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Atmospheric Measurement Techniques Discussions

Interactive comment on "Depolarization measurements using the CANDAC Rayleigh-Mie-Raman Lidar at Eureka, Canada" *by* Emily M. McCullough et al.

Anonymous Referee #3

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General Comments:

The paper presents a method to calibrate the newly installed depolarization channels of the CRL lidar instrument at Eureka, Nunavut. The depolarization channels make use of only a small fraction of the available light collected by the lidar instrument since initially the lidar was not designed to retrieve depolarization products. The study is designed to overcome this drawback by calibrating these channels.

The calibration method for this study implies the use of additional optics to test the receiving unit. As presented in the manuscript, the optical components situated "upstream" the depolarization analyzer have significant influence on the lidar products.

When performing this calibration, the effects on the depolarization channels are removed with some degree of accuracy. The paper starts with a detailed description of the instrument together with the motivation for adding depolarization capabilities to the instrument. The paper gives descriptions of experimental setups and optical constrains of the instrument, but also an introduction on the Mueller matrix formalism. Still some algebra in the theoretical description is not fully explained and some comments are insufficient. Explanations on why some simplifications are used are missing and part of the optical chain is ignored without any additional details. This part should be improved if the paper is published. Also the state of the art on depolarization lidars and their calibration can be improved.

The results show a calibration value over 20, meaning that the perpendicular signal was drastically reduced within the lidar optics – this result should be further discussed. Comments and conclusions on the calibration technique were also expected in the concluding part of the paper.

Specific comments:

Abstract:

P01 L05: "well-characterized lidar channels" - how are the channels well characterized and how does a new depolarization channel influence this characterization? Suggest replacing with "To reduce its impact on the existing lidar channels,...."

P01 L09: "within $\pm$20% ..." - is this value sufficient to express the results of the calibration? Is this value similar both for low and high depolarization layers? If this is the case than this should be stated (perhaps not in the abstract but in the paper itself)

Introduction:

P01 L21: "the phase of cloud particles" – needs a reference

Installation of depolarization hardware:

P03 L09-11: “This design reduces the number of differences between the hardware of both depolarization channels because the backscattered light traverses identical optics and uses the same photomultiplier tube. Given” - yes this design reduces the number of differences due to identical optics but can include additional errors from the rotation of the polarizer. What is the rotation accuracy of this module and the stability? A short comment on this issue would be welcomed.

Polarotor:

P03 L21: “90 degree” – a comment on the rotation accuracy of the polarotor should be included? How does this accuracy influence the results?

P03 L22: “Two recording buffers are used in the Licel Transient Recorder, one for parallel and one for perpendicular photocount profiles.” - is this comment necessary?

P03 L23-24: “The extinction ratio of the polarizer was characterized by the manufacturer to be $5\times10-5$ or smaller ” - it is also given by the accuracy of the rotation angle. This section should better describe the polarotor.

Figure 1 shows a collimating lens between points 2 and 3. Could the authors describe the purpose of this lens.

P04 L08: could you provide more detail on how was this channel characterized

P04 L08-11: “installation. Therefore, a regular plate beamsplitter or dichroic mirror could not be used to pick off the light for the depolarization channel; this would have translated the transmitted 607nm light too much, and the downstream channel would have had to be realigned.” - But still a collimating lens was introduced before the 607/532p and c channels. How does this lens affect the alignment? Why is the collimating lens placed in front of the pellicle beamsplitter and not after the splitter? This way the lens would only affect the 532.1nm channel.

P05 L05: “angle of 15degree” – please mention “full angle”

P05 L06-07: “It is also convenient to have the cables from the polarotor to the electronics rack be accessible without the need to open the polychromator.” – is this comment really necessary?

P07 L30: llaser purity - was this verified by any experimental measurement. According to Freudenthaller 2016, laser emission is not 100% polarised.

