# CALIPSO Lidar Performance Over The First Three Years

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## INTRODUCTION

After three years in orbit and a switch to the backup laser, the overall performance of the CALIPSO lidar remains very close to what it was at the start of the mission (i.e. excellent).

This poster presents some performance information that is new since the last CALIPSO Science Team Meeting.

## LASER SWITCH

During testing prior to launch it was discovered that the canister of the CALIPSO primary laser (LOM2) had a slow leak, and it was anticipated that the pressure would drop low enough to necessitate a switch to the backup laser (LOM1) near the end of the prime (three-year) mission. After monitoring the on-orbit pressure for a sufficient time, a switch to the backup laser was scheduled for around the first of March, 2009, at which point the pressure was expected to be about a factor of two above the point at which corona discharges of the high voltage within the canister should occur..

The backup laser was activated on March 9, 2009, as scheduled, and routine operations with that laser began on March 17, 2009. Operations with the primary laser were terminated on February 16, 2009, somewhat earlier than had been anticipated, because that laser had become increasingly erratic in its operation. It is believed that the erratic operation over the last month of operation was the result of corona discharges or arcing that began occurring at a higher pressure than had been anticipated. An error in one of the dimensions between high voltage terminals was the probable cause of the incorrect estimate.

Except for short periods when there were many low (or zero) energy shots, sometimes resulting in a payload shutdown, the primary laser continued to produce acceptable average energy and good science results up until its operation was terminated, in spite of the so-called "laser spikes" (low energy shots) that were occurring with increasing frequency.

### PERFORMANCE OF THE BACKUP LASER

Activation of the backup laser went smoothly and with no surprises. The energies were easily adjusted to values similar to the initial values for the primary laser. Boresighting and etalon adjustment were readily accomplished, with the final parameters being within the expected range. All key performance parameters were quite good:

- The 532 nm signal level and SNR were equal to what they had been with the primary laser at the beginning of the mission, indicating that the beam expander was functioning properly and the divergence and line width were similar to those of the primary laser.
- The clear air depolarization measurement gave very low results, as had been the case with the primary laser, indicating excellent polarization purity and correct alignment of the polarization axis.
- No "laser spikes" or other anomalies have been observed with the backup laser after four months of operation.
- There were four diode bar drops in the first three months of operation, but none in more than a month since then (occasional bar drops are expected).

## NEW SNR MEASUREMENTS

A much more comprehensive set of Signal-to-Noise Ratio (SNR) measurements have been done, allowing compliance with all requirements to be verified and trend plots to be generated, including some cases of interest for which there are no requirements.

### SOME SPECIAL CONDITIONS TO BE CONSIDERED

All SNR measurements were done at night outside the SAA, and daytime values were derived from the night measurements by computing the effect of the specified amount of daylight background on the SNR. This approach must be supplemented by including the effects of two special conditions:

**Special Condition 1: Increased 532 Channel Dark Noise in the SAA**

The SNR values for the trend plots were measured outside the SAA, where the PMT dark noise is low enough to have only a minor influence on the SNR, even at 30 km. However, upon passing through the SAA the dark noise increases markedly (Figure 1), reaching a value at which it is a significant factor in the SNR at high altitude at night. However, even at the higher value in the SAA the dark noise remains a relatively insignificant factor in daylight, or with larger backscatter signals.

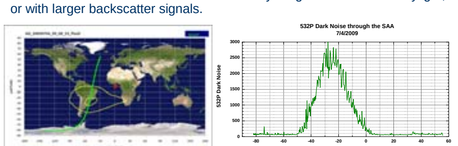


**Figure 1 Increased PMT Dark Noise in the SAA**

**Special Condition 2: Thermal misalignment in the daytime**

As has been discussed in previous science team meetings, the backscatter signal drops to as low as 70% of its nighttime value at certain points in the daytime at certain times of the year. This causes a corresponding drop in the SNR.

## SNR – 532 Parallel Channel at night

The payload statement of work (SOW) includes the following requirement for the 532P channel at night.

| Channel | Lighting | SNR Requirement | Target | Altitiude (km) | Bksct Coeff ($km^{-1}sr^{-1}$) | Horiz Res (km) | Vert Res (km) |
|---|---|---|---|---|---|---|---|
| 532 Parallel | Night | 50 | Rayleigh | 30 | 2.39E-5 | 1500 | 5 |

This requirement flows from the need to perform the primary lidar calibration using the high altitude 532P signal at night. Such a calibration is necessary in order to carry out the scientific measurement requirements that flow from the science objectives.

Figure 2 shows the SNR for this case measured outside the SAA at various times throughout the mission (curve at top), with some key events labeled. The value required by the SOW is shown as a dashed line. The single diamond near the bottom center shows the result of a spot check of the SNR with dark noise of 2500, corresponding to the center of the SAA.

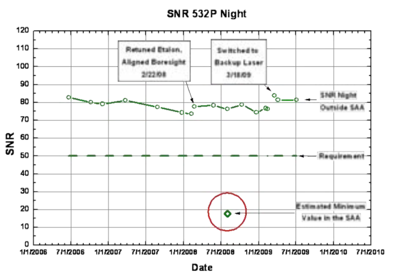


**Figure 2 532P SNR at Night**

The SNR outside the SAA satisfied the SOW requirements with at least 50% margin at all times. There was little loss of SNR as the mission progressed, even in the presence of "laser spikes" during the latter portion of the primary laser operation. With the switch to the backup laser, the SNR returned to its value at the beginning of the mission.

