Responses to Reviewer #2 – Z. Wang (amt-2018-206-RC2.pdf)

1. Even the paper presented detail error estimations. But not all potential sources are included. Based on Figures 1, 2, and 4, there are large calibration variations with time or locution. Although the potential mechanisms to day and night time calibration differences were discussed, what control these spatial variations during daytime were not touched. These daytime in-granule variations could indicate that there is a possibility for large between granule variations, which could be a large random error source. Is there any way to quantify this?

   We do not dig deeply into "what control(s) these spatial variations during daytime" because the full extent of all mechanisms involved is not precisely known. But we can make some definitive statements about the general nature of the underlying cause. Post launch thermal modeling by the CALIOP engineers at Ball Aerospace Technology Corporation demonstrates that the predominate source of these variations is thermally induced misalignment of the CALIOP transmitter and receiver (e.g., see Hunt et al., 2009; Powell et al., 2010; and Stephens et al., 2010).

   As illustrated in Figure 5, these thermal beam steering effects manifest themselves differently for the two lasers. Of more relevance, perhaps, is the fact that the relative magnitudes of these effects within any given orbit vary seasonally as a result of changes in solar incidence angle with respect to the satellite. Our averaging scheme is specifically designed to capture and characterize these changes. Furthermore, because the thermal mass of the instrument is large and essentially constant, any changes in the sunlight-induced, time-varying thermal stress profile from orbit to orbit are expected to be very small, and thus would not serve as "a large random error source" for "large between granule variations" in the 532 nm daytime calibration procedure.

2. Section 4.2 and Fig. 6: There are few major questions related to the discussion here. First, I don't think that the comparison gives you a real independent evaluation of daytime calibrations because your approach assumes that the day and night are same. The results only indicate that the approach is properly implemented.

   The only independent evaluation of the daytime calibration is done is section 4.4 (Comparisons to HSRL measurements), where the backscatters between the HSRL and CALIPSO are compared. It is not the intent of figure 6 to show independence, rather to verify that the scaling of the day to the night is working. This is noted on page 17, lines 4 – 6, where we say:

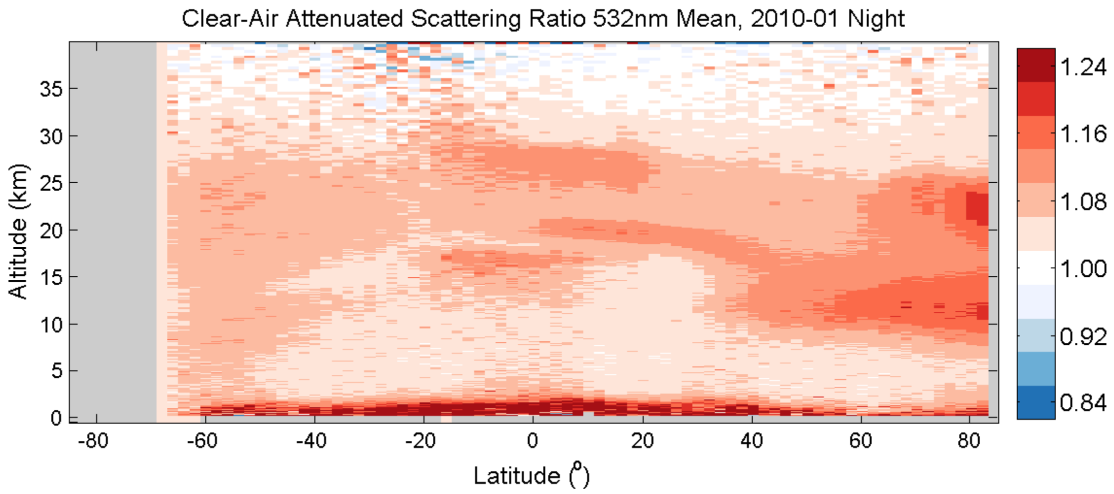
   Given that the daytime calibration is scaled to the night-time, one should expect to see that the daytime and nighttime attenuated scattering ratios should tightly follow each other within this altitude band. Figure 6 confirms this expectation.

