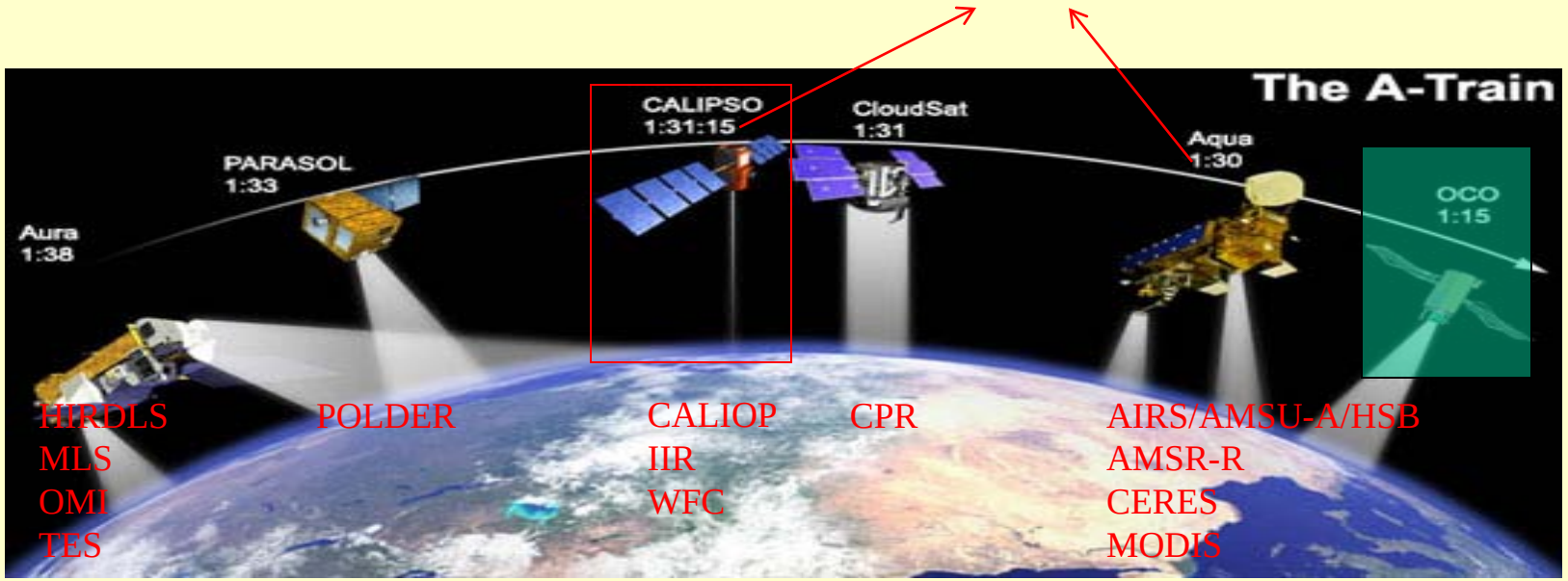
# Lab10.

## CALIPSO lidar sensing of aerosols and clouds.

CALIPSO: http://www-calipso.larc.nasa.gov/

CALIPSO Data User's Guide:
http://www-calipso.larc.nasa.gov/resources/calipso_users_guide/

