CALIPSO LIDAR PERFORMANCE TRENDS OVER THE FIRST TWENTY MONTHS

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ABSTRACT

The CALIPSO Lidar (CALIOP) has been making backscatter measurements almost continuously since it began on-orbit operation in June 2006. After twenty months in orbit, the lidar continues to perform well and produce high quality science data products. Trend plots show no unexpected degradation in any critical parameter values. The main performance issues that have shown up are alignment stability during the daytime, unexpected color ratio behavior, and radiation-induced noise from the 532 channel detectors. None of these are show stoppers, though they do require special treatment during data processing.

1. INSTRUMENT DESCRIPTION

The CALIPSO (Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations) satellite [1] was launched on April 28, 2006 into a sun-synchronous orbit with 98° inclination and 705 km altitude. The primary payload instrument is CALIOP (Cloud-Aerosol Lidar with Orthogonal Polarization), a three-channel lidar making polarization-insensitive backscatter measurements at 1064 nm and polarization-sensitive backscatter measurements at 532 nm. The detectors are photomultipliers (PMTs) for the two 532 nm channels, and an avalanche photodiode (APD) for the 1064 channel.

2. PERFORMANCE TRENDS

2.1 Laser Energy

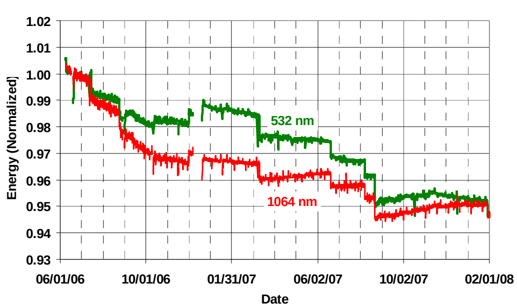

Figure 1 Laser Energies - June 2006 to February 2008

With no tuning or adjustments since June 2006, the energy has remained within 94% of its original value (Figure 1).

Most of the energy decrease after the first few months has resulted from individual diode bar dropouts. Such occasional bar dropouts are considered normal.

2.2 Signal-To-Noise Ratio (SNR)

The most critical SNR value is that of the 532 parallel channel at night in the 30-34 km altitude region, where the primary system calibration measurements are made.

When measured soon after activation, the 532 parallel channel nighttime SNR was more than 50% above its requirement (except in the South Atlantic Anomaly which will be the subject of a later discussion). Twenty months later, the SNR has only decreased by a little more than 6% (Figure 2).

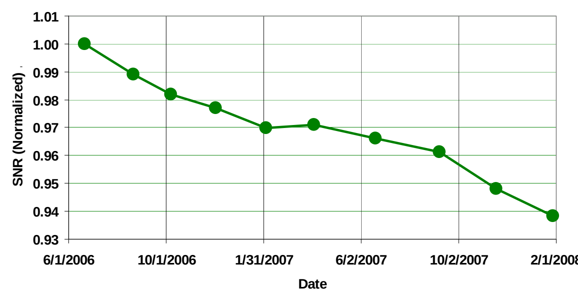

Figure 2 532 parallel channel SNR at night - June 2006 to February 2008

The other channels also continue to comfortably exceed their requirements, both day and night. The SNR of the 1064 channel was expected to decrease more rapidly than that of the 532 channels, due to increased dark noise caused by cumulative radiation damage to the APD. After twenty months, the 1064 channel daytime SNR has decreased by about 25%, but it still is a factor of two above its requirement.

2.3 Calibration Coefficients – 532 Parallel Channel at Night

The primary calibration is derived from the 532 parallel channel signal at night at high altitude. The other channels and the daytime calibrations are referenced to the primary calibration. Since this calibration is normalized by the laser energy, the value of the calibration coefficient is a good indicator of the receiver performance.

After twenty months, the 532 channel night calibration coefficient has decreased by about 12% (Figure 3).