However, the SNR in the middle of the SAA is well below the requirement , necessitating the use of historical calibration constants in some instances when the signal is too noisy to make accurate new calibration measurements. The loss of calibration accuracy resulting from this procedure is thought to be fairly minor.

## SNR-532 Parallel Channel in the Daytime

The SOW includes the following requirement for the 532 Parallel channel in the daytime.

| Channel | Lighting | SNR Requirement | Target | Altitiude (km) | Bksct Coeff ($km^{-1}sr^{-1}$) | Horiz Res (km) | Vert Res (km) |
|---|---|---|---|---|---|---|---|
| 532 Parallel | Daytime | 10 | Rayleigh | 1 | $1.45 \cdot 10^{-3}$ | 33 | 1 |

This requirement is taken directly from the scientific measurement requirements that flow from the science objectives.

Figure 3 shows the daytime SNR values derived from the night measurements (top curve), and those for backscatter signals that are 70% of the daytime values. These two curves should bound the SNR as the lidar goes through the day. Also shown as diamonds are the corresponding values in the center of the SAA, which are very close to the values outside the SAA. The dashed line is the requirement.

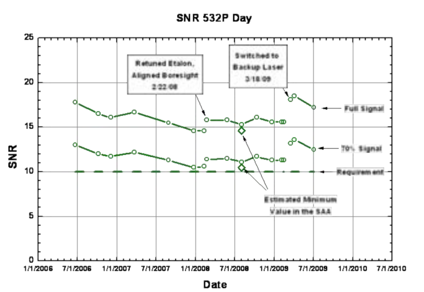


**Figure 3 532P SNR in the Daytime**

The daytime SNR always met the requirement, though only barely so in the worst case.

## SNR-532 Perpendicular Channel

The SOW requirement for the 532 Perpendicular channel SNR is as follows:

***The 532 Perpendicular channel must satisfy the same SNR requirements as the 532 Parallel channel when illuminated with the same signal and background.***

This requirement encompasses, but is somewhat more stringent, than the one that flows from the science objectives.

Measurements of the SNR during polarization calibration operations, where the optical signals on the two 532 channels are equal, show that this requirement is being met. Thus all the trend plots shown for the 532 Parallel channel also can be applied to the 532 Perpendicular channel.

## SNR – 1064 Channel, Night and Day

The SOW includes the following requirement for the 1064 channel in the daytime.

| Channel | Lighting | SNR Requirement | Target | Altitiude (km) | Bksct Coeff ($km^{-1}sr^{-1}$) | Horiz Res (km) | Vert Res (km) |
|---|---|---|---|---|---|---|---|
| 1064 nm | Daytime | 5 | PBL | 1 | $1.00 \cdot 10^{-3}$ | 50 | 1 |

This requirement is taken directly from the scientific measurement requirements that flow from the science objectives. There is no night requirement for this channel.

Figure 4 shows the measured night SNR trend (included for information, even though there is no requirement), along with the day SNR at full signal, the day SNR at 70% signal, and the day requirement. There are no points shown for the SAA because the effect on the 1064 channel is negligible.

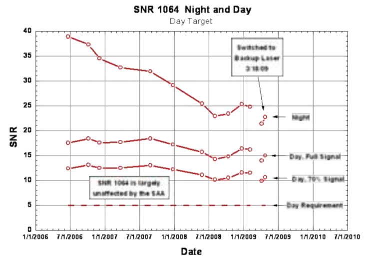


**Figure 4 1064 SNR Night and Day**

The day SNR continues to be at least a factor of two above the requirement, even though there has been a gradual decrease because the APD on this channel has experienced gradually increasing dark noise as a result of cumulative radiation damage (as expected). The effect of the increased dark noise is much more evident at night than in the day.

## SNR FOR CIRRUS CALIBRATION TARGETS

Since the 1064 channel is currently calibrated by comparing cirrus cloud returns for the 532 and 1064 channels, it is useful to show the cirrus cloud SNR trend, even though there no requirement has been defined. For the purpose of trending, we define the following targets.

| Channel | Lighting | SNR Requirement | Target | Altitiude (km) | Bksct Coeff ($km^{-1}sr^{-1}$) | Horiz Res (km) | Vert Res (km) |
|---|---|---|---|---|---|---|---|
| 532 Parallel Or 1064 | Night or Day | None Specified | Cirrus clouds | 10 | 2.7E-2 (Scatt ratio = 50 at 532 nm) | 10 | 0.15 |

Figure 5 shows the Night, Day, and 70% Day SNR trends for the 532P Channel, and Figure 6 shows the same plots for the 1064 channel. The SAA effect is negligible for either channel.

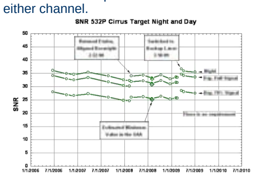


**Figure 5 532P SNR for Cirrus**

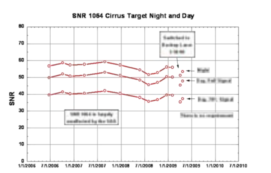


**Figure 6 1064 SNR for Cirrus**

Since there is no requirement for this case, the only observation is to note that the increasing dark noise has only a very minor effect on the 1064 channel SNR.