

# REVISED CALIBRATION STRATEGY FOR THE CALIOP 532-NM CHANNEL: PART II – DAYTIME

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## ABSTRACT

The CALIPSO lidar (CALIOP) makes backscatter measurements at 532 nm and 1064 nm and linear depolarization ratios at 532 nm. Accurate calibration of the backscatter measurements is essential in the retrieval of optical properties. An assessment of the nighttime 532 nm parallel channel calibration showed that the calibration strategy used for the initial release (Release 1) of the CALIOP lidar level 1B data was acceptable. In general, the nighttime calibration coefficients are relatively constant over the darkest segment of the orbit, but then change rapidly over a short period as the satellite enters sunlight. The daytime 532 nm parallel channel calibration scheme implemented in Release 1 derived the daytime calibration coefficients from the previous nighttime coefficients. A subsequent review of the daytime 532 nm parallel channel calibration revealed that the daytime calibration coefficients do not remain constant, but vary considerably over the course of the orbit, due to thermally-induced misalignment of the transmitter and receiver. A correction to the daytime calibration scheme is applied in Release 2 of the data. Results of both nighttime and daytime calibration performance are presented in this paper.

## 1. INTRODUCTION

Release 1 of the CALIPSO (Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations) [1] data included the CALIOP Level 1B profile products and the Level 2 Vertical Feature Mask and Cloud and Aerosol Layer products. Release 1 data begins June 13, 2006 and ends October 31, 2007. Data products included in the second major release, Release 2, were available February 2008. All Release 1 data were reprocessed for Release 2. New to Release 2 are the Level 2 Cloud and Aerosol Profile products.

In both Release 1 and 2, the nighttime 532 nm parallel channel calibration coefficients are determined by comparing the 532-parallel signals in 30 km to 34 km altitude range to a scattering model derived from molecular and ozone number densities provided by NASA's Global Modeling and Assimilation Office (GMAO) [2,3]. During daytime, the noise associated with solar background signals degrades the backscatter

signal-to-noise ratio (SNR) in the calibration region. Therefore, the CALIOP daytime 532 calibration coefficients are interpolated from the adjacent nighttime data segments.

An assessment of the 532 nm parallel channel nighttime and daytime calibration for both Release 1 and 2 of the CALIOP data used attenuated scattering ratios in clear air regions between 8 km to 12 km altitude range. By definition, clear air regions are essentially free of aerosols and, therefore, the aerosol to molecular scattering ratios are expected to be approximately 1.0. However, aerosol loading below the CALIPSO detection threshold will sometimes cause larger values.

For the assessment, regions with clear air above 8 km and extending for at least 200 km along the orbit track were identified using the CALIOP Lidar Level 2 Cloud and Aerosol Layer data product. For each 200 km segment, profiles of clear air attenuated scattering ratios between 8 km and 12 km in altitude were calculated as the ratio of 532-total attenuated backscatter signals to a scattering model derived from molecular and ozone number densities provided by GMAO. For each attenuated scattering ratio profile, a mean value was calculated, and then the individual profile means were averaged over the 200 km segment. The averaged, mean clear air attenuated scattering ratios,  $R'_{clear}$ , were stored along with the segment mid-point location and time stamp. The mid-point time stamps were defined as an elapsed time relative to the start of the orbit segment.

Figure 1 contains a plot of nighttime  $R'_{clear}$  for the month of January 2007 (Release 2) as a function of elapsed time from the start of the nighttime orbit segment. The  $R'_{clear}$  values are grey circles and the black markers are the medians of  $R'_{clear}$  over each 10 second interval. The median or smoothed  $R'_{clear}$  values are within three percent of the expected value for most of the orbit segment. The exception is at the two endpoints where  $R'_{clear}$  increases to approximately seven percent. Fluctuations near 2400 seconds are due to the sparse amount of data. Monthly plots of nighttime  $R'_{clear}$  for the entire mission for both Release 1 and 2 were generated. All cases produced similar results, providing a high level of confidence in the 532 nm parallel channel calibration.

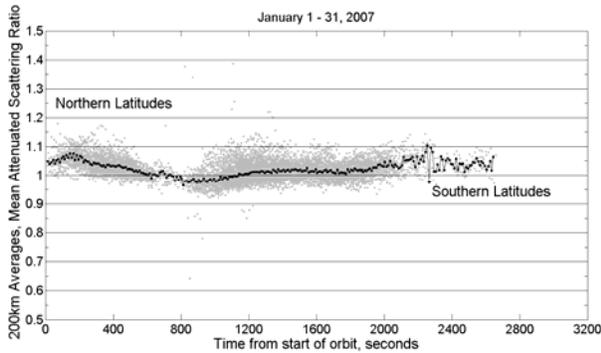


Figure 1. Nighttime mean attenuated scattering ratios for January 2007.