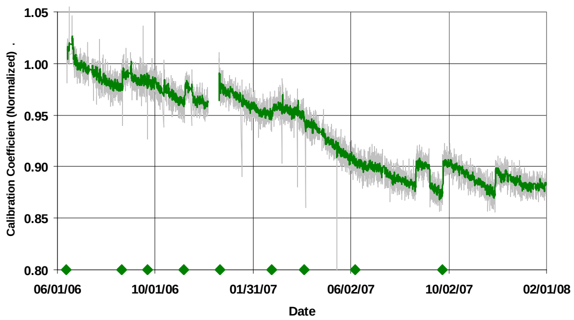

Figure 3 532 Channel Night Calibration Coefficient - June 2006 to February 2008. Diamonds across the bottom indicate the times that boresight alignments were done.

The primary contributors to a gradual long-term decrease in this quantity are optical contamination and PMT aging. Short-term changes are associated with boresight alignments and other operations.

2.4 Polarization Gain Ratio

The polarization gain ratio is defined as the 532 perpendicular channel signal divided by the 532 parallel channel signal when the two channels are receiving equal optical signals. This quantity is used, along with the 532 parallel channel calibration, to derive the 532 perpendicular channel calibration.

The polarization gain ratio is determined by inserting a depolarizing element into the optical beam, causing equal optical signals to fall upon the detectors of the two 532 channels. The ratio of the two signals is then the gain ratio.

A polarization calibration has been done every few months (Figure 4). After an initial small drop, the measured polarization gain ratio increased by about 6% over the first year, and has remained relatively constant since that time

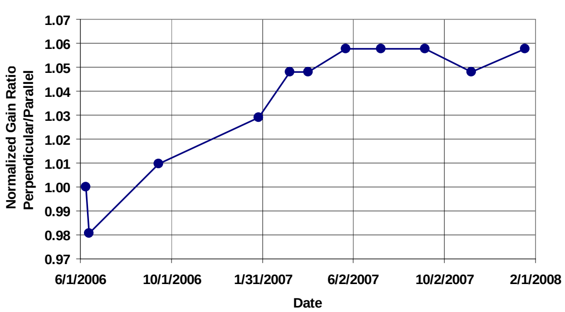

Figure 4 Polarization Gain Ratio - June 2006 to February 2008

2.5 Polarization Cross-Talk

With sufficient averaging, CALIOP can make a measurement of the depolarization ratio of clear air. The difference between the measured value and the true value (approximately 0.35% when measured at the bandwidth of the CALIOP optical filters) sets an upper limit on the amount of total polarization crosstalk in the lidar.

Clear air depolarization measurements early in the mission gave values around 0.6%, indicating crosstalk on the order of 0.3%, an outstanding result. Later the measured value abruptly jumped to about 0.9%, still an excellent result. Values since that time have made several abrupt jumps between these two values (Figure 5). The abrupt jumps always seem to occur when the lidar is restarted after a period in Safe mode (e.g. after an orbit correction maneuver). Their cause is not known.

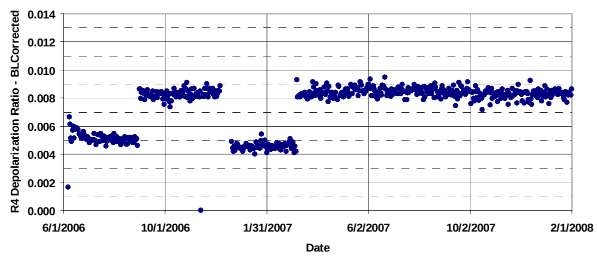

Figure 5 Clear air depolarization ratio - June 2006 to February 2008

2.6 Boresight Aligned Positions

CALIOP incorporates an active boresight mechanism (ABM) which can adjust the laser pointing direction to maximize the backscatter signal. Boresight alignment operations are done upon command, and only at night.

Boresight alignments have been done every few months. The aligned position has been gradually drifting, and is currently about 42 microradians away from the initial on-orbit aligned position (Figure 6).

