3.3 First Results from CALIOP

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1. INTRODUCTION

The CALIPSO satellite was launched on 28 April, 2006 and is now flying as part of the Afternoon Constellation (A-train). The CALIPSO mission was designed to provide unique measurements to improve our understanding of the role of aerosols and clouds in the Earth's climate system. CALIPSO carries the Cloud Aerosol LIdar with Orthogonal Polarization (CALIOP, pronounced as "calliope"), the first polarization lidar in orbit, along with infrared and visible passive imagers.

CALIOP is a three-channel elastic-backscatter lidar optimized for aerosol and cloud profiling. Linearly polarized laser pulses are transmitted at 532 nm and 1064 nm. The 1064 nm receiver channel is polarization insensitive, while the two 532 nm channels separately measure the components of the 532 nm backscatter signal polarized parallel and perpendicular to the outgoing beam. Profiles from CALIOP provide information on the vertical distributions of aerosols and clouds, cloud ice/water phase (via the ratio of signals in two orthogonal polarization channels), and a qualitative classification of aerosol size (via the wavelength dependence of the backscatter).

The current A-train configuration consists of five satellites, all flying at an altitude of 705 km in a sun-synchronous polar orbit, with an equator crossing time of about 1:30 PM local solar time. CALIOP is a nadir-viewing instrument so it produces a curtain of profile data along the subsatellite point, providing sparse global coverage. The orbit inclination of 98° provides coverage between 82°N and 82°S.

This paper presents a summary of the on-orbit performance of CALIOP and an overview of initial results.

2. THE CALIOP INSTRUMENT

CALIOP consists of a laser transmitter subsystem and a receiver subsystem. The transmitter subsystem includes two identical, redundant laser transmitters, each with a beam expander, and a beam steering system that ensures alinement between the transmitter and receiver. The Nd:YAG lasers produce simultaneous pulses at 1064 nm and 532 nm at a pulse repetition rate of 20.16 Hz. Each laser generates 220 mJ of 1064 energy, which is frequency-doubled to produce 110 mJ of energy at each of the two wavelengths. The output pulse energy at each wavelength is measured using energy monitors located within each laser canister. The measured pulse energy is then used to correct the magnitude of the return signals for variations in magnitude due to changes in laser pulse energy. Key payload specifications are summarized in Table 1.

Table I. Key characteristics of CALIOP

Laser	Nd:YAG
Pulse Energy	110 mJ: 532 nm 110 mJ: 1064 nm
Repetition Rate	20.16 Hz
Pulse Length	20 nsec
Polarization Purity	> 1000:1 (532 nm)
Receiver FOV	130 µrad
Vertical sampling	10 MHz (15 m)
Footprint spacing	333 m
Linear Dynamic Range (all three channels)	4E+6 : 1

A 1-meter telescope receives the backscattered light. Photomultiplier tubes (PMTs) are used for the 532 nm detectors as they provide very low dark noise and reasonable quantum efficiency. The sensitivity and large linear dynamic range of the PMTs allows measurement of molecular scattering in the stratosphere as well as signals from dense

