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CALIOP CALIBRATION: VERSION 4.0 ALGORITHM UPDATES

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ABSTRACT

The Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP) lidar, onboard the Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) satellite, has been providing a near continuous record of high-resolution vertical profiles of clouds and aerosols properties since the summer of 2006. Key to the generation of these vertical profiles is proper calibration of the 532 nm and 1064 nm channels. This abstract summarizes improvements to the calibration techniques used to calibrate the 532 nm and 1064 nm signals for the recent version 4 (V4) Lidar Level 1 data release.

1. INTRODUCTION

Because of differences in signal-to-noise ratios and intra-orbit thermal stability, CALIOP uses different techniques to calibrate the 1064 nm measurements and the 532 nm daytime and nighttime measurements. The 532 nm nighttime calibration procedure [1] uses a high-altitude molecular normalization technique [2] in which the calibration is determined by taking the ratio of the measured signal to the expected signal computed using an atmospheric model. This approach assumes that all constituents of the nighttime normalization region (i.e., including aerosol loading) can be accurately modeled or characterized. Unfortunately, the same technique cannot be used during daytime, because the signal-to-noise ratio (SNR) is not sufficient due to the influence of background solar radiation. Instead, the 532 nm daytime calibration coefficients are derived by matching the daytime 'clear air' scattering ratios (i.e., the ratio between measured backscatter and modeled molecular signal) to previously calibrated nighttime clear air scattering ratios measured at the same latitude. For the version 3 (V3) data, the clear air calibration transfer region was located between 8 km and 12 km globally [3]. Similarly, the 1064 nm channel does not have sufficient molecular backscatter to allow referencing to clear air at high altitudes, so instead, a scale factor is computed to match the 1064 nm signals from dense cirrus clouds to the corresponding 532 nm signals, with the assumption that the 1064 nm/532 nm particulate backscatter ratio should be close to 1. The 1064 nm calibration coefficient is then the product of this 1064 nm scale factor and the previously determined 532 nm calibration coefficient [4].

The new calibration techniques used for V4 retain the underlying scientific basis established in V3, but with several key modifications. For the 532 nm nighttime calibration, the height of the calibration altitude was increased from 30-34 km to 36-39 km in order to mitigate the influence of stratospheric (volcanic) aerosols [5]. The 532 nm daytime continues to match day to night scattering ratios in a calibration transfer region, but now this region has been raised to a higher altitude in V4 to avoid clouds and increase the number of samples used in calculating daytime calibration coefficients. The V4the transfer region is still 4 km deep, but it now follows the 400K isentropic surface which is typically between 13-18 km, always above the tropopause and above the meteorologically active part of the atmosphere [6], thus better satisfying the assumption that there is no diurnal variability of the scattering ratios in the transfer region. For the 1064 nm calibration, the scale factors are in V4 calculated and applied as a function of the granule elapsed time, to better represent the relative variations of the 532 nm and 1064 nm signals along daytime or nighttime orbit segments. The criteria for selecting the dense cirrus clouds that are used in the scale factor calculation have also been changed significantly.

2. AVERAGING & ERROR MITIGATION

To compensate for the significant reduction in the SNR at the higher calibration altitude regions, the number of orbits required for calibration was increased. To keep the random uncertainty at or below standards established in the V3 release requires averaging nighttime data over 11 orbits and daytime data over 105 orbits (~7 days). The increase in the number of orbits applied also compensates for nighttime signal spikes due to the South Atlantic Anomaly.

3. 532 NM NIGHTTIME RESULTS

Figure 1 shows nighttime monthly mean 532 nm calibration coefficients for October 2010 computed for version 3 (left) and for the V4 algorithm (right). In the V3 the presence of the stratospheric aerosol layer in the tropics is clearly visible as a region of high calibration coefficients located between the equator and 20°N. The South Atlantic Anomaly (SAA) is also visible as an oval of reduced calibration coefficients centered at ~20°S and ~40°W. By contrast, neither of these geophysical features appears in the V4 data. In both images, the diminution of the calibration coefficients in the southern hemisphere, as the satellite approaches the night-to-day terminator, indicates changes in the on-board thermal environment that perturb the alignment between the laser transmitter and receiver.