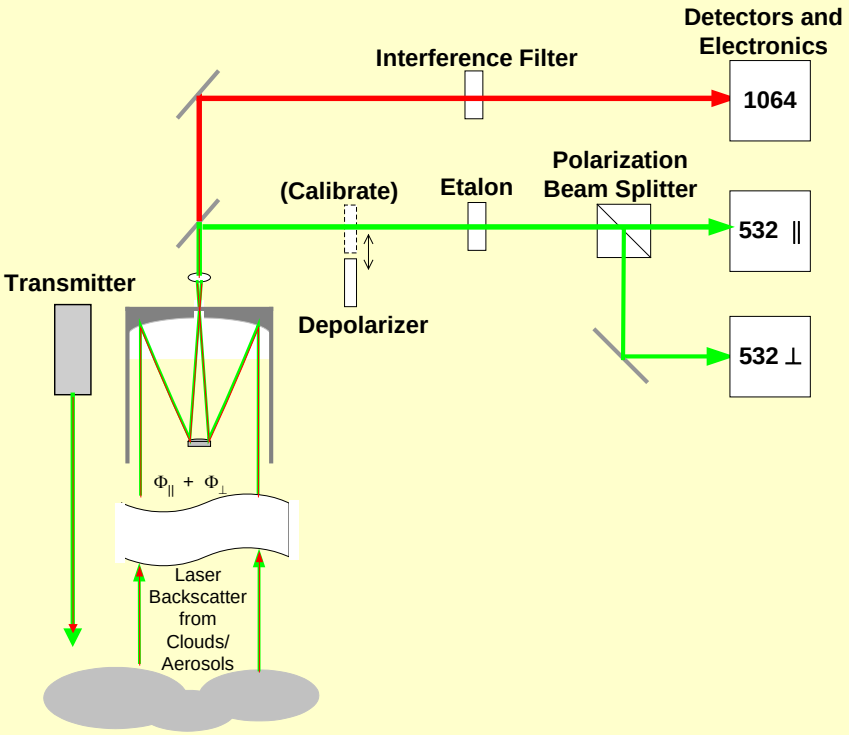
# CALIPSO and A-Train




- CALIPSO: Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations
- Three co-aligned instruments:
  - **3-channel lidar** (**CALIOP**) : 532 nm (ll, ⊥), 1064 nm
  - **Imaging IR radiometer (IIR)**
  - **Wide-field camera (WFC)**
- Launch: April 28, 2006
- A-train constellation
  - Orbit: 705 km, in formation with Aqua, CloudSat, Parasol, and Aura
  - TERRA crosses the equator at approximately 10:30 a.m., local time, about 3 hours before Aqua

# CALIPSO payload:

- polarization-sensitive, two-wavelength lidar (CALIOP)
- three-channel (8.65, 10.6 and 12.05 microns) Infrared Imaging Radiometer (IIR)
- visible channel Wide Field Camera (WFC)



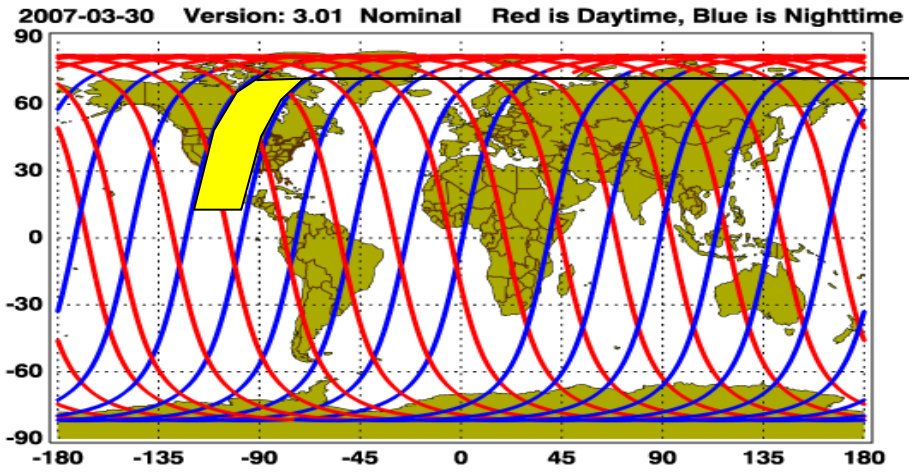

**CALIOP:**

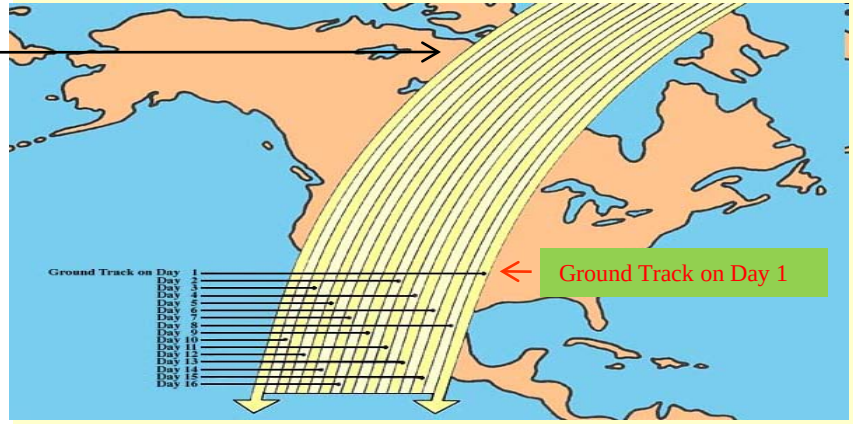
• two-wavelength (532 nm and 1064 nm) polarization-sensitive lidar

• has three receiver channels: one measuring the 1064-nm backscattered intensity, and two channels measuring orthogonally polarized components (parallel and perpendicular to the polarization plane of the transmitted beam) of the 532-nm backscattered signal.

