Early Results from CALIPSO

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with help from:
First polarization lidar in space
Joint NASA-CNES collaboration

Proposed: 1998

Objectives:
- Improved understanding of aerosol and cloud effects on radiation budget
- Improved understanding of cloud-climate feedback processes
- Improve aerosol and cloud information from other A-Train sensors
- Improved predictive capability for climate, weather, and air quality

Approach:
- Produce a global aerosol and cloud dataset consisting of:
  - Profiles, optical properties, microphysical properties
  - Identify cloud ice-water phase, aerosol type
- Combine CALIPSO and other A-Train observations
705 km, sun-synchronous orbit
Three co-aligned instruments:
- CALIOP: polarization lidar
  - laser linewidth \( \sim 1 \text{ cm}^{-1} \)
- IIR: Imaging IR radiometer
- WFC: Wide-Field Camera

Launch: 28 April 2006
Payload Specifications

**CALIOP**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laser</td>
<td>Nd: YAG, 2x110 mJ</td>
</tr>
<tr>
<td>Wavelength</td>
<td>532 nm, 1064 nm</td>
</tr>
<tr>
<td>Repetition rate</td>
<td>20.16 Hz</td>
</tr>
<tr>
<td>Receiver telescope</td>
<td>1.0 m diameter</td>
</tr>
<tr>
<td>Polarization</td>
<td>532</td>
</tr>
<tr>
<td>Footprint/FOV</td>
<td>100 m / 130 μrad</td>
</tr>
<tr>
<td>Vertical resolution</td>
<td>30 - 60 m</td>
</tr>
<tr>
<td>Horizontal resolution</td>
<td>333 m</td>
</tr>
<tr>
<td>Lin. dynamic range</td>
<td>22 bits</td>
</tr>
</tbody>
</table>

**Wide-Field Camera (WFC)**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wavelength</td>
<td>645 nm</td>
</tr>
<tr>
<td>Spectral bandwidth</td>
<td>50 nm</td>
</tr>
<tr>
<td>IFOV / Swath</td>
<td>125 m / 61 km</td>
</tr>
</tbody>
</table>

**Imaging Infrared Radiometer (IIR)**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wavelength</td>
<td>8.65, 10.6, 12.05 μm</td>
</tr>
<tr>
<td>Spectral resolution</td>
<td>0.6-1.0 μm</td>
</tr>
<tr>
<td>IFOV / Swath</td>
<td>1 km / 64 km</td>
</tr>
<tr>
<td>NETD @ 210K</td>
<td>0.3 K</td>
</tr>
<tr>
<td>Calibration</td>
<td>±1 K</td>
</tr>
</tbody>
</table>
Post-Launch Chronology

- 28 April – Launch
- 10 May – IIR ‘First Light’
- 15 May – WFC ‘First Light’
- 23-24 May – Initial laser tests (LOM 2)
- 7 June – CALIOP ‘First Light’
- 8-9 June – Laser tuning
- 22 Jul - Initial release of data to Science Team
- 5 Sep - Public release of browse images
- 3-5 Oct - Science Team meeting
- 8 Dec – First public release of science data
Laser continues to perform well

CALIPSO Risk Reduction Laser
6% loss after 2.1B shots

Laser Adjustment Threshold

Minimum Energy Required to Meet Level 1 Requirements

- LOM #2 532nm
- LOM #2 1064nm

March 23, 2007
Signal strength and SNR ~50% greater than predicted
Clear-air Profiles

2006-06-14, 13:52:31 UTC: Average of 6000 profiles from 30.4° N, 179.3° W to 12.5° N, 176.4° W

- 532 nm Scattering Ratio
- 1064 nm Scattering Ratio
- 532 nm Depolarization Ratio
Pointing Biases and Uncertainties

Biases in relative pointing between star trackers and CALIOP/WFC/IIR have been identified and corrected.

Relative to satellite geodetic nadir point:

**Control** (req’ t = ±1 km)

<table>
<thead>
<tr>
<th></th>
<th>Cross-track</th>
<th>Along-track</th>
</tr>
</thead>
<tbody>
<tr>
<td>CALIOP</td>
<td>-55 m</td>
<td>-428 m</td>
</tr>
<tr>
<td>WFC</td>
<td>372 m</td>
<td>126 m</td>
</tr>
<tr>
<td>IIR</td>
<td>270 m</td>
<td>500 m</td>
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</tbody>
</table>

**Knowledge:**

<table>
<thead>
<tr>
<th></th>
<th>Cross-track</th>
<th>Along-track</th>
</tr>
</thead>
<tbody>
<tr>
<td>RMS</td>
<td>29 m</td>
<td>26 m</td>
</tr>
<tr>
<td>CALIOP</td>
<td>35 m</td>
<td>40 m</td>
</tr>
<tr>
<td>IIR</td>
<td>100 m</td>
<td>100 m</td>
</tr>
</tbody>
</table>
532-parallel channel calibrated by normalization of high-altitude returns (30-34 km) to molecular density.

Calibration coefficients during a 2-week period, derived from 30-34 km signal averaged 6000 km along-track.

