Referee Comments

Depolarization measurements using the CANDAC Rayleigh-Mie-Raman Lidar at Eureka, Canada
Emily M. McCullough et al.

General Comments

This paper describes a very challenging retrofit of a depolarization channel to an existing lidar, in which optical elements upstream of the polarization analyzer had a major effect on the ratio of the parallel and perpendicular signals; there were a limited number of places in the optical path where test instruments could be inserted; and only a small fraction of the received light (<3%) was available for the measurements. In addition, some of the measurements required working above the roof hatch in an extremely cold and windy environment.

The history of the CANDAC lidar and the motivation for adding a depolarization channel are introduced well, and the paper is well organized and very well written. It includes very thorough and detailed explanations of experimental procedures and data analyses. It is fun for an experimentalist to read, because of the wealth of detail (including items such as the properties of two kinds of waxed paper and the use of foam core frames to hold sheets of them) and the fact that the Mueller matrix algebra is explicit and hence easy to follow.

A lengthy series of measurements showed that the perpendicular signal was suppressed by a factor of 21 relative to the parallel signal, and the optical components with the largest suppressing effects were identified. This part of the paper deserves a few more explanatory comments. There are many elements in the optical train with an incidence angle of 45 degrees. These are the classic cause of a polarization dependence, and a competent optical engineer will take each one into account to maximize the parallel signal, which necessarily minimizes the perpendicular signal. Was the CANDAC lidar designed this way, and is this the basic reason that the suppression factor is so high? In particular, the roof hatch/telescope system was a main contributor. By looking up the reference Nott, et al. (2012), one discovers that the telescope is Newtonian. Is not the secondary mirror the likely culprit? On the other hand, the focus stage has *four* 45-degree mirrors and yet it was found not to be a major contributor, surprisingly. What type of mirrors are used in it? Some comments on these issues would be most welcome. Also, when describing waxed paper as a depolarizer, it would be good to mention that it is also a highly scattering material, so that when the entire roof hatch window is covered with it, the received lidar signal is greatly reduced.

Unfortunately, the paper is an amalgam of obsolete and modern treatments in the lidar literature that perpetuates an old and misleading notation and terminology based on the notion that non-spherical particles in the air backscatter light that is polarized either parallel to the transmitted beam polarization or perpendicular to it. This idea is consistent with Eq. (1), in which parallel and perpendicular subscripts are attached to the backscatter coefficient. The depolarization ratio δ is defined as the ratio of "photons returned with polarization perpendicular to that of the transmitted laser beam, to those returned with polarization parallel to that of the transmitted laser beam" (page 2 line 17). Do cloud particles rotate the polarization of part of the backscattered light by exactly 90 degrees? The authors say as much, for example in this sentence: "For d =1, half of the backscattered light reaching the roof window is parallel, and the other half perpendicular." (page 25 line 22). This notion is unphysical, of course, but the notation in Eq. (1) and the associated terminology were standard in the lidar literature until 2008, when C.J. Flynn et al. brought the appropriate Mueller matrix to the attention of the lidar community, enabling a reexamination by G.G. Gimmestad (as the authors correctly point out) and sparking a transition to analysis methods and terminology for lidar that is consistent with the rest of optical physics and scattering theory. There is now no reason to continue the obsolete and incorrect rubbish, and this problem in the paper is easily corrected with a few edits, as detailed in the next section of this review. Incidentally, the authors appear to lump the mutually exclusive pre- and post-2008 techniques together under the label "traditional", so this term should be re-visited everywhere it appears in the paper.

An experimental paper on a retrofit to a unique lidar is necessarily somewhat arcane, and so the authors include appropriate references to other lidar depolarization instrumentation papers that tie into a larger body of work and hence make the paper of wider interest. In this vein, this quite recent one could be added:

> Freudenthaler, V., About the effects of polarising optics on lidar signals and the Δ90-calibration, *Atmos. Meas. Tech*., 2016, 9, 4181-4255, doi: 10.5194/amt-9-4181-2016

This reference was not available when the work described in the paper was done of course, but it is a quite general treatment of the effects of lidar system optics on depolarization signals, and it includes a calibration procedure for such lidars. The 74-page paper is very comprehensive, and the techniques described in it can be applied to a large variety of lidar systems. The Freudenthaler paper will likely be useful to anyone interested in the CANDAC paper. The authors might comment on how their work does or does not fit in with the analysis and calibration procedures in this reference.

<u>Specific Comments</u>

As background to these comments, here are the key facts for understanding lidar backscatter from randomly-oriented particles:

A. The two classes of "photons returned" are
    a. with polarization parallel to that of the transmitted laser beam, and
    b. unpolarized.
B. One-half of the unpolarized light goes through the perpendicular polarization analyzer and *one-half of it also goes through the parallel analyzer*.

These key facts are completely consistent with the Stokes and Mueller matrix formalism in the paper, as is easily verified by inspection and Eq. (5) can be derived from them with simple algebra, without recourse to the formalism. The following lines need to be revised for consistency with the key facts:

Page 2 lines 17-21: for Schotland et al., it was really the ratio of the cross pol signal to the parallel pol signal, with proper calibration. Flynn did, in fact, have the definition of *d* wrong in words, but it is the fraction of the backscattered light that is unpolarized.

Page 3 lines 5-6: change it to …and that which is returned unpolarized.

Page 5 lines 16-17 & Eq. (1): change the words to be correct and change the equation to be

$\delta = \frac{kS_{\perp}}{S_{||}}$. That's all δ has ever really been. The signals are all we have to work with!

Page 24 line 15 – delete the words perpendicular-polarized.

Page 25 line 7 – replace perpendicular with unpolarized.

Page 25 lines 22-24 – this was cited under General Comments. Re-write in light of the key facts.

<u>Technical Corrections</u>

Page 7 line 8 – "in equal numbers" is redundant and should be deleted.

Page 8 line 1 – isn't "to the sky" redundant/ unnecessary?

Page 10 line 11 - delete second "this".

Page 11 line 3 – change "the all the" to all the.

Page 13 Fig. 2 – Photocounts were defined on the previous page as "photons per time bin per altitude bin", This should be mentioned in the caption, and the readers would like to know how many altitude bins were included in the data.

Page 16 line 18 should read …to go through …

Page 22 Fig. 5. The parameter $\sigma\delta$ has not been defined.

Page 24 line 6 – change photons to photocounts.

Page 25 line 12 "… in practice <u>this</u> means a lower gain …" (missing word).