Ocean color related studies using CALIPSO data

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And

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Thanks for the support from Hal Maring, Don Anderson, Paula Bontempi and Tsengdar Lee of NASA HQ

Presented by Yongxiang Hu

Outline

1. Background
2. CALIPSO's ocean relevant signal
3. Preliminary ocean color study results:
   - Particulate Backscatter
   - Wind speed
   - Deep particle maxima
   - Cloud-aerosol-ocean linkage
   - Absorbing aerosols

Background: Toward a joint Active-Passive mission

Objectives (from Paula's email)*: Demonstrate enhanced science returns available through a joint Aerosol-Ocean mission regarding climate variability, ocean carbon and ecosystem function, and Earth system feedbacks*

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1. **March 2005**: Behrenfeld and McClain called to introduce the PHYLM concept, asking for ocean color studies using both CALIPSO and MODIS

2. **November 2005:** Behrenfeld and McClain brief NASA HQ program managers on a joint Aerosol-Ocean mission concept that combines lidar and passive instruments

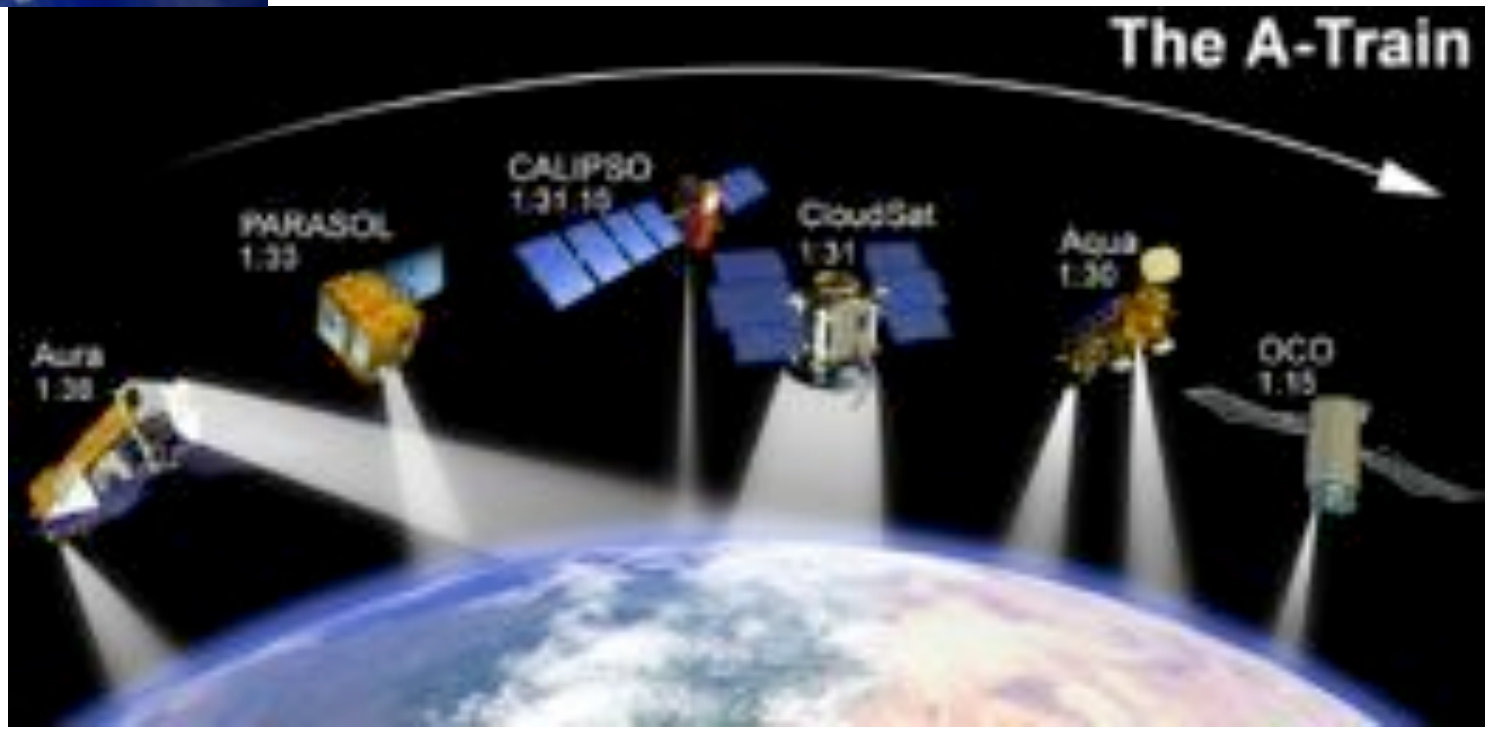
3. **April 2006**: CALIPSO launch

4. **Dec 2006**: Paula Bontempi, Hal Maring and Don Anderson called for Aerosol-Cloud-Ecosystem mission concept studies and the CALIPSO ocean color studies started

CALIPSO and A-Train

CALIPSO: **Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation**

CALIPSO is 75 seconds behind Aqua, with MODIS, CERES, AMSR, …, onboard



CALIPSO Payload
Three Near Nadir Viewing Instruments

Lidar

CALIOP

Cloud-Aerosol Lidar with Orthogonal Polarization

Vertical profiles of atmosphere

2 wavelength polarization sensitive lidar:

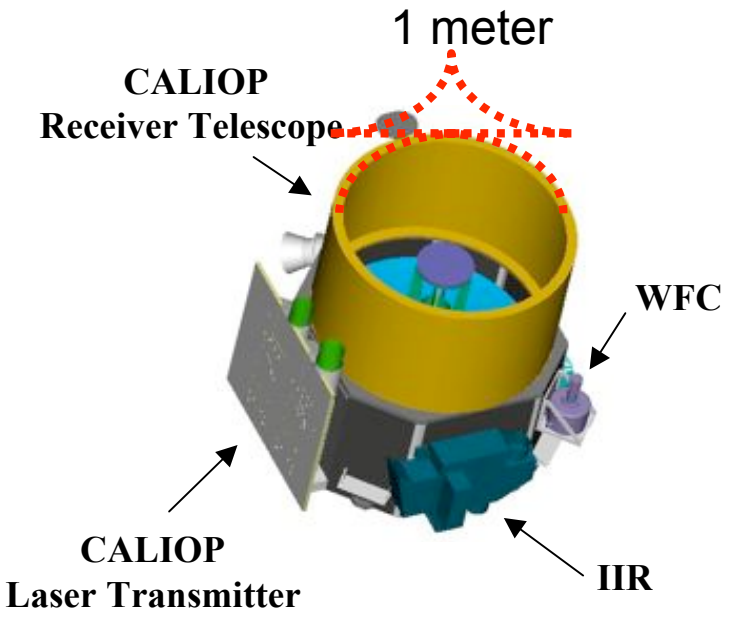
1064 nm, 532 nm (parallel and perpendicular)

Imaging Infrared Radiometer (IIR)

High-resolution image (swath product)

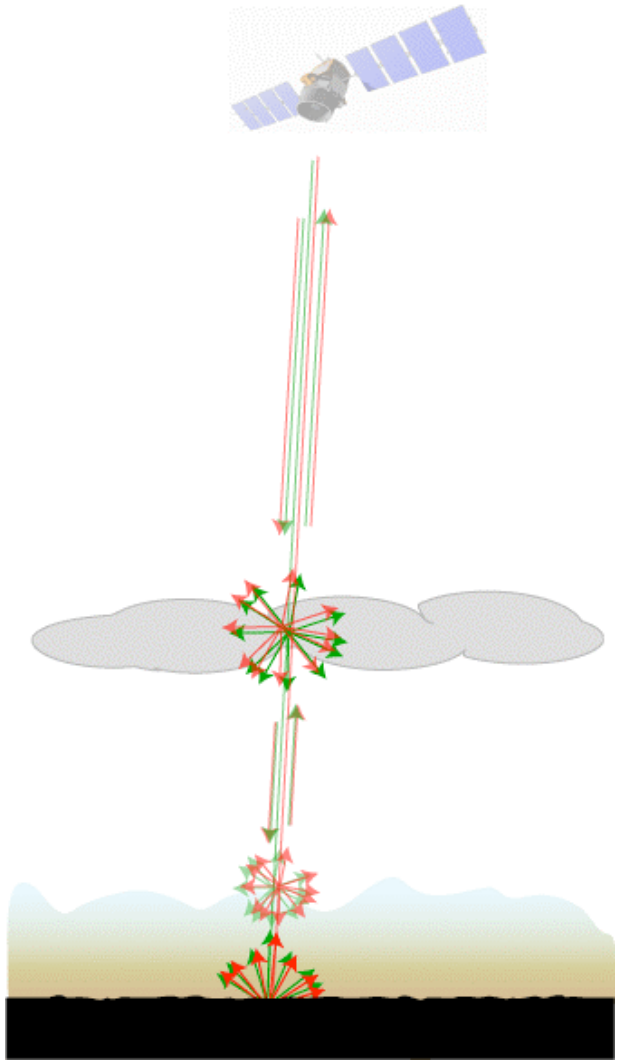
Wide Field Camera (WFC)