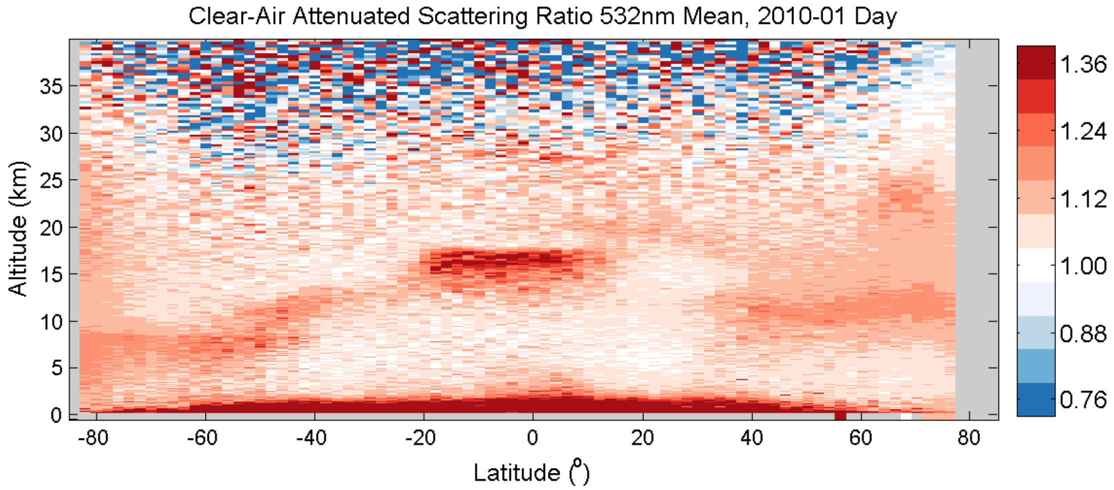
   If the algorithm was not working properly we would not expect to see the very close correspondence that is shown in the plot.

   It is not clear which zonal clear air data are used here, all clear air or only in the calibration transferring zone? If the results are for the calibration transferring zone, the attenuated scattering ratio given in the figure is too high for me because the upper troposphere and low stratosphere have very low scattering ratio, especially under background conditions.

   Figure 6 is made from data in the calibration transfer region, as noted in the figure title. Figure 7 looks at a fixed altitude band above the calibration target region of 24-30km, but is a ratio between the day and the night, not the actual scattering ratios.

   The two figures below show the 532 nm mean clear-air attenuated scattering ratios measured by CALIPSO and reported in our Lidar Level 2 product as a function of height and altitude for the month of January 2010, which corresponds to Figure 6(a). These clear-air attenuated scattering ratios are computed using only those profiles in which are found to be "feature-free" by the CALIOP layer detection algorithm. A mean scattering ratio of ~1.1, both in the calibration transfer region and again from 24–30 km, is wholly consistent with the zonal means shown in figure 6 below. Note that the daytime image shows enhanced residual effects of failed detections of (presumably) subvisible cirrus in the tropical tropopause layer (i.e., at ~17 km between -20°S and 10°N).





3. Page 4, line 9: should Eq. 2 be Eq. 3?

   You are correct, I meant to reference equation 3. The correction to page 4 line 9 is high-lighted in red.

   …, are calculated using the same formula as in Eq. 3, except using nighttime signals…