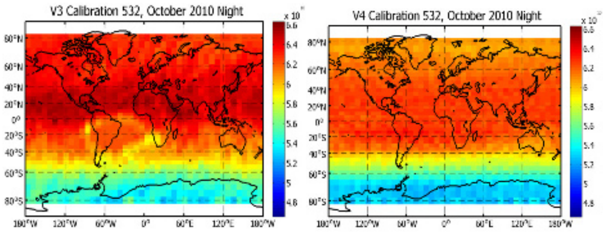

Figure 1: 532 nm night-time calibration for V3 (left) and V4 (right) for October 2010.

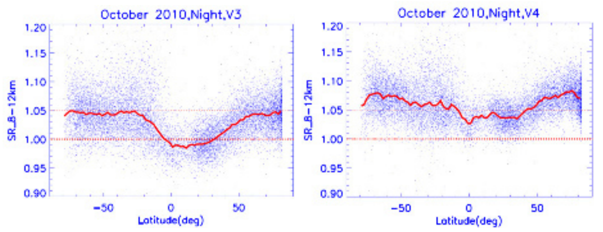

Figure 2: 532 nm night-time scattering ratios derived from clear-air at 8-12km for version 3 (left) and version 4 (right) for October 2010.

The median reduction in the calibration coefficients from V3 to V4 is ~3%. This in turn leads to an increase in the total attenuated backscatter coefficients by the same amount. The attenuated scattering ratios in the 30–34km region are now increased by up to 5% over previous versions, indicating seasonal variations which are consistent with the independent predictions [4]. Stratospheric aerosol loading at these altitudes is now clearly captured by CALIOP measurements, showing up as spatial structures which are consistent with stratospheric dynamics. Similarly, the clear-air scattering ratios at 8–12 km showed an anomalous dip (scattering ratios < 1) in the tropics in V3 (figure 2, left), and are all correctly greater than one in V4 (figure 2, right).

4. 532 NM DAYTIME RESULTS

In the V3 release, the agreement between day and night clear-air attenuated scattering ratios at high altitudes was poor and varied with latitude, possibly due to diurnal variability in aerosol loading and clouds reducing the potential number of clear-air samples in the 8-12km V3 calibration transfer region (figure 3, top). V4 (figure 3, bottom) shows a marked improvement in the agreement between day and night clear-air attenuated scattering ratios above the V4 calibration transfer region (to within 1 ± 3%), demonstrating (1) the validity of assuming that there is no diurnal variability in stratospheric aerosol loading at these altitudes, (2) that the day/night agreement of clear-air attenuated scattering ratios holds even above the night to day calibration transfer region where they are forced to agree, and (3) the V4 calibration procedure adjusts for differences in day and night instrument behavior.

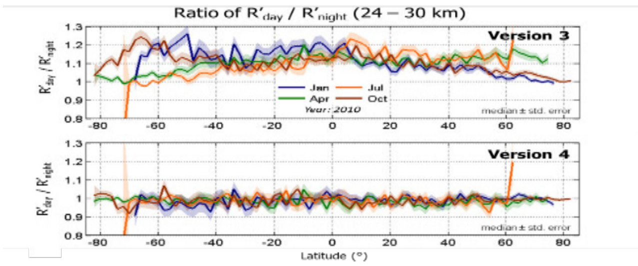

Figure 3: ratio of day to night clear-air attenuated scattering ratios at 24-30km for V3 (top) and V4 (bottom) for January, April, July and October 2010. The South Atlantic Anomaly has been excluded.