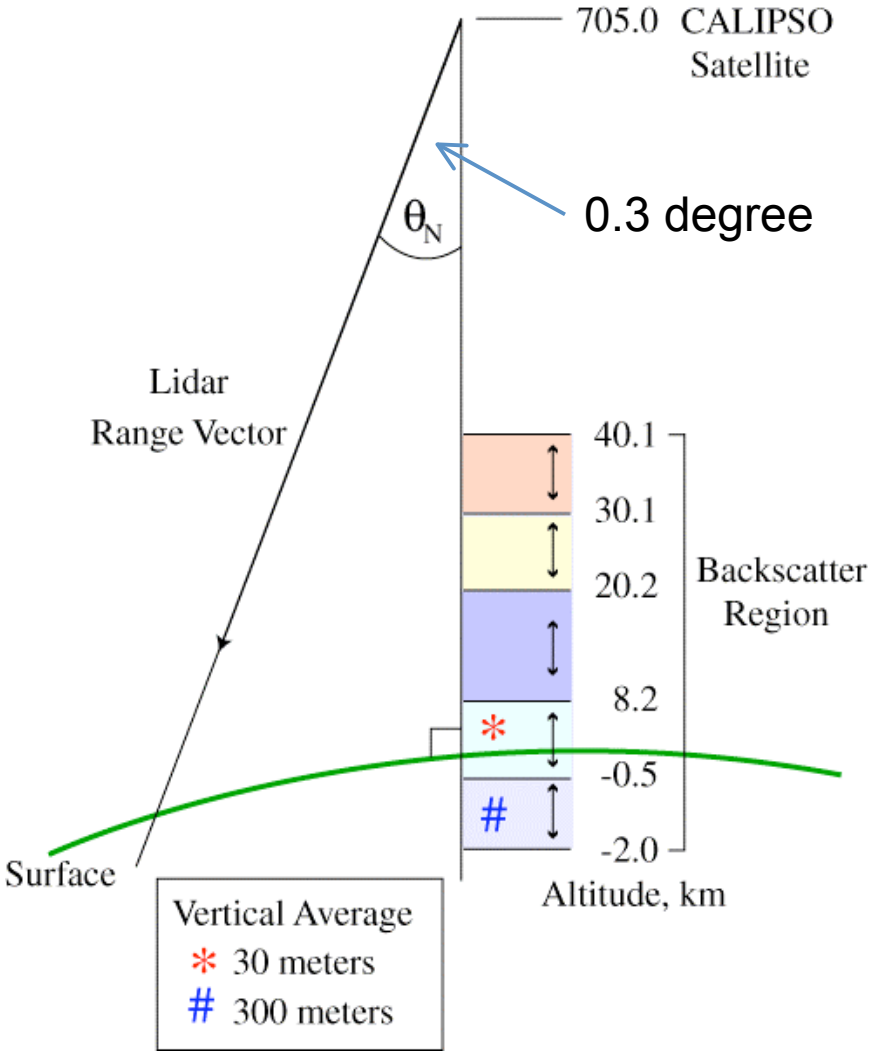
High-resolution image (125m resolution)



CALIPSO Payload

Altitude Region





What's new from CALIPSO?

- **Vertical profiling** capability: Signal return is measured as a function of time of flight of laser pulse - giving altitude resolved signal that is proportional to the backscatter cross-section.

- **Separating aerosols, ocean surface reflection and ocean particulate backscatter**

- Cross polarization ocean signal are primarily a result of **particulate backscatter in water**

- Making measurements both **day and night**

CALIPSO provides new information on….

- Ocean particle distributions
- Depth of particle maxima, potentially
- Absorbing aerosols for correcting passive data
- Cloud droplet number density and distribution
- Ocean surface wind speed

…all of which evidence the value of a joint aerosol-cloud-ocean ecosystem mission for understanding the Earth system, its functioning and feedbacks.

Application 1: Subsurface Particulate Backscatter from Cross Polarization Signal

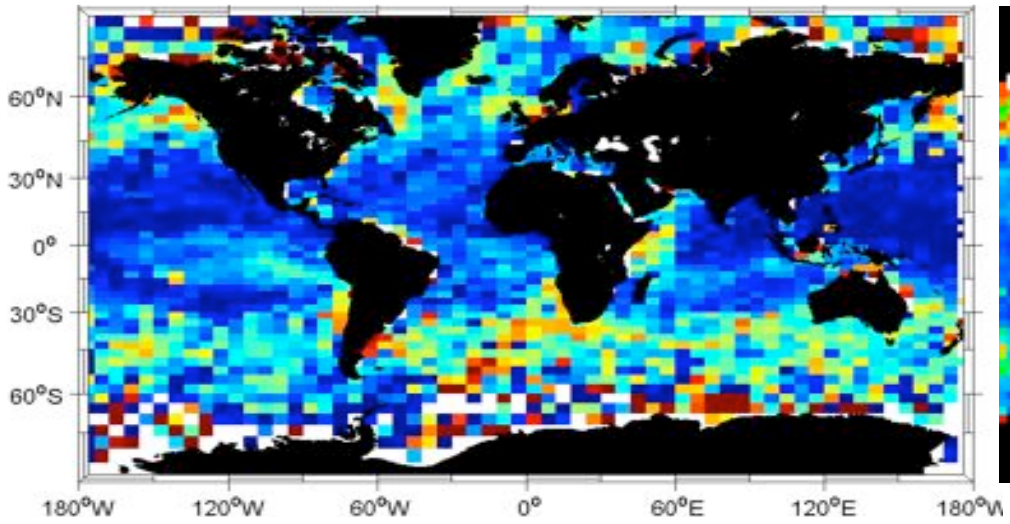
- For a linearly polarized incident lidar beam (e.g., CALIOP), spherical particles, Rayleigh scattering, and reflection at the ocean surface do not contribute significantly to cross polarization

- Cross polarization (measured by the perpendicular channel) is dominated by backscattering of **non-spherical particles**

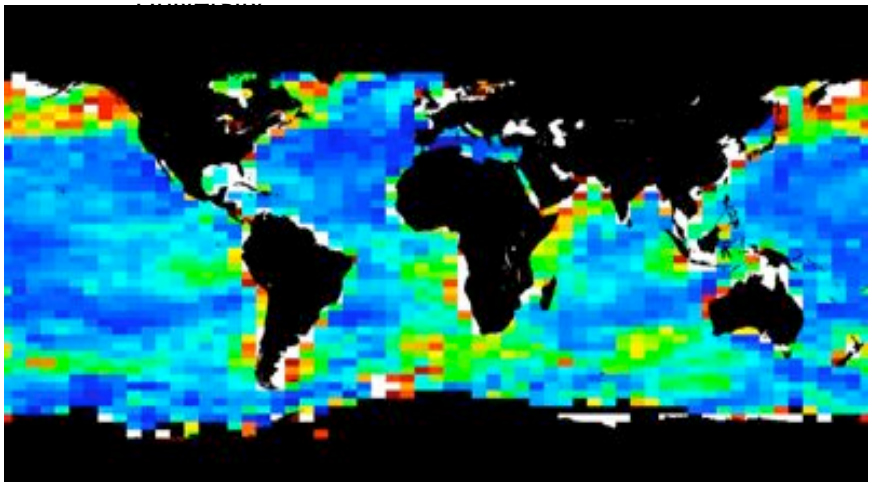
e.g., cloud ice crystals in atmosphere
plankton and other non-spherical particles in the water

First Result: Ocean Particulate Backscatter

CALIOP subsurface backscatter



SeaWiFS backscatter from GSM model

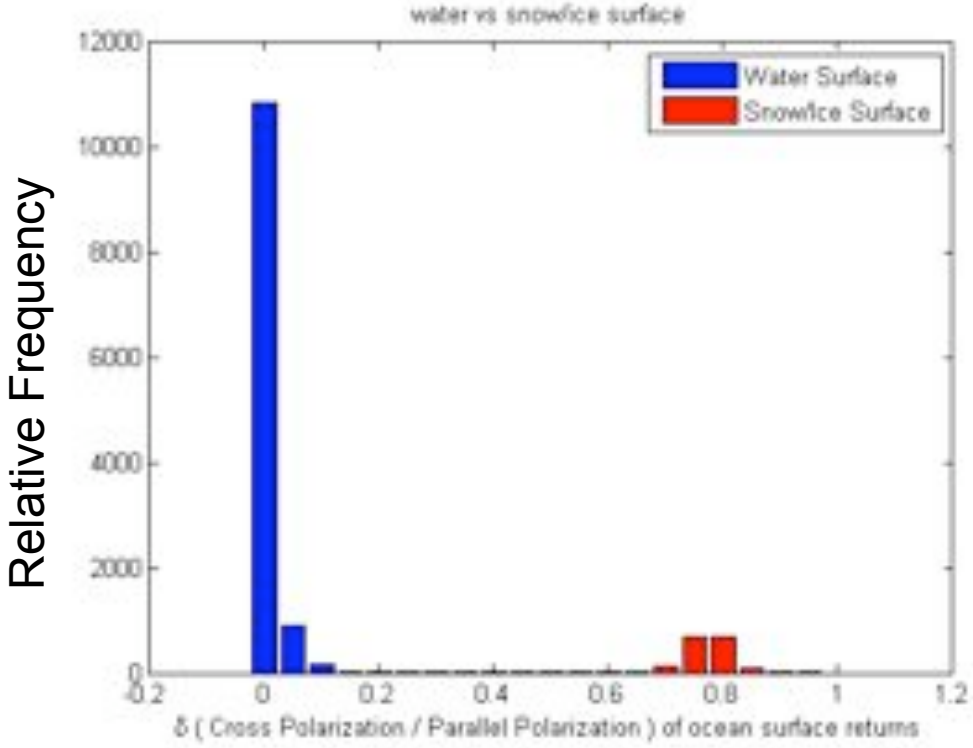


1. ***Statistics:*** roughly 3600 lidar shots per 3^0X6^0 grid box
2. ***Application:*** an independent, active measurement of particle abundance for estimating particulate organic carbon (POC), phytoplankton carbon biomass, and for cross-calibration with passive ocean color inversion products

