CALIPSO Laser Performance

Ron Verhappen[1], Chip Trepte[2], Jason Tackett[2], Sharon Rodier[3]

[1]Analytical Mechanics Associates, Inc., Hampton, VA, USA, Ron.verhappen@nasa.gov
[2]NASA Langley Research Center, Hampton, VA, USA
[3]ADNET Systems Inc., Bethesda,MD, USA

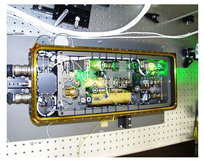
Acknowledgments: *Chris Hostetler, Floyd Hovis, Bill Hunt, Bill Luck, John Rogers, Dave Rosenbaum, John Stadler, Mark Vaughan, Carl Weimer, Dave Winker*

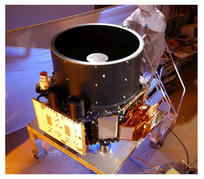
Introduction

CALIPSO was a highly successful spaceborne lidar mission that helped to transform an understanding of how clouds and atmospheric aerosols influence climate, weather and air quality. The mission operated for ~18 years (2006-2023), far beyond the notional 3-year lifetime of the payload. Here we report on the performance of the primary and redundant lasers that were at the heart of the mission's success.

Laser Specifications

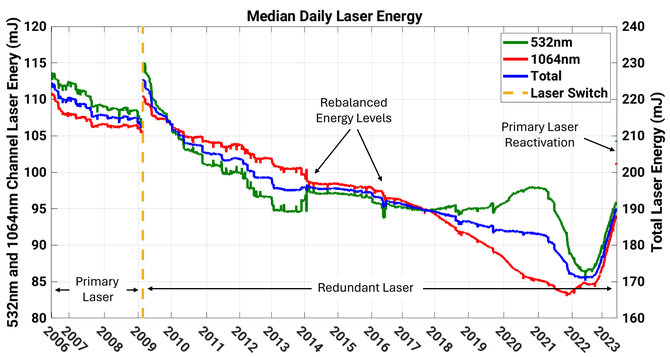
- Two Q-switched diode-pumped ND:YAG lasers built by Fibertek.
  - Each laser pumped by two banks of 192 diode bars
- Transmitted light at 532 and 1064 nm at 20.16 Hz.
- Nominal total pulse energy at laser start up: 220 mJ (~110 mJ/channel).
- Primary and redundant lasers housed in separate pressurized canisters (pressurized with dry air to ~18 psia (1.24 Bar)).
- Independent energy monitors sampled output laser pulse energy for each shot.
- Level 1 requirement for minimum total laser energy: 120 mJ.





Daily Median Energy Trends

- Primary laser operated for 32 months and maintained 90% of its total energy.
  - After initial tuning no adjustments were made to the laser.
  - The small step-wise drops in total energy were caused by the loss of individual diode bars (observed for both lasers).
  - The primary laser was deactivated in February 2009 because of operational issues with corona discharges at the Q-Switch (see section on low energy shots).
- The redundant laser was powered on in March 2009 and operated until June 2023
  - Two laser adjustments were made to rebalance the output of 532 and 1064 nm energy January 2014 and June 2016
  - The gradual decrease in total energy between 2014 and 2021 is consistent with overall degradation of laser performance.
  - The trends in the 523 and 1064 nm channels after 2018 are unexplained as the performance of the monitors are independent for one another and the trends are uncorrelated with changes in laser/monitor temperatures or diode voltage levels
  - The steady rise in total energy in 2023 is also unexplained.
- The primary laser was restarted on June 29, 2023, and operated for 3 days as an end-of-mission assessment (see section on restarting the laser).

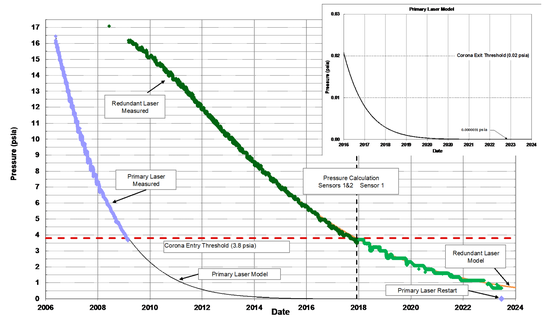


Laser Canister Pressure

The lasers were housed in sealed canisters with dry air to reduce concerns with possible contamination effects on the exposed optics with the operation the laser. Because of a slow leak in the canister of the primary laser prior to launch, it was selected for initial operations. Occasional low energy shots started occurring early in the mission and they became more frequent overtime and were correlated with decreasing pressure. The same behavior occurred with the redundant laser.

