cloud width, height and overlap; LWC is a microphysical property.

Response: The text in question has been changed to:

"The degree of measured depolarisation depends on the lidar characteristics (e.g. wavelength and receiver field-of-view) as well as the cloud macrophysical (e.g. cloud base altitude) and microphysical (e.g. effective radius, liquid water content) properties."

3. Section 2.1, equations 4, 12 and others: please provide all equations in SI units, rather than containing arbitrary powers of 10 to convert between SI units. In Eq. 4, the units of Reff are not stated - are they microns? Best to have their units and those of "z" as metres, and to add the reference height zref = 100 m into the equation.

Response: The suggestions have been adopted through the text

4. Last line of page 9932 and elsewhere: Specify that this is the error covariance matrix of the observations.

Response: The suggestions have been adopted

5. Equation 27: Rather than using ln(Ref f,100) and α100 as state variables, which are likely to be strongly correlated, it seems more natural to choose, say, total number concentration NT and the liquid water content gradient dLWC/dz. Then one could add a sensible a-priori estimate on both, and even add physical constraints such as that the gradient of LWC should not be steeper than adiabatic.

Response: We agree that**,** in nature, values of $R_{eff,100}$ and $α_{100}$ are indeed likely to strongly correlated. However, they are the physical variables most directly connected with the lidar multiple-scattering problem and lead to at least somewhat orthogonal responses in our cost function. This simplifies the problems of initialization, minimization and error estimation. If, in the formulation of our cost-function, we attempted to include formal a-priori estimates on $R_{eff,100}$ and $α_{100}$ the fact that they are likely strongly correlated would indeed be a problem. However, it was found not to be necessary at all to include $R_{eff,100}$ and $α_{100}$ as part of the a-priori cost-function term.

Further, in the development phase of this work, initial trials were indeed conducted using N and dLWC/dz as state variables (but without a priori or physical constraints). It was found that convergence was slower and less reliable (i.e. convergence to spurious local minima) that the strategy ultimately used in this work. However, we concede that our investigation into this matter was by no means exhaustive.

In response to this point the following text was added just before the start of Section 3.1.

The form of the cost-function and state-vector presented here was found to be lead to rapid and reliable convergence, but should not be regarded as definitive. The reader should be aware that other strategies may be more appropriate, depending on the signal-to-noise ratio of the observations and the availability (or lack thereof) of useful a-priori information. For example, N_o and Γ_l could be used instead of α_{100} and $R_{\mathrm{eff},100}$. This would enable a-priori estimates of both N_o and Γ_l to be taken into account as well as physical constraints such as that the gradient of LWC should not be steeper than adiabatic. In our formulation however, it was found not to be necessary to include a-priori constrains on any state variables beyond C_r, δ_c and C_N.

6. Last paragraph of page 9938: Gradient-free minimizations are used, but then the curvature is used to compute the error covariance of the solution. If the curvature of the cost function in the form of the Hessian matrix is available, can't this be used in a more efficient minimization method such as Gauss-Newton or Levenberg-Marquardt?

Response: The curvature was estimated numerically via finite difference using the look-up tables only after convergence. It was deemed to be more trouble that it would be worth to make the procedure to numerically estimate the Hessian fast and accurate enough to drive a G-N or L-M solver. For future applications this point may need to be reconsidered though.

The final sentence in the paragraph describing "Step 3" has been accordingly altered to make the situation clearer. "Finally, as described in Press et al. (2007) after convergence the curvature matrix around the minimisation point was numerically evaluated and the resulting covariance matrix of the retrieved parameters was found."

7. Figure 5: It would help if the caption could say what is plotted so the reader doesn't need to turn his/her head to read what's written up the side of the colorbar. This applies to some of the other figures too.

Response: The caption of Fig 5 does state what is being plotted, apparently this was unclear. Accordingly the captions of Figs 5 and 7 have been edited for clarity.

8. Figure 12: State if this is observations or simulation.

Response: The following sentence has been added to the caption. "The data consists of measurements made using the ALS-450 system at Cabauw."