Improving lidar sub-surface backscatter of high latitudes

1. Identifying Open Ocean from Snow/Ice using lidar depolarization ratio (δ)

$$\delta = \frac{I_{cross\ \ polarization}}{I_{parallel\ polarization}}$$

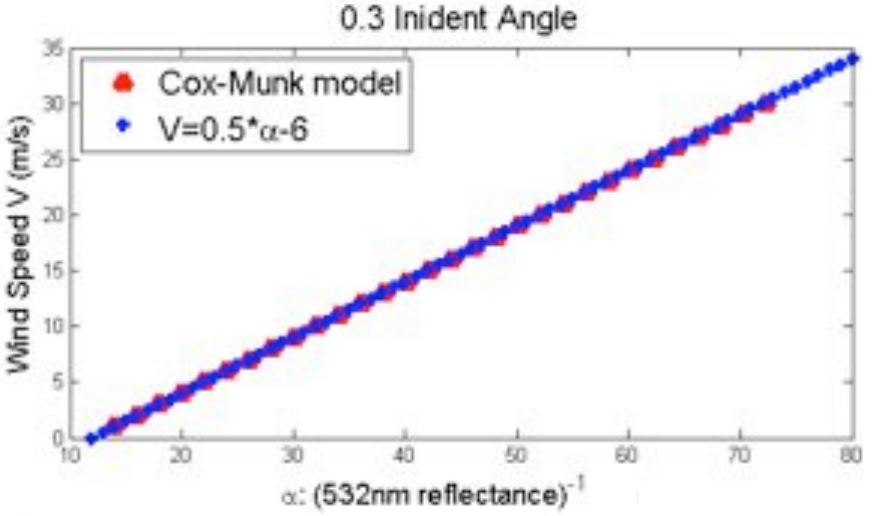


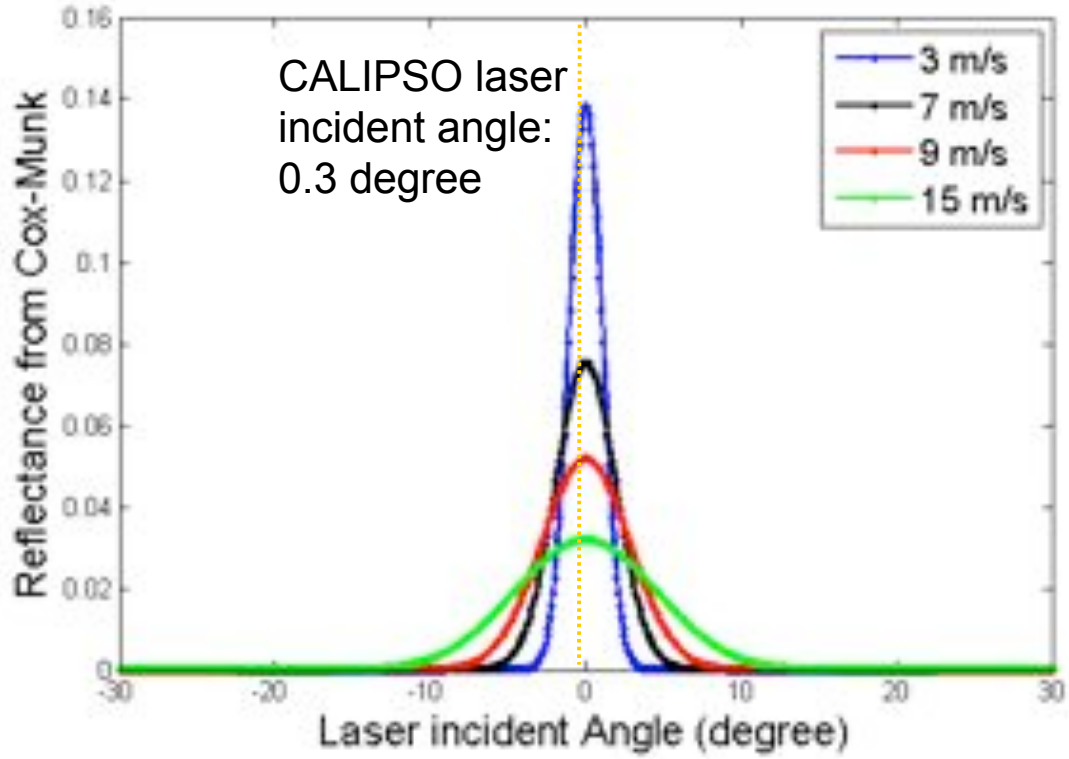
2. Correct for bubbles using wind information from co-polarization signal

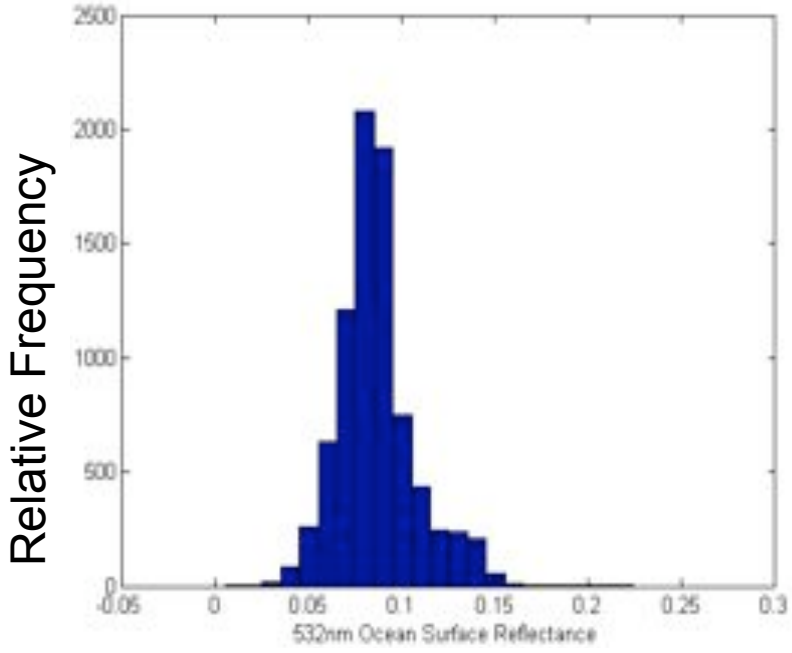
Application 2: Retrieving Wind Speed with Cox Munk relations

$$\frac{\sin\theta_i}{\sin\theta_r} = 1.3; \qquad \frac{\sin^2(\theta_i - \theta_r)}{\sin^2(\theta_i + \theta_r)} \approx 0.0197$$