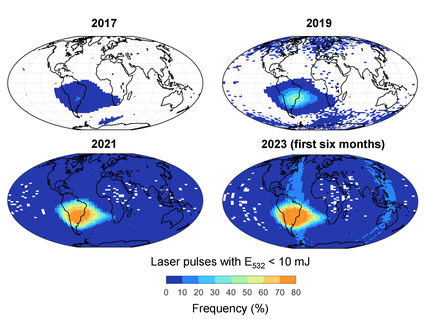
Daily Averaged Pressure Trends

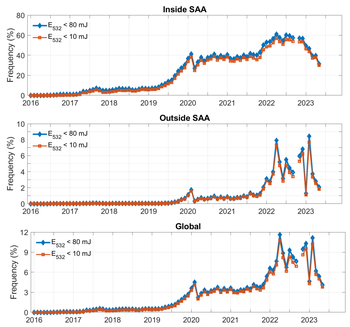
- Each laser contained to pressure sensors for pressure monitoring.
- Sensor Analog to Digital conversion optimized for measurements above 3.5 psi.
- Trends were estimated from measurements acquired during the first several months of operation for each laser and they indicated that the pressure loss was steady.
- The highlighted green regions indicate pressures at which corona discharges across the Q-Switch were likely below a value of 3.8 psia and above 0.02 psia.
- The inset displays predicted pressure trend for the primary laser while it was de-activated and suggested that the primary laser could be reactivated below the corona region starting in 2016.



Laser Low Energy Shots

- Corona discharges were expected to occur across the laser Q-Switch voltage terminals when pressure fell below 3.8 psia and affect the release of light for individual pulse shots.
- The observed magnitude of the reduced energy shots was correlated with decreased pressure.
- The occurrence of low energy shots were also correlated with regions and periods of enhanced energetic exo-atmospheric particle occurrence such as in the South Atlantic Anomaly (SAA) and polar regions, especially during periods of increased solar activity.
- The frequency of low energy shots impacted the calibration of the lidar algorithm and, eventually, the ability to average lidar shots for Level 2 data products.
- During the operation of the primary laser, the occurrence of corona discharges affected laser operations and a decision to switch to the redundant laser was made to reduce the impact on the operations staff. Later changes to the operation of the redundant laser was made to mitigate impacts to the mission operation staff.

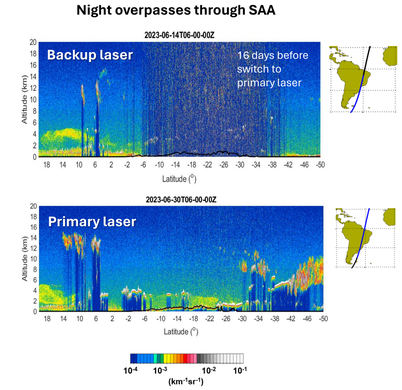




Reactivation of Primary Laser

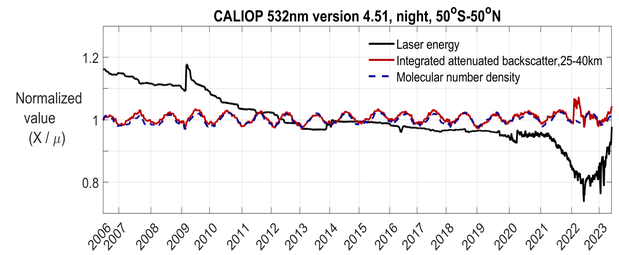
Prior to the planned end of science operations for the mission in August 2023, the primary laser was reactivated to examine several outstanding questions: 1) can a laser hibernate for a long period in space (**14** years) and operate successfully, and 2) could the primary laser operate in near vacuum conditions, and 3) would low energy shots disappear?

- The primary laser was reactivated on June 28, 2023.
- Total energy levels were very similar to levels in February 2009 prior to its deactivation.
- The revived laser exhibited no evidence of low energy shots and confirmed the hypothesis that the laser was operating outside the corona region.
- Moreover, there was no evidence that tin whiskers grew in an appreciable degree that could have shorted a large fraction of diodes.



Overall Lidar Performance

The stability of CALIOP measurements and robustness of calibration procedures is evidenced by the time series of global 532 nm integrated attenuated backscatter (IAB) from 25-40 km over the course of the mission. In this largely aerosol-free region of the atmosphere, the seasonal trend in IAB tracks that of molecular number density as expected. Despite the reduction in 532 nm laser energy and increased occurrence of low energy shots within the SAA since 2017, the IAB remains well behaved. Each time series above is normalized by its respective mean.



Summary

The CALIPSO mission was a hallmark of success that featured a reliable laser system. Of perhaps greater importance, yet of less visible appearance, was the strength of an enduring partnership between NASA and CNES that sustained the mission through unexpected challenges. We wish to recognize and express our gratitude to the many individuals and the institutions that contributed to the mission.