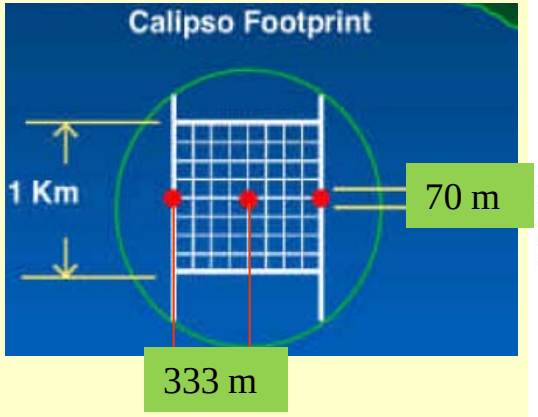
• footprint at the Earth's surface (from a 705-km orbit) of about 90 meters and vertical resolution of 30 meters.

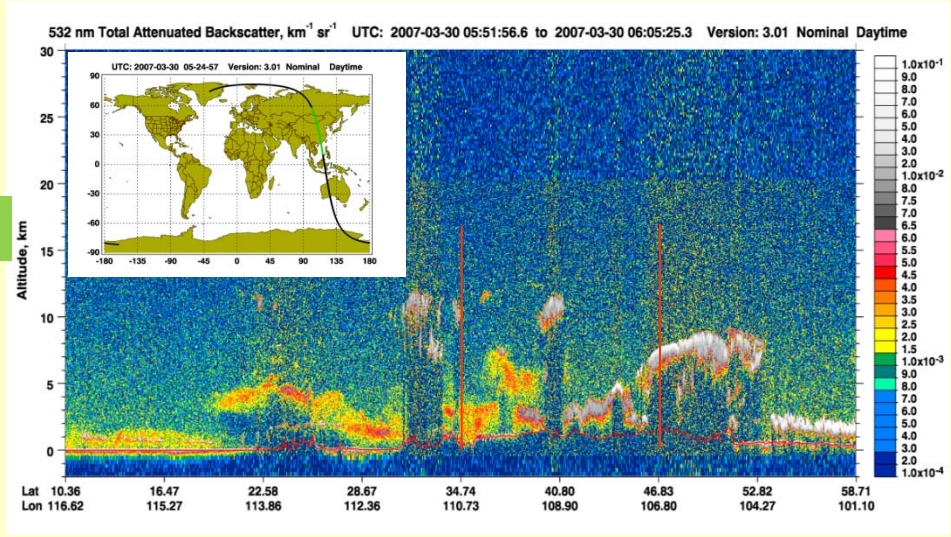
# CALIPSO lidar spatial and temporal coverage




- 1 day coverage area, Cover whole area: 16 days
- Cover whole area: 16 days




- Footprint (70m) spacing: 333 m (1 km~3 points)
- 532 nm total attenuated backscatter, $km^{-1}$ $sr^{-1}$ (Level 1B data)

# CALIPSO data:

- Data products are grouped into the following categories:
  - CALIOP level 1 and level 2 products
  - IIR level 1 and level 2 products
  - WFC level 1 products

- CALIPSO data product description:

http://www-calipso.larc.nasa.gov/resources/calipso_users_guide/data_summaries/

- CALIPSO version 3.01 data products are available from the Langley DAAC (http://eosweb.larc.nasa.gov/).

# CALIPSO data (cont.):

**IIR Data:**

Level 1B radiance data: Geolocated, calibrated radiances.

Level 2 track data: Emissivity and cloud particle data related to pixels that have been co-located to the Lidar track.

Level 2 swath data: Emissivity and cloud particle data assigned to IIR pixels on a 1 km grid centered on the Lidar track.

**WFC Data**

The primary Wide Field Camera Level 1B data products are calibrated radiances and bidirectional reflectances registered to an Earth-based grid centered on the lidar ground track. During normal operations, the WFC acquires science data only during the daylight portions of the CALIPSO orbits. For each daytime orbit segment, three different data products are produced: 1 km Native Science grid, 125 m Native Science grid, and 1 km Registered Science grid.

In addition to radiance and reflectance grids, the WFC Level 1 data products include two parameters that quantify the homogeneity of the cross track image frames: swath homogeneity and track homogeneity.

Level 1B 125m Native science data: Contains only the central 5 km-wide high resolution (125 m) portion of the WFC swath.

Level 1B 1 km Native science data: Covers the full 61 km swath centered on the Lidar track.

Level 1B 1 km Registered science data: On the identical grid as the CALIPSO IIR data and is produced to facilitate the use of the WFC data in the IIR retrievals.

# CALIPSO data (cont.)

- **CALIOP** Products are built around two tightly coupled data types: column properties and layer properties.