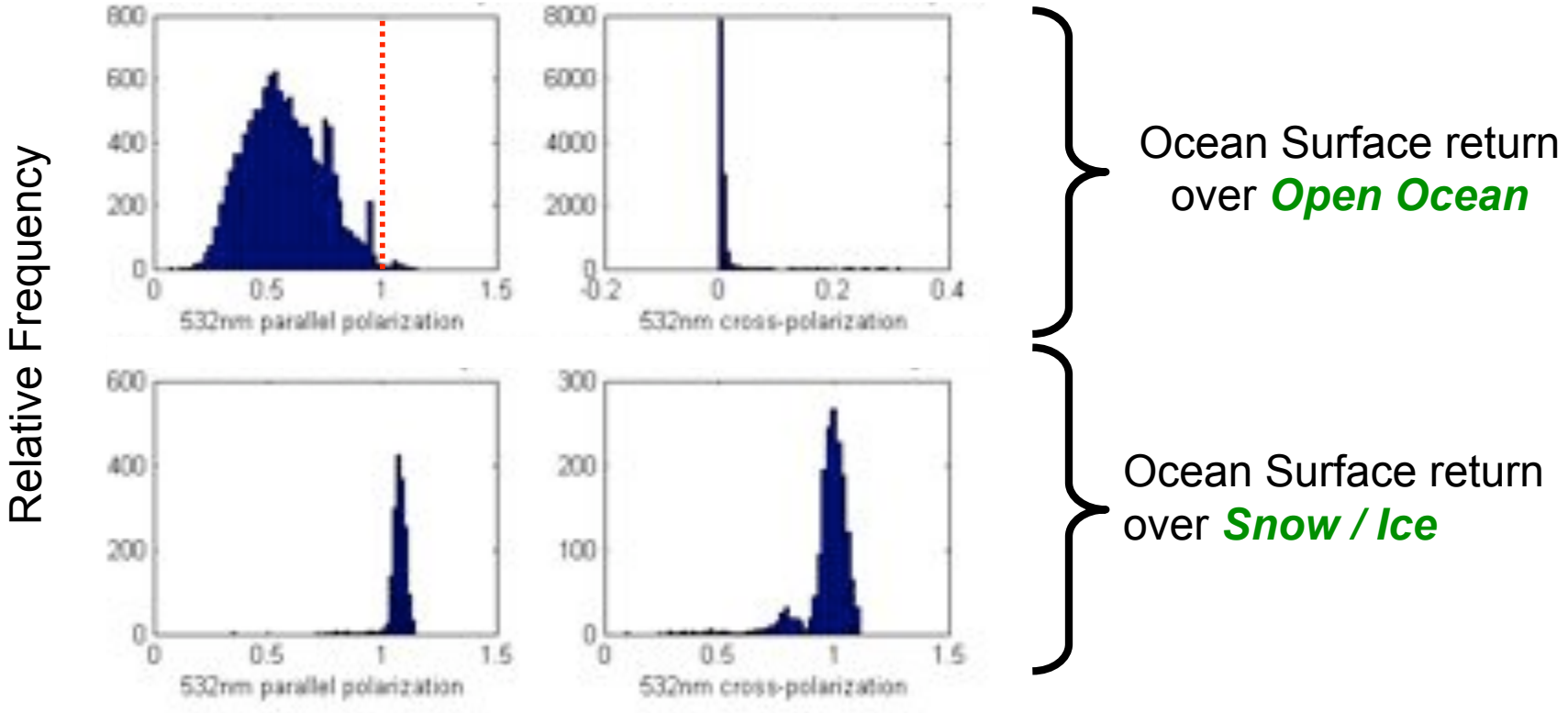
$$R = \frac{0.0197}{\pi} \frac{e^{-0.5s^2/(0.003+0.00512U_{10})}}{\sqrt{2\pi}(0.003+0.00512U_{10})}$$



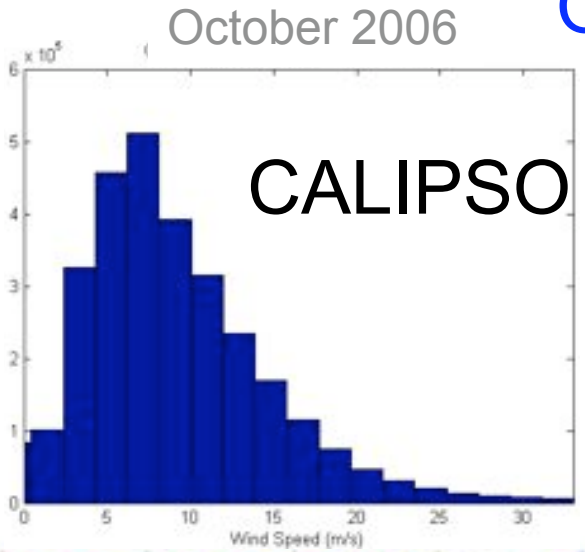


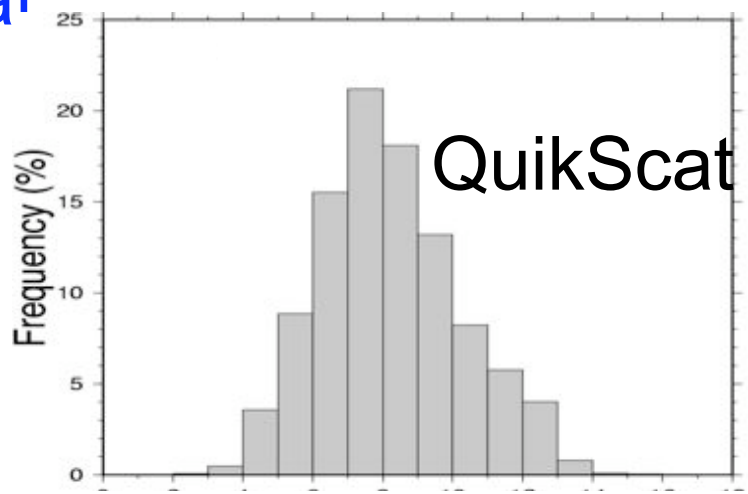


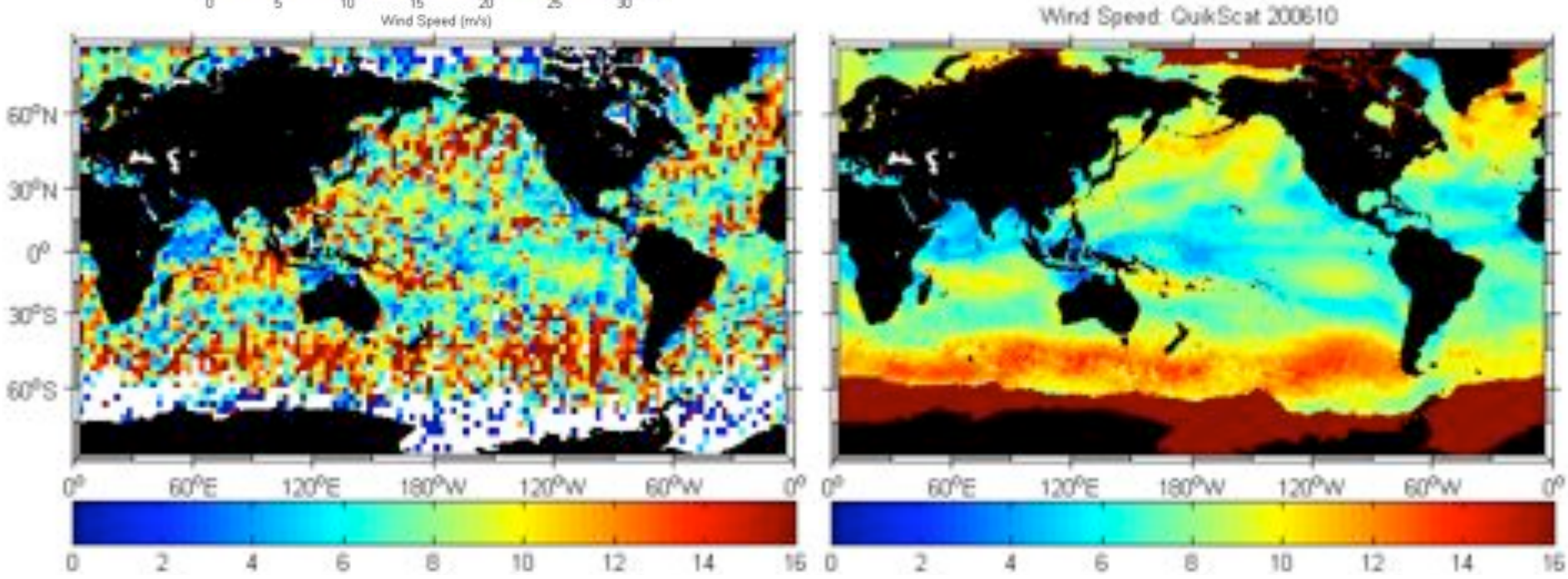
Does Ocean surface reflectance saturate the CALIOP detector? - no -