Figure 4 shows the 532 nm daytime calibration (top) and ratio between V3 and V4 (bottom) over 79 months. Discontinuities in the data reflect those instances when calibration could not be performed due to a change of state of the instrument (e.g., bore-sight alignments) or when there was an appreciable gap in the data record (e.g., solar flares). Seasonal differences in V3/V4 calibration at high latitudes are attributable to differences in anchoring neighboring day-to-night orbits.

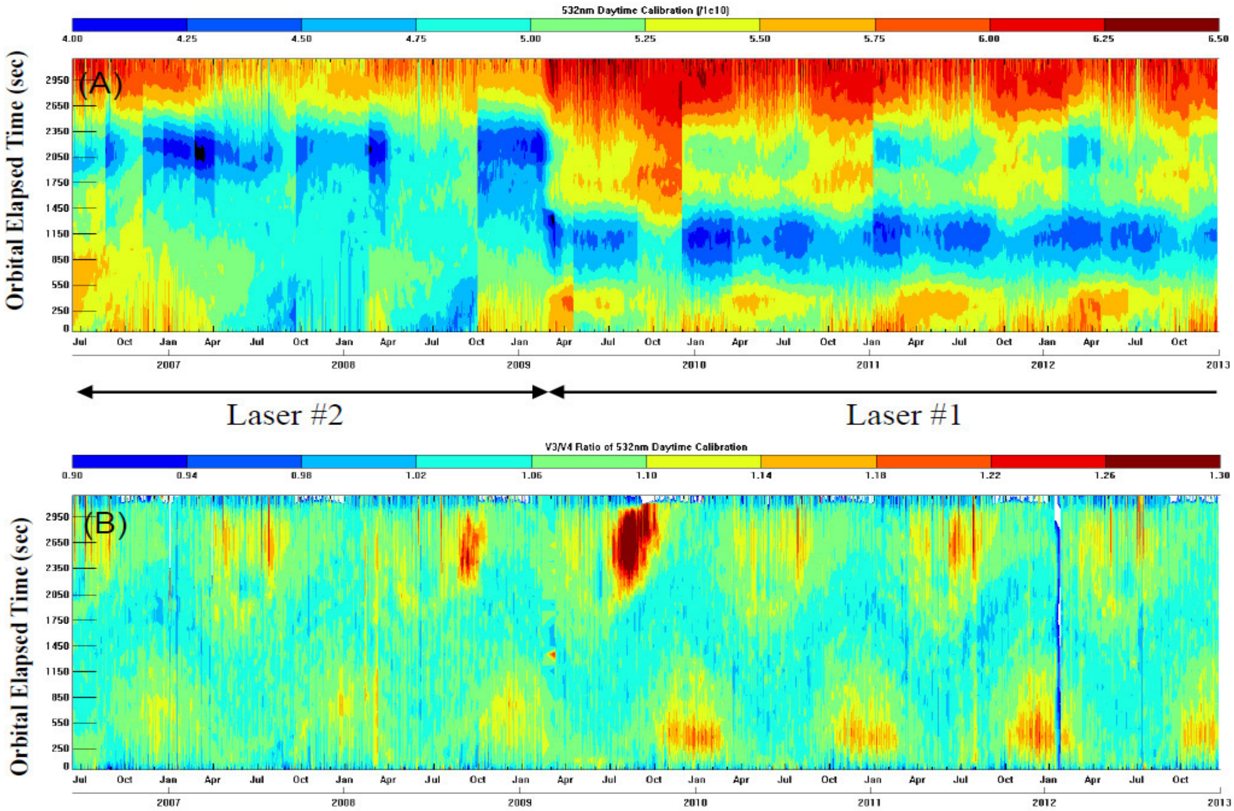

Figure 4: 532 nm daytime calibration (top) and Version 3 / Version 4 ratio of 532 nm daytime calibration from June 6, 2006 to December 31, 2012.