For each set of column properties, there is an associated set of *layer properties*. These layer properties specify the spatial and optical characteristics of each feature (clouds or aerosols) found, and include quantities such as layer base and top altitudes, integrated attenuated backscatter, layer-integrated volume depolarization ratio, and optical depth (http://www-calipso.larc.nasa.gov/resources/calipso_users_guide/data_summaries/layer/#heading02 ).

- Level 1B Profile Data: contains a half orbit (day or night) of calibrated and geolocated single-shot (highest resolution*) lidar profiles, including 532 nm and 1064 nm attenuated backscatter and depolarization ratio at 532 nm. The CALIOP Level 1B data product also contains additional parameters such as post processed ephemeris data, celestial data, and converted payload status data.

- Each granule of the level 1B profile products is further processed to generate the suite of level 2 lidar data products described below.

*Level 2 Layer Data*. The level 2 analyses of the CALIOP lidar backscatter data begins with an attempt to locate all coherent "features" - i.e., clouds and aerosol layers - in each granule of the level 1 data. The results of this search are reported in four different lidar level 2 layer products. Cloud layers are reported at three different horizontal averaging resolutions: 1/3-km, 1-km, and 5-km. The 1/3-km data is reported only in those regions where single shot information is available in the downlinked data; that is, between ~8.2-km and -0.5-km. The 1-km and 5-km cloud layers are reported between ~20.2 and -0.5-km. Aerosol layers are reported between at a 5-km horizontal resolution between ~30.1-km and -0.5km. Layers detected in the stratosphere are recorded in the aerosol layer products, and thus users seeking measurements of polar stratospheric clouds should order the 5-km aerosol layer products. Note that the layers reported in the 5 km horizontal resolution data products may have been required averaging to as much as 80 horizontally before being detected by the feature finder algorithm. However, these fainter layers are still reported on the same uniform 5-km horizontal grid. To effectively use the 5-km layer products, users should first thoroughly familiarize themselves with the multi-gridded averaging scheme described here and in the feature finder ATBD.

*Level 2 Profile Data*. Each layer identified in the 5 km cloud and aerosol layer products is further analyzed to determine the profiles of particulate extinction and backscatter within the layer. This profile data, along with ancillary information (e.g., meteorological data from the GMAO) is reported in the 5 km cloud and aerosol layer products. As in the layer products, clouds and aerosols are reported in separate data products, and the profile data for stratospheric features is included in the aerosol profile products.

*Level 2 Vertical Feature Mask* (VFM) The feature mask data set describes the vertical and horizontal distribution of cloud and aerosol layers observed by the CALIPSO lidar. Each range bin in the Lidar Level 0 data is characterized by a single 16-bit integer, with the various bits in the integer representing flags that describe some aspect of the data measured within the bin. Instructions on how to decode these integer data are given in the vertical feature mask summary page. The data are recorded in nominal increments of 15 consecutive laser pulses, which is nominally equivalent to a distance of 5-km along the laser ground-track.

| Processing Level | Data Product Name | Data Maturity | Example File Name* |
|---|---|---|---|
| Level 1 | 1B Profile | Validated Stage 1 | CAL_LID_L1-ValStage1-V3-01 |
| Level 2 | 5 km Aerosol Layer | Provisional | CAL_LID_L2_05kmALay-Prov-V3-01 |
| | 5 km Cloud Layer | Provisional | CAL_LID_L2_05kmCLay-Prov-V3-01 |
| | 1 km Cloud Layer | Validated Stage 1 | CAL_LID_L2_01kmCLay-ValStage1-V3-01 |
| | 333 m Cloud Layer | Validated Stage 1 | CAL_LID_L2_333mCLay-ValStage1-V3-01 |
| | 5 km Aerosol Profile | Validated Stage 1 | CAL_LID_L2_05kmAPro-Prov-V3-01 |
| | 5 km Cloud Profile | Provisional | CAL_LID_L2_05kmCPro-Prov-V3-01 |
| | Vertical Feature Mask | Validated Stage 1 | CAL_LID_L2_VFM-ValStage1-V3-01 |

**Lidar equation** (Lecture 13)

$$P_r(R) = \frac{C}{R^2}\frac{h}{2}\frac{k_b}{4\pi}\exp(-2\int_o^R k_e(r')dr')$$

where C is the lidar constant (includes $P_t$, receiver cross-section and other instrument factors);

$\kappa_b/4\pi$ (in units of $km^{-1}sr^{-1}$) is called the backscattering factor or lidar backscattering coefficient or backscattering coefficient;

$\kappa_e$ is the volume extinction coefficient; and

$t_p$ is the lidar pulse duration ($h=ct_p$)

## CALIOP retrievals: concepts of “feature” and feature boundaries

The term “feature” describes any extended and contiguous region of enhanced backscatter signal that rises significantly above the expected molecular (Rayleigh) value (that is, clouds, aerosol layers, and surface returns).