Ocean Surface Wind Speed: CALIPSO vs QuikScat



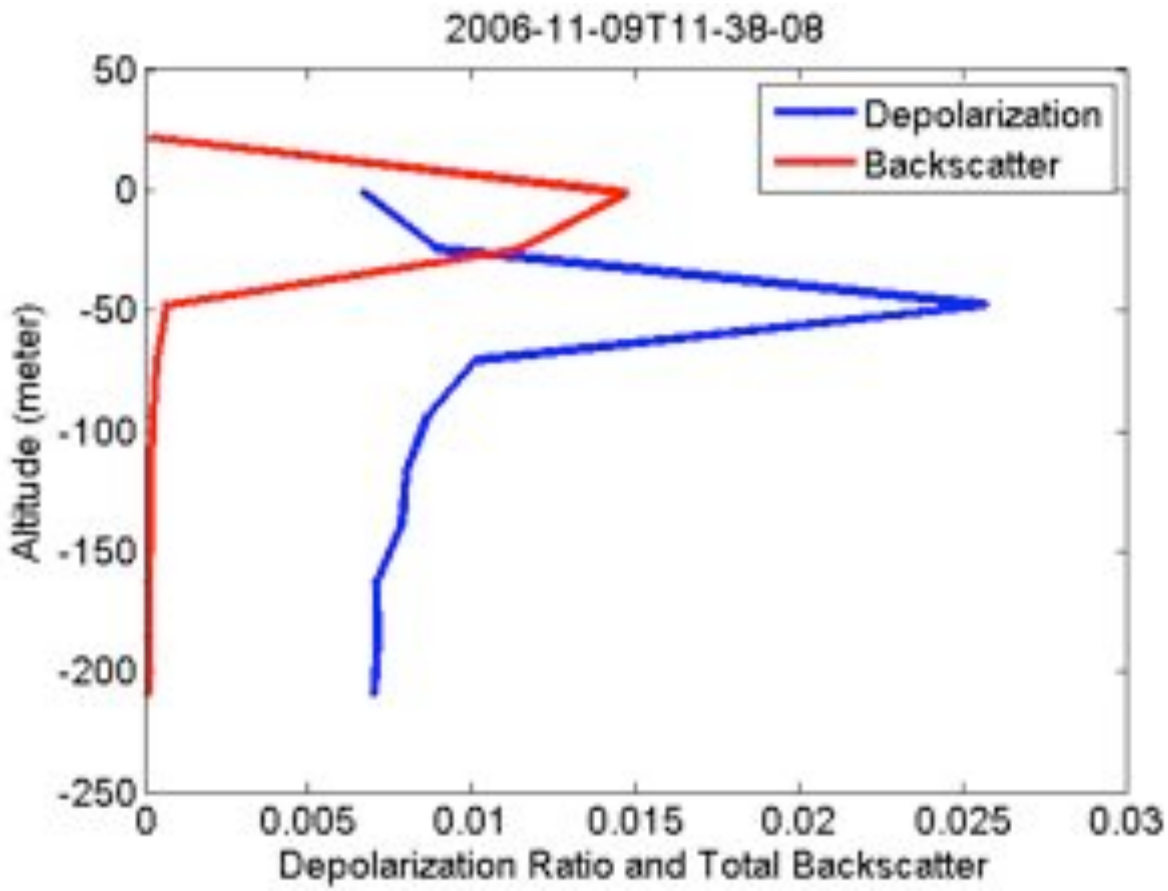




Application 3: Subsurface Particle Maxima
-- How deep space can lidar signal be detected

Depolarization:

$$\frac{\text{Cross-Polarization}}{\text{Parallel-Polarization}}$$



Application 3: Subsurface Particle Maxima, continued

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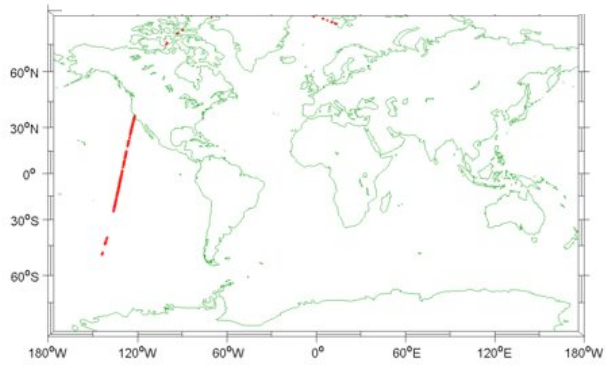

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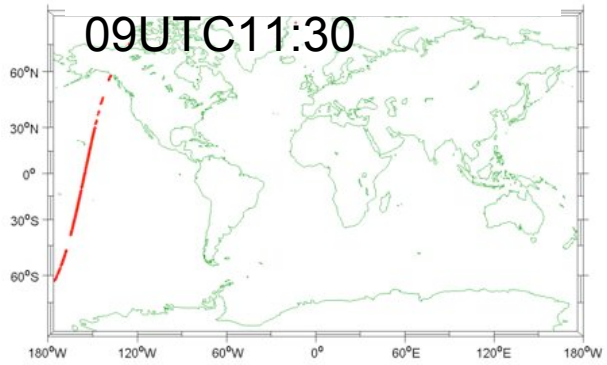

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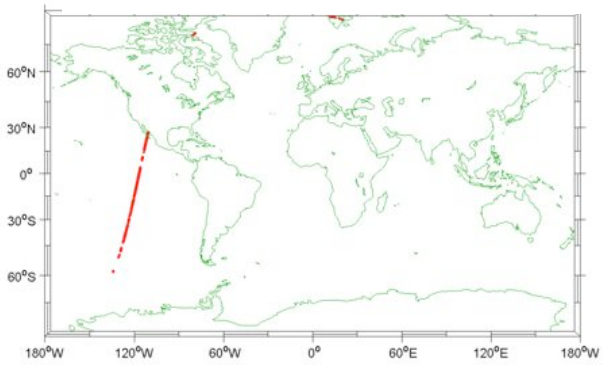

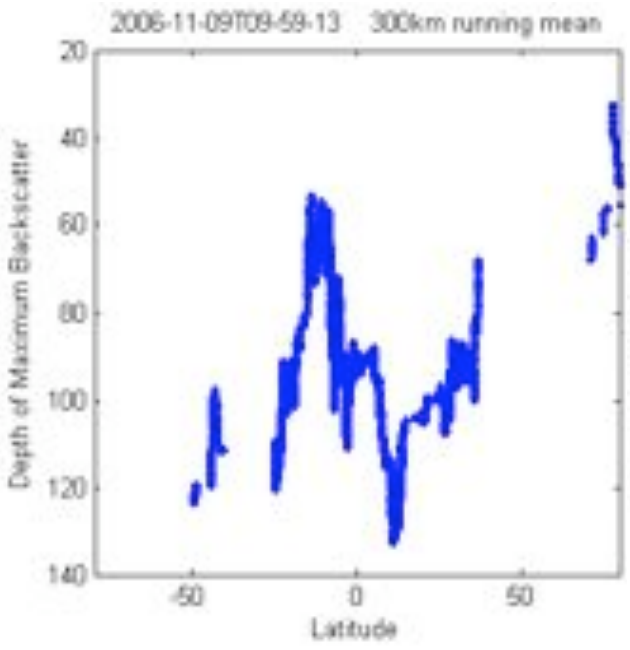

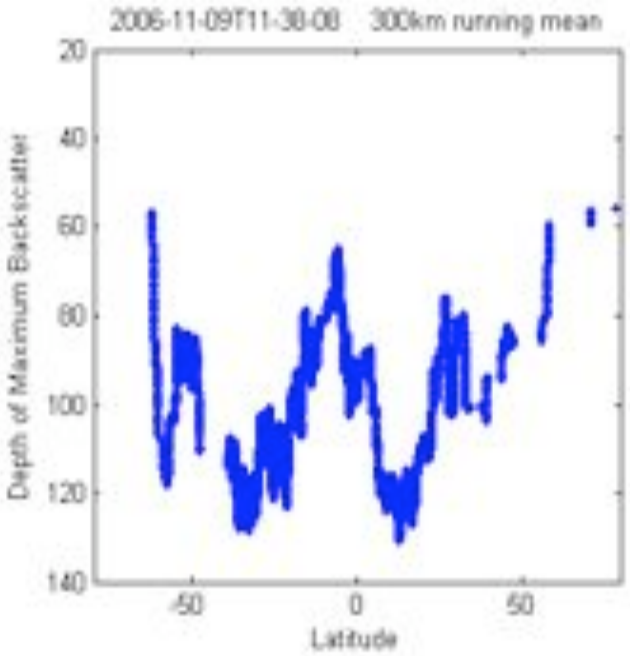

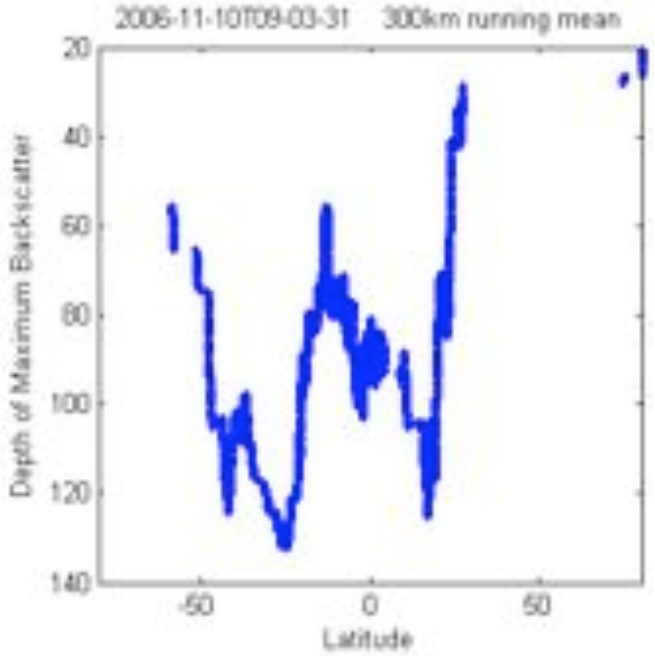

Scatter Maxima for 16 day repeat orbit

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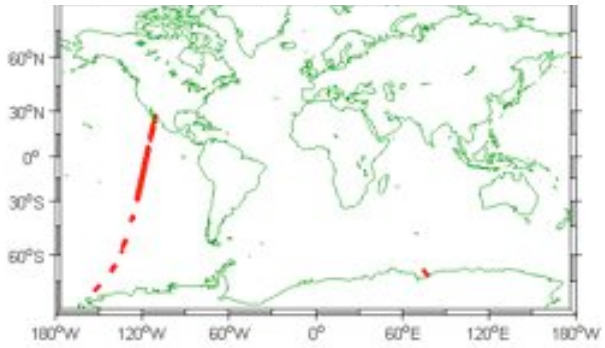

