Dear Edit

We sincerely thank the reviewers for their valuable comments, which greatly improved the quality of this manuscript. We highly appreciate the time and effort they devoted to reviewing our work.

Our responses to each comment are provided below in **blue**.

Reviewer #1's Comments:

The manuscript describes a technique to assess the polarization gain ratio of spaceborne lidar systems using the unpolarized backscattered light by optically thick ice clouds. This method is very valuable to calibrate the polarization sensitive parts of lidar systems in space and to deliver observations of the depolarization ratio with high accuracy as needed for correct aerosol typing. Having an atmospheric target outside of the onboard calibration possibilities is extremely useful to control the polarization gain ratio once the lidar is deployed in space. Besides the application to CALIPSO, the opportunities for ACDL and ATLID are shortly discussed – the present study will support these ongoing space missions. The paper is clearly written and fits well in the scope of AMT. I would recommend publication after addressing minor revisions.

Response: thank you for your encouraging words as well as your invaluable comments. Please see our responses below.

Minor comments:

1. Although the original Liu et al., 2004, paper already discussed it, it would be valuable to highlight the application to airborne lidar calibration as well. It would be especially important for those lidars which do not operate at 1064 nm and have to correct for molecular scattering. Here, the distance between the lidar and the optically thick ice cloud has to be taken into account. Similar to Sect. 3.2, I would recommend to add a Sect. 3.3 shortly discussing the application to airborne lidars.

   Response: good suggestion. We have added a paragraph as follows:

   4 Application to airborne measurements

   The OTIC technique can also be applied to airborne polarization-sensitive backscatter lidar measurements, as demonstrated using the CPL observations (Liu et al., 2004). As in spaceborne lidar applications, a molecular scattering correction is required at shorter wavelengths to achieve more accurate polarization calibration. Although dense water clouds can also serve as suitable calibration targets for spaceborne lidars because of the significant multiple scattering among water droplets within the large lidar footprint, as illustrated in Fig. 2, they may not be appropriate calibration targets for airborne lidars. The much smaller footprint of an airborne lidar results in substantially weaker multiple scattering, making the depolarization produced by multiple scattering much less pronounced and, consequently, rendering dense water clouds less suitable as calibration targets.

2. Line 105: Here, the manuscript refers suddenly to the appendix. Some more lines would be nice to smoothen the transition from L104 to L105 and to introduce shortly the appendix.

   Response: Good point, thank you. We have added a short paragraph to the manuscript: "In Appendix A we present mathematical derivations of two different approaches that can be used to calibrate the PGR. The first uses the ratio of the directly measured mean background signals (e.g., as in Liu et al., 2004) while the second uses the ratio of the root-mean-squares (RMS) of the background signals. Because identical results are obtained using either method, data availability will dictate the choice of technique to apply. The following discussions leverage the mathematical derivations given in Appendix A to further explore both approaches.

   Replacing the expression for digitizer counts measured in the perpendicular and parallel channels of the lidar receiver (i.e., $N_{dc,\perp}$ and $N_{dc,\parallel}$ in Eq. (A5)) with $BKG_{\perp}$ and $BKG_{\parallel}$, the equation for deriving PGR from OTIC background measurements at long wavelengths becomes" This addition addresses both this comment and a related comment from Reviewer #2.

3. Fig 2, especially 2c+d could be improved. The resolution is low and, in the legend, I just see (very small) grey dots. Furthermore, the fraction of 0.17 mentioned in line 175 is hard to imagine from Fig 2c (maybe in the tropics we see a high fraction of BDR).

   Response: We have revised Figs. 2c and 2d with improved resolution and enlarged the legend to make the plotted symbols more clearly visible.

   The molecular scattering fraction of 0.17 mentioned in the manuscript refers to the orbit-averaged value, calculated by averaging over all columns along the orbit. The molecular scattering fraction for an individual column depends strongly on the atmospheric and surface backscatter targets within that column. For columns containing optically thick clouds or strong land-surface returns, such as the OTIC columns selected for calibration, the molecular scattering fraction is relatively small because the particulate or surface backscatter dominates. In contrast, for cloud-free columns over the ocean, where atmospheric molecular scattering is the primary contributor, the molecular scattering fraction is much larger. We have clarified this point in the revised manuscript to avoid confusion.

Include the new/modified text here?

4. L258 – 266 You may cite Donovan et al., AMT 2024 for the description of the primary ATLID algorithms.

   Response: Thank you for the suggestion. We have cited Donovan et al. (2024) in the revised manuscript. We had intended to include this reference in the original submission, as it is an important reference describing the primary ATLID retrieval algorithms. We appreciate the reviewer bringing this omission to our attention.

Technical corrections

- Affiliations: The county is missing for all affiliations: USA – I suppose.

  Response: done.

- Date format: I know that the version month-day-year is commonly used in US. However, it would be more logical to use day-month-year as done in line 234. Please harmonize.

  Response: we have revised the date format through the manuscript.

- Subscripts in the formula should not be italic (see e.g., eq 1 + 2) except for counting indices.

  Response: Thank you for pointing this out. We have revised the notation throughout the manuscript so that descriptive subscripts are set in upright (roman) font, while only counting indices remain italic, consistent with the journal's formatting conventions.

- RMS – abbreviation is not introduced.

  Response: Thank you for pointing this out. In the revised manuscript, we have introduced the abbreviation RMS (root mean square) when it first appears.

- Fig 3 caption – you want to refer to Fig 2 not 3 in line 205.

  Response: done. Thank you for capturing this.

- L225 refers to eq 6 whereas L233 (figure caption) refers to eq 5 for the PGR with and without MSC.