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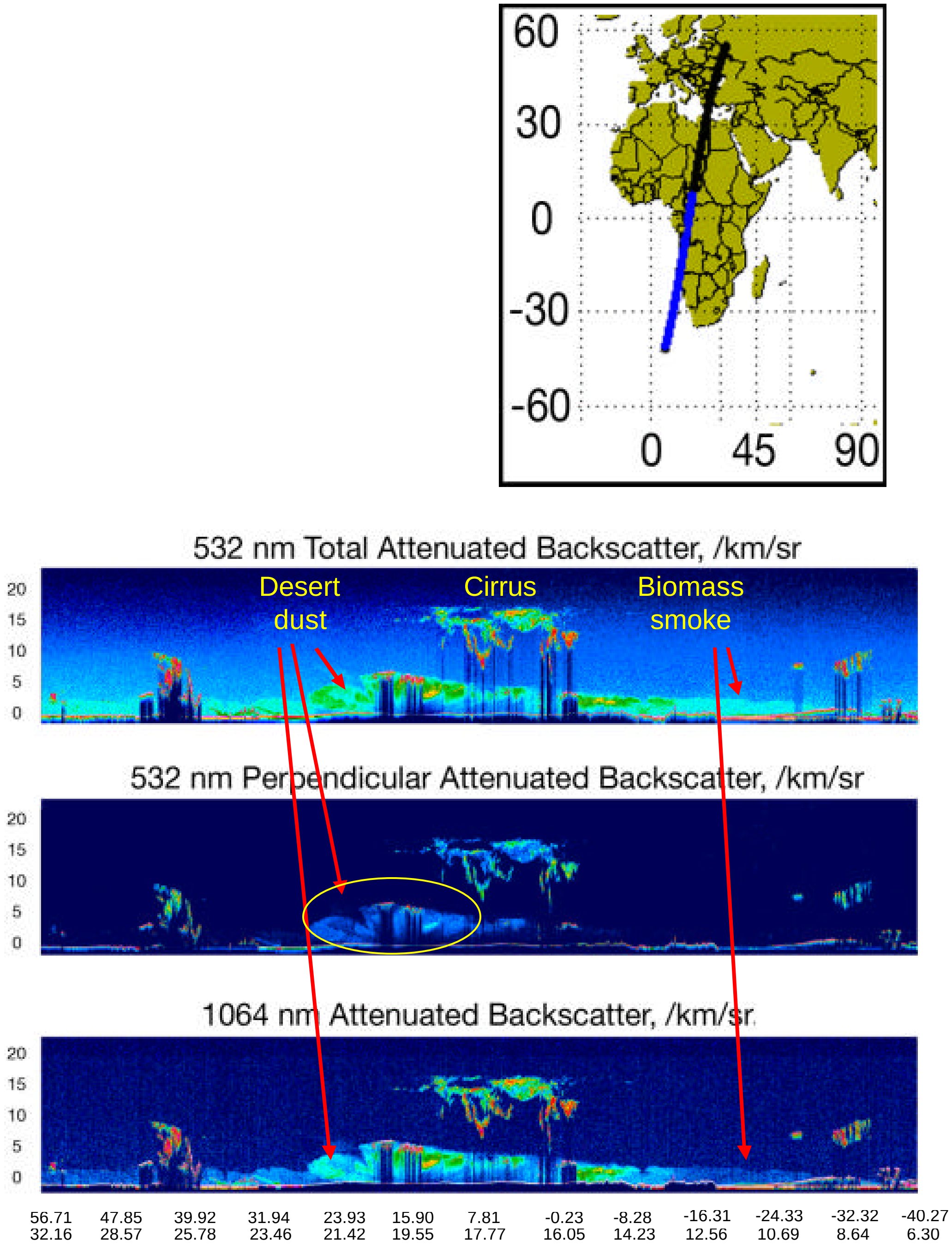

532 nm Total Attenuated Backscatter, /km/sr

532 nm Perpendicular Attenuated Backscatter, /km/sr

1064 nm Attenuated Backscatter, /km/sr

Figure 1. CALIOP observations from 9 June 2006, during the first week of on-orbit operation. The three panels show Level 1 data acquired along the orbit track shown in the map inset, from northern Europe across Africa into the south Atlantic. In the color coding scheme used in these panels, red represents strong returns from clouds and from the surface. Greens and yellows represent weak cloud and strong aerosol scattering, blues represent weak aerosol and molecular scattering. The middle panel indicates that depolarizing targets (cirrus and dust) produce a perpendicular return signal which is typically ¼ to ½ of the parallel return signal.

boundary layer clouds. An avalanche photodiode (APD) is used at 1064 nm as PMT detectors have poor quantum efficiency at that wavelength. The APD has good dynamic range and quantum efficiency but the dark noise is much larger than for the PMTs. Thus the 532 nm channels are more sensitive. A rotating mechanism allows a depolarizer to be moved into the 532 nm beam for depolarization calibration.

The backscattered signals are sampled at 10 MHz, corresponding to a 15 meter range increment. To match the bandwidth of the receiver electronics, the 532 nm channels are then averaged to 30-m resolution and the 1064 nm channel is averaged to 60-m resolution. To reduce requirements on downlink telemetry bandwidth, the lidar profile data is further averaged on-board the satellite prior to downlinking. To preserve the maximum amount of spatial information, only the upper portions of the profiles are averaged, according to the scheme shown in Table 2.

Further details on the CALIOP instrument are given in Winker, et al (2004). Details on CALIOP retrieval algorithms and data products are given in Vaughan, et al. (2004).

Table 2. Spatial resolution of downlinked data.

Altitude Range (km)	Horizontal Resolution	Vertical Resolution	
		532 nm	1064 nm
30.1 to 40.0	5.0 km	300 m	---
20.2 to 30.1	1.67 km	180 m	180 m
8.2 to 20.2	1.0 km	60 m	60 m
-0.5 to 8.2	0.33 km	30 m	60 m
-2.0 to –0.5	0.33 km	300 m	300 m

3. ON-ORBIT PERFORMANCE

CALIOP ‘first light’ occurred on 7 June 2006. An example of data acquired early in the mission is shown in Figure 1 and discussed below. As this is written, CALIOP is approaching 5 months of near-continuous operation, and initial assessments indicate excellent on-orbit performance. Figure 2 compares a highly averaged atmospheric profile acquired by the CALIOP 532 nm parallel channel with the predicted signal from a purely molecular atmosphere. The observed data shows negligible scattering contributions from aerosols or clouds above 18 km. The comparison shows the observed high altitude signal strength is about 30% greater than predicted by the instrument performance model, probably due to an overestimate of optical transmission losses in the model.