P07 L04: - rotation of the plane of polarization of the laser with respect to a reference (usually the polarizer separator) must also be accounted for. For a rotation of Mreceiver and Mtransmitter with respect to the laser polarization, the collected polarized light could be also altered. Some comments must be included. The study should also take into account these effects (Bravo-Aranda, J. A. 2016)

P07 L05: “The optical backscattering effects of the atmosphere can be described as Matm.” - Mtransmitter is initially mentioned but left out further in the study. According to Nott et al 2012 - the number of emission optics is significant and could influence the polarization purity of the emitted light (this added to the assumption that the laser unit is emitting 100% polarized light). Comments should be included to explain these assumptions.

P07 L12: “The gain factor is not stable long term, but for any given minute of data it will be constant for both channels” - please give more details

P08 L01-02: “The overlap varies with changes to the lidar’s alignment to the sky” – consider reformulation

P08 L07-09: “During setup, the “parallel” analyzer position was also oriented such that it can be represented as a horizontal polarizer (by aligning the parallel direction with the direction of maximum signal in a low depolarization sky).” - As stated before, also the rotation of the optics (Mtransmitter and Mreceiver) must also be accounted for. For Mtransmitter and Mreceiver rotation with respect to the laser polarization, collected polarized light could be altered.

P08 L19-21: “These Mueller matrices combine to make an overall equation for each channel which describes the action of all optical components on the light, and results in Stokes vectors (shown in full in Eq. (9)) and I (which differs from only by two minus signs in the polarizer matrix):”

The author must include a comment on the effects of the polarotator rotation uncertainties. An extra comment is also required for the rotation of the laser polarization purity.

The author provided information on how the rotation of the laser plane of polarization is corrected but no information on possible rotation of the receiving optics is provided.

Again more detail should be given to the "... action of all optical elements ...". Many optical components are excluded (transmission and part of the receiving optics) - this should be clearly mentioned. Suggest changing to: "A simplified version of the overall equations combine to make an ..... " - ..... including ideal laser polarization purity, no emission optics, no laser rotation, no optics rotation, no retardation effects, ideal polarizer and so on. How will these simplifications affect the final results?

P09 L02-03: “lidar, we solve for the depolarization parameter d to learn about the atmosphere” - consider reformulating

P09 L04: “to solve for the” - consider reformulating

P09 L10: Another option would be to use the three signal calibration since the lidar instrument is able to measure the total, parallel and cross 532.1nm components. This will be a nice add-on to this study: a comparison between the current calibration and the suggested calibration.

Polarization and Depolarization generating calibration optics

Title - consider reformulating

P09 L25: “It is placed immediately downstream of the focus stage and” - please indicate

on the picture

P10 L08-09: “This product was mounted in such a way as to be held relatively taut in a frame, or held gently in place by other mechanical means.” – Too vague, consider reformulating

P10 L24: Fig 2 - why do we have such different photoncounts for the two channels? Why do you have a setup counting so few photons per time-bin? Could this be improved by expanding the time bin?

P11 L05: “properties: a 1m diameter circle” - Consider reformulating

P11 L10: “held between the telescope’s tertiary mirror and the focus stage worked better” - please indicate on Fig 2 (label 7?)

P11 L12: “By sacrificing the inclusion of both” - what do you mean by sacrificing the inclusion?

P11 L15: “It” should be replaced by -> The cube beamsplitter

P11 L17: “test, there is no advantage to using lidar returns as the light source”- usually when using the lidar return as the light source we take into account the height dependency of the optics (Freudenthaler 2016): Light collected from different heights have different lightpaths and different incidence angles in the receiving modules. this must be taken into account since the lidar optics are not polarization independent - see fig 2 - count number is strongly different for the same initial light source. This issue should be reconsidered.

P11 L25: “optics are contributing any non-simple-gain effects to the signals” - please reformulate. It is not clear.

P11 L26-27: ““If we consider the optics and detector starting after the focus stage, can we use the simplified Eq. (4) and Eq. (5) to find the calibration constant, and then to determine depolarization ratio and depolarization parameter” - the three signals

calibration would include all optics in the receiving unit of the lidar instrument. This should be a viable option for this study.

P12 L07: “There are very similar equations for the case in which we use backscattered laser light rather than lamp light.” - This is not fully correct if we consider the laser polarization purity, laser rotation, emission optics

P12 L11-12: “The absolute angles were determined in post-processing, such that the maximum in the parallel channel is 0.” - This data combined with information on the actual position of the cube could be used to extract the laser rotation relative to the parallel detection. Was this study performed?

