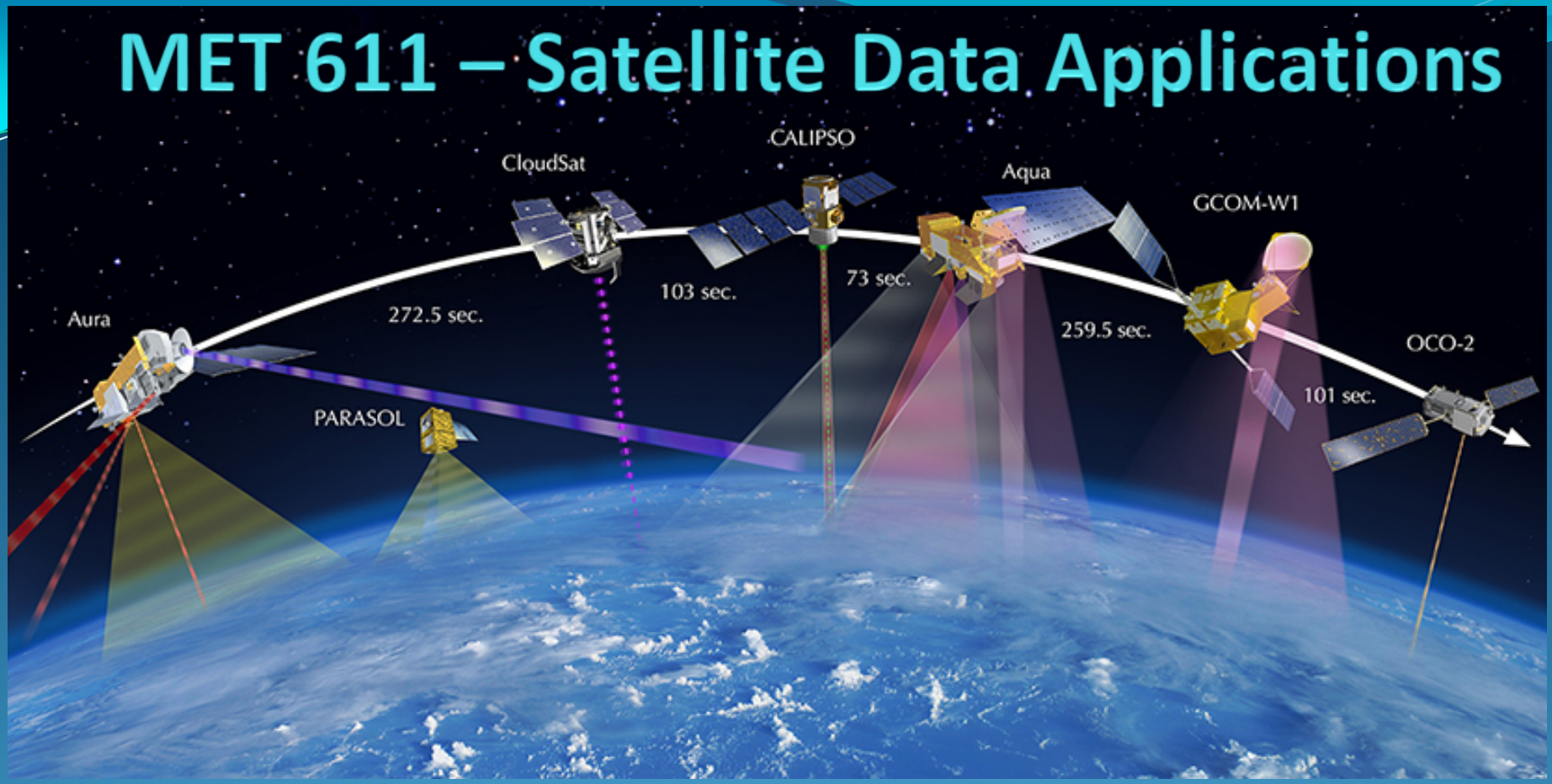
MET 611 – Satellite Data Applications



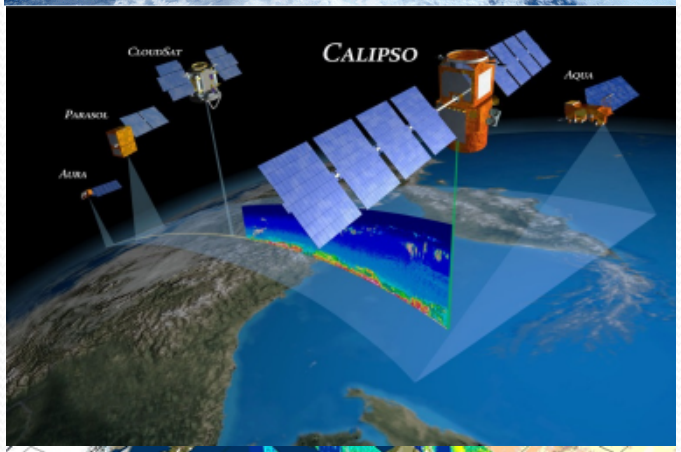
CALIPSO Introduction

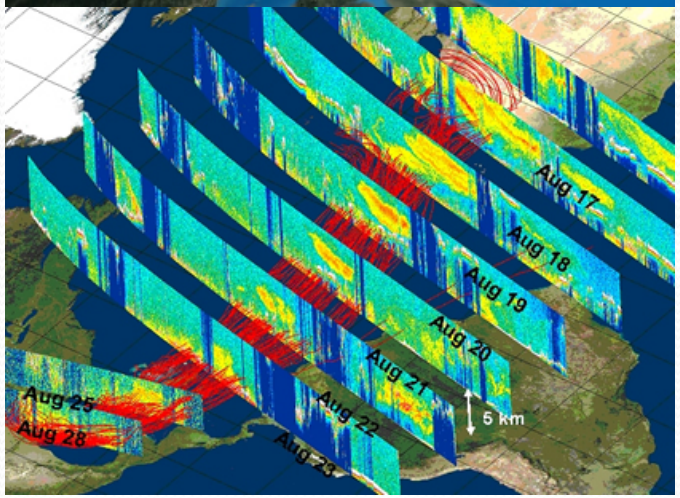
Many slides are from a talk by Meloë Kacenelenbogen, Mark Vaughan, and Jens Redemann for a NASA ARSET- AQ DRI Course June 11 - 14, 2012

Jennifer D. S. Griswold

CALIPSO

- The **C**loud-**A**erosol **L**idar and **I**nfrared **P**athfinder **S**atellite **O**bservation (CALIPSO)
- Launched **April 28 2006 with CloudSat**
- **Provides new insight into:**
  - The role that clouds and atmospheric aerosols (airborne particles) play in regulating Earth's weather, climate, and air quality.
  - With Cloudsat – **3D perspective on cloud-aerosol interactions**
  - How clouds and aerosols form and evolve
  - Weather and climate studies
- Combines an **active lidar** instrument with **passive infrared and visible imagers** to probe:
  - vertical structure and properties
  - Focus on: thin clouds and aerosols over the globe.



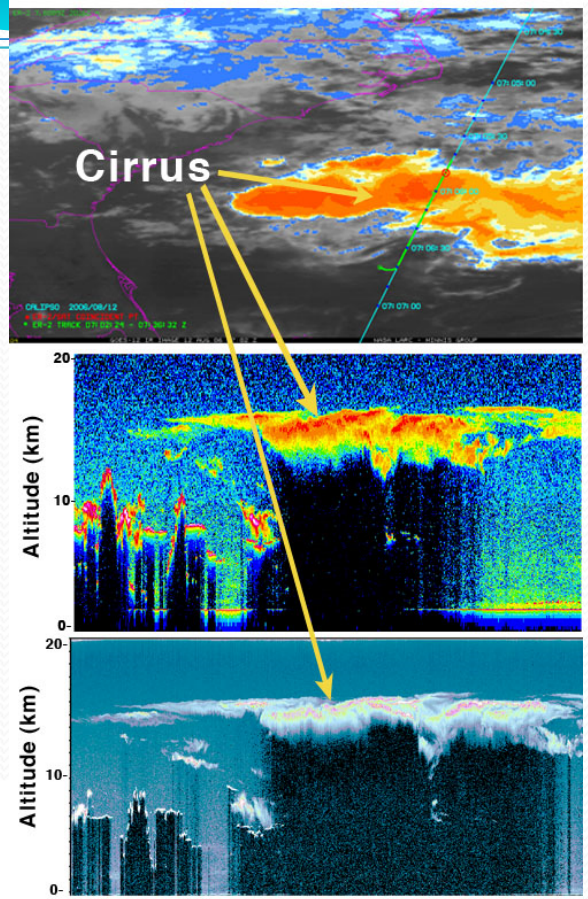


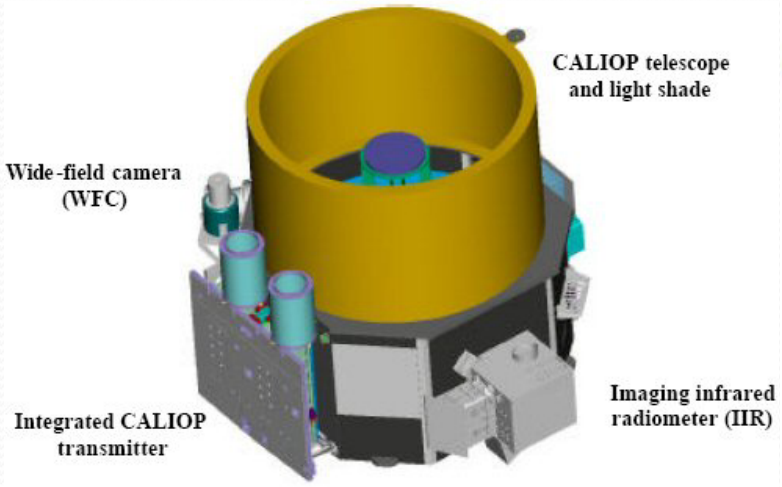
CALIPSO - CALIOP

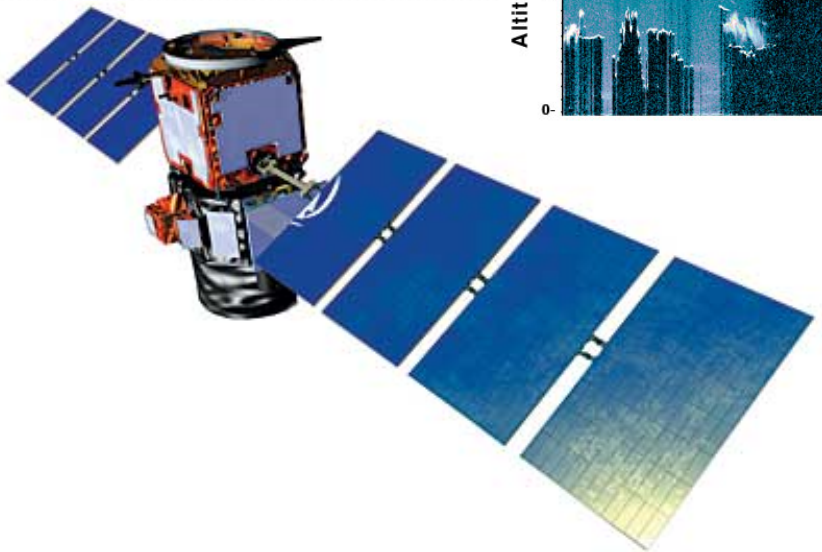
- Joint NASA/CNES satellite

Rhymes with "eye-oh-pee"

- Three instruments:
  - **Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP):** Two wavelength polarization-sensitive Lidar that provides high-resolution vertical profiles of aerosols and clouds
  - **Wide Field Camera (WFC):** Fixed, nadir-viewing imager with a single spectral channel covering the 620-670 nm region
  - **Imaging Infrared Radiometer (IIR):** Nadir-viewing, non-scanning imager