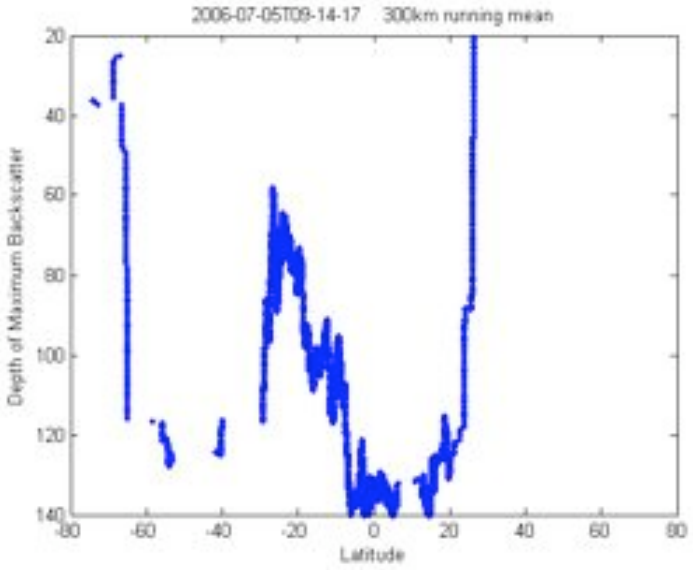

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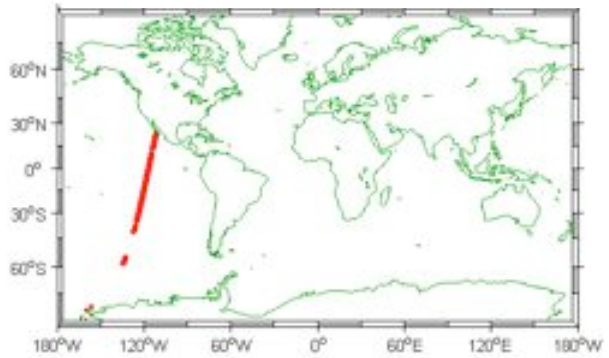
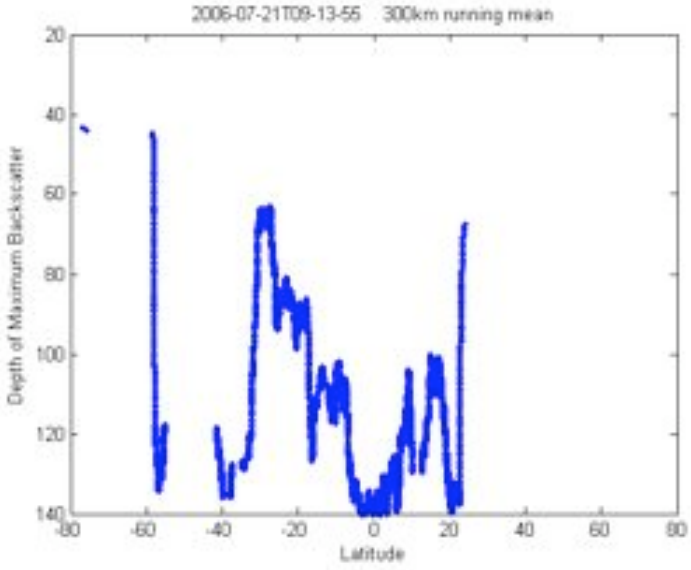
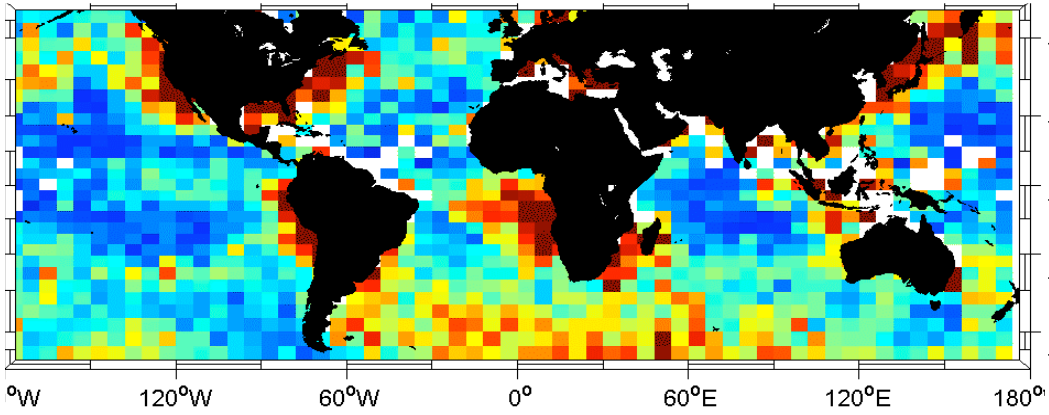


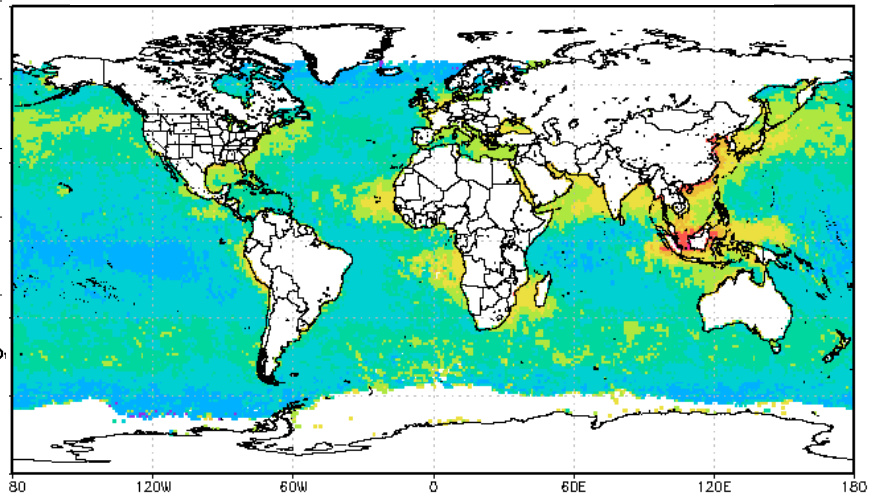


Application 4: Cloud droplet number density, ocean particulate backscatter, and the link between ocean biology and cloud albedo

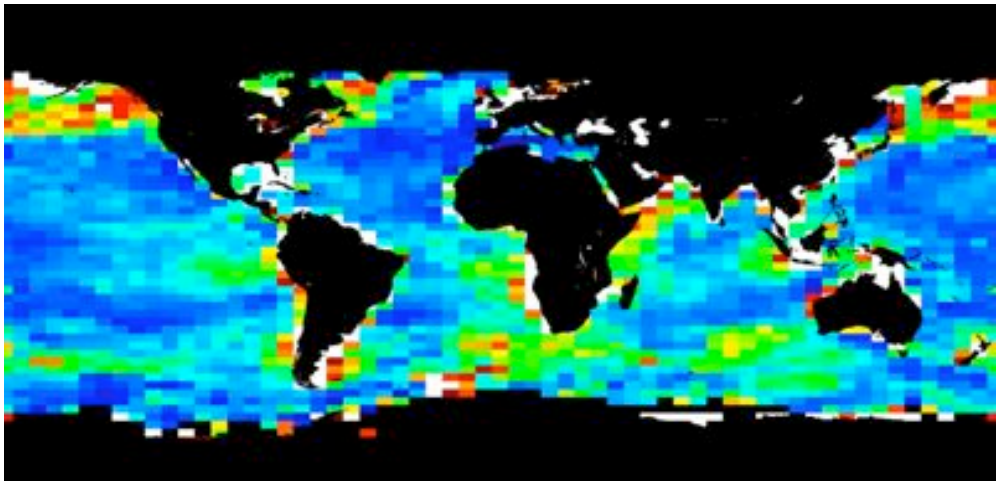
Cloud Droplet Number Density
from CALIPSO+MODIS (Hu et al, 2007)