P12 L14: 7.5m - if the light source is a lamp placed on the telescope frame, the range dependence should be inexistent. Under these assumptions, the altitude bin could be extended to several hundred meters or even km to improve the photocounts number. By using this method Fig 2b would have a much better fit in the n*pi regions (n=0,1,2).

P12 L14: “There is approximately a 2 degree or 0.035 radian uncertainty” – Is this uncertainty taken into account in the study?

P12 L14: “angles” - what angles? The calibrator or polarotor - it should be the calibrator, right?

P12 L15: “The overall signals in S parallel far exceed the overall signals S cross.” - Why? What does this indicate?

P12 L16-17: “by allowing them as free parameters in a fit to these signals,” - Does this return a unique solution?

P12 L20-22: please give more details on why is this

P13 L01: “If our measurements are symmetric, with ...” - A detailed explanation must be included. What are the considerations that are the base of this result? This explanation must be detailed in the manuscript.

P14 L04-05: please reformulate also including detailed explanations

P14 L10-11: “The mean signal values are ... perpendicular” - is this relevant?

P14 L20: “the parallel and perpendicular channel signals each go to zero” - Fig 2 b shows the number of photon counts as a function of incident light polarization angle. The low amount of photons used for each point makes it difficult to perform a fit on the data. The mean values around n*pi (n=0,1,2) are clearly forced to be zero. We can see six values around pi that are zero. To clearly say that ".....perpendicular channel signal each go to zero" it is mandatory to have a higher amount of photons. This may also apply to Fig 2 a. This could be accomplished if the author increases the time and height bins

P15 L14-15: “For situations in which the true signal is zero, a mean of the measured signal will be reported as a larger value, thus not being indicative of the most probable photon counting result.” - This is one reason why the number of photoncounts must be increased either by increasing the time interval or by increasing the altitude window to hundred of meters or even to km

P15 L24-25: “This assumes that the telescope does not contribute to these quantities in a significant way.” - is this assumption based on any measurement? We see that the telescope includes many 45 degree mirrors. This should have a significant influence.

P15 L25-26: “This result is reasonable, as the reflectivity of all telescope mirrors are high.” - How does this statement exclude any depolarization effects that the optics may have on the collected light?

P16 L08-09: “It includes no effects of the telescope or focus stage.” - In the upper paragraph the author stated that: ".... This assumes that the telescope does not contribute to these quantities in a significant way. This result is reasonable, as the reflectivity of all telescope mirrors are high." This paragraph states that the results are not representative since the telescope is not included. These two statements contradict each other.

Please reconsider the statements.

P16 L10: “Because of these limitations ..... k, using an unpolarized light test” - unpolarized light was also used in the upper section. Please reformulate so that the reader clearly understand what the author mean by this statement.

P16 L12-13: “optics. Having measured the partial-polarizer-like form of the upstream optics Mueller Matrix using the polarized calibration test, we can proceed with confidence in the tests in the following section.” – consider reformulating

P16 L20: “it enters the lab” – could be changed to: is collected by the instrument

P16 L22: “complete depolarization is” - what is complete depolarization? is this complete for cases when the depolarization ratio is 1? Is this condition satisfied in ice clouds?

P17 L23: “Using a flexible material like glassine was important in the Arctic winter.” – is this sentence important?

P18 L03-09: is this explanation really necessary? Could this be replaced with a comment on what were the requirements of the setup?

P18 L14: “and has been indicated here in white.” – Please remove

P20 L01-07: this section could be reduced.

Suggestion: "Different approaches showed that the best retrieval method for the assessment of k was to .....(2.).....

P20 L17-18: “directly before the polarotor. It was moved sequentially upstream, placed between any two optics where there was room to safely insert it, up to and including right in front of the lamp, upstream of the focus stage” – suggest changing to -> “before the polarotor and then moved sequentially upstream .”

P20 L19: “Industrial kitchen grade waxed paper was used for this test” - since the

author presented a better solution for this material - the test should at least include a comparison between the two and a explanation on why this material is still presented in the manuscript.