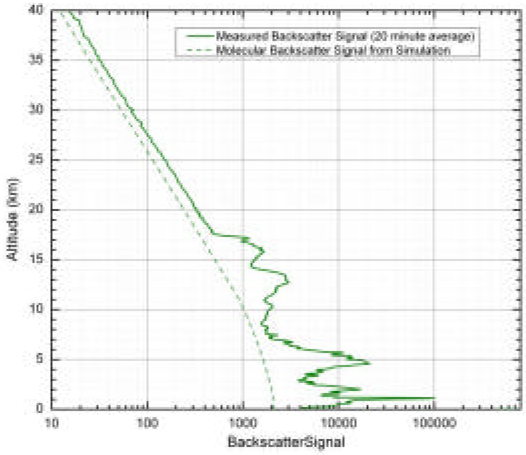

Figure 2. Comparison of averaged on-orbit profile from the 532 nm parallel channel with signal strength predicted by the CALIOP instrument performance model assuming a purely molecular atmosphere.

The 532 nm parallel channel is calibrated by comparing the observed signal to the predicted molecular volume backscatter coefficient in the 30-34 km region. The molecular backscatter coefficient is estimated using temperature and pressure profiles from a gridded meteorological analysis product. The uncertainty in the absolute magnitude of the molecular backscatter coefficient computed in this way is estimated to be 3% (Reagan, et al., 2002). Initial calibration efforts indicate the instrument calibration is stable to better than 1% over several weeks.

4. INITIAL OBSERVATIONS

Figure 1 shows calibrated Level 1 data from all three lidar channels: 532 nm total and perpendicular attenuated backscatter, and 1064 nm total attenuated backscatter (“attenuated backscatter” is calibrated return signal, not yet corrected for attenuation). The image shows a nighttime transect from northern Europe southward across Africa to the Atlantic Ocean. Inspection of these three images illustrates the capability of CALIPSO to observe aerosol underneath cirrus and to discriminate different aerosol types.

High cirrus is seen in the center of the image, located over tropical Africa. The backscatter signal from the cirrus is similar at both wavelengths, characteristic of the relatively large cirrus particles. The cirrus is strongly depolarizing and produces a significant signal in the perpendicular channel. To the south of the cirrus (on the right) is a smoke layer originating from biomass fires in southern Africa, which are widespread during this time of year. Unlike the cirrus, this aerosol is weakly scattering at 1064 nm and non-depolarizing and produces negligible signal in the perpendicular channel.

The aerosol immediately to the north of the cirrus (toward the left) is primarily dust. Dust particles are relatively large and irregular, so they also produce strong signals in the 1064 nm and perpendicular channels. It can be seen that the aerosol north of about 25 N is non-depolarizing and more weakly scattering at 1064 nm. This signature is indicative of secondary aerosol originating from anthropogenic activities.

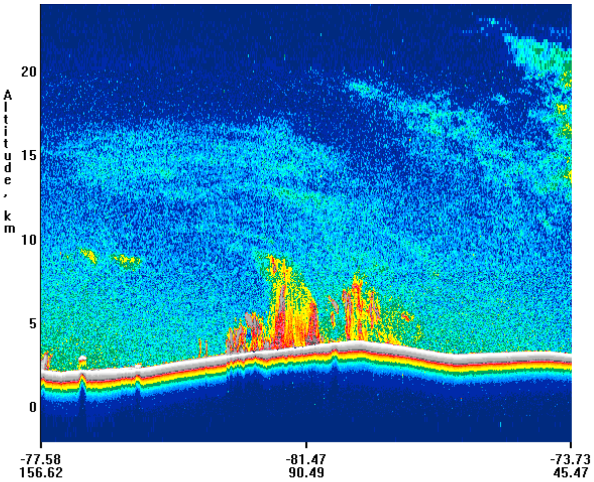

Figure 3. Cloud structures over the East Antarctic plateau on 12 August 2006, CALIPSO 532 nm attenuated backscatter.

CALIPSO provides many new observing opportunities. For example, CALIPSO crosses Antarctica 14 times per day, providing high resolution vertical profiles to a latitude of 82^o S. Figure 3 shows clouds observed over the East Antarctic plateau in the middle of Antarctic winter. The morphology of the clouds located near the surface is interesting, although it is not clear what the formation mechanism is that leads to the observed structure. Higher up, cyan shading indicates relatively tenuous polar stratospheric clouds (PSCs) extending nearly to 25 km altitude. Extensive PSCs were observed over large regions of Antarctica throughout the 2006 Austral winter. This example hints at the complex mechanisms at work in the polar atmosphere and the multitude of new discoveries laying ahead as analysis of CALIPSO data begins.

5. ACKNOWLEDGEMENTS

The CALIPSO mission was developed within the framework of a collaboration between NASA and the French space agency, CNES. Also, I would like to acknowledge Kathy Powell, who developed the software used to produce the data images shown here.

6. REFERENCES

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