(RMS ~ 1%)

RMS variability of calibration coefficients slightly larger than expected from signal noise alone.
CALIPSO First Light Observations
(all 3 channels)

June 9, 2006

532 nm Total Attenuated Backscatter, /km/sr

532 nm Perpendicular Attenuated Backscatter, /km/sr

1064 nm Attenuated Backscatter, /km/sr

Fire locations in southern Africa from MODIS, 6/10/06
Validation Activities

Validation includes:
– Targeted aircraft campaigns
– International field campaigns
– Ground-based networks
– Satellite comparisons

Activities to date:

• Flights of LaRC HSRL  
  Jun-Sep 2006, Jan 2007  
• CALIPSO-CloudSat Val Exp (Georgia)  
  Jul-Aug 2006
  — CPL, CRS (ER-2), HSRL
• Flights of CNES HSRL (Niger)  
  Jul 2006
• NASA AMMA (Cape Verde)  
  Aug 2006
• GoMACCS (Houston)  
  Aug-Sep 2006
• Canadian Cold Weather Study  
  Winter 2006/2007

Plans for 2007:

• DLR ASTAR (Svalbard)  
  Mar-Apr
• NASA TC^d (Costa Rica)  
  Jul-Aug
• More comprehensive validation relying on ground-based instruments
532 nm Calibrated Attenuated Backscatter

Coincidence

validation intercomparisons: clouds
August 12, 2006
Validation Intercomparisons: Aerosols

August 10, 2006

Coincidence

Calipso

LaRC HSRL

Coincidence

532 nm Attenuated Backscatter (km\(^{-1}\) sr\(^{-1}\))

1064 nm Attenuated Backscatter (km\(^{-1}\) sr\(^{-1}\))
Lidar Data Products*

Level 1 (geolocated and calibrated)
- DP 1.1 - profiles of attenuated lidar backscatter (532, 532⊥, 1064 nm)
- DP 1.2 – IR radiances (8.65, 10.6, 12.05 μm)
- DP 1.3 – Visible radiances (650 nm) (WFC)

Level 2
- DP 2.1A – Cloud/Aerosol layer product
  - layer base and top heights, layer-integrated properties
- DP 2.1B – Aerosol profile product
  - backscatter, extinction, depolarization profiles
- DP 2.1C – Cloud profile product
  - backscatter, extinction, depolarization, ice/water content profiles
- DP 2.1D – Vertical Feature mask
  - cloud/aerosol locations
- Also: products from IIR + CALIOP + WFC: cloud \( T_B(\lambda) \), emissivity, \( r_e \)

Level 3
- Summary statistics on a global grid

*Initial data release (Dec 8)
(available at http://eosweb.larc.nasa.gov)
CALIPSO Data Products

2006-08-12 02-00-17UTC Nighttime Conditions
Version: 1.06 Image Date: 09/11/2006

Cloud-Aerosol Mask

Cloud Phase

Level 1: 532 nm total atten. backscatter

Aerosol Subtypes
Information from Depolarization

Arctic clouds
identification of water, and both random and oriented ice crystals

Sahara dust with embedded water clouds

532 nm total attenuated backscatter

532 nm volume depolarization
2-\(\lambda\) Cloud-Aerosol Discrimination

2-wavelength comparisons allow unambiguous discrimination of small aerosols from large cloud particles.

- Cloud and aerosol can often be separated by scattering strength. But aerosol and cloud cannot be unambiguously discriminated using a single wavelength.

- Errors lead to biases in aerosol optical depth, and aerosol forcing.

Separation of cloud and aerosol using \(\chi' = \beta'_{1064}/\beta'_{532}\)

532 nm

1064 nm
Impacts of smoke above cloud

Observations on 10 August 2006

Retrieved smoke properties
AOD (532) = 0.69
avg depol = 0.04

Heating in smoke layer:
~70 W/m² (ω₀ = 0.9)

Heating within the smoke layer stabilizes the atmosphere and traps the layer.
Smoke plumes over Canada – July 5\textsuperscript{th}

CALIPSO observes plume injection height: model initialization, assessment

Night

Daytime
Major Saharan Dust Transport Event: Aug 17-28

CALIPSO can identify aerosol transport pathways and provide data to improve and verify models.
Antarctic Polar Stratospheric Clouds
July 24, 2006

1-day coverage

532 nm Total Attenuated Backscatter

532 µm Total Attenuated Backscatter

532 µm Perpendicular Attenuated Backscatter
Cloud Top Comparisons
CALIPSO vs. MODIS (June 15, 2006)

68% of lidar shots reach surface

PDF of top height of lowest detected layer
CALIPSO Zonal Cloud Occurrence

July 2006 Day-Night Cloud Fraction

September 2006 Day-Night Cloud Fraction

November 2006 Day-Night Cloud Fraction

January 2007 Day-Night Cloud Fraction
CALIPSO Geographical Cloud Occurrence
Tropical Subvisible Cirrus
Optical Depth Histograms

Daytime Jan 2007

Nighttime Jan 2007
CALIPSO and CloudSat

Observations over the Western Pacific

CALIPSO (532 nm)

CloudSat
CloudSat/CALIPSO Joint Cloud Mask

Combined Radar/Lidar Mask

Produced by CloudSat
Many thanks to the CALIPSO development team:

A cast of hundreds at NASA LaRC, CNES (Toulouse), Ball Aerospace (Boulder), SODERN (Paris), Alcatel (Cannes), and NASA GSFC

www-calipso.larc.nasa.gov