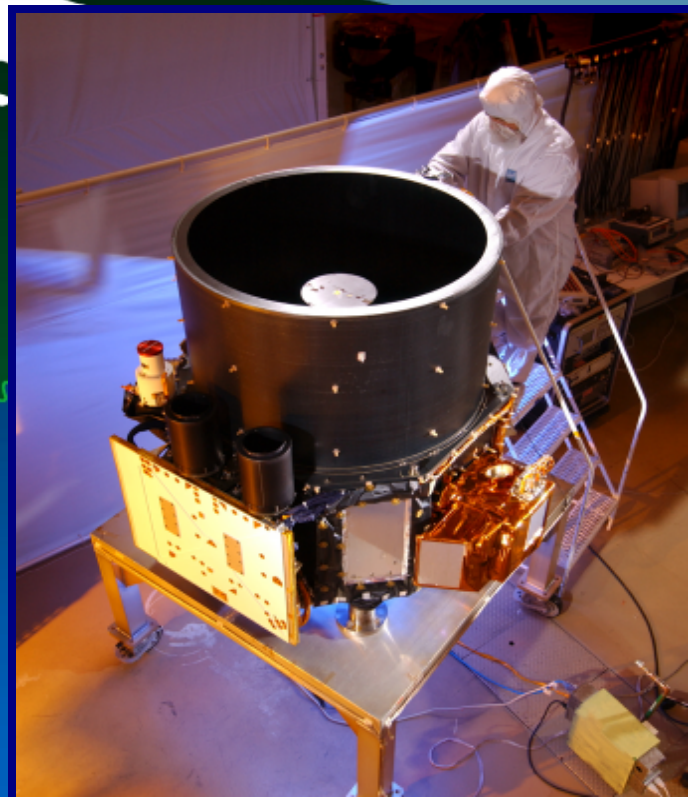


Launch: 28 April 2006

705 km, sun-synchronous

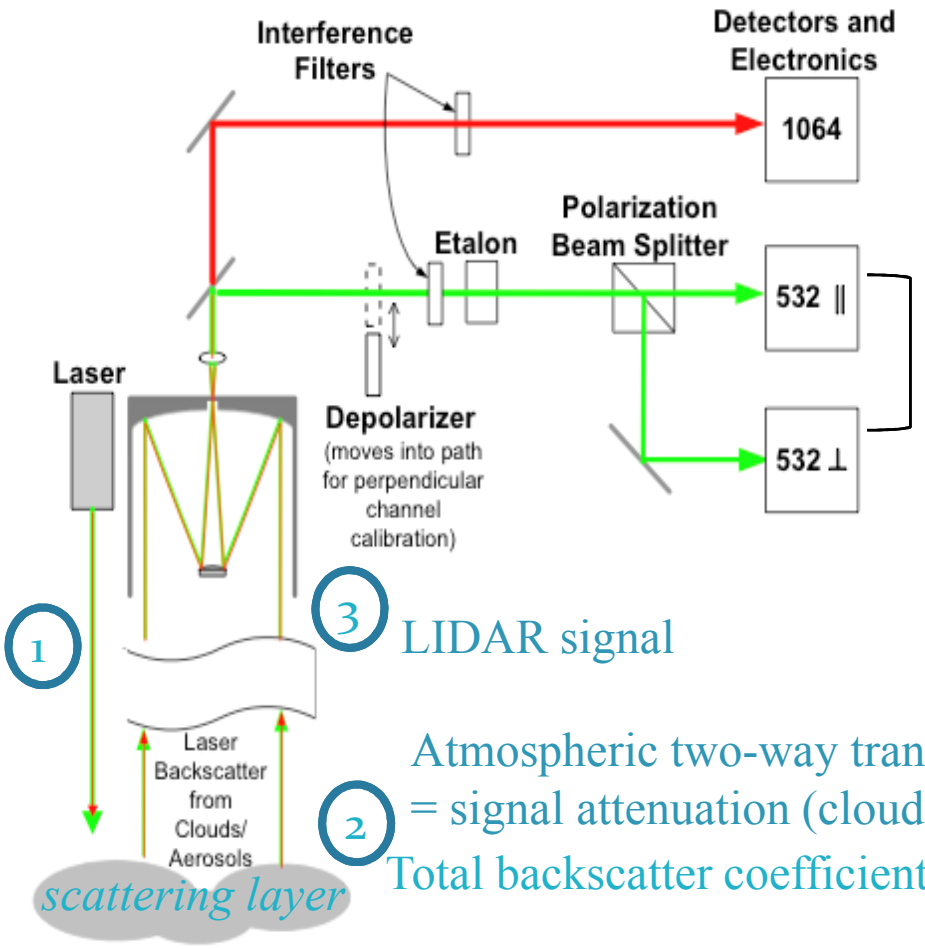
CALIOP:

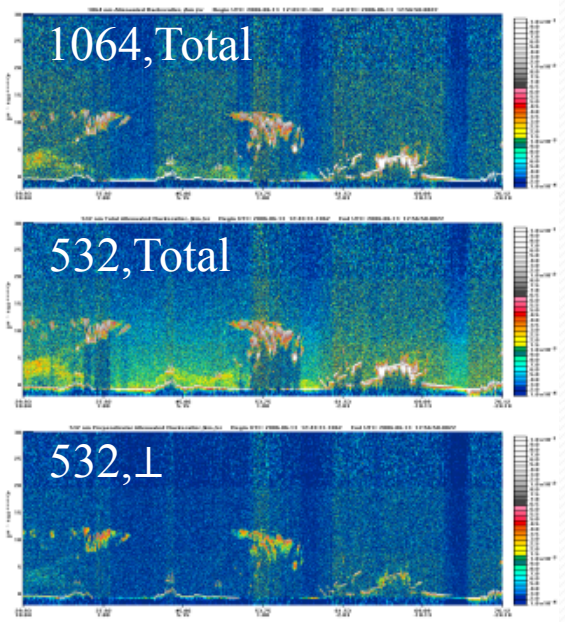
- backscatter Nd:YAG lidar
- 532, 532-perp, 1064



- **Active downward pointing elastic backscatter LIDAR (LIght Detection And Ranging)**
- **90 m diameter foot print every 333m; No daily global coverage, covers a given region every 16 days**

How does CALIOP work?





Important Points to Know about CALIOP

Lidar signal β' **Is a function of extinction and backscatter**

Aerosol and molecular backscatter

LIDAR Ratio S_a $= \alpha_a/\beta_a$ **Aerosol extinction-to-backscatter ratio (Assumed for CALIOP)**

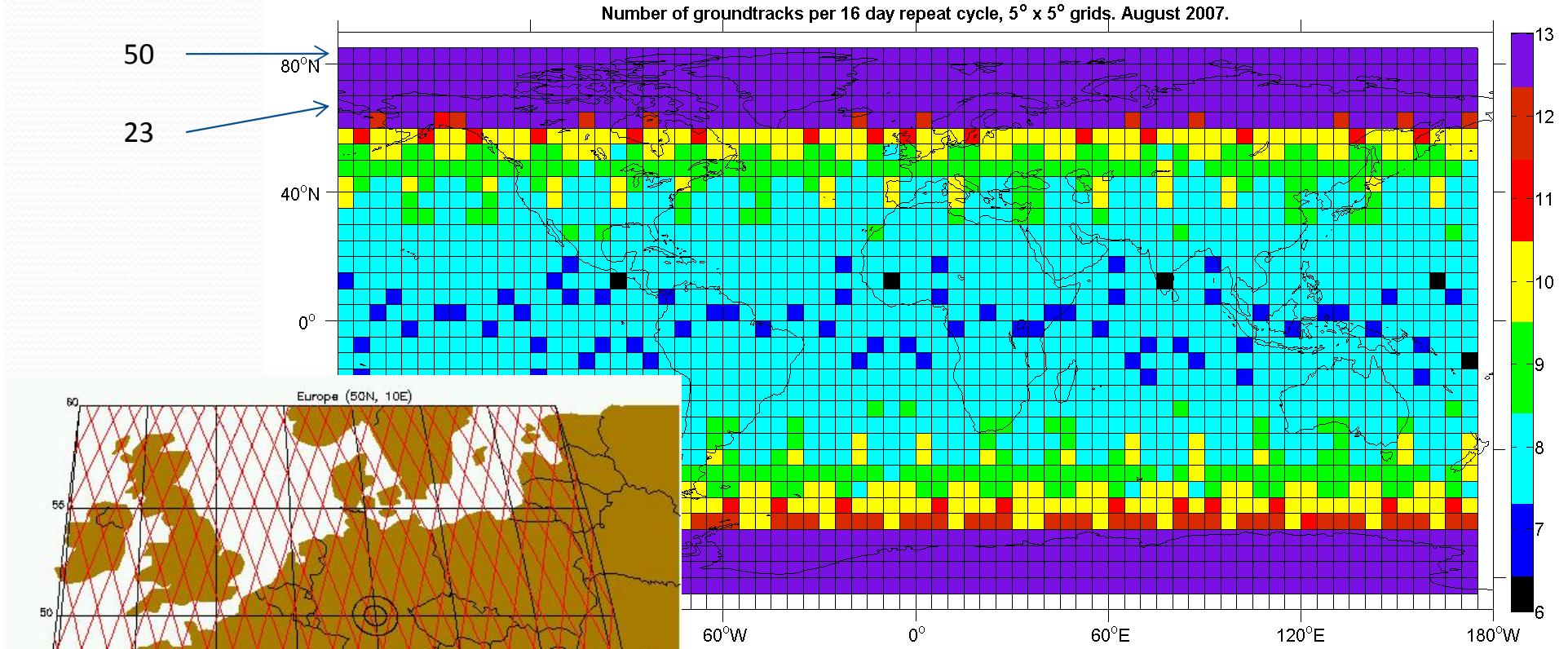
Color Ratio

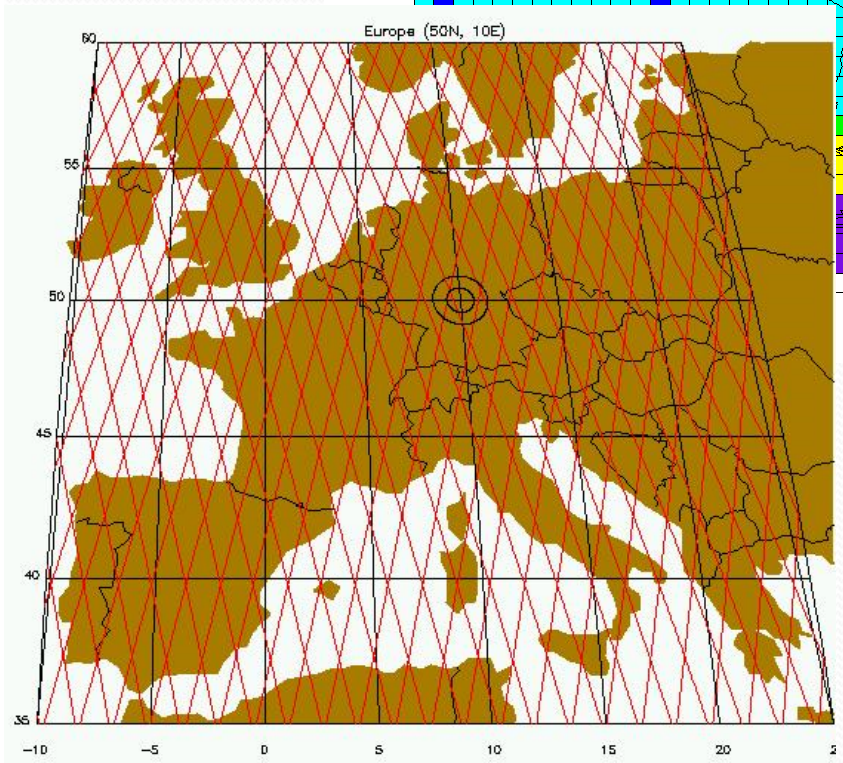
The ratio of the short to long wavelength.
Gives information on particle size.
For multiple wavelength lidars.

Lidar Signal Interpretation

β'_{532}	$\beta'_{532\perp}$	β'_{1064}	Particle Type
Enhanced Signal	Enhanced Signal	Same intensity as 532	Non-Spherical Coarse
Enhanced Signal	Enhanced Signal	Lower intensity than 532	Non-Spherical Fine
Enhanced Signal	Non Enhanced Signal	Same intensity as 532	Spherical Coarse
Enhanced Signal	Non Enhanced Signal	Lower intensity than 532	Spherical Fine

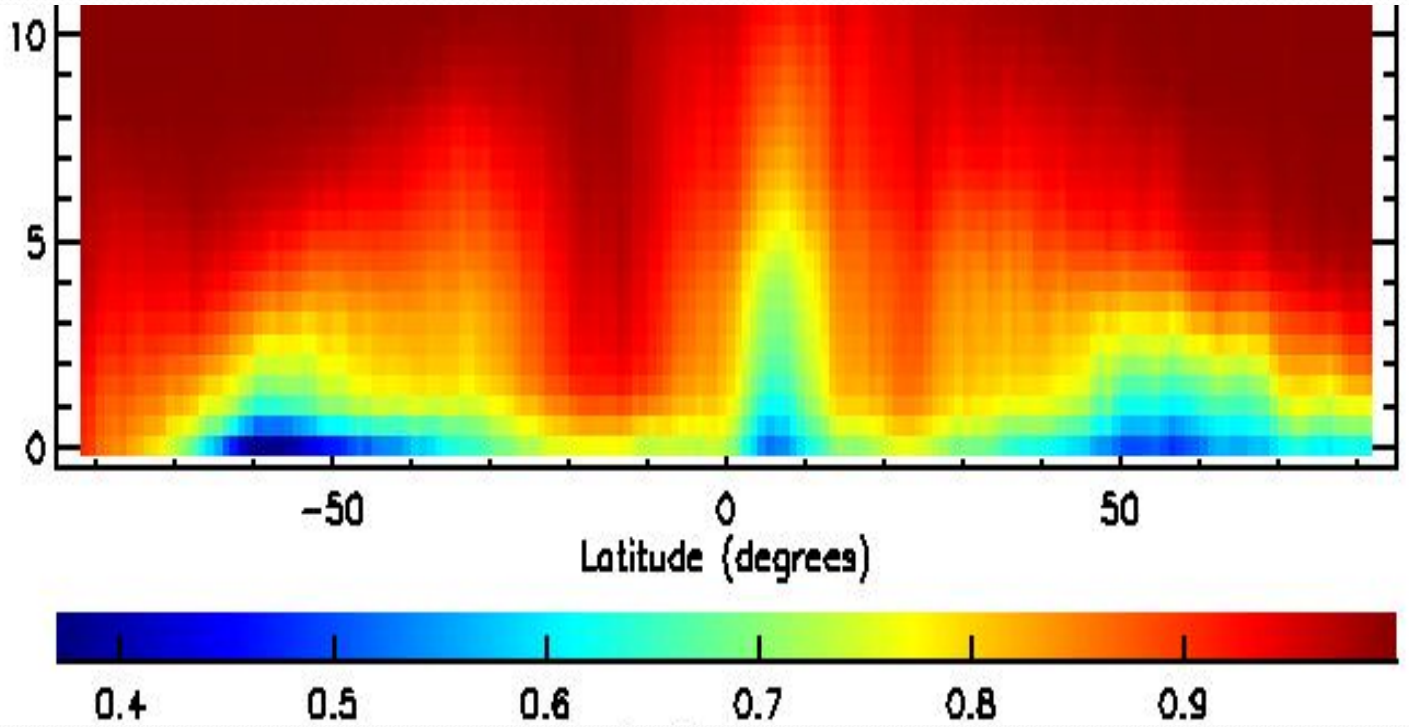
Tracks per 5x5 grid cell over 16 days





Penetration Statistics

Zonal average penetration frequency (5-km average profiles)