5. 1064 NM RESULTS

Figure 5 illustrates the changes in the 1064 nm scale factor between V3 (left) and V4 (right) for both nighttime data (top row) and daytime data (bottom row) for the month of October 2010. The V3 scale factors show a large discontinuity between the very high night-time values and the very low day-time values, along with abrupt changes in value between adjacent orbit segments. The V4 scale factors, on the other hand, vary smoothly as a function of orbit elapsed time, with continuous values at both terminators. The magnitudes of the changes from V3 to V4 in the nighttime mean scale factors range between 20% lower (northern hemisphere) to 7% higher (southern hemisphere), with the median nighttime difference being 6% lower. The daytime mean scale factors range between 14% lower (northern hemisphere) to 19% higher (southern hemisphere), with the median daytime difference being 3% lower. Figure 6 illustrates the changes in the 1064 nm calibration coefficients between V3 (left) and V4 (right) for both nighttime data (top row) and daytime data (bottom row) for the month of October 2010.

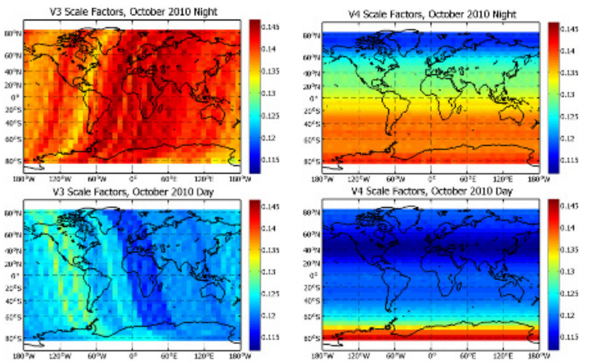

Figure 5: Monthly mean 1064 nm calibration scale factors for October 2010, with V3 shown on the left and V4 on the right. Upper panels show nighttime data; lower panels show daytime data.

The data in the top row of Figure 6 represents the 532 nm nighttime calibration coefficients shown in Figure 1 multiplied by the nighttime 1064 nm calibration scale factors shown in the top row of Figure 5. Similarly, the data in the bottom row of Figure 6 represents the 532 nm daytime calibration coefficients shown in Figure 1 multiplied by the daytime 1064 nm calibration scale factors shown in the bottom row of Figure 5.

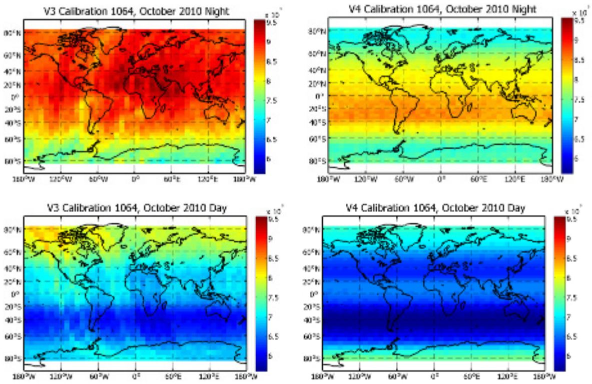

Figure 6: Monthly mean 1064 nm calibration coefficients for October 2010. V3 calibration coefficients are shown on the left; V4 calibration coefficients are shown on the right. The upper panels show nighttime data and the lower panels show daytime data

The V3 1064 nm calibration coefficients exhibit spatial artifacts and irregularities that arise from both the V3 532 nm calibration coefficients and from the V3 1064 nm scale factors. In contrast to the V3 data, the V4 1064 nm calibration coefficients produced by the new calibration and scale factor algorithms are seen to vary smoothly both latitudinal and longitudinally. The magnitudes of the changes from V3 to V4 in the nighttime mean 1064 nm calibration coefficients range between 22% lower (northern hemisphere) to 8% higher (southern hemisphere), with the median nighttime difference being 8% lower. The daytime mean 1064 nm calibration coefficients range between 20% lower (northern hemisphere) to 10% higher (southern hemisphere), with the median daytime difference again being 8% lower.

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