A feature finding algorithm is required to separate the genuine features from noise (see CALIOP SYBIL algorithm)

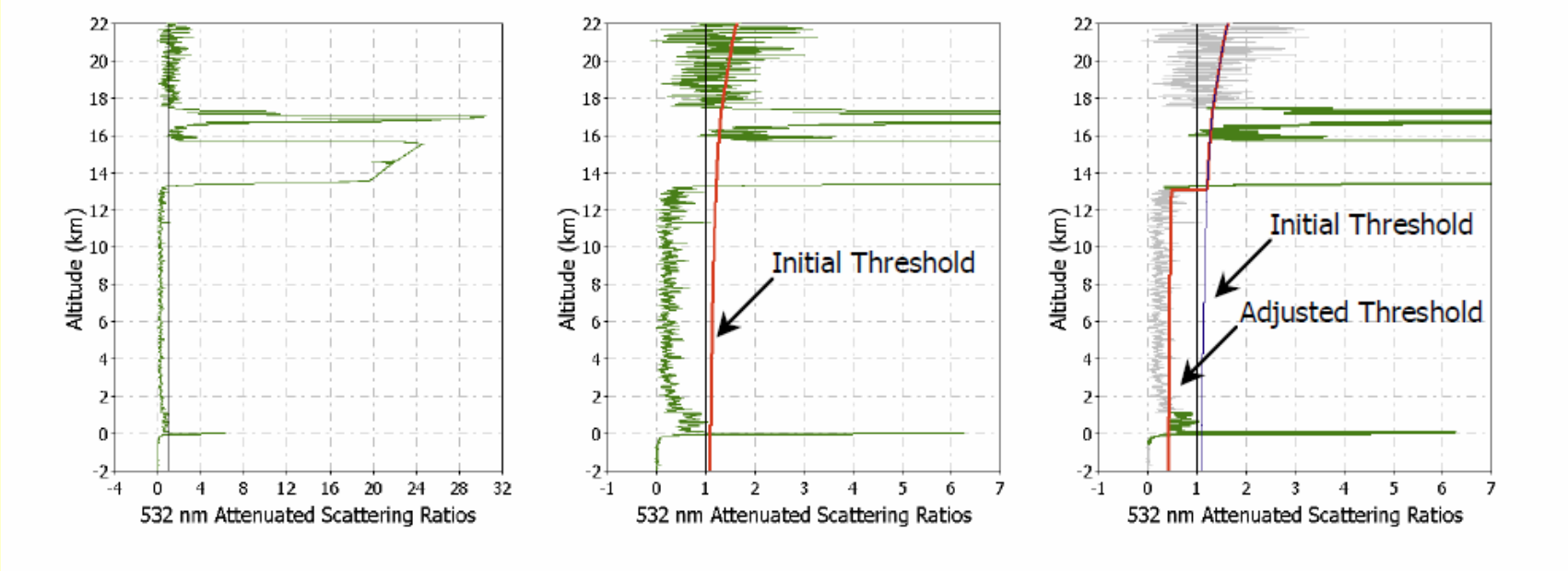
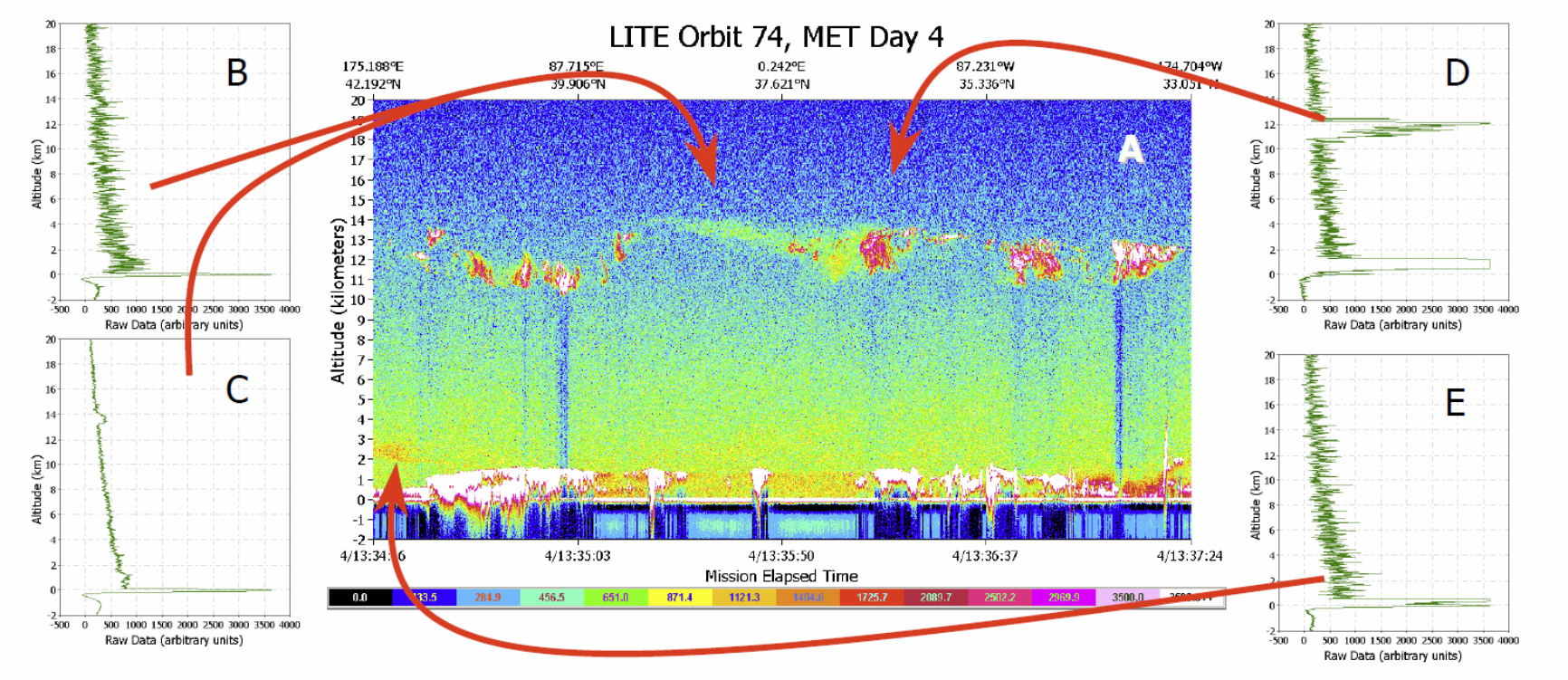
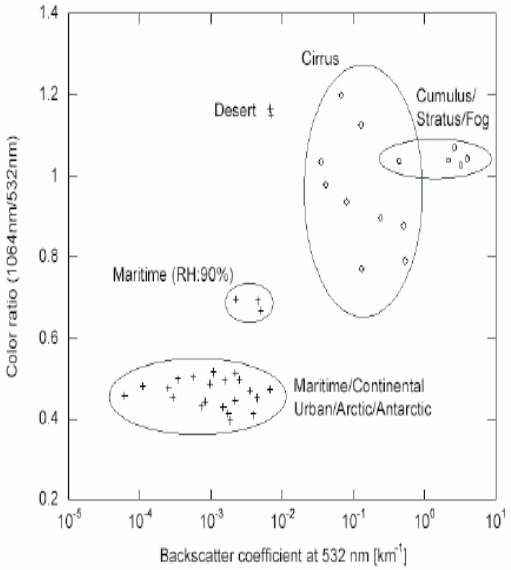