Global average (single shots) CALIPSO

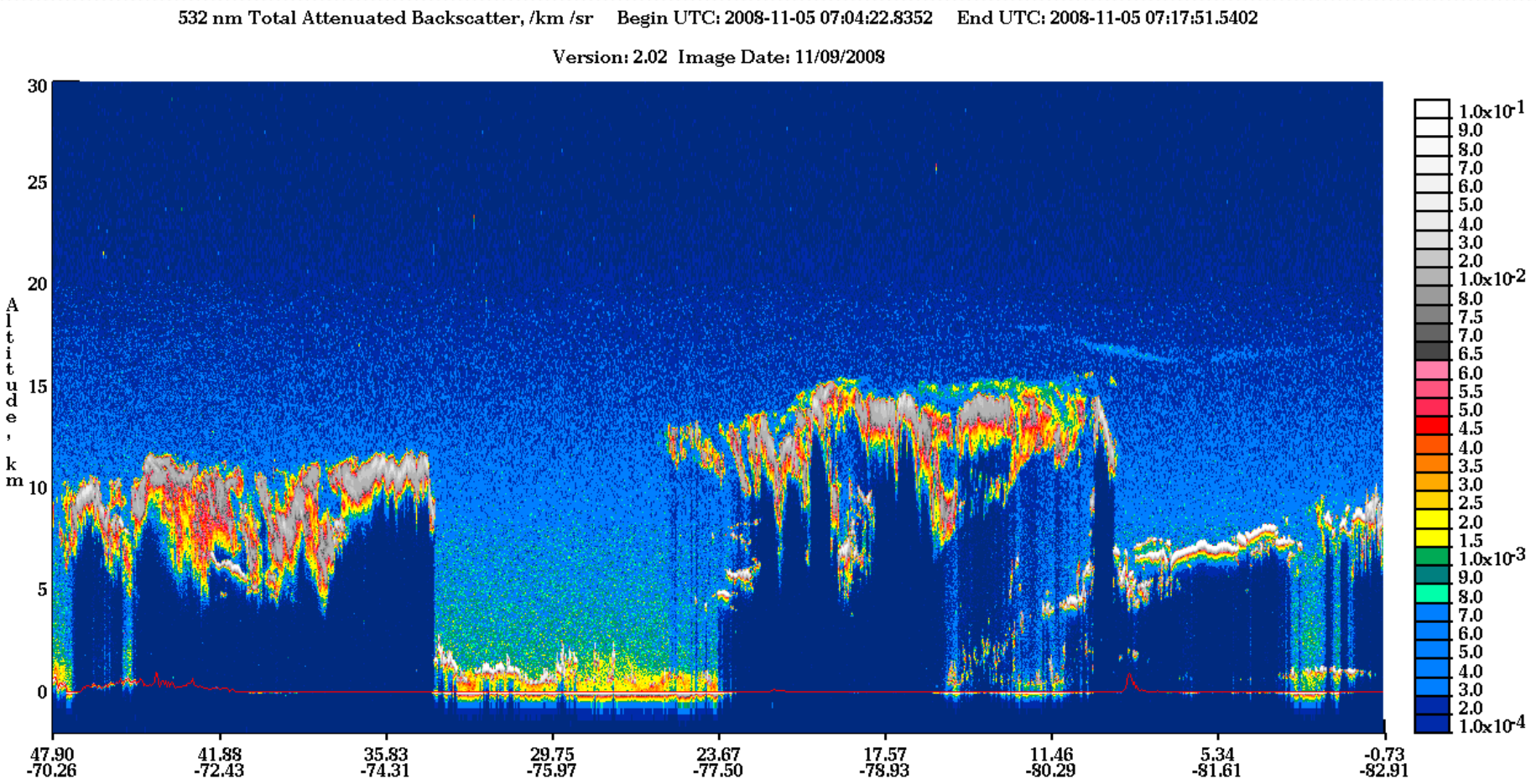
6 km	58%
4 km	52
2 km	43
Sfc	31

CALIPSO	
orbit	705 km
energy	110 mJ

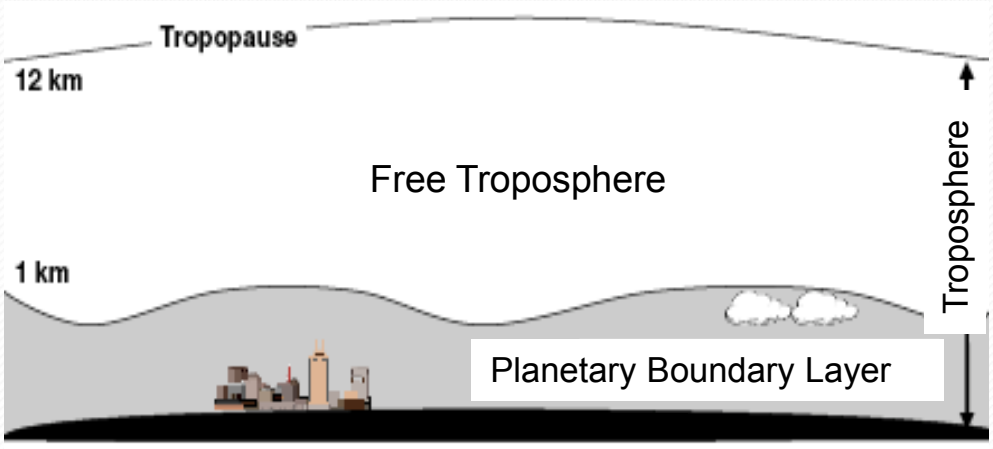
CALIPSO

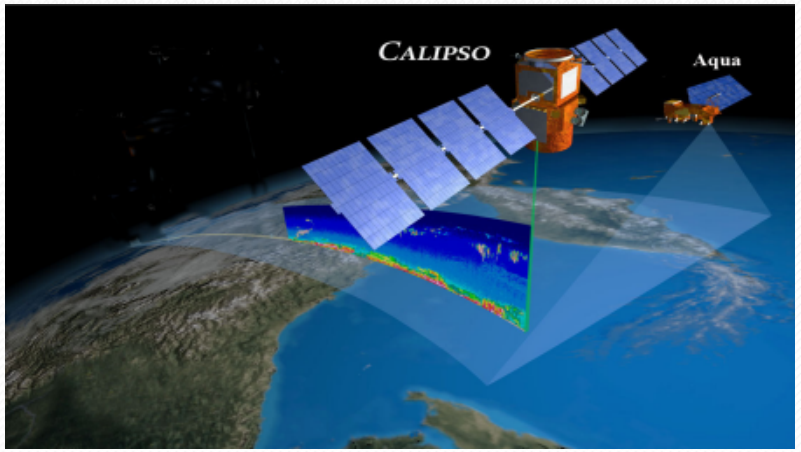
- **"Curtain"**

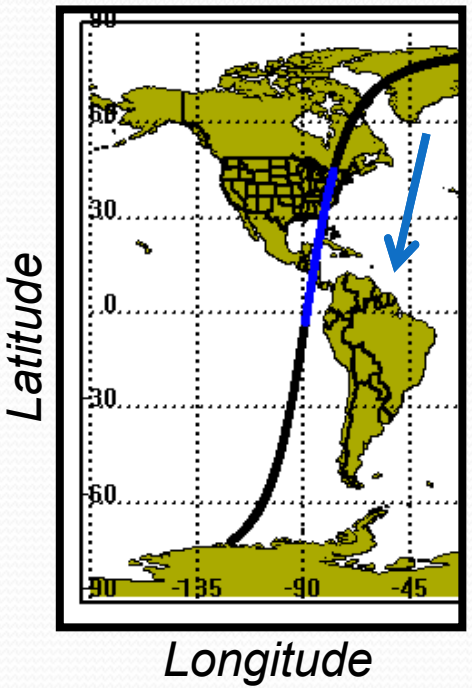
"/km /sr" - per km per steradian (square radian)

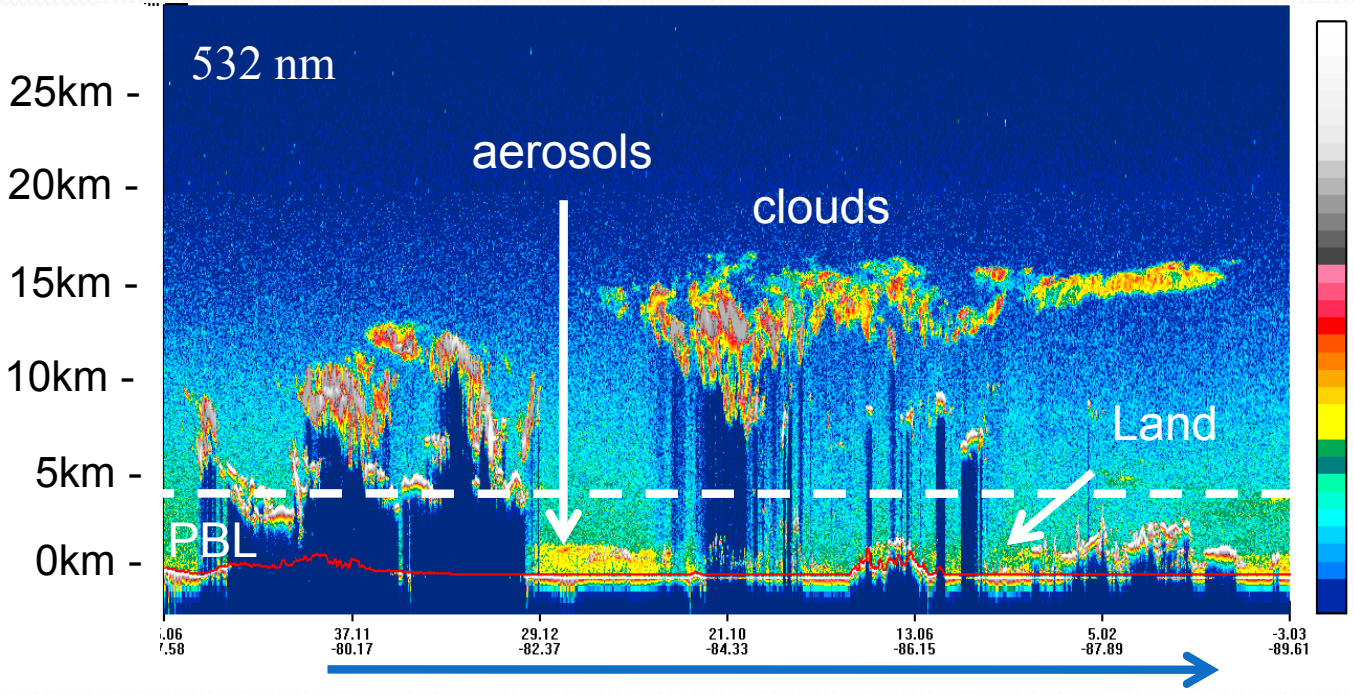


What's a CALIPSO Curtain Scene?









CALIPSO products

Version 3.3 Product	Primary Parameter	Resolution due to averaging	
		Horizontal	Vertical (<8km)
Level 1 Measured	Total_Attenuated_Backscatter_532 Perpendicular_Attenuated_Backscatter_532 Total_Attenuated_Backscatter_1064	1/3km	30m
Level 2 LAYER Retrieved	Cloud Layer_Top/ Base_Altitude	1/3, 1, 5km	30m
	Aerosol Layer_Top/ Base_Altitude	5km	30m
Level 2 PROFILE Retrieved	Cloud and Aerosol Total_Backscatter_Coefficient_532 Extinction_Coefficient_532	5km	60m
Level 2 Vertical Feature Mask Retrieved	Feature_Classification_Flags	5km	30m

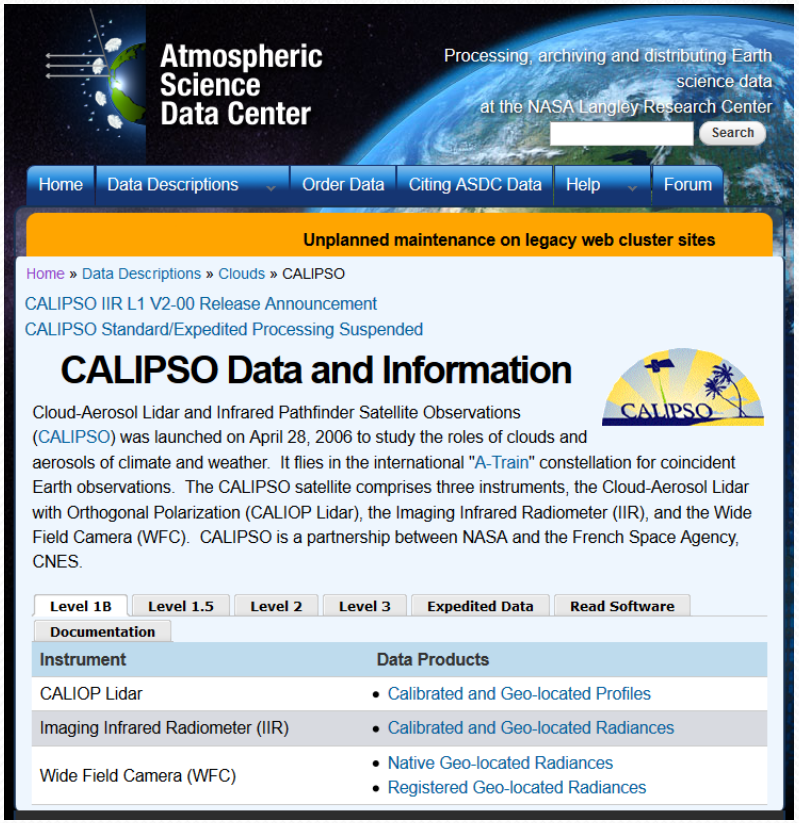
Lidar Data Products

Level 1 (geolocated and calibrated)

