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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Assessment of the CALIPSO Lidar 532 nm attenuated backscatter calibration using the NASA LaRC Airborne High Spectral Resolution Lidar" *by* R. R. Rogers et al.

Anonymous Referee #2

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GENERAL COMMENTS

The paper presents an extensive and careful investigation of the CALIPSO calibration accuracy based on comparisons of the 532-nm attenuated backscatter with independent measurements of the same quantity with an internally calibrated airborne high-spectral-resolution lidar (HSRL). The work is based on 86 underflights of the CALIPSO satellite between 2006 and 2009 and can be considered as the most extensive CALIPSO validation effort so far. The authors investigate and try to minimize the various error sources of the validation which are related to the calibration procedures, necessary methodical corrections, and the temporal and spatial variability of the

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atmosphere. It turns out that the most important bias, that prevents the validation to be better than say 2%-3%, is caused by undetected cloud and aerosol optical thickness between the uppermost measurement height of the HSRL (at about 7 km) and the CALIPSO calibration range (30–34 km). Unfortunately, there are some unclear statements and probably incorrect estimates in this context which must be revised (see specific comments below). In view of the generally very careful and important work the authors present, I also have some problems with the lax use of physical terminology. The discussion of errors is a bit confusing, because the authors do not clearly distinguish between uncertainties and biases (in the sense of precision and accuracy). Also, the use of terms with respect to the state of polarization is rather sloppy throughout the paper. For instance, we find wordings like parallel power, parallel backscatter, or parallel calibration. Such kind of "lab slang" should be avoided in a scientific publication.

I summary, the paper is an important contribution to the field and should be published after mandatory revision by taking the following comments into consideration.

SPECIFIC COMMENTS

p. 28357, l. 15: …several studies have been conducted… Please provide references.

p. 28357, l. 28: Please provide original citation for HSRL (Shipley et al. 1983).

p. 28358, l. 15: Give an outline of the paper.

p. 28360, last paragraph, discussion on calibration: What about the calibration of the 532 nm perpendicular component?

p. 28369, l. 29: The value of the scattering ratio should be 1.05 (not 0.05).

p. 28370, first paragraph of Sec. 4.2.: You speak about "ozone and molecular" or "ozone and molecules". Ozone is a molecule, of course. What you mean is ozone absorption and molecular scattering. Thus, again, use the physically correct terms!

p. 28370 – 28371, discussion in Section 4.2: The two-way transmittance between the

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uppermost HSRL measurement height and the CALIOP calibration region obviously is the most important source of uncertainty in the comparisons. Therefore, this discussion needs a bit more care.

First of all, there are a couple of mistakes in the numbers which contribute to the confusion here: - p. 28370, l. 27: 0.075 – you certainly mean 0.0075 (but this estimate is probably wrong, see below) - p. 28371, l. 8: . . .we estimate the minimum detectable cloud optical thickness to be 1.2%. . . – you certainly mean 0.012 (absolute value, not percent) - p. 28371, l. 8: 0.978 – you certainly mean 0.987

Then, you should check and discuss the following issues:

- p. 28370, l. 20: What is the horizontal scale of cloud detection for the histogram in Fig. 3? What is the difference in detection sensitivity during day and night?

- p. 28370, l. 21: . . .maximum bias introduced by undetected clouds. . . What is the uncertainty related to the temporal and spatial inhomogeneity of cloud fields? Clouds can move in or out the flight track between the CALIOP and the HSRL observation.

- p. 28370, l. 27: When estimating the undetected COT you speak about "multiple-scattering enhancement" and you multiply the CALIOP value with 0.6. Is this the correct way to deal with the multiple-scattering influence? I think we need some more discussion here. What does "multiple-scattering enhancement" mean? Generally, multiple scattering increases the attenuated backscatter signal within a thin cloud, because forward scattered light doesn't get lost instantaneously. As a consequence, the observed optical thickness is reduced compared to the true optical thickness of the cloud. Thus the apparent COT should be divided by the approximate factor of 0.6, and not multiplied, to get the (ice) cloud's single-scattering optical thickness (you should mention that you speak about thin ice clouds; the factor is only valid in this case). Then, you would end up with a COT of 0.0208 and you have a bias of 4% and not 1.5%. On the other hand, you retrieve the COT distribution from the CALIOP Level 2 cloud layer product. To my knowledge, there is already a multiple-scattering correction applied

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in the CALIOP retrieval scheme for ice clouds (see, e.g., Winker et al. 2009, Young and Vaughan 2009). Thus it is probably not necessary to apply this multiple-scattering factor in your estimate. Please clarify!