P21 L15: “Many lidar groups” - please provide examples

P21 L28: “the more convenient calibration is insufficient.” - What does this mean?

P21 L30: “remove or upgrade the” – suggest changing to -> “change the”

P21 L30: “we change optics in” – suggest changing to -> We upgrade

Figure 5: “25%” – how did you estimate this value?

P22 L02: “on 12 March 2013,” - this date is prior to the calibration date. It must be stated that the calibration factors are constant and can be used for measurements collected before the actual calibration date.

P22 L03: “because two distinct cloud morphologies are present” - A simpler example should be used at the beginning since the aim is to demonstrate the performance of the instrument.

P22 L10: “regions, but this does not tell the whole story” - is this part necessary?

P22 L10: “This calculated uncertainty expresses only the uncertainty in the calculated result from Eq. (4)” – consider reformulating

P22 L14: “valid as a proxy for particle phase – despite our (possibly precise) ability to calculate it.” - consider excluding this section

P22 L15: “is decreasingly trustworthy high in the cloud” – consider reformulating

Figure 6: could this figure be included in fig 5 with two color scales for the two parameters?

P23 L01-03: “A further possible contributing factor is that the two channels may have differing amounts of extinction if the transmission function of the atmosphere is

polarization-dependent." – It is not clear what the author meant by this statement. More explanations are required.

P23 L11 – P24 L03: "Compare the .... as well" - please rephrase. This section is meaningful to the study but care must be given in phrasing the message.

P24 L07-10: "However, this can only be carried out to a certain point, after which the low resolution depolarization measurements will be misleading, as any instances of thin liquid layers (low d and delta) residing within an ice cloud (high d and delta) would, at low resolution, show a smooth region with intermediate values of d and delta which are not actually present anywhere within the binned region. " - Please divide this section into several sentences. It is relatively hard to follow the message.

P24 L16-17: "There are several possibilities for improvement of the depolarization measurements: Changes to the depolarization parameter calculation method, and changes to lidar hardware." – Please rephrase

P24 L22-27: Please rephrase. Too vague

P24 L29 – P25 L02: "Hardware....channels." – Please rephrase

P25 L03-19: is there really a necessity for this paragraph?

P25 L20: "Throughout this work, k values far from unity have been presented as being undesirable. There" – Is this the transmitted message? As a reader, I do not understand this message from the manuscript.

P25 L31-34: is this section necessary for the manuscript?

Conclusions - detailed information on the calibration method and its particularities must be presented. Conclusions on what is the most polarization sensitive optics in the lidar receiving unit must also be included.

P26 L11: "night" to "period"

P26 L12-13: "and the reduced reliability of the depolarization measurements farther into the thick cloud are evident as multiple scattering becomes important." – Please rephrase

P26 L13: "above it was present" – please rephrase

P26 L14: "sensitive to the low" – suggest changing to -> "sensitive also in low"

P26 L15: "functioning, well-characterized depolarization" – ambiguous

P26 L15-19: consider excluding from the manuscript

Technical corrections:

P05 L19: beam,

P06 L12: "and solving for k." – consider reformulating

P06 L21: "allowing for optical effects in the upstream optics" – consider reformulating

P09 L14: "would" to would be

P10 L05: Product to product

P11 L03: "A 1m depolarizing optic to initially depolarize the all the backscattered" to A 1m depolarizing optic to initially depolarize all the backscattered...

P11 L05-07: "which could be held completely flat, which could survive the harsh outdoor conditions of Arctic winter, which could be easily and repeatably rotated to the appropriate orientation, and which had sufficient optical polarization quality." – to -> which could be held completely flat and could maintain within required characteristics even in harsh outdoor conditions of Arctic winter. The depolarizing optic must be easily and repeatable rotated to the appropriate orientation and should have sufficient optical polarization quality.

P11 L27 parameter?".

P12 L15: “each” –> each of the two channels

P15 L23: “by others in the community” to -> in the remote sensing community

P16 L08: “rather the of the polychromator” -> one extra “the”

P17 L23: When the roof hatch open is open – please review

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