- DP 1.1 - profiles of attenuated lidar backscatter (532, $532_{\perp}$, 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



(available at https://eosweb.larc.nasa.gov/project/calipso/calipso_table

From lidar signal to extinction profile? -Theory-

Lidar signal => **calibration** => **Attenuated backscatter coefficient β'**

In a cloud-free atmosphere:

$$\beta' = (\beta_a + \beta_m) T_a^2 T_m^2 T_{O_3}^2$$

Aerosol and molecular backscatter

Atmospheric two-way transmittance = signal attenuation Aerosols, Molecules, Ozone

For aerosols:

$$T_a^2 = \exp\left(-2 \int \alpha_a(z) dz\right)$$

Aerosol extinction coefficient

Molecular backscatter and attenuation can be computed

=> **β' function of β_a and α_a**

One measurement

Two unknowns

If we assume an aerosol extinction-to-backscatter LIDAR ratio $S_a = \alpha_a/\beta_a$

function of particle size and shape and β' in 3 channels

=> Retrieval of β_a and α_a

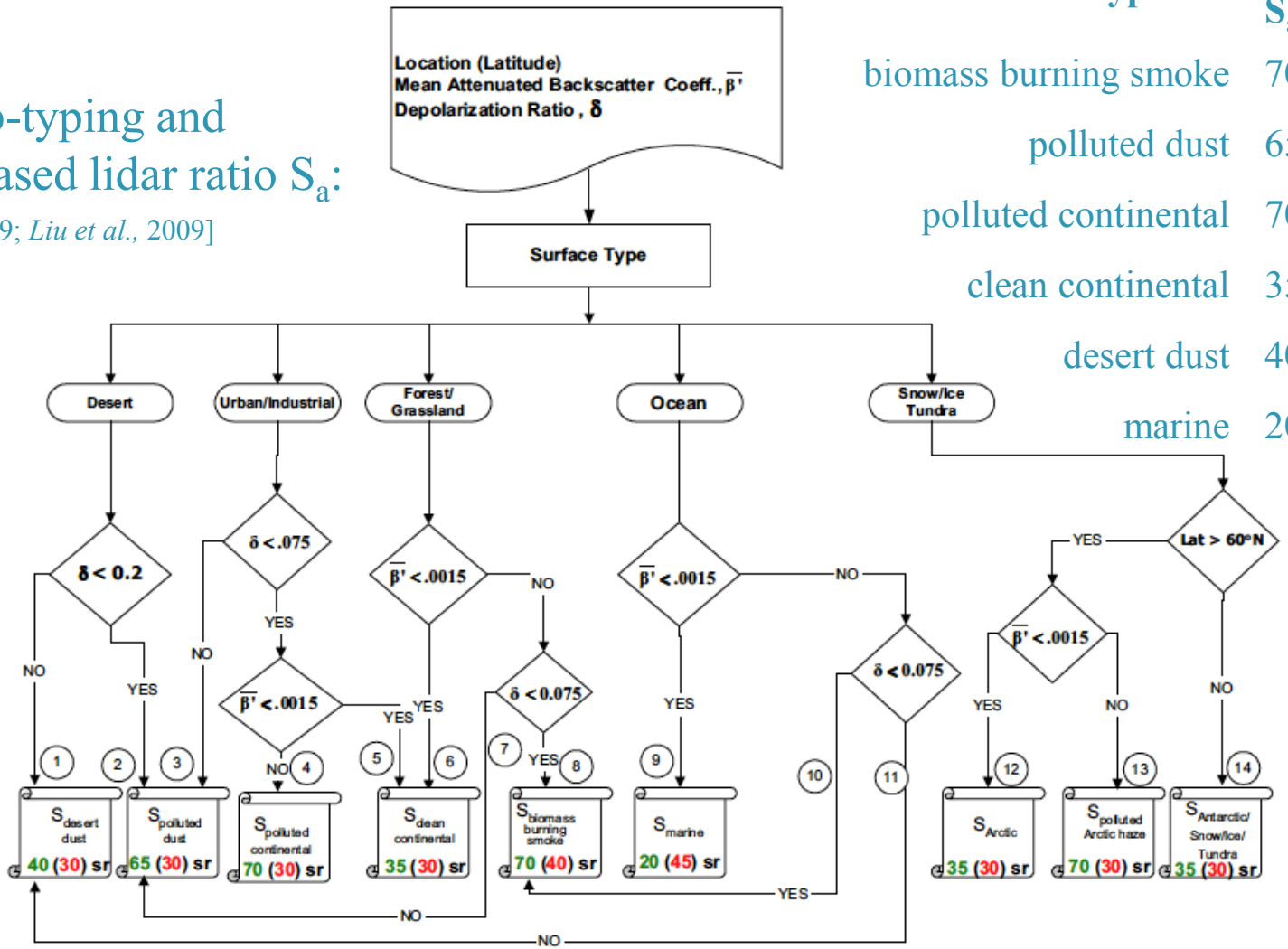
Layer classification

a) Cloud-Aerosol Discrimination [*Liu et al.*, 2004, 2009]

b) Cloud ice-water phase discrimination [*Hu et al.*, 2009]

c) Aerosol sub-typing and observation-based lidar ratio S_a:

[*Omar et al.*, 2005, 2009; *Liu et al.*, 2009]



Look Up Table

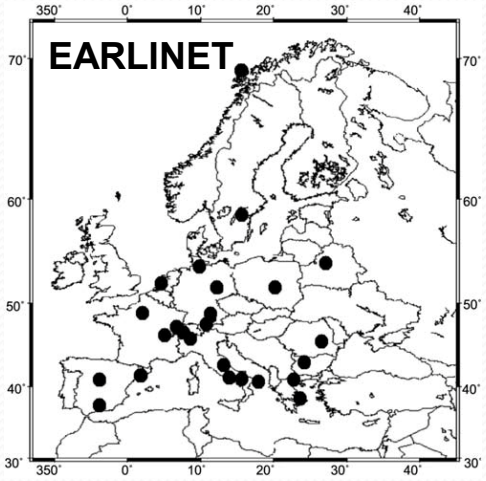
Aerosol Sub-type	Initial $S_{a,532}$
biomass burning smoke	70
polluted dust	65
polluted continental	70
clean continental	35
desert dust	40
marine	20

CALIPSO validation

Level 1 CALIOP attenuated backscatter

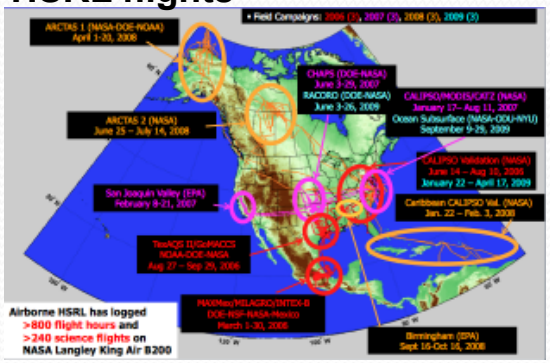
✓Absence of evident bias in CALIOP level 1 attenuated backscatter profiles

✓CALIOP 532 nm calibration algorithm seems fairly accurate



1. Ground-based validation with EARLINET (European Aerosol Research LIdar NETwork):
Relative mean difference of ~4.6% between CALIOP and EARLINET since June 2006 over Europe [*Pappalardo et al.*, 2010]

HSRL flights



2. Airborne validation with HSRL (High Spectral Resolution Lidar):
HSRL and CALIOP (coincident data from 86 underflights) agree on average within 2.7±2.1% (CALIOP lower) at night and within 2.9±3.9% (CALIOP lower) during the day [*Rogers et al.*, 2010]

CALIPSO validation

Level 2 CALIOP layer boundaries, backscatter and extinction

✓Very little validation of CALIOP level 2 data: few case studies

✓Significant uncertainties associated with level 2 data

1. Ground-based validation with EARLINET

Example: CALIPSO **underestimate**s Sa (40 instead of ~50 sr, hence underestimates AOD) during 26–31 May 2008 Saharan Dust outbreak [*Pappalardo et al.*, 2010]

2. Airborne validation with HSRL

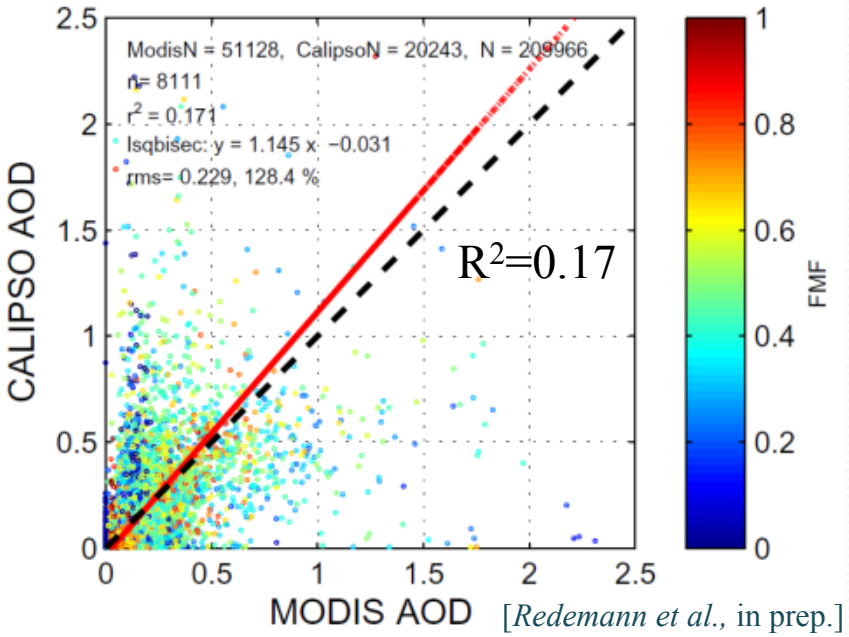
CALIOP **overestimates** HSRL extinction with an average extinction bias of ~ 24% during CATZ (CALIPSO and Twilight Zone campaign) and ~59% during GoMACCS (Gulf of Mexico Atmospheric Composition and Climate Study) [*Omar et al,* 2009]

CALIPSO validation

3. CALIOP versus other A-Train satellite AOD

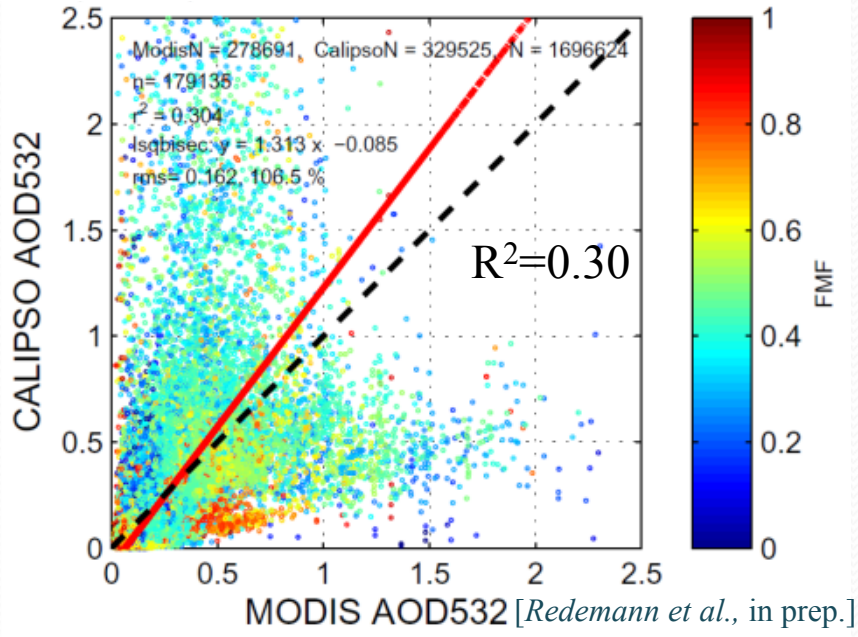
• CALIOP (V2) **underestimates** both POLDER and MODIS AOD (also AERONET and HSRL) on August 04 2007 by 0.1-0.2 during CATZ [*Kacenelenbogen et al.*, 2010]

CALIOP Version 2



[*Redemann et al.*, in prep.]