4. Page 5, Eq. (5): Is Cnight a constant here?

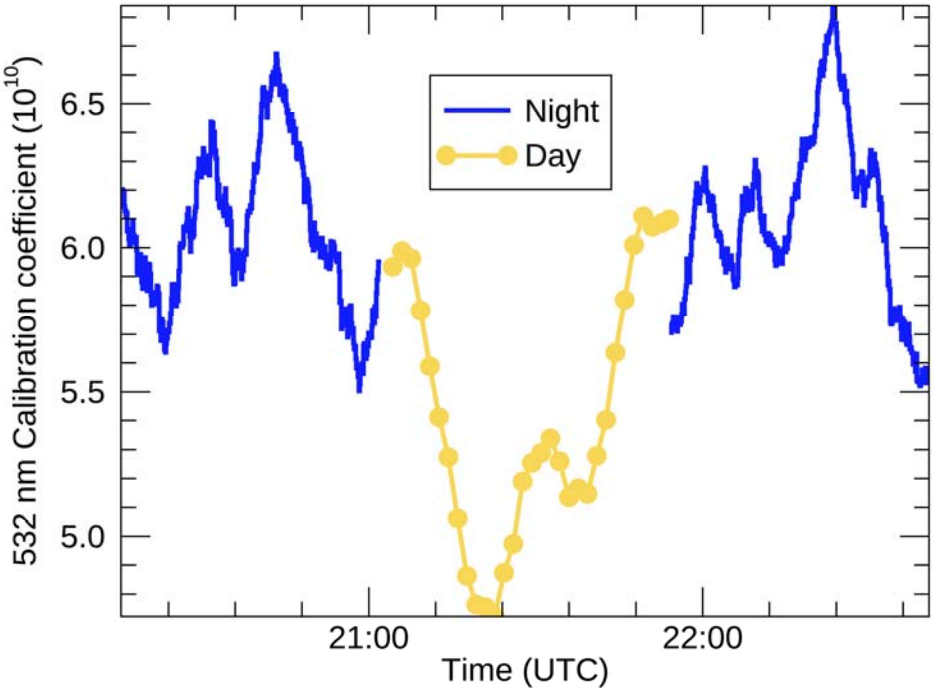
   The parameter contained in Eq. (5) is defined in the text on page 4, lines 2 - 5:

   The clear-air attenuated scattering ratios in the V3 8-12 km calibration transfer region were assumed to be diurnally invariant. Based on this assumption, initial estimates of the mean attenuated scattering ratios, $\overline{R'}_{day,initial}$, are calculated for each daytime frame ***using the mean of the 532 nm calibration coefficients, $\tilde{C}_{night}$, computed during the previous nighttime granule.***

   (Bold gold emphasis added.) It is a constant in terms of Eq. (5).

5. Figure1: use large font sizes for labels and legends

   The label font (Helvetica) and size (12 pt) is consistent with the other figures in the paper. The figure has been recreated to increase the size of the legend (Night and Day) to also be 12pt Helvetica.



6. Page 6, section 3.1: the baseline slope correction is hard to follow. Can you provide equations to support the discussion?

   We have replaced the first two paragraphs of section 3.1 with a more in-depth explanation of the baseline slope corrections. In doing so, we have also replaced ‘baseline slope’ with ‘baseline shape’, as using the term ‘slope’ implies a linear correction, whereas in fact the correction we actually apply is a quadratic function of the measured background light intensity.

   The V4 calibration procedure applies two new corrections to the daytime signal prior to the calibration: an adjustment to remove photomultiplier (PMT) baseline shapes and an updated day-to-night gain ratio. The motivation and implementation of these two corrections are discussed in the paragraphs below.

   The output of PMTs exposed to constant background light (e.g., sunlight reflected from dense water clouds) typically increases with time after the PMT is gated on, thus generating a signal-induced baseline shape that varies as a function of the background light level. Prior to launch, the baseline shapes for the CALIOP detectors were repeatedly measured in the laboratory, and the magnitudes of the required signal adjustments were found to be quite small relative to the atmospheric signals typically measured in the troposphere. Consequently, because the prelaunch daytime calibration strategy was simply to interpolate daytime calibration coefficients between neighboring nighttime molecular normalizations (Hostetler et al., 2006; Powell et al., 2008), baseline shape corrections were deemed to be unnecessary and thus were not implemented. This assessment changed with the V4 redesign of the daytime calibration algorithms. The V4 daytime calibration relies on highly averaged daytime measurements in the middle-to-lower stratosphere where the expected molecular signals are substantially weaker, and hence biases due to baseline shape artifacts are potentially significant. To mitigate *these concerns, we used prelaunch laboratory measurements together with post-launch extended background measurements acquired periodically throughout the mission to characterize the PMT baseline shapes:*

$$\mathrm{shape}(z,B) = (z_{\mathrm{offset}} - z)\left(X_1 B + X_2 B^2\right)10^{G/20}\,. \qquad (6)$$