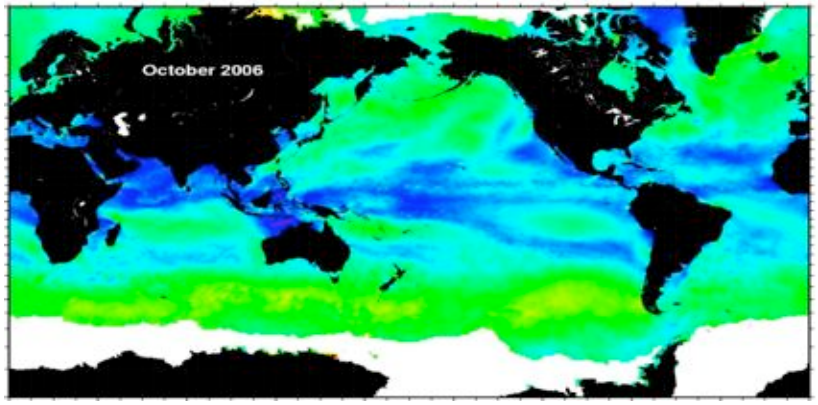
MODIS Aerosol Product:
Condensation Nuclei



SeaWiFS B. backscatter from GSM model

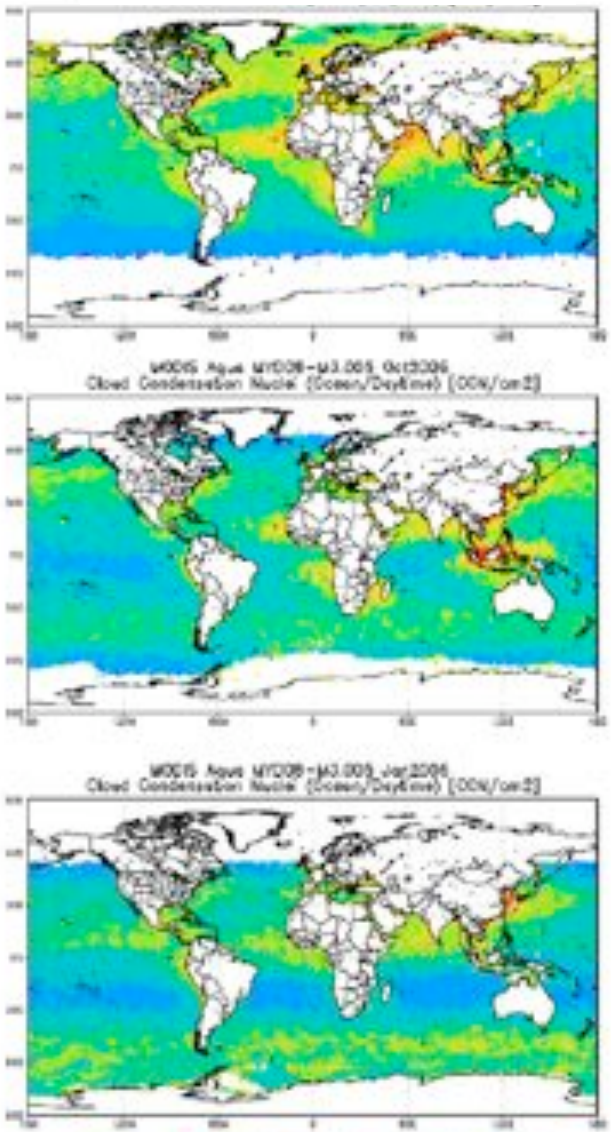


Wind Speed

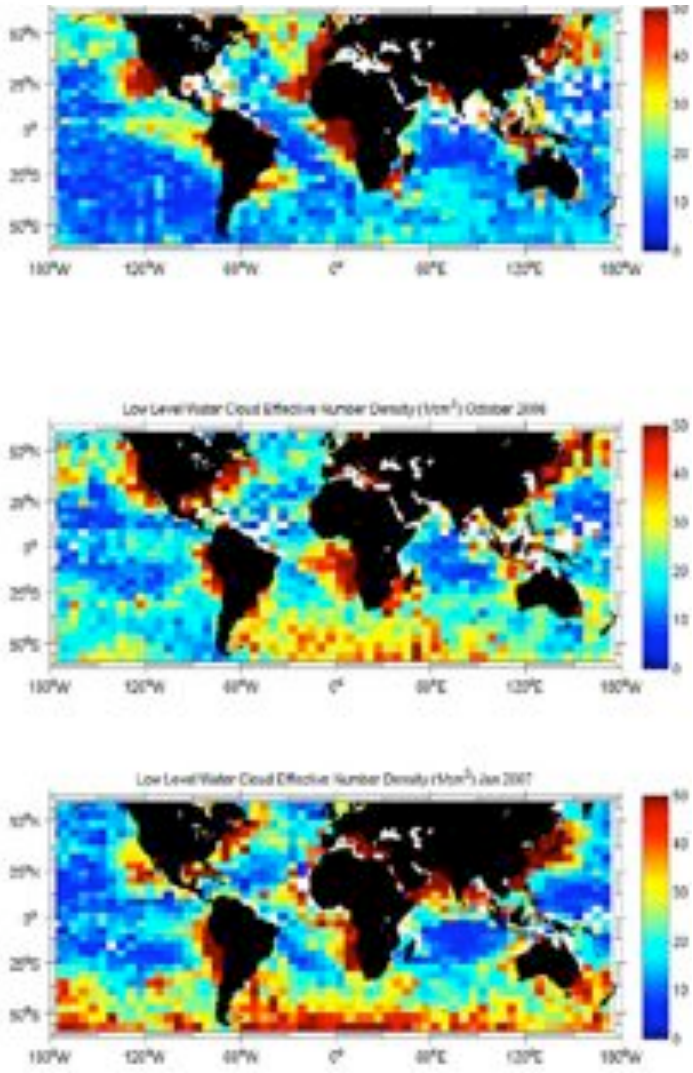


High number concentration of water cloud droplets in summer high latitudes: Seeded by phytoplankton isoprene?