CALIOP Version 3.01



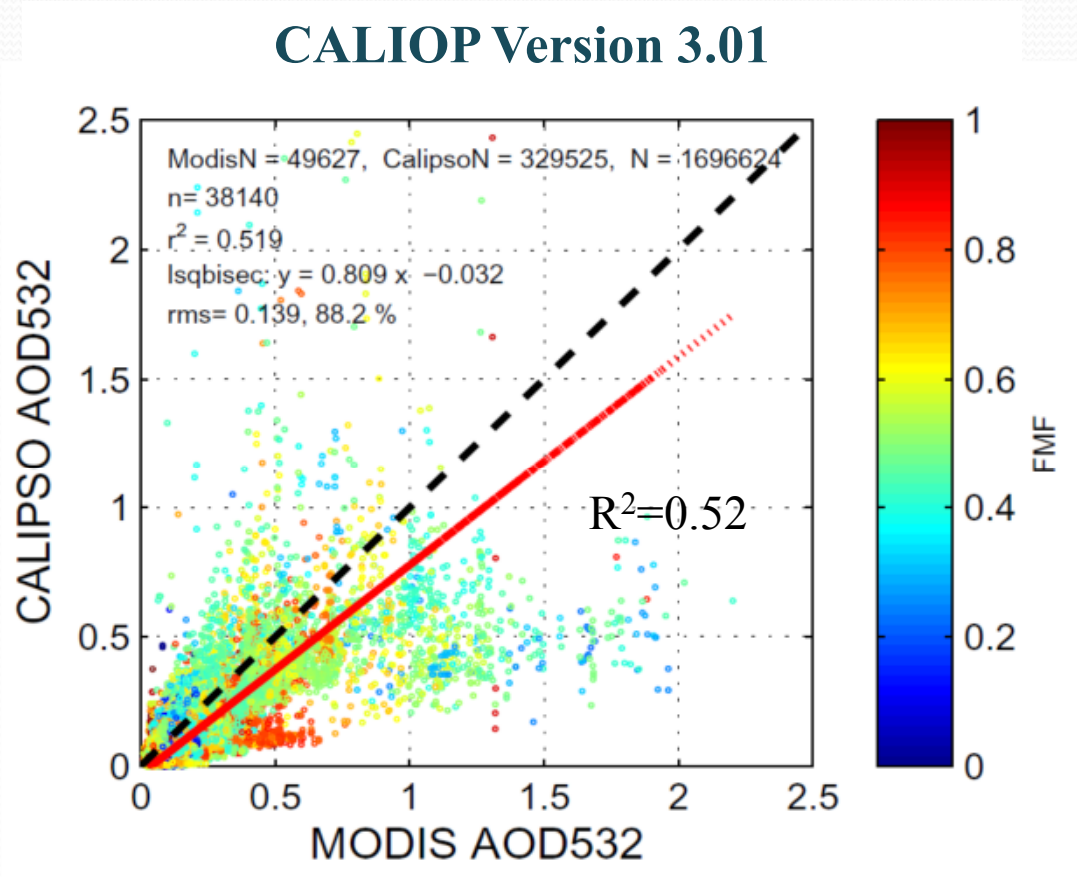
[*Redemann et al.*, in prep.]

•CALIOP **(V3.01) better** than CALIOP (V2)-MODIS AOD but still not satisfactory

•**CALIOP (V3.01) globally overestimates** MODIS AOD over ocean with R^2=0.30 in January 2007

CALIPSO validation

Additional cloud-screening on both datasets with MODIS cloud fraction



Reduces discrepancies between two data sets due to cloud contamination

Higher correlation coefficient (0.52 instead of 0.30)

CALIPSO slightly **underestimates** MODIS AOD

Level 2 data uncertainties

Low Signal to noise ratio

CALIOP will fail to detect layers with aerosol backscatter < 2~4 10^{-4} km^{-1} sr^{-1} in troposphere [*Winker et al.,* 2009] (S_a of 50sr, α of 0.01-0.02 km^{-1}, AOD of 0.02-0.04 in 2km)

➔CALIOP not measuring tenuous aerosol layers

➔ Lack of photons returned from underneath highly attenuating layers (dense aerosol or cloud) leading to erroneous or total lack of aerosol identification in the lower part of a given atmospheric profile

Miss-classification of layer type (aerosol or cloud) and aerosol sub-type (biomass, dust, etc…)

➔ leading to incorrect assumption about lidar ratio Sa

Improved calibration technique

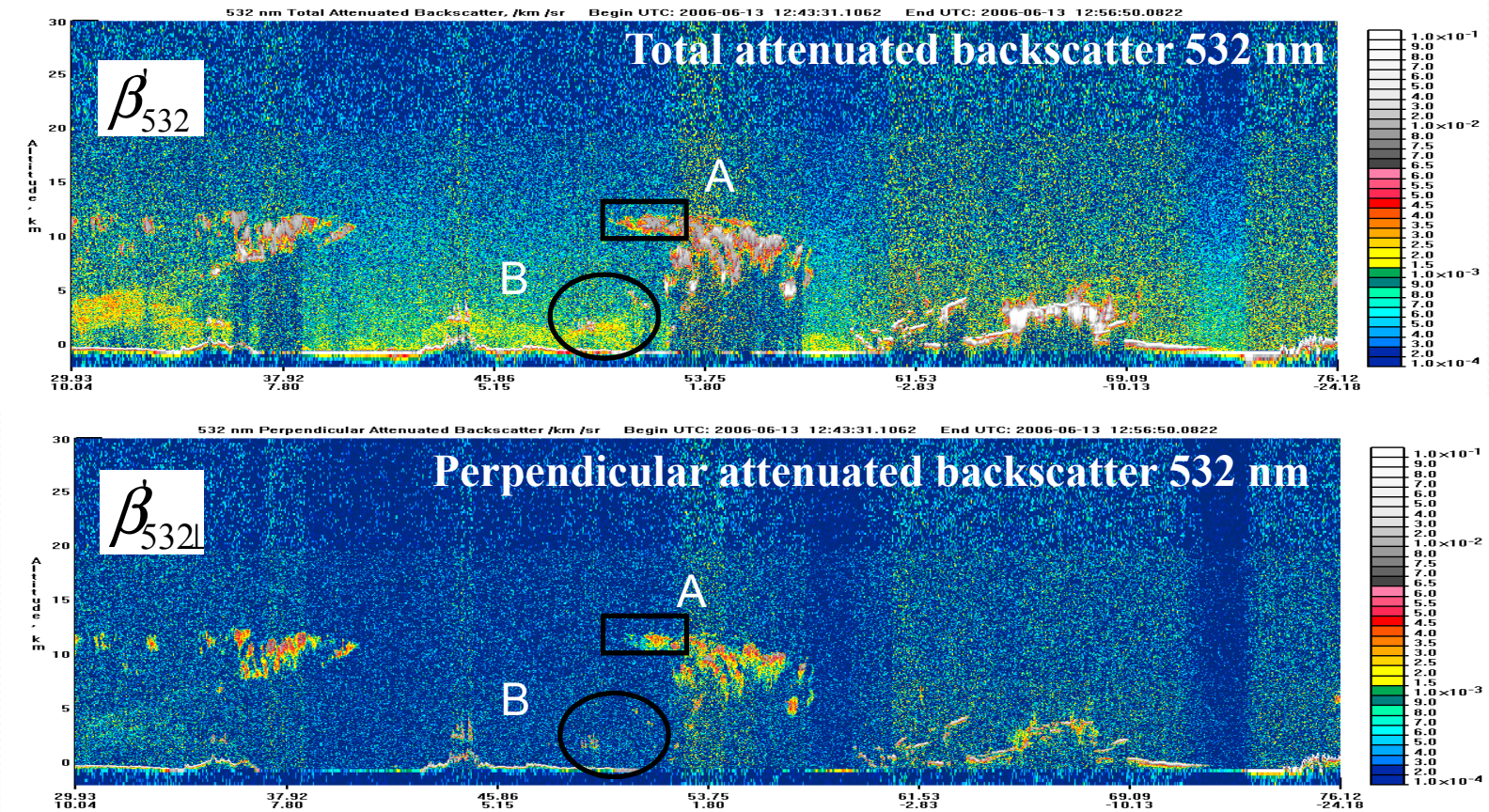
➔ for the lidar Level 1 532 nm daytime calibration in Version 3.01 [*Powell et al.*, 2010]

Multiple scattering is assumed negligible in current algorithm

➔ Impact on cases with dense dust plumes recording high AOD where effects of multiple scattering applies

CALIPSO browse images online

Level 1 products



If enhanced signal in both images then non spherical particles (Region A)

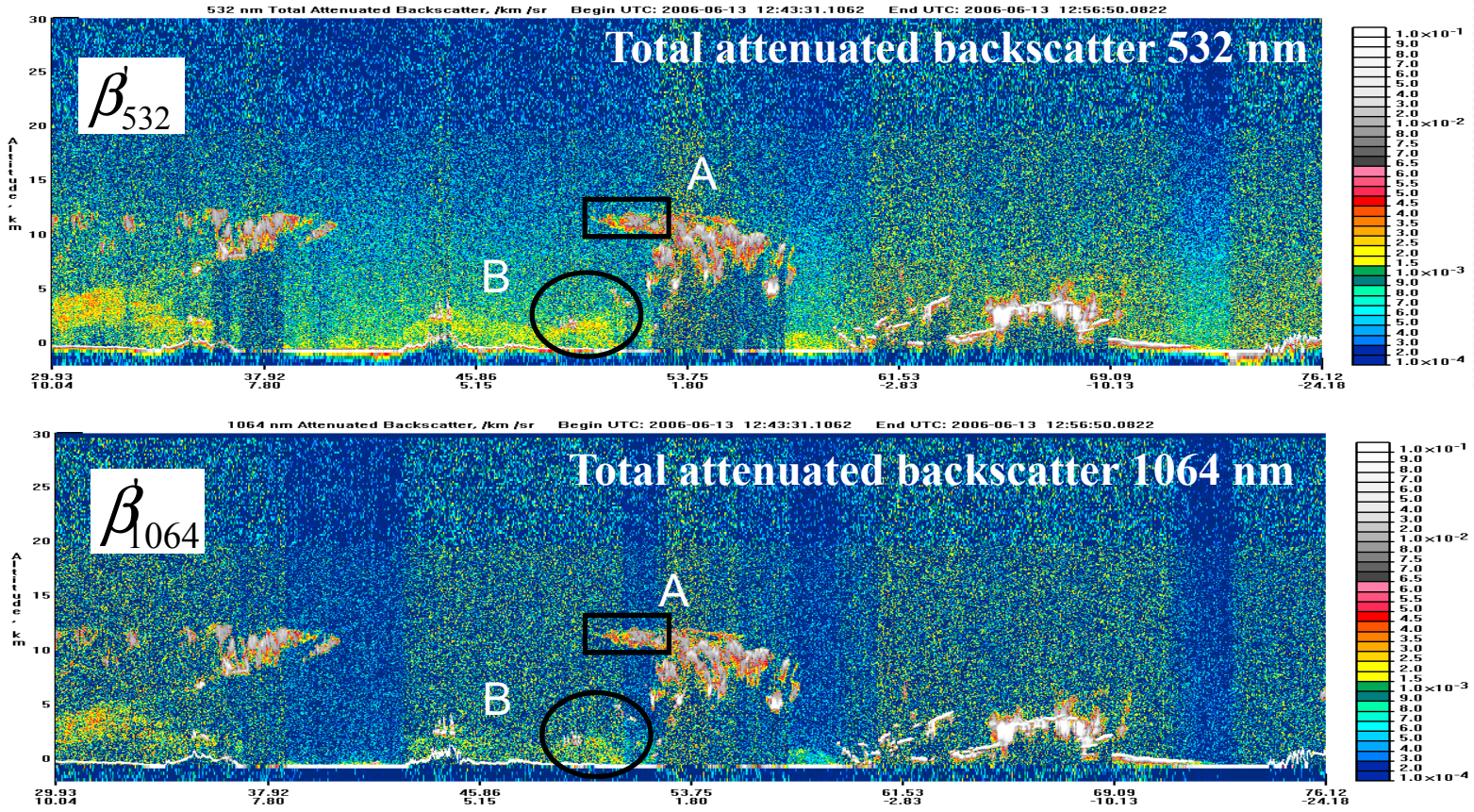
If enhanced signal in total backscatter image but little or no enhancement in the perpendicular image, then spherical particles (Region B)

Lidar Signal Interpretation

β'_{532}	$\beta'_{532\perp}$	β'_{1064}	Particle Type
Enhanced Signal	Enhanced Signal	Same intensity as 532	Non-Spherical Coarse
Enhanced Signal	Enhanced Signal	Lower intensity than 532	Non-Spherical Fine
Enhanced Signal	Non Enhanced Signal	Same intensity as 532	Spherical Coarse
Enhanced Signal	Non Enhanced Signal	Lower intensity than 532	Spherical Fine