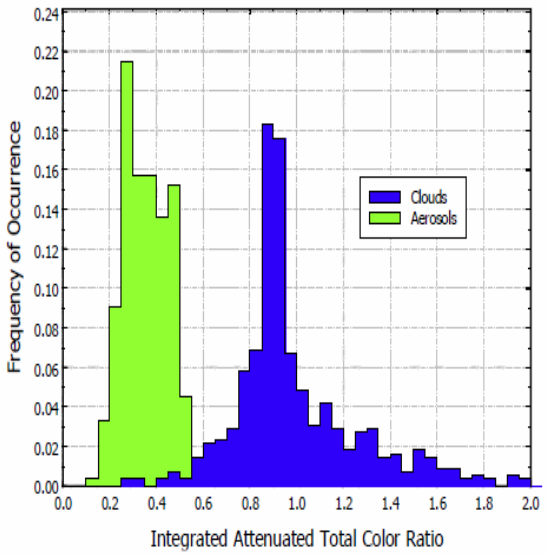

**Illustration of the adaptive threshold technique (profile measured by LITE)**
http://www-calipso.larc.nasa.gov/resources/pdfs/SPIE_5575-4.pdf

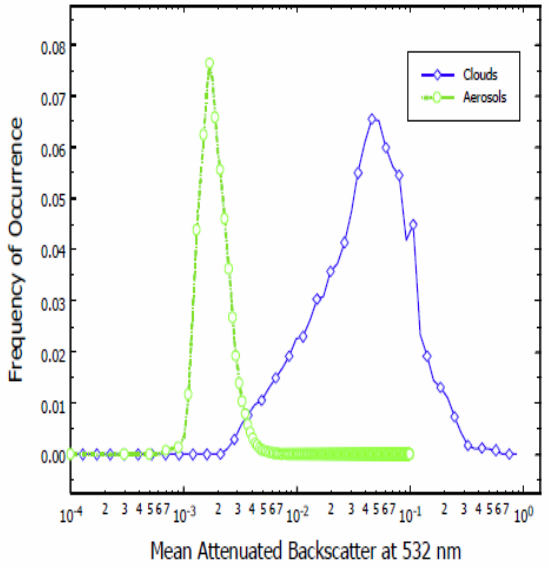



Example of analysis of space lidar data:
(a) scene measured by LITE;
(b) single-shot profile showing thin cirrus and aerosol layers;
(c) as in b, but averaged to a 20-km horizontal resolution;
(d) single-shot profile showing strong cirrus overlying stratus;
(e) single-shot profile showing thin stratus overlying PBL aerosols.
http://www-calipso.larc.nasa.gov/resources/pdfs/SPIE_5575-4.pdf