  Response: We've changed Eq. 5 in Fig. 4 Caption to Eq. 6.

- L288 There is a typo in Version 4.5

  Response: corrected the typo.

- L307 [26] probably refers to a reference. It seems to be copied from another document.

  Response: Thank you for pointing this out. The citation "[26]" was inadvertently left in the manuscript during editing. It should have referred to Liu et al. (2006). In the revised manuscript, we have replaced the reference number with the appropriate citation.

- L308 PIN ?

  Response: we have replaced "PIN" with "photodiode".

Reviewer #2's comments:

This paper discusses a method for evaluating calibration constant (gain ratios) with higher precision by removing the contribution of scattering from atmospheric molecules, as an improvement upon the existing method (OTIC calibration technique) that uses sunlight scattered by optically thick ice clouds to perform polarization calibration of space-borne polarization lidar. The paper also demonstrates the effectiveness of this method using actual satellite observation data (CALIOP); it also discusses the applicability of this method to other satellite lidars (ADCL, ATLID). The description is clear, and the paper contains all the information necessary for understanding it, with neither excess nor deficiency. Considering the novelty and applicability of the method proposed in this paper, as well as the quality of its description, it is recommended that this paper be published in AMT.

It does not appear that a major revision is necessary. Several minor points are listed below.

Response: We sincerely appreciate the time and effort you devoted to reviewing our manuscript. We also thank you for your positive and constructive comments. Our responses to each of your comments are provided below.

L61: λ-4 => λ^4?

Response: It should be λ^{-4}, thank you for capturing this. We also noted that λ^4 had to be replaced with λ^{-4} in L155 of the submitted manuscript.

L114-L127: In this part, it would be less confusing if you first explained that there are two methods for calculating PGR: one based on received photons (Eq. A5) and one using RMS (Eq. A8). It would then be easier to understand if you explained that CALIOP adopted Eq. A8 due to system constraints.

Response: Good point, thank you. We have added a short paragraph to the manuscript: "In Appendix A we present mathematical derivations of two different approaches that can be used to calibrate the PGR. The first uses the ratio of the directly measured mean background signals (e.g., as in Liu et al., 2004) while the second uses the ratio of the root-mean-squares (RMS) of the background signals. Because identical results are obtained using either method, data availability will dictate the choice of technique to apply. The following discussions leverage the mathematical derivations given in Appendix A to further explore both approaches.

Replacing the expression for digitizer counts measured in the perpendicular and parallel channels of the lidar receiver (i.e., $N_{dc,\perp}$ and $N_{dc,\parallel}$ in Eq. (A5)) with $BKG_{\perp}$ and $BKG_{\parallel}$, the equation for deriving PGR from OTIC background measurements at long wavelengths becomes"

L133, Eq. 6: What does the "c" in RMS_c stand for?

Response: This is a very good question. The "c" originally stands for cirrus clouds. However, since the method is not limited to cirrus clouds, we have replaced it with OTIC (optically thick ice cloud) in the revised manuscript to avoid confusion.

L133, Eq. 6: BDDR => BDR?

Response: thank you for carefully checking equations. We changed BDDR to BDR.

L128-L155: The sudden introduction of "BDR" in the text is somewhat confusing. If additional explanation were provided—including the relationship between Equation (7) and Equation (2)—the connection between the first half of Section 2 and this part would become clearer, which would likely deepen the reader's understanding.

Response: This is a very good suggestion. To improve clarity, we have added additional explanation of the bidirectional reflectance (BDR) and its role in the molecular scattering correction. Specifically, we added the following text:

"where *BDR* is the bidirectional reflectance, which describes how the atmosphere–surface system reflects incoming light as a function of both the illumination and viewing geometries. In the molecular scattering correction presented here, only the contribution from atmospheric molecular scattering is considered. The quantities BDR_I and BDR_Q are derived from the Stokes parameters (I) and (Q), which represent the intensity and linear polarization components of the scattered light, respectively. These Stokes parameters are calculated for molecular scattering using a polarization-sensitive vector radiative transfer model (VRTM, Zhai et al., 2009 We note that, whereas Eq. (2) describes the scattering of incident light by a single particle, the BDR terms used in Eq. (7) characterize the emergent radiation field of the atmosphere–surface system after radiative transfer, in which extinction, multiple scattering, and polarization are taken into account. Consequently, the bidirectional reflectance varies with both the solar illumination and sensor viewing geometries. ”

We also changed the word “intensity” to “power” on Line 68 and clarified that the equations apply for “single” cloud droplets. In addition, we replaced (I) with (P) in Eqs. (1) and (2) to differentiate power from intensity.

L292: “The method can also be applied to ADCL/DQ-1 to calibrate its HSRL 532 nm polarization measurements.”

In L253–L257, it appears that the application of OTIC is described as “challenging”—doesn’t this contradict the description here?

Response: We have revised this sentence as follows: “The method can also theoretically be applied to ACDL/DQ-1 to calibrate its HSRL 532 nm polarization measurements. The main challenges are the limited sampling height (40.4 km) and photon folding for the second shot of each laser pulse pair.”

Fig.2 & Fig. 5: The image looks a little blurry. Is it a resolution issue?

Response: We have revised both plots.

Fig.3: Around ±80 degrees, the RMS ratio values appear to be widely scattered. Is this normal? It also appears that the latitudes at which the values are scattered differ somewhat from those in Fig. 2(d).

Response: Large variations at high latitudes are expected because the solar elevation angle is low, resulting in weaker solar background signals and lower signal-to-noise ratios (SNRs).