CALIPSO browse images online

Level 1 products



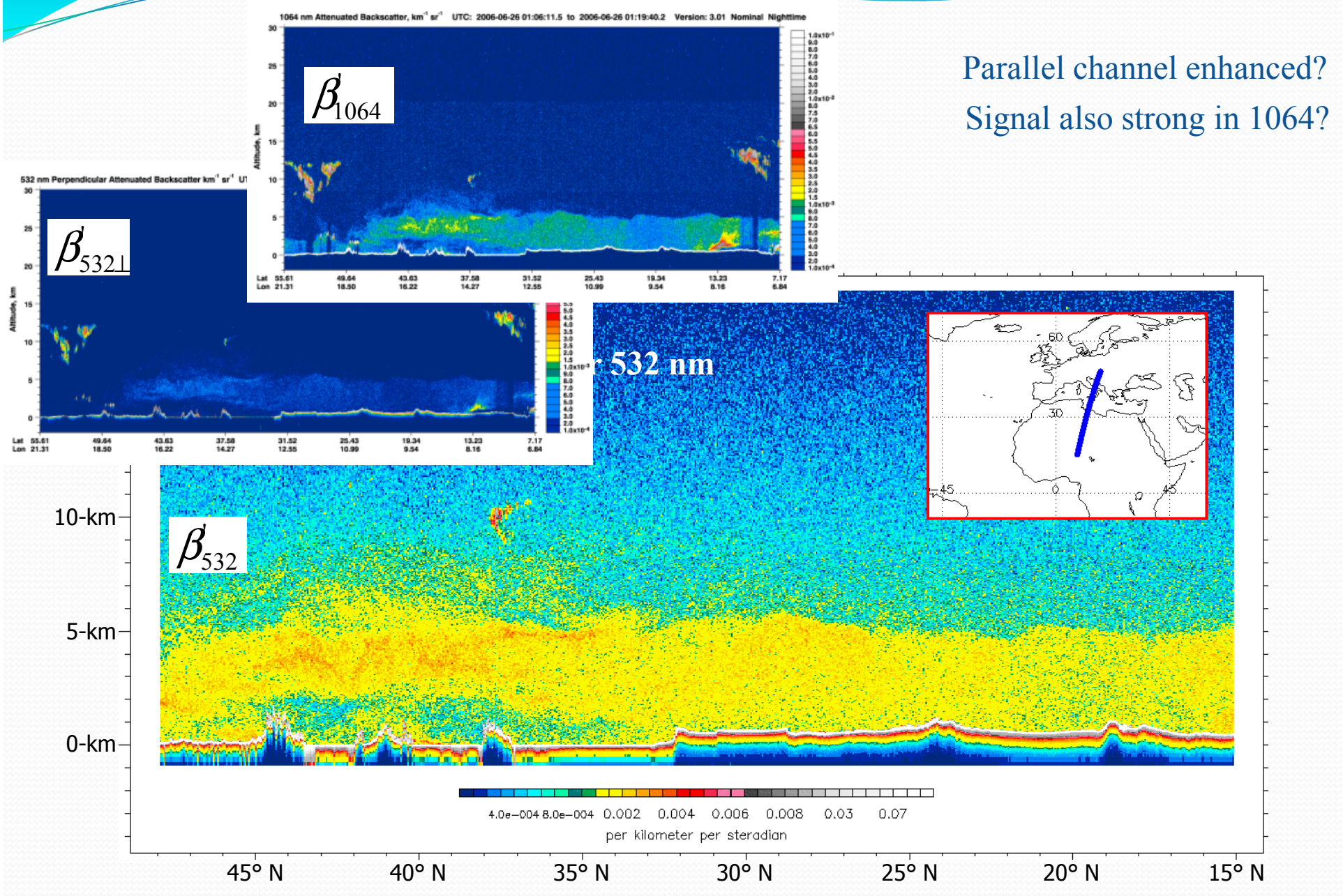
If same intensity in both channels, coarse particles

If signal more intense in β'_{532}, fine particles

Region A: coarse non spherical = cirrus cloud?

Region B: fine spherical = urban pollution?

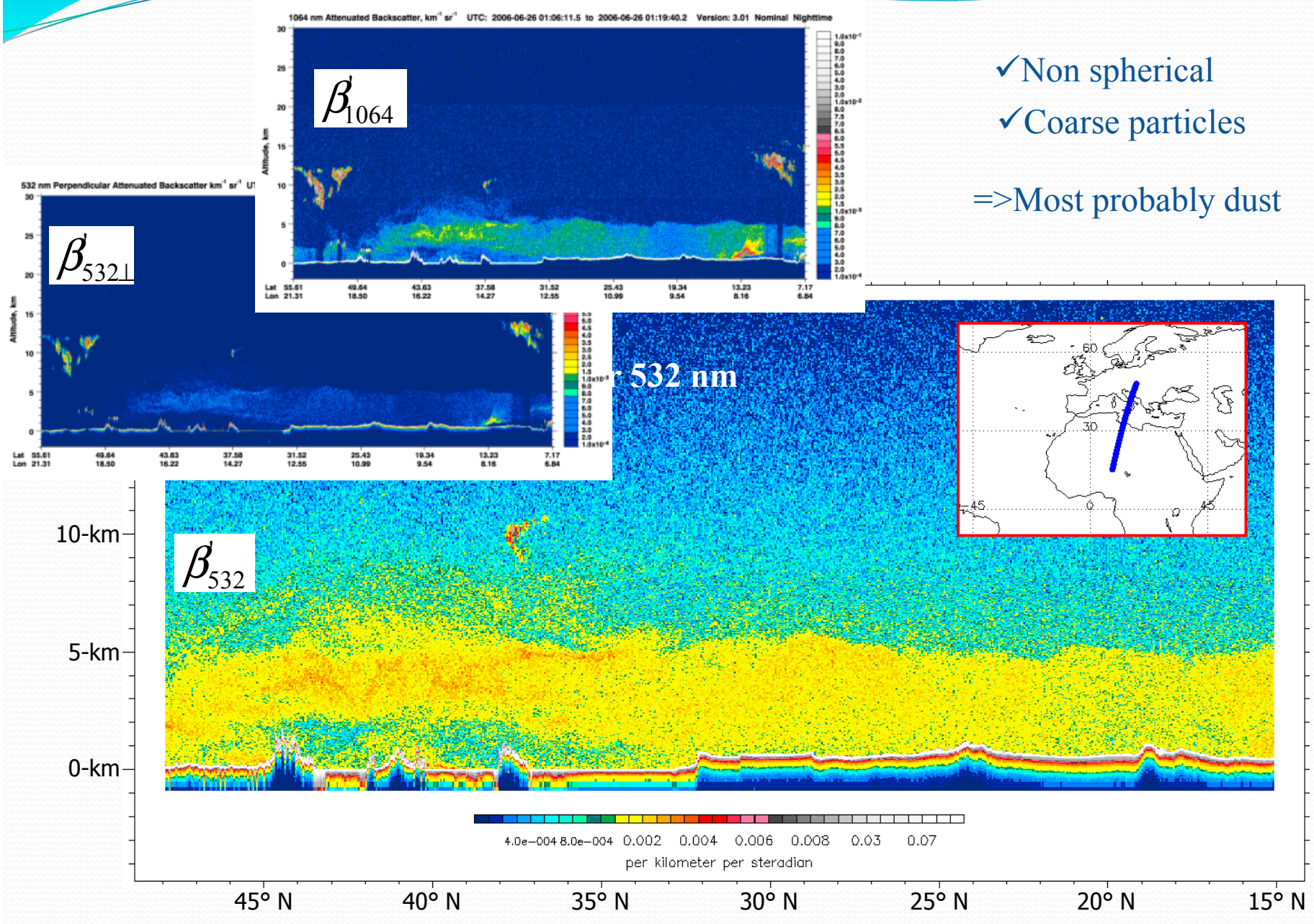
Example: June 26, 2006



Parallel channel enhanced?

Signal also strong in 1064?

Example: June 26, 2006



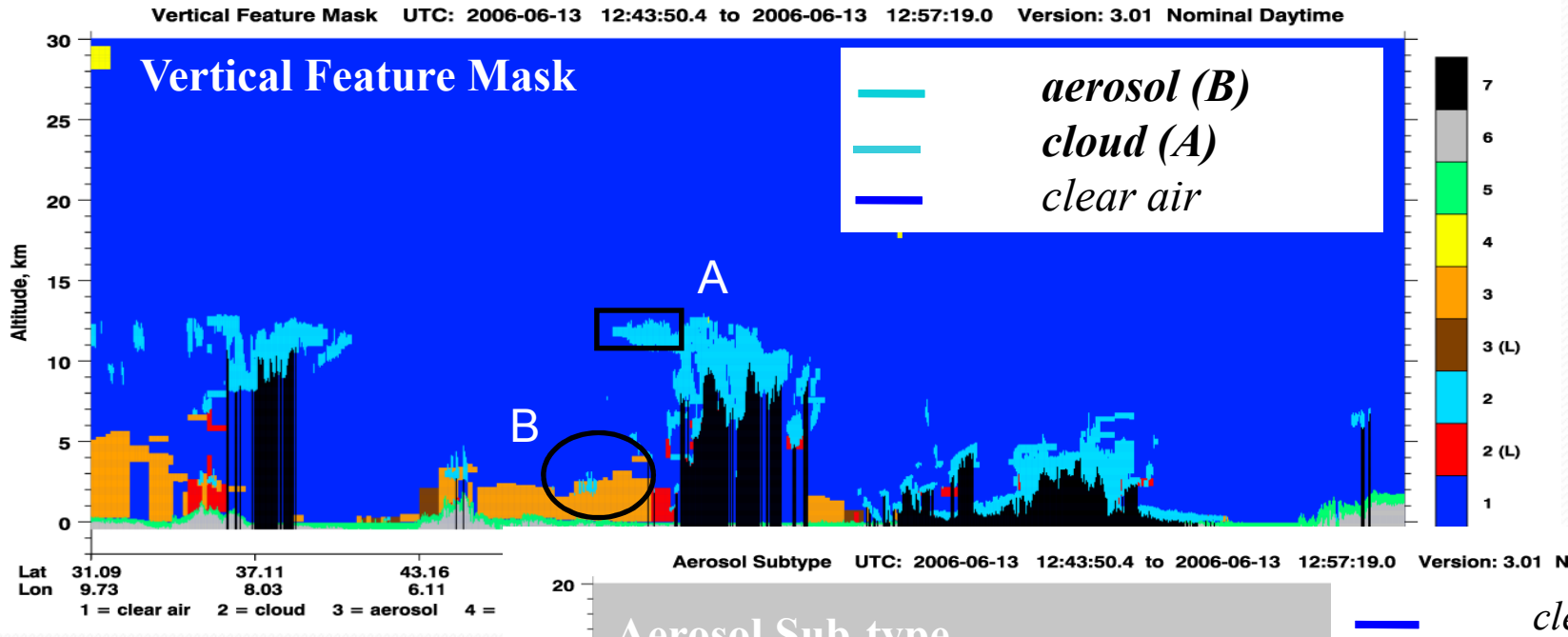
✓Non spherical

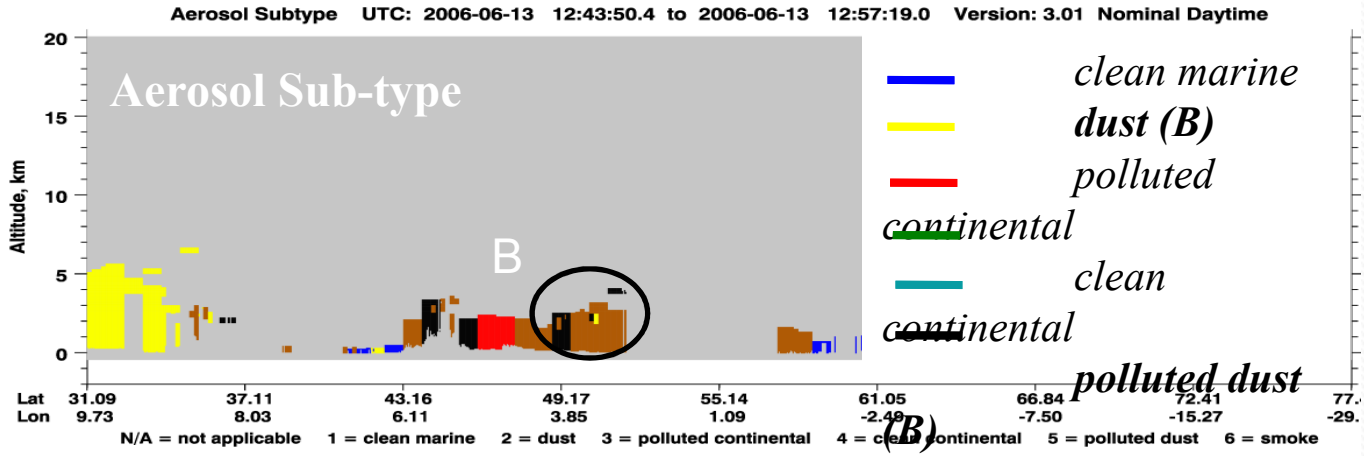
✓Coarse particles

=>Most probably dust

CALIPSO browse images online

Level 2 products





According to Level 2,
Region A: cloud
Region B: dust/ polluted dust for B

Different from Level 1 Analysis…

Which data should I use?