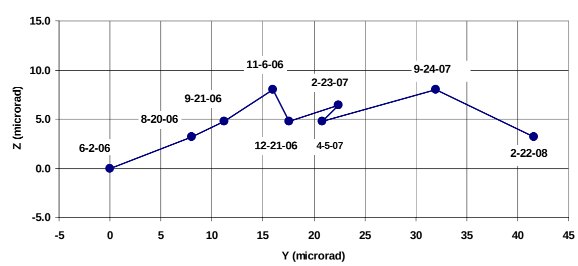

Figure 6 Boresight aligned positions - June 2006 to February 2008

2.7 Laser-to-Etalon Wavelength Matching

The CALIOP receiver incorporate an etalon optical filter in the 532 nm channels. The etalon passband is similar to the laser line width, and the two wavelengths must be closely matched by adjusting the temperature of the etalon. There is no active feedback between the laser and the etalon.

The etalon temperature was optimized soon after launch, and was not adjusted again until February 2008. An etalon temperature scan at that time revealed that the etalon center wavelength had become mismatched by about 7 picometers with respect to the laser, causing the backscatter signal to be a little more than 5% below optimum. The etalon temperature was subsequently reset to the new optimum temperature.

3. CALIBRATION ISSUES – 532 CHANNEL DAYTIME

The daytime 532 channel calibration must be based upon the measured nighttime values because the SNR is inadequate to calibrate during the daytime using high altitude molecular signals. The calibration algorithm originally used in the data processing was based upon the assumption that the calibration coefficient does not change between night and day. Subsequent careful analysis shows that the daytime calibration coefficient differs from the nighttime value by as much as 30% during some times of the year (Figure 7). Integrated modeling done by Ball Aerospace & Technologies Corp., the prime contractor for the lidar, supports the assumption that the daytime change is a result of thermally-induced misalignment [2]. The amount of misalignment is a function of both the time of day and the time of year.

Once the daytime behavior was characterized, a new daytime calibration algorithm was developed and incorporated into version 2 processing software, giving greatly improved results.

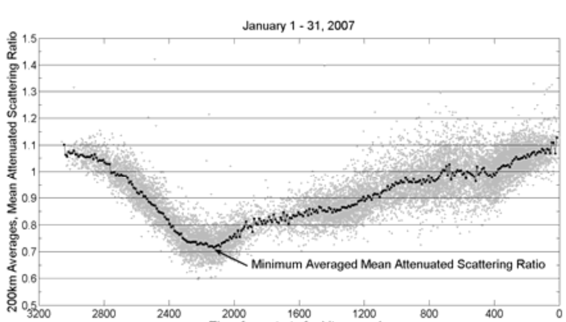

Figure 7 532 channel daytime scattering ratio as a function of time after the start of the orbit segment—January 2007

4. CALIBRATION ISSUES – 1064 CHANNEL DAY AND NIGHT

For the 1064 channel, the SNR is insufficient to calibrate using a high altitude molecular signal, even at night. As an alternative, the 1064 channel calibration is also based upon the 532 channel nighttime calibration. The scale factor between the two channels is derived from measurements of the backscatter from upper tropospheric cirrus clouds, using the assumption that the color ratio (1064 backscatter / 532 backscatter) for such clouds is a constant.

Analysis of color ratio data from the first part of the mission does not appear to support that assumption. It appears that the measured color ratio, both night and day, has a latitudinal dependence, with the ratio at northern latitudes being smaller than it is at southern latitudes (Figures 8 and 9).

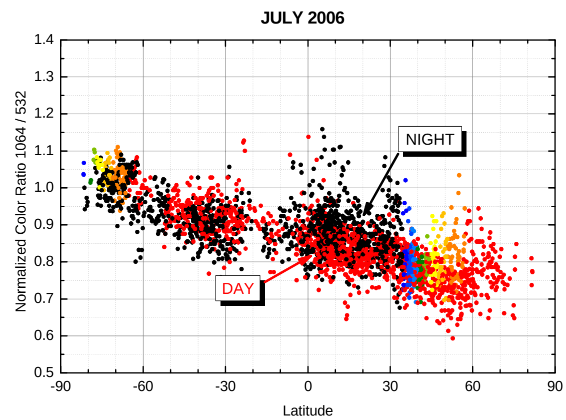

Figure 8 Color ratio (1064/532) for raw signals as a function of latitude in July. In July there is only a small difference between day (red) and night (black).