Daytime  $R'_{clear}$  for the January 2007 Release 1 data are displayed in Figure 2. The  $R'_{clear}$  values exhibit a characteristic V-shape pattern that is repeated for all of the Release 1 daytime data. At the beginning of the orbit segment (zero seconds),  $R'_{clear}$  is 1.1. It drops to  $\sim 0.7$  between 2000 and 2400 seconds of elapsed time, and recovers back to 1.1 at the end of the orbit segment. Monthly, 1 day, 3 day, and 5 day plots of daytime  $R'_{clear}$  were generated for all of the Release 1 data. For all time scales examined, the minimum values for  $R'_{clear}$  clustered near 2100 seconds and ranged in value between 0.62 and 0.92.

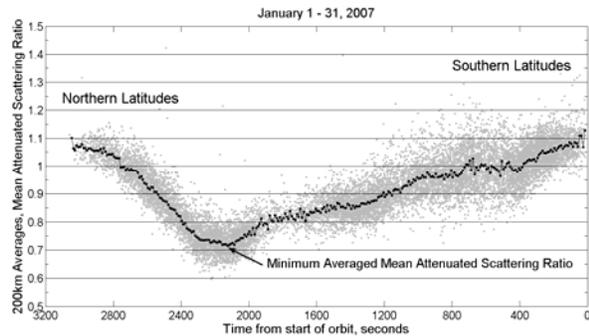


Figure 2. Daytime mean attenuated scattering ratios for January 2007.

The drop in the daytime  $R'_{clear}$  appears to be related to a thermally-induced misalignment of the laser transmitter and receiver [4]. The misalignment reduces the signal magnitudes during the daytime, and thus the assumptions required for transferring the nighttime calibration coefficients to the daytime are no longer valid. In order to bring daytime  $R'_{clear}$  values up to nighttime levels, the daytime calibration coefficients must be reduced. Implemented in Release 2 are time dependent calibration coefficient Correction Factors to decrease the daytime calibration coefficients. The Correction Factors are derived using the daytime  $R'_{clear}$  values computed from Release 1.

## 2. CALCULATING CORRECTION FACTORS

Figure 3 shows the minimum  $R'_{clear}$  values computed over 1 (cyan), 3 (red), and 5 (blue) days plotted as functions of time. The month and year are labeled along the lower edge of the plot. The daytime calibration coefficient Correction Factors were obtained by applying a series of linear fits to the minimum  $R'_{clear}$  values for the combined 1, 3, and 5 day data. The Correction Factors are displayed as black solid lines in Figure 3. Along the top of plot are the dates of Boresight Aligns. Some of the Boresight Aligns produced an abrupt change in the minimum  $R'_{clear}$  value.

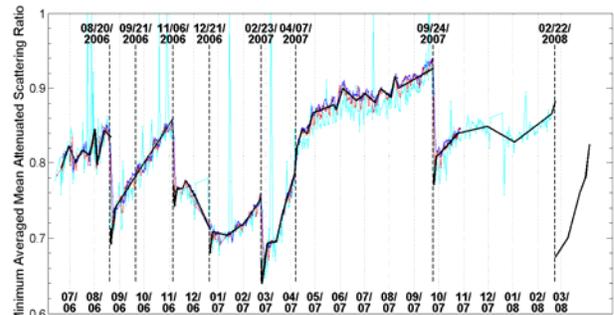


Figure 3. The black lines are the linear fits to the minimum clear air (8-12 km) mean attenuated scattering ratios  $R'_{clear}$  calculated for 1 (cyan), 3 (red), and 5 (blue) days. Boresight Alignments occurred at dotted lines.

## 3. DAYTIME CALIBRATION SCHEME

The CALIOP daytime 532-parallel signals are calibrated using the adjacent nighttime calibration coefficients. For both Release 1 and 2, the daytime calibration coefficients are derived from a piecewise linear approximation anchored by the calibration coefficients from the previous and following nighttime orbit segments. Figure 4 contains an illustration of the daytime calibration schemes for both Release 1 and Release 2.

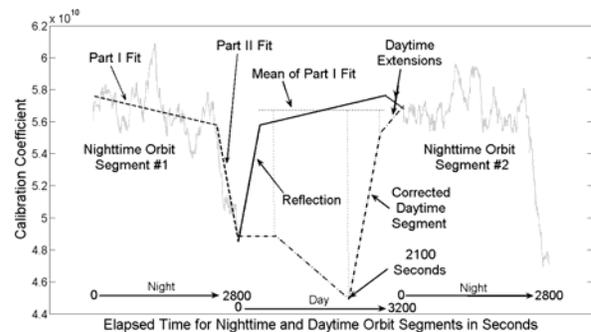


Figure 4. Illustration of 532 nm parallel channel daytime calibration scheme.