- **Safest is qualitative** use of **level 1 latest version** (currently 4) attenuated backscatter data in 3 channels

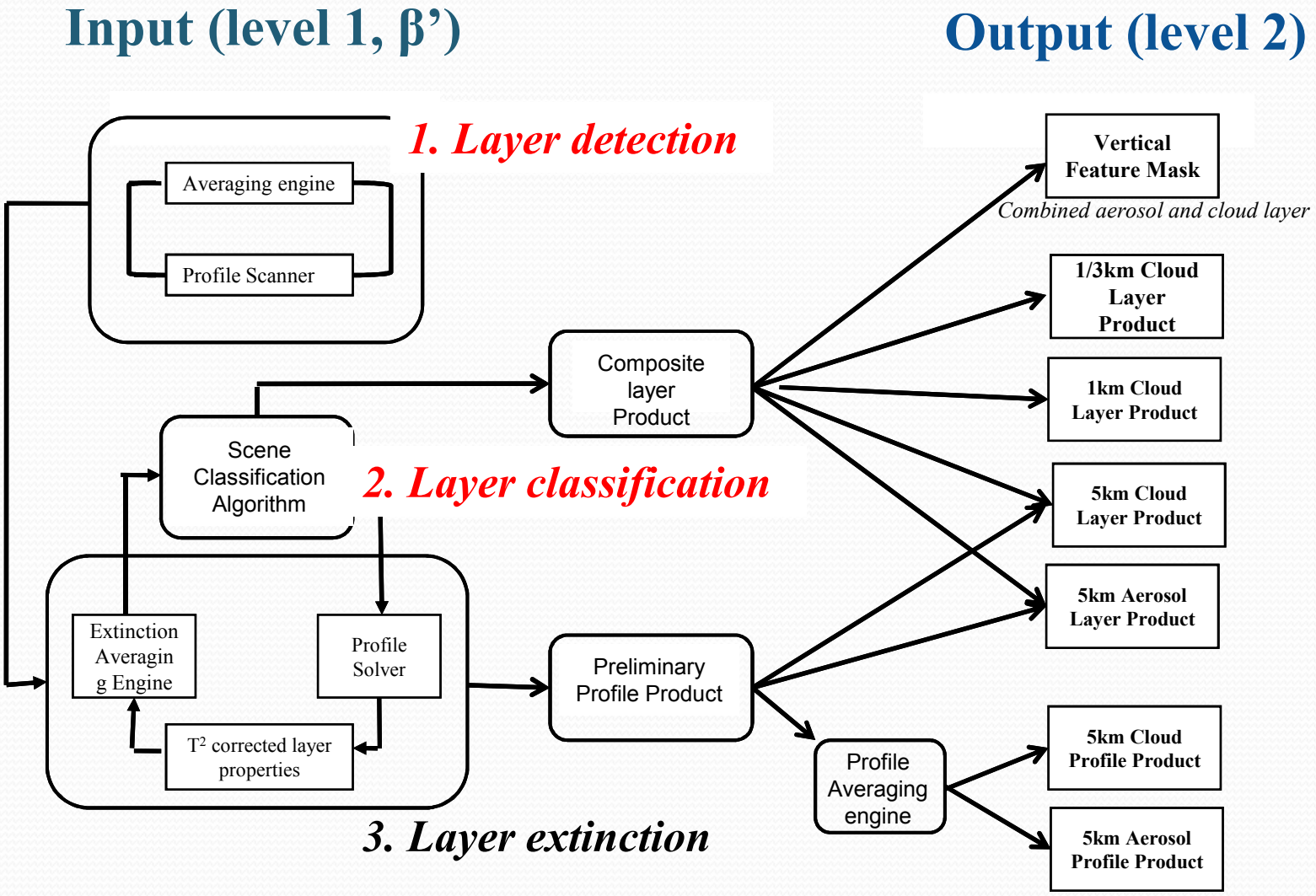
→ Browse **standard product lidar images** online

- For quantitative use, **level 1 data contains less uncertainties than level 2 data**

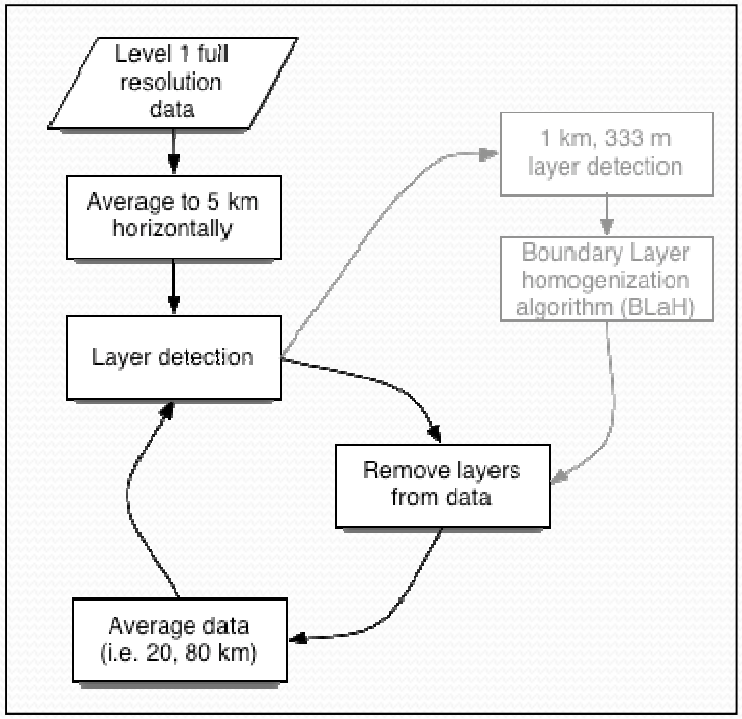
- **If you use level 2 data, you need to know the associated uncertainties** (and most of these are reported in the level 2 data products)

Some knowledge on Level 1-to-level 2 algorithm…

Level 1-to-level 2 algorithm

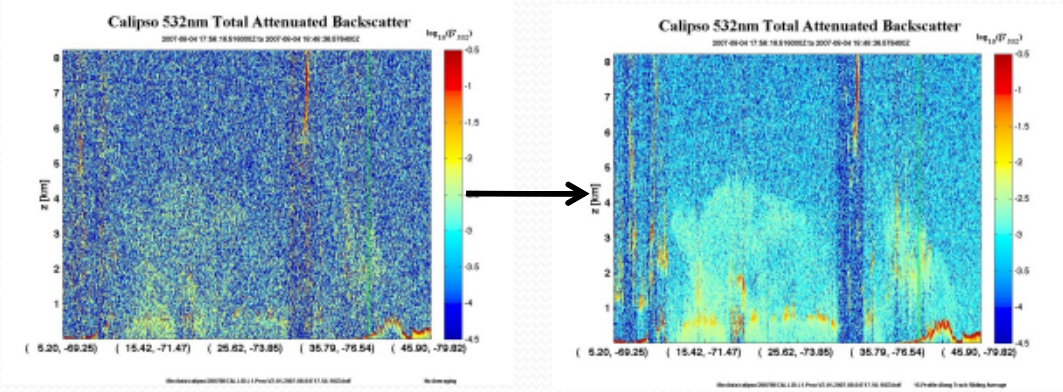


Layer Detection



a) Input is level 1 attenuated backscatter

b) Data averaged from 333m to 5km



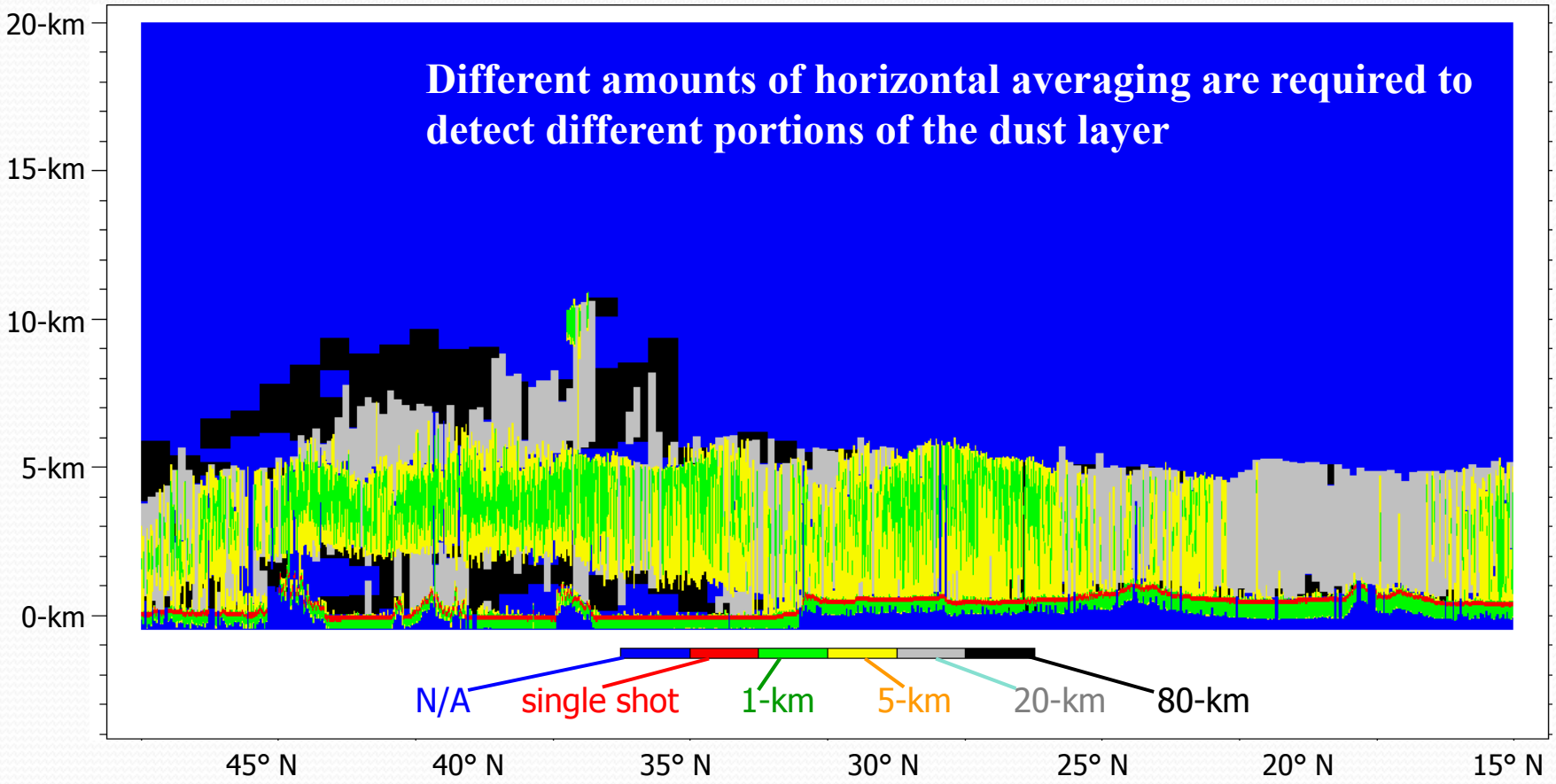
c) Layers identified as enhancements above molecular background (adaptive threshold using $\beta'_{532,\perp}$ and $\beta'_{532,//}$ and molecular model)

Here cloud detected at 333m; aerosol at 5km

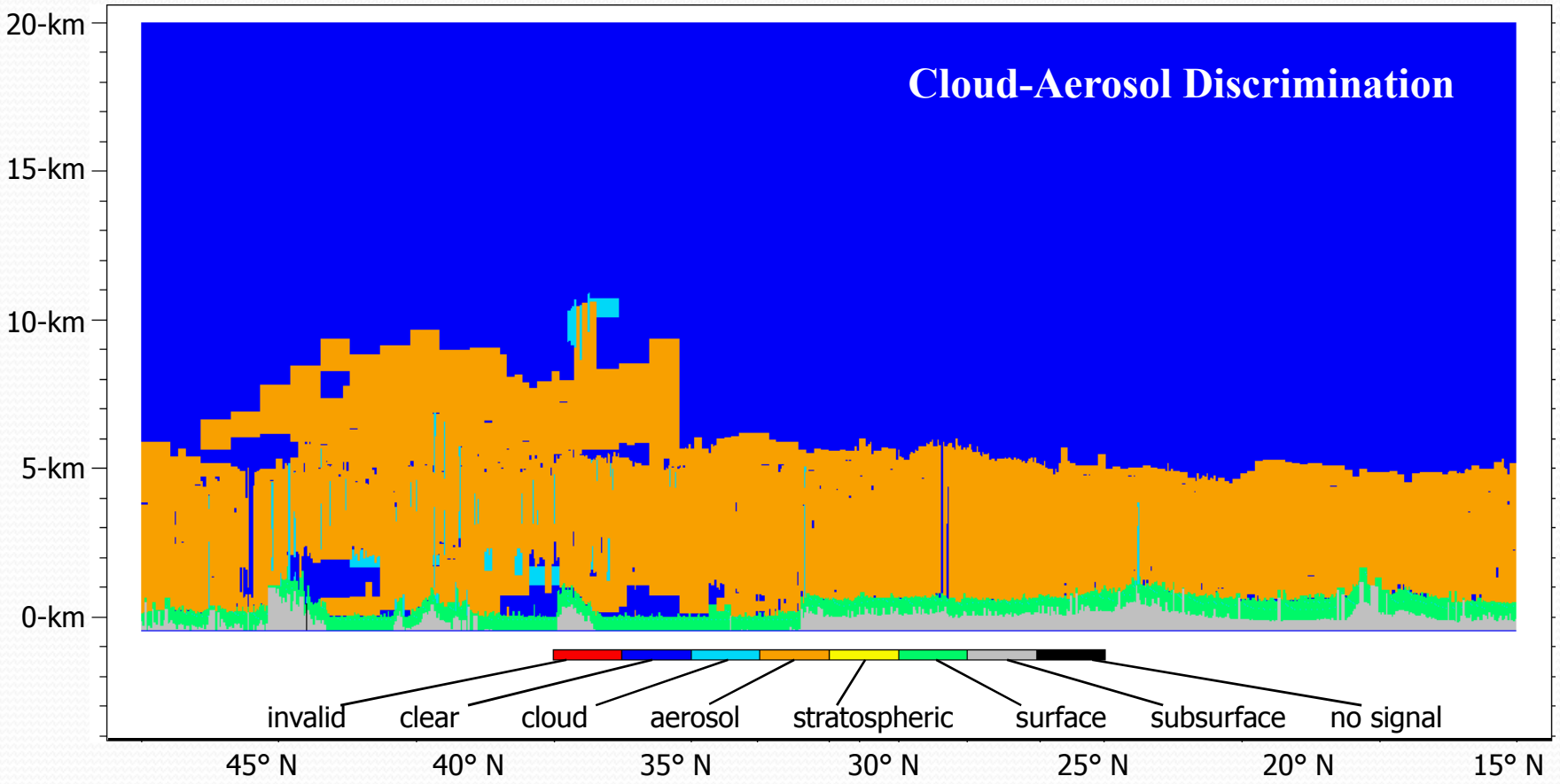
d) Detected layers removed from curtain scene

