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Atmospheric Measurement Techniques Discussions

Interactive comment on "Cloud Aerosol Transport System (CATS) 1064 nm Calibration and Validation" *by* Rebecca M. Pauly et al.

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I have read the paper by Rebecca Pauly and co-authors with great interest. The article describes the calibration of CATS 1064 nm attenuated backscatter and depolarisation (level 1 data). Calibration is achieved on a per-granule basis, by normalisation of nighttime signals with modelled atmospheric backscatter at an altitude of 22-26 km, where account is made for Rayleigh scattering (derived from the MERRA-2 re-analysis) and aerosol scattering (inferred from CALIPSO measurements). Moreover, attenuated backscatter by opaque cirrus clouds is exploted for two further calibrations: daytime calibration, on a monthly basis, is achieved by matching the overall frequency distribution of daytime and nighttime opaque cirrus attenuated backscatter, and the calibration of depolarisation signals, on a yearly basis, is obtained by matching the parallel and

perpendicular signals for this type of clouds. The uncertainties that derive from this approach are discussed and quantified, and comparison with a number of validation sources is described: CALIPSO, airborne lidar, and ground-based lidar.

This research has a high significance, due to the fact that two and a half years of CATS data have been collected in 2015-2017, on-board the International Space Station. This dataset is still to be exploited in full, and it provides information on global aerosols and clouds, under an unusual orbit type (the one of the ISS) which permits an investigation on diurnal cycles (as opposed to the more traditional sun-synchronous orbits). It also demonstrates that, depending on instrument design, direct calibration of 1064 nm lidar channels is possible, without needing to transfer the calibration from channels at shorter wavelengths.

The paper is well written but a few more points need to be addressed before it can be published, in order to clarify better the methods to the reader. I feel that there are still a few major points as follows, some of which were already raised in the previous "quick review". Underpinning science to the CATS processing is addressed here and I believe that the explanation of the methodology should clarify all doubts.

MAJOR COMMENTS:

1) I suggest to add more in the conclusions. CATS has been used and will continue to be used for cloud, aerosol, and radiative budget studies that will benefit from the new data version. What are the most significant results obtained so far from CATS datasets? how would they be affected if they were to be reprocessed using V3 data? how does the V3 level 1 calibration affect the level 2 data (before any changes to the V3 level 2 processing)? are there any useful lessons from your research that can be useful for EarthCARE and Aeolus? and for future follow-on missions?

2) In the daytime calibration (section 2.2) , you specify that you are looking for a specific type of target: opaque and geometrically thin clouds, and you specify "A layer is classified as opaque if no layer or ground signal is detected below it". In the previous

review I raised the question of how you could know that such a cloud is physically thin, since opaque and deep clouds could look similar on a lidar signal. I don't believe that this point has been addressed.

3) Equation 9: discuss numerical differences between Cday and Cnight and their evolution; what causes them? instrument temperature?

4) Section 2, lines 6-26: A few pieces of information on the instrument, that one deducts whilst reading the paper, should go in this section, so that the reader can begin thinking about them. I would discuss the following in this section: (1) how laser 1 and laser 2 are associated with modes 7.1 and 7.2; (2) the difference in PRF between the two lasers (4 and 5 kHz); (3) the signal folding due to the choice of PRF; (4) how this is reflected in the signal acquisition (with a data frame from -2 to 28 km); (5) the raw vertical and temporal resolution; and (6) any integration that is applied to the data prior to the signal processing described in the present paper.

5) Equation 3: the colour ratio 0.4 is assumed because it is the value also assumed by Hair et al (2008). However, Hair et al do not give any explanation on why this value has been chosen, nor do they provide a reference! This should be discussed, and the error estimate on the colour ratio should be given explicitely. It could be useful to mention that this assumed colour ratio corresponds to a backscatter Angstrom exponent of 1.3, and that it is a colour ratio for "nearly clear air" (so is stated by Hair et al).

6) P5 L12-17: please explain these criteria better: (1) why has each of them been chosen and what do they signify in terms of cloud physics? (2) why do they differ from the criteria used for daytime calibration? (3) how is the temperature determined? (please state if it comes from the reanalysis); (4) clarify how you determine the depolarisation delta before you know PGR: are you using a previous data version for this? (5) equation 7 is missing the PGR as a multiplicative constant: have you already incorporated this into NRBperp? If this is the case, it is confusing, and I would recommend to write PGR explicitely, or to call NRBperp' = PGR * NRBperp.