In Figure 4, the daytime orbit segment is at the center and is flanked by the preceding nighttime orbit segment

to the left and the following to the right. Beginning with the preceding nighttime segment, “Part I Fit” is a linear least squares fit of nighttime calibration coefficient as a function of time. “Part II Fit” is a linear approximation of the nighttime calibration coefficients for the last 400 seconds of the segment. The calibration coefficients within “Part I Fit” are in the darkest part of the orbit and the slope of the linear fit tends to remain small. Within the segment labeled “Part II Fit”, CALIPSO is exposed to sunlight and the rapid change in calibration coefficients are due to the thermally-induced misalignments.

In Release 1, the Part I and II linear approximations were reflected as a single unit about the last nighttime endpoint. Since the duration of nighttime (~2800 seconds) and daytime (~3200 seconds) are not equal, a linear approximation between the last daytime calibration coefficient and the first nighttime coefficient of the following nighttime segment completes the daytime extension.

The Release 2 calibration scheme was designed to have minimal impact on the structure of the Release 1 Level 1B production code. The first step in the Release 2 scheme eliminates “Part II Fit” and replaces it with a constant calibration coefficient. The constant value is the first element in the reflected “Part II Fit” and it is replicated for the first 700 seconds of elapsed time. The second step scales the final “Part I Fit” calibration coefficient by 0.97 and stores it at 2700 seconds. The third step applies the time dependent Correction Factor (Figure 3). The Correction Factors are obtained from a lookup table and are applied to the mean of the “Part I Fit”. The corrected calibration coefficients are stored at 2100 seconds of elapsed time. The fourth step performs a linear interpolation between the three points at 700, 2100, and 2700 seconds. The final step performs linear interpolation between the 2700 second point and the first nighttime calibration coefficient for the following segment.

In Figure 4, the Release 1 daytime calibration coefficients are drawn as a solid line and the Release 2 daytime coefficients are drawn as a dashed line.

#### 4. RESULTS

The improvements obtained by Release 2 can be seen in the July 2006  $R'_{clear}$  values (Figure 5). This figure contains nighttime and daytime smoothed  $R'_{clear}$  values as a function of latitude for both Releases 1 and 2. Nighttime  $R'_{clear}$  values for both Releases are coincident from 60N to 60S. Below 60S differences in nighttime  $R'_{clear}$  are due to different versions of the GMAO data. The nighttime  $R'_{clear}$  values are approximately  $1.0 \pm 0.5$  except for below 60S, where few data points contribute to large fluctuations in the smoothed values. For

daytime conditions, the characteristic V-shape in  $R'_{clear}$  for the Release 1 data is apparent. The minimum  $R'_{clear}$  is approximately 0.85 near 45N-60N. The Release 2  $R'_{clear}$  values in this same region are nearly coincident with the nighttime values, and the downward edge of the V-shape from 60S to 60N is eliminated. The daytime  $R'_{clear}$  values are consistent with the nighttime  $R'_{clear}$  at the day/night orbit segment endpoints, but remain higher over mid-latitudes. Overall, the daytime  $R'_{clear}$  values are within ten percent of the nighttime values. Further work to bring the daytime  $R'_{clear}$  within closer agreement with the nighttime  $R'_{clear}$  is planned as future work.

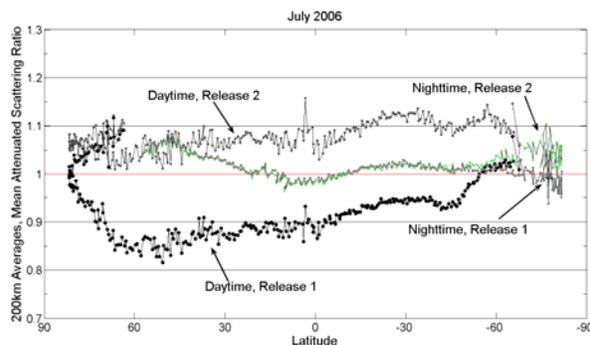


Figure 5. July 2006 nighttime and daytime  $R'_{clear}$  for Releases 1 and 2.

Improvements to 532 nm daytime calibrations are directly evident in the of the Level 2 data products. Figure 6 contains CALIOP measurements over Eastern Europe and Saudi Arabia. An aerosol layer from the surface to 5 km extends across most of the image. A long stretch of clear air lies above the layer from 11.6N to 35.97N. Profiles of attenuated scattering ratio (Release 1 and 2) averaged over approximately 2000 km (within rectangle of Figure 6) are displayed in Figure 7. Within the clear air region (above 5 km), the Release 1 averaged attenuated scattering ratios are less than 0.8. For the same region, the Release 2 averaged attenuated scattering ratios are greater than 0.9. The result of this improvement can be seen in the Level 2 layer detection results. Figure 8 contains the Lidar Level 2 Vertical Feature Mask (VFM) results using Release 1 data. The aerosol layer (colored orange) is almost entirely missed for this scene because the signal falls below the detection threshold of the layer detector. Figure 9 contains the VFM results for the same scene, except using Release 2 data. In this case, the aerosol layer is detected for the entire scene.