e) Further averaging of the data (20, 80km)…

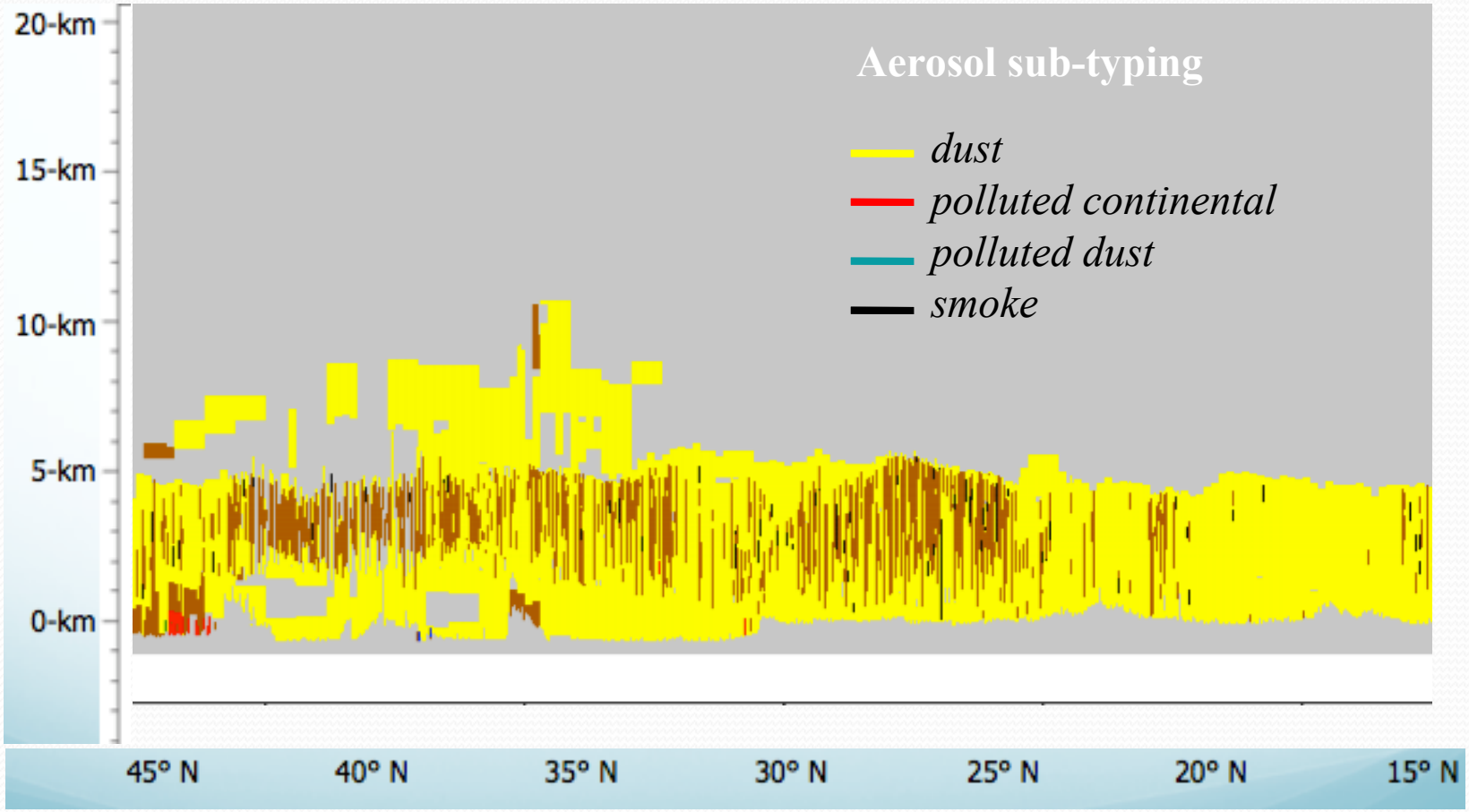
Example: June 26, 2006



Example: June 26, 2006



Example: June 26, 2006



CALIPSO: example of application

The detection of aerosols over clouds

Aerosols and their radiative effects are a major uncertainty in predictions of future climate change

Biomass burning aerosols usually strongly absorbing, may cause local positive radiative forcing when over clouds

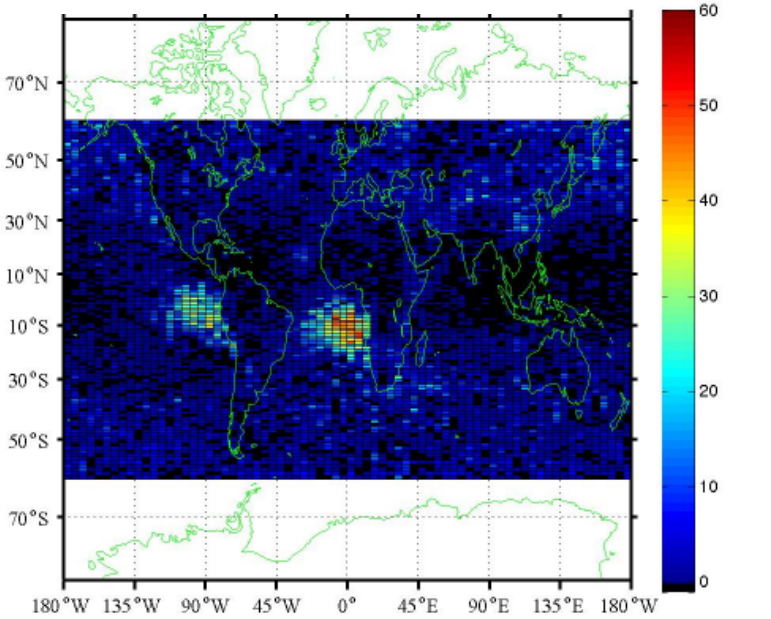
CALIOP is the only satellite sensor capable of observing aerosol over clouds without any auxiliary data (OMI or POLDER need to combine with MODIS and/ or CALIOP)

Before studying aerosol radiative effects over clouds, we need to know where and when aerosol over clouds occur as well as their intensity

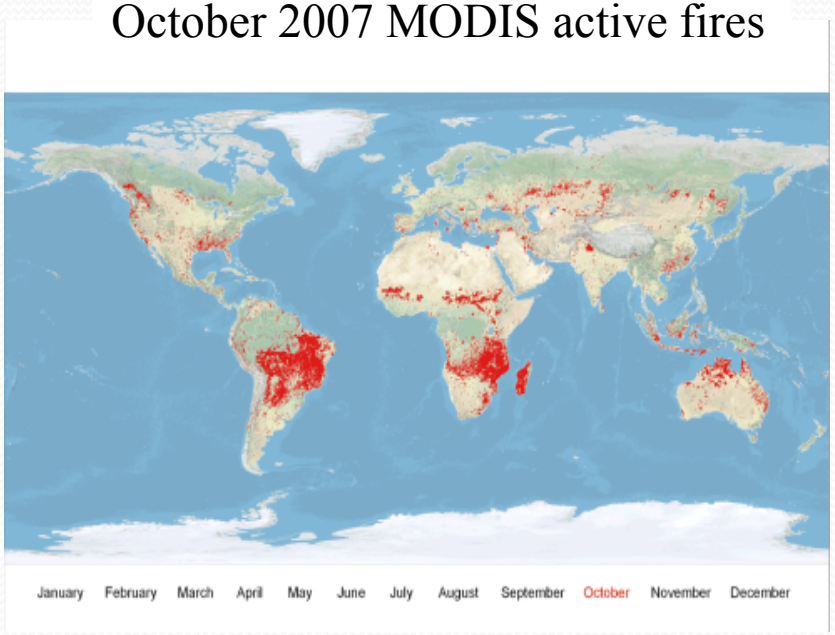
We use the CALIPSO level 2 aerosol layer product…

Aerosol Over Cloud (AOC)

October 2007 AOC occurrence



October 2007 MODIS active fires



Over 50 % AOC (/CALIOP data) offshore from South America and South Africa

Probably mostly biomass burning smoke

"…huge increase in fire activity in 2007… largest over the last ten years" and "largest 6-month (May–October) precipitation deficit of the last ten years in South America occurred during 2007 [Torres et al., 2009]

Take home message

CALIOP/ CALIPSO provides aerosol vertical distribution and info on type of particle (size and shape)

Safest use of CALIOP data:
1. Qualitative (browse lidar images online)
2. Latest version (currently V3.01)
3. Level 1 (contains less uncertainties than level 2 data)

Concerning the use of CALIOP Level 2 data,
- recognize the unvalidated nature of the data
- keep in mind the uncertainties
- make sure to read all quality assurance information and to apply the appropriate quality flags (see user guide, http://www-calipso.larc.nasa.gov/resources/calipso_users_guide/)
- If you have any concerns, ask the CALIPSO team

Online

- ***User Guide*:** *Note they're doing maintanence on their websites right now

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

  FAQ, Essential reading, Data Product Descriptions, Data quality summaries (V3.3), Example and tools, Order Data, Publications

- ***Data download***

  https://eosweb.larc.nasa.gov/HORDERBIN/HTML_Start.cgi

  http://www-calipso.larc.nasa.gov/search/ **for subset files**

- ***LIDAR browse images***

Level 1 and Level 2 Vertical Feature Mask; No level 2 profile

EXPEDITED 12h-RELEASE with kmz files

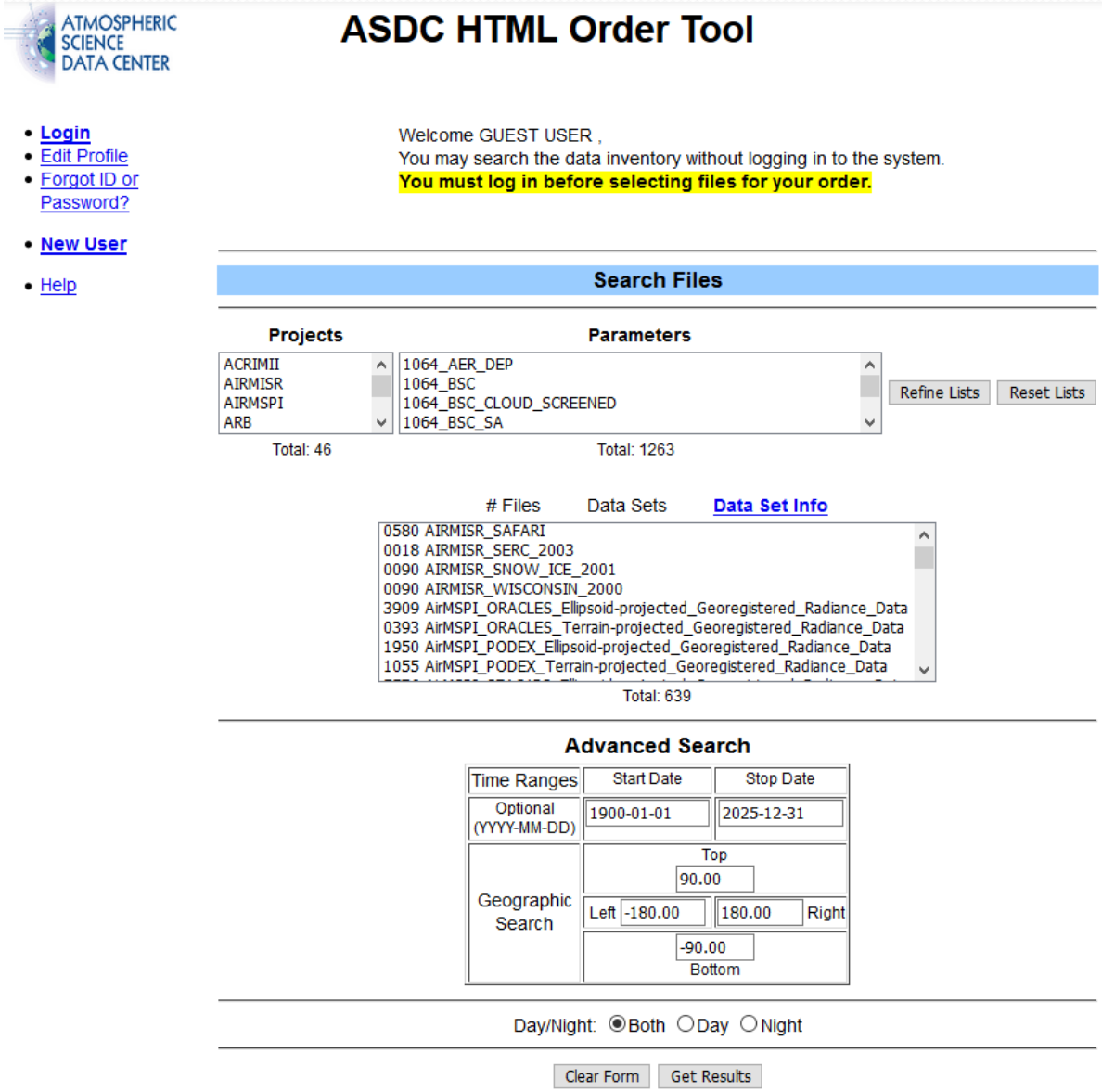
http://www-calipso.larc.nasa.gov/products/lidar/browse_images/expedited/

STANDARD PRODUCT for detailed science analysis

http://www-calipso.larc.nasa.gov/products/lidar/browse_images/show_calendar.php/

Also provides horizontal averaging, Ice/ Water phase and aerosol subtype

Data Access Interface



- You need to know
  - Project = CALIPSO
  - Parameter
    - e.g. Variety including 532nm backscatter coefficient
  - Data Set
    - Different data sets, processed with different version of the algorithm.
    - Current Version is ValStage 1 3.40 for Level 1 data and Level 2 data like the virtual feature mask
  - Time Frame
    - Remember it went up in 2006