**CALIOP retrievals: features' classification**



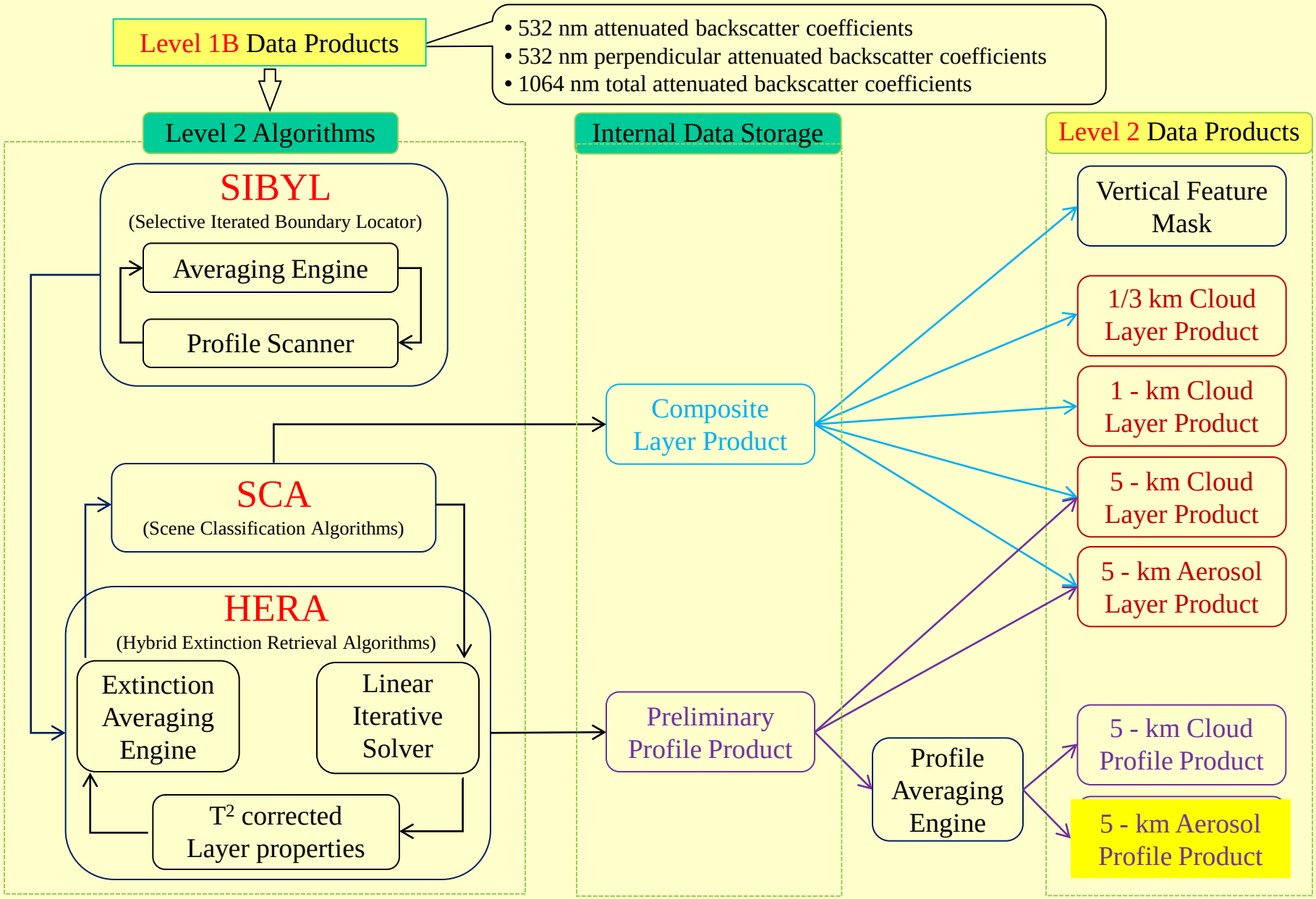




Example of optical properties of clouds and aerosols; (a) OPAC model predictions of color ratio $\chi$ and backscattering coefficient $\beta_{532}$, (b) LITE measurements of $\chi'$, and (c) LITE-derived distributions of $\beta'_{532}$ for clouds and aerosols found between 0 and 10 km

http://www-calipso.larc.nasa.gov/resources/pdfs/SPIE_5575-4.pdf

# Flow Chart of CALIOP(lidar) Data Processing



# Comparison of level 2 aerosol data: version 2.01 vs. new version3.01

| Parameters | Version 2.01 | Version 3 |
|---|---|---|
| Vertical Feature Mask | Based on 3-D PDFs<br>- Mean attenuated backscatter at 532 nm<br>- Total color ratio, - Midlayer altitude<br><br>Classification of 8 types:<br>Invalid, clear air, cloud, aerosol, stratospheric layer, surface, subsurface, no signal (totally attenuated) | Based on 5-D PDFs<br>- Mean attenuated backscatter at 532 nm<br>- Total color ratio, - Midlayer altitude<br>- Volume depolarization ratio, - Latitude<br><br>Classification of 9 types:<br>Clear air, cloud, cloud(L), aerosol, aerosol (L), stratospheric layer, surface, subsurface, totally attenuated,<br>L=low/no confidence |
| Aerosol Type | Based on the following parameters:<br>- Observed backscatter strength<br>- Depolarization ratio<br>- IGBP surface types<br><br>Classification of aerosol types (assigned $S_a$ at 532/1064 nm)<br>- Not applicable<br>- Clean marine (20/45 sr)<br>- Dust (40/30 sr)<br>- Polluted continental (70/30 sr)<br>- Clean continental (35/30 sr)<br>- Polluted dust (65/30 sr)<br>- Smoke (70/40 sr) | Based on the following parameters:<br>- Observed