- p. 28371, l. 3–4: …at 20 km (multiply by 0.25)… Please explain this factor! You may refer to Fig. 4 in Winker et al. 2009; from this figure it also becomes clear that the factor holds for nighttime only.

- p. 28371, l. 7: Again, how do you deal with the multiple-scattering factor?

- Volcanic activity in Alaska, Kamchatka, the Aleutian and Kuril Islands has been increased since the eruption of Mt. Okmok in July 2008. Since then, stratospheric optical depth in the northern hemisphere has been considerably higher than the typical background values you discuss. Mattis et al. (2010) found aerosol optical depths of up to 0.025 at 532 nm in the upper troposphere and the stratosphere over Europe. The values might have been even higher over North America which is much closer to the source region. The aerosol layers are often visible in the CALIPSO browse images of attenuated backscatter, but not always in the VFM. You should check whether you see an enhanced bias in your comparisons after July 2008.

p. 28372 – 28373, discussion in Section 4.4 and Table 2: You should clearly distinguish between uncertainties and biases (throughout the paper, see also the general comments). Only uncertainties ($\pm$ errors) can be treated in a root-sum-square sense. The biases which are caused by the undetected cloud and aerosol optical depths between the HSRL height and the CALIPSO calibration height have a well-defined sign and do not cancel each other out in the root-sum-square sense. From Table 2, I would calculate your overall error to +3.7% $\pm$ 2.6%. Thus you would expect to obtain a positive value of the difference (HSRL – CALIOP) within these error limits, and that is exactly what you find in your data.

p. 28374, l. 11–16: Wouldn't aerosol loading in the CALIPSO calibration range lead to the opposite effect (CALIOP too high compared to HSRL, i.e. a negative bias)? Such

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a negative bias would reduce the positive bias you get from the unknown cloud and aerosol transmission above the HSRL. If you can quantify the bias, you may include it in your overall error estimate (see previous comment). Check whether increased volcanic activity can explain the larger positive biases in the respective measurements instead!

p. 28374, l. 28: Give a hint to Fig. 7.

p. 28378 – 28380, Section 6: Please consider all aspects discussed above in your conclusions (especially wrt biases and uncertainties).

TECHNICAL CORRECTIONS

In general all equations should be embedded in complete sentences, including punctuation.

Please check all occasions where you refer to the difference HSRL–CALIOP for consistency, especially the figures and tables. Sometimes you write HSRL–CALIPSO or LIDAR–CALIOP.

Check your reference list. There are several inconsistencies between the citations in the text and the reference list (e.g., Hunt et al. 2009, McGill et al. 2006 or 2007).

p. 28356, l. 13: delete "an"

p. 28359, l. 13: long-term

p. 28359, l. 16: primary (not primarily)

p. 28359, l. 24-26: Check sentence wrt level 1 and level 2.

p. 28360, l. 2: coefficient (not coefficients)

p. 28361, l. 12-13: Subscripts of beta must be parallel (not perpendicular).

p. 28365, l. 15: ...to produce the 532 nm total... (delete "of")

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p. 28366, l. 17, Eq. 10: Subscript of r in the middle part of the equation should be 30 km.

p. 28371, l. 4: Please correct the sentence: . . .a lidar ratio of a mean lidar ratio. . .

p. 28371, l. 15: Jäger (not Jager)

p. 28374, l. 1: You obviously mean Fig. 6, not Table 2.

p. 28376, l. 26: . . .this selection criterion (not criteria).

p. 28388, Fig.1: What campaign is "CALIPSO" in the map?

p. 28394, Figure caption 7: . . .same as Fig. 2 (not Fig. 1)

REFERENCES

Mattis, I., P. Siefert, D. Müller, M. Tesche, A. Hiebsch, T. Kanitz, J. Schmidt, F. Finger, U. Wandinger, and A. Ansmann, 2010: Volcanic aerosol layers observed with multi-wavelength Raman lidar over central Europe in 2008–2009, J. Geophys. Res., 115, D00L04, doi:10.1029/2009JD013472.

Shipley, S.T., D.H. Tracy, E.W. Eloranta, J.T. Trauger, J.T. Sroga, F.L. Roesler, and J.A. Weinman, 1983: A High Spectral Resolution Lidar to measure optical scattering properties of atmospheric aerosols , Part I: Instrumentation and theory, Applied Optics, 23, 3716-3724.

Young, S. A., and M. A. Vaughan, 2009: The Retrieval of Profiles of Particulate Extinction from Cloud-Aerosol Lidar Infrared Pathfinder Satellite Observations (CALIPSO) Data: Algorithm Description. J. Atmos. Oceanic Technol., 26, 1105–1119.

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