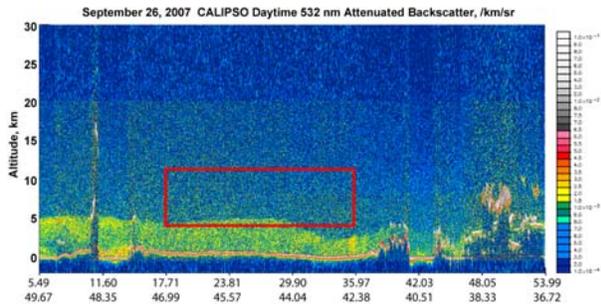


Figure 6. CALIOP measurements of clear air over Eastern Europe and Saudi Arabia.

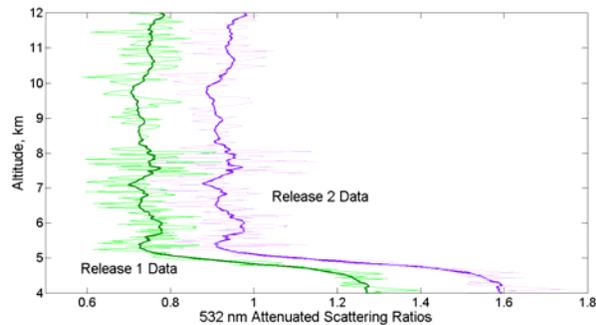


Figure 7. Release 1 and 2 attenuated scattering ratio profiles for region within rectangle in Figure 6.

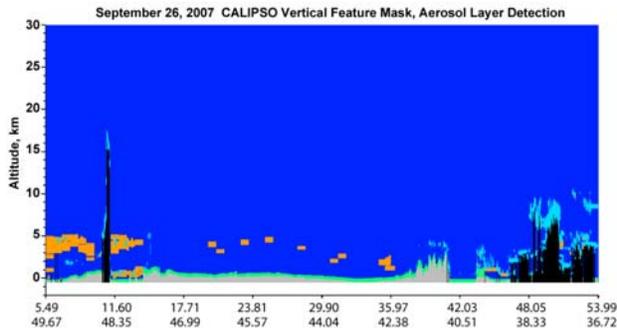


Figure 8. CALIOP lidar level 2 aerosol layer detection results using Release 1 lidar level 1 data (see Figure 6).

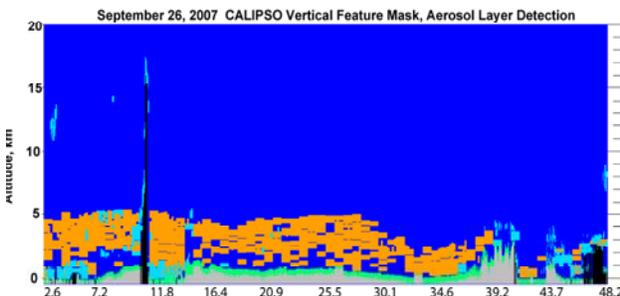


Figure 9. CALIOP lidar level 2 aerosol layer detection results using Release 2 lidar level 1 data (see Figure 6).

## SUMMARY

An assessment of the 532 nm parallel channel nighttime and daytime calibration for both Release 1 and 2 of the CALIOP data was performed using attenuated scattering ratios in clear air regions between 8 km to 12 km altitude range. The results showed that the nighttime calibration scheme implemented in Release 1 of the CALIOP data produced favorable results. However, the daytime calibration scheme implemented in Release 1 over estimated the calibration coefficients. Thermally-induced misalignments of the laser transmitter and receiver reduced the signal magnitudes during the daytime, and the assumptions made in Release 1 to transfer the nighttime calibration coefficients to the daytime were no longer valid. The errors in daytime calibration were identified by observing how the mean attenuated scattering ratios changed over the course of the daytime orbits. Mid-way through the daytime orbit segments, the daytime mean attenuated scattering ratios were up to 30% lower than the nighttime values. Correction Factors were derived using the minimum mean attenuated scattering ratios as a function of time. The Correction Factors were implemented in the Release 2 daytime calibration scheme. The Release 2 daytime mean attenuated scattering ratios are within ten percent of the nighttime.

## REFERENCES

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- [3] Lee, K., M. Vaughan, Z. Liu, W. Hunt, K. Powell, 2008: Revised Calibration Strategy for the CALIOP 532 nm Channel: Part I – Nighttime, *current proceedings*.
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