backscatter strength<br>- Depolarization ratio<br>- IGBP surface types<br><br>Classification of aerosol types (assigned $S_a$ at 532/1064 nm)<br>- Not applicable<br>- Clean marine (20/45 sr)<br>- Dust (40/55 sr)<br>- Polluted continental (70/30 sr)<br>- Clean continental (35/30 sr)<br>- Polluted dust (55/48 sr)<br>- Smoke (70/40 sr) |
| Aerosol Optical Depth (AOD) | Based on Forward solution | Based on Forward solution<br>Includes the aerosol layer base extension algorithm |
| Volume Depolarization Ratio ($\delta_v$) | Direct measurement<br>Quality<br>depends on the accuracy of the top and base identification | Direct measurement<br>Quality<br>depends on the accuracy of the top and base identification |
| Particulate Depolarization Ratio ($\delta_p$) | - | Post-extinction quantity<br>Quality<br>- SNR of the backscatter measurements in parallel and perpendicular<br>- Accuracy of two-way transmittance estimates |
| Particulate Color Ratio ($\chi_p$) | - | Post-extinction quantity<br>Quality<br>- Accuracy of layer top/base altitudes<br>- SNR of the backscatter data<br>- Success of the HERA profile solver |

## Essential Reading for CALIPSO Data Users

http://www-calipso.larc.nasa.gov/resources/calipso_users_guide/essential_reading/index.html

**CALIOP Algorithm Theoretical Basis Document Part 1 : CALIOP Instrument, and Algorithms Overview**

http://www-calipso.larc.nasa.gov/resources/pdfs/PC-SCI-202.Part1_v2-Overview.pdf

## CALIOP Browse Image Tutorial

http://www-calipso.larc.nasa.gov/resources/calipso_users_guide/browse/index.html

**LIDAR BROWSE IMAGES FOR PRODUCTION RELEASE [V3-01]**
http://www-calipso.larc.nasa.gov/products/lidar/browse_images/show_calendar.php