7) is the daytime or nighttme calibration coefficient and the PGR stored in the level 1 data files available for download? please state in the paper.

8) The specifications of the units used is missing in several places: (1) Equation 1, what are the units for Ns? counts? count rate? voltage? and what are the units of NRB (e.g. counts * km2 / J)? (2) Equation 8, what are the units for C (e.g. counts * km2 * sr / j)? (3) P6 L7, specify the units with the calibration coefficients given here; (4) P7 L9, specify units of iATB values given (e.g. sr-1); Table 1 misses the specification of units (sr-1); etc.

MINOR COMMENTS:

9) The paper uses the normalisation technique to calibrate the signal; however, since aerosols have to be accounted for at the altitudes considered, I suggest that it should not be called a "molecular" normalisation technique. This can be achieved by removing the word "molecular" from lines 17 and 35 (abstract) and in a few places within the manuscript. In the conclusions, line 22, "Rayleigh profile" –> "Rayleigh profile corrected for aerosol contributions".

10) P2 L26: we have no measurements of crystal size, hence I would either remove the words "comprised of large ice crystals", or I would word it as a caveat (e.g. "thought to be mainly associated with ice crystals larger than the lidar wavelength").

11) P3 L16: How is the laser energy E determined? Is it measured on-board? Is E an instantaneous value, a nominal one, or an average over a given time period?

12) P3 L22: "averaging the signal acquired after the signal attenuated by the Earth's surface" add the words "after correction for the signal folding time (see below)".

13) P4 L6: You earlier specified that the data frame is limited to -2 to 28 km; the fact that you use signals between -2.5 and -4.5 km for the evaluation of the background seems in my opinion to contradict this fact. Please explain, and please specify whether the data frame between -2 and 28 is limited by hardware design (acquisition electronics).

14) P4 L23: "28 km" –> "26 km"

15) P5 L7: remove "reflected" (this is scattered light, rather than reflected).

16) P5 L22: add "(multiplied by PGR)" after "perpendicular"

17) P5 L24: add the following before "To prepare", so as to clarify to the reader better what is the overall approach: "Nighttime calibration is applied on a per-granule basis, where a single calibration coefficient is determined as follows, for each data granule".

18) P5 L33: specify the value used for minimum and maximum thresholds.

19) P6 L1-4: is there any flagging of cases where the per-granule approach fails and you revert to using the previous week data? or is it exactly coincident with the flagging of files with a poor depolarisation quality?

20) P6 L6-13: please explicitely state that an instrument temperature dependence is thought to be responsible for these fluctuations. Do you have any suggestion on which piece of the CATS hardware could be responsible?

21) P6 L22: precede line with "Instead,". "singular" –> "single". "month": specify if this is calendar month (from 1 to last day of the month) or a rolling 30-day period.

22) P6 L23: "colder than -20C": how is the temperature determined? see comment 6 on specifying how temperatures are determined.

23) Figure 4: why does the shape of the distribution change so much? I would only expect a horizontal shift on the plot.

24) P7 L6: add "on a monthly basis" after "V3-00".

25) P7 L8: I thouht that equation 9 would esnure that the bias on the mean would be zero. Please explain better why a residual bias persists.

26) P7 L28: "transmission" before "uncertainty".

27) P7 L37: please give a numerical estimate of (delta C / C)_sys before discussing

the random error.

28) P8 L11-12: if the multiple scattering factor is the same for daytime and nighttime measurements, does it not cancel out? please explain if it is different for day and night instead.

29) P9 L20: scattering ratio of 1.27: how much is the comparison with CATS sensitive to R? discuss the consequences of this assumption and its effect on the estimate of measurement errors; please specify if R is specified at 1054 or 532 nm.

30) P10 L2: "some of the differences in the ATB signal": I am not sure which differences you are referring to: the two do not look too different from each other!

31) P10 L30: add "PollyXT" before "1064 nm"

32) P10 L39: specify how many profiles are accumulated in 30 min of PollyXT measurements.

33) P10 L40: add "CATS-like" between "mean" and "signal"

34) P13 L30: please specify what changes to instrument design could permit the use of a higher calibration region. I suppose that one of them could be a reduction of the laser PRF (responsible for signal folding).

35) Figures 10 and 11, y-axis: please specify whether this is a relative frequency expressed in % or an absolute frequency distribution. In Figure 11 make the x-axis label consistent with Fig. 10 for a better readability.

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