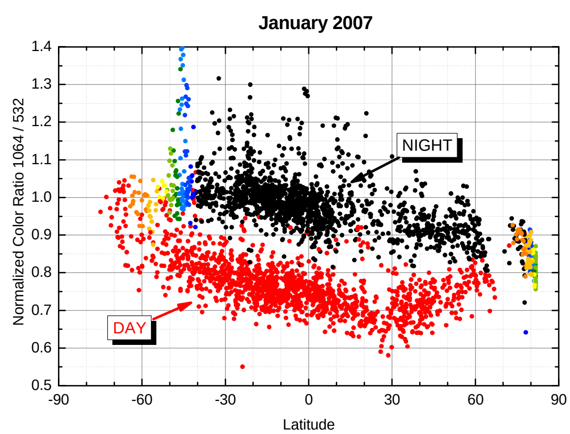

Figure 9 Color ratio (1064/532) for raw signals as a function of latitude in January. In January there is a large difference between day (red) and night (black).

Secondly, it appears that the measured color ratios in the daytime differ from those at night, with the difference being a function of both latitude and time of year. This is similar to the day/night difference seen in the 532 channel signals, but the change in the 1064 signal must be different from that in the 532 signal, since the ratio of the two signals changes.

5. RADIATION-INDUCED DETECTOR NOISE

The PMTs on the 532 channels occasionally produce large current spikes that appear to be the result of encounters with cosmic radiation. The spikes are most frequent when passing through the South Atlantic Anomaly (SAA). Such radiation encounters are not unexpected at CALIPSO's 705 km orbit.

The effect of the current spikes can clearly be seen in a global plot of the RMS dark noise from the parallel channel PMT (Figure 10).

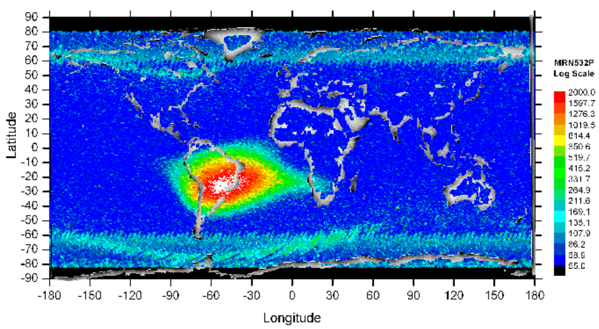

Figure 10 Geographic distribution of PMT dark noise for 16 days in April 2007 (covering all possible orbit tracks). The increased noise in the SAA can be seen clearly, along with smaller noise increases in belts around the two poles. The lighter colored horizontal bands near ±65° latitude are from scattered sunlight.

One obvious result of the increased dark noise in the SAA is a corresponding decrease in SNR. For the 532 parallel channel, the night SNR drops from approximately 80 outside the SAA to about 15 at the center of the SAA.

Another undesirable effect of the noise spikes is a noticeable bias in the signal average for any averaging interval that includes a large noise spike and few photons.

The data processing algorithms include special provisions to minimize the effects of the noise spikes. When possible, the larger spikes are removed from the data prior to processing. When the noise level becomes too high to give reliable calibration data (as it frequently does in the SAA), an alternate calibration algorithm based upon historical data is used.

Though the noise spikes require some additional effort in data processing, the overall effect on the final data products is fairly small.

6. SUMMARY

In nearly all respects, CALIOP performance was outstanding at the beginning of the mission, and has remained so up to this time. No unexpected performance degradation has occurred in any area, though some problems have been discovered with respect to daylight stability and radiation-induced noise. Algorithm changes have been implemented to deal with these problems, and their effect on the final data products is relatively small.

REFERENCES

[1] Winker, D. M., J. Pelon, and M. P. McCormick, 2003: The CALIPSO mission: spaceborne lidar for observation of aerosols and clouds, *Proc. SPIE*, 4893, pp. 1-11.

[2] M. Lieber, C. Weimer, M. Stephens, R. Demara: .Development of a validated end-to-end model for spacebased lidar systems., in SPIE vol 6681, U.N.Singh, Lidar Remote Sensing for Environmental Monitoring VIII, Aug 2007.