This approximation is a function of both altitude (z) and background light intensity (B). X_1 and X_2 are polynomial coefficients separately determined for the 532 nm parallel and perpendicular channels, B is the measured background light level for each laser pulse, G is the channel-dependent electronic amplifier gain, z is the measurement altitude for each range bin in a CALIOP backscatter profile, and z_{offset} = 72.5 km is the midpoint of CALIOP's high-altitude digitizer DC offset measurement region (Hunt et al., 2009). Shape correction profiles are computed on a shot-by-shot basis and applied to all data acquired during daytime measurements.

7. Page 8, lines 30-33: Why not using the new data to re-calculate altitude?

   Page 8, lines 28-33:

   At the time of the V4 algorithm development and deployment, GMAO provided an updated meteorological reanalysis product, MERRA-2 (Modern-Era Retrospective analysis for Research and Applications, Version 2) (Gelaro, 2017), which includes Microwave Limb Sounder (MLS) temperatures and is a marked improvement over earlier GMAO-FPIT products. This new meteorological data was incorporated into the V4.10 L1 and L2 data products, but was not used to re-compute the 400 K altitudes used by the 532 nm daytime calibration algorithm to set the calibration transfer region base altitude.

   For a majority of the development of the new algorithm we only had the GMAO FP-IT data, which was used for V3. The selection of the MERRA-2 was made much later in the algorithm development cycle. The rationale for not using MERRA-2 to rebuild the 400K tables was two-fold. First, based on internal analysis of the differences, the 400K line did not deviate significantly between GMAO FP-IT and MERRA-2. Second, since we are adding a 2km correction above the 400K line we felt that that provided enough margin to account for any possible differences if they indeed existed.

8. Page 10, line 24: Is 15 m here right?

   Page 10, lines 23-25:

   …where N represents the number of profiles averaged and RMS_{1064} is the root-mean-square of the baseline signal measured on-board the satellite for each laser pulse at 15 m vertical resolution and subsequently recorded in the L1 data products. The layer detection threshold, $T(z)$, is then computed as a function of the on-board averaging using…

   Yes, 15 m is correct here. This is the fundamental resolution of the measurements collected, before the on-board averaging is carried out.

9. Figure 3: Using a nighttime case to illustrate the approach is fine, but it will be good to see a daytime case because it is the focus of the paper. Due to the lower SNR, daytime data are challenging to handle.

   The 1064 nm detection is applied to both day and night orbits, so the purpose of figure was strictly illustrative and meant show a simplified case. I chose a night-time orbit because I wanted Figure 3(a), (c) – (e) to be relatively clean – precisely because of the lower SNR. As noted, the daytime 532 nm total attenuated backscatter case contains more noise (see figure below).

   The other take-home from Figure 3 is that what is actually being used is the region above the 400K line (yellow line in figure 3(b)), and not what was done in V3 (red boxes in figure 3(b))).

References

Hunt, W. H., Winker, D. M., Vaughan, M. A., Powell, K. A., Lucker, P. L., and Weimer, C.: CALIPSO Lidar Description and Performance Assessment, J. Atmos. Oceanic Technol., 26, 1214–1228, doi:10.1175/2009JTECHA1223.1, 2009.

Powell, K. A., Hostetler, C. A., Liu, Z., Vaughan, M. A., Kuehn, R. E., Hunt, W. A., Lee, K. P., Trepte, C. R, Rogers, R. R, Young, S. A., and Winker, D. M.: CALIPSO Lidar Calibration Algorithms: Part I - Nighttime 532 nm Parallel Channel and 532 nm Perpendicular Channel, J. Atmos. Oceanic Technol., 26, 2015–2033, doi:10.1175/2009JTECHA1242.1, 2009.

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