Aerosols as CCN



Cloud Droplet Number Density



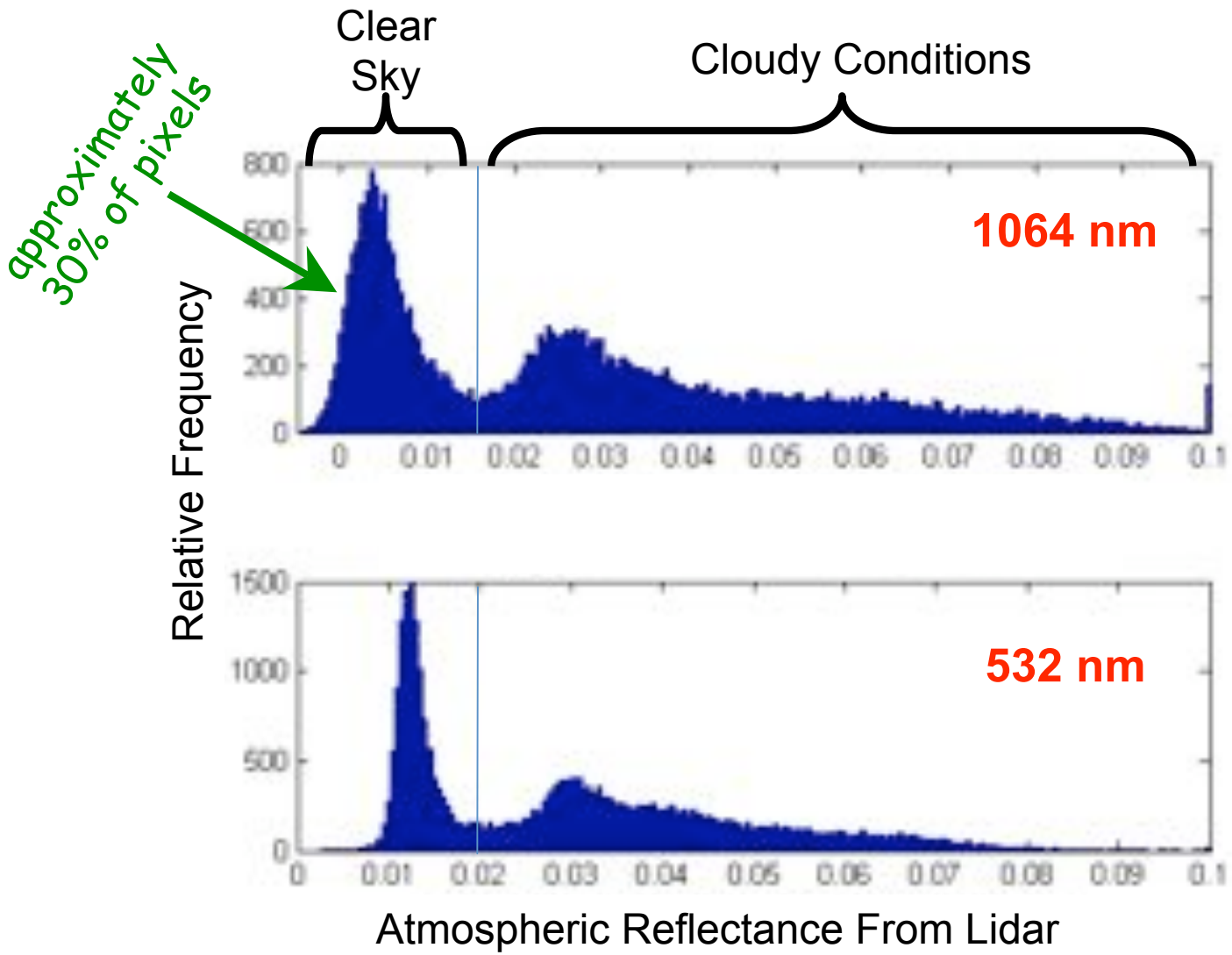
July

Oct

Jan

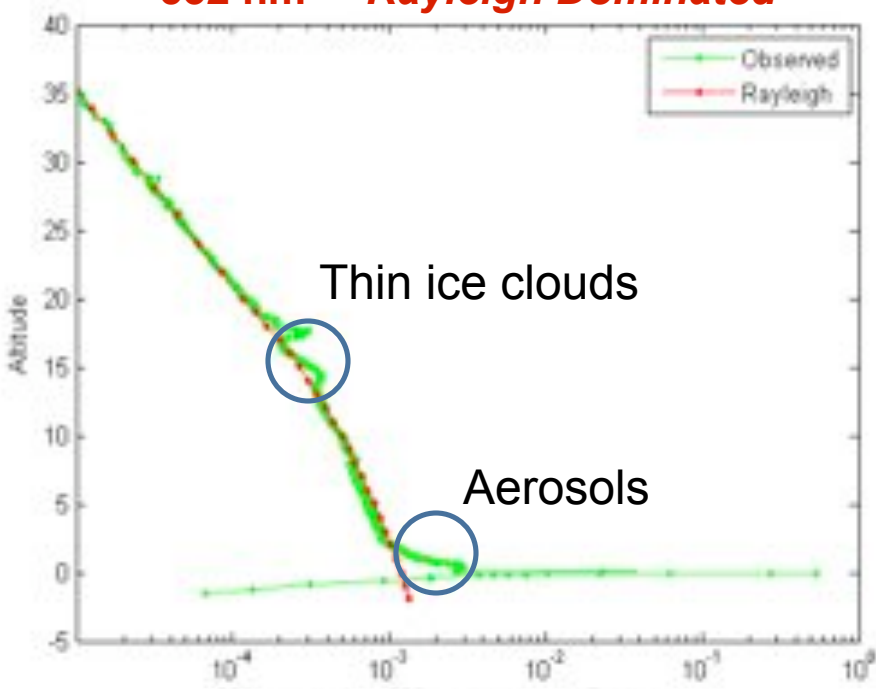
Application 5: Absorbing aerosols

Aerosol Study: Identifying Clear Sky Based on Atmospheric Lidar Backscatter

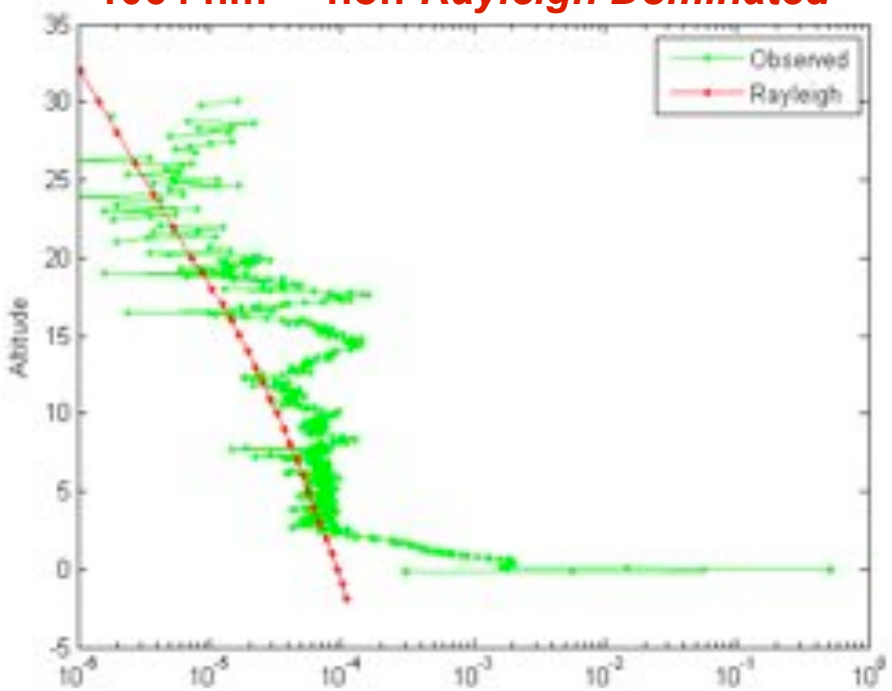


Clear-sky observation vs Rayleigh scattering

532 nm – '*Rayleigh Dominated*'



1064 nm – 'non-*Rayleigh Dominated*'

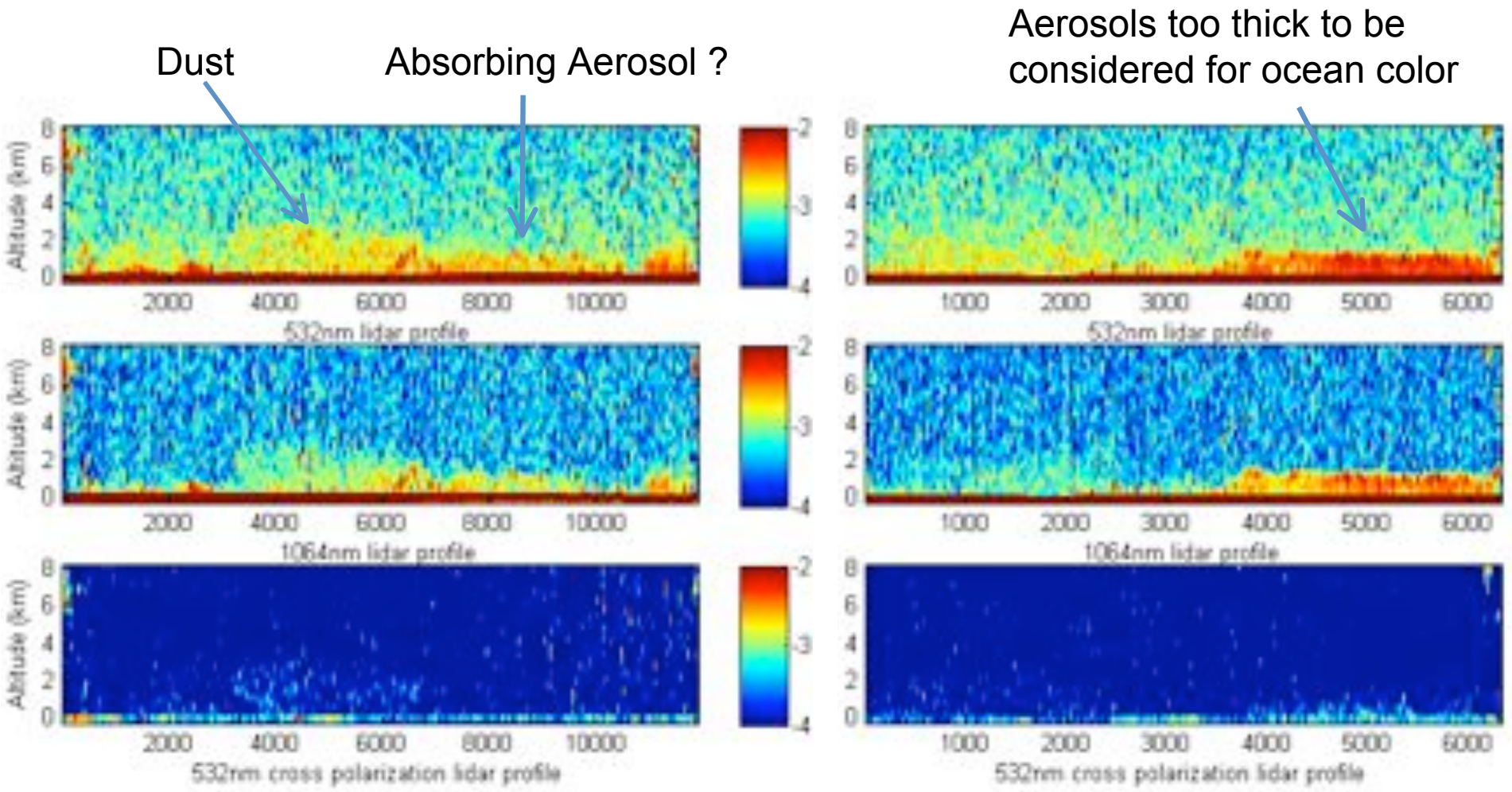


Attenuated Backscatter

…even the cleanest air is not so clear…

1. Aerosols between 0-3 km
2. Very thin cirrus clouds (τ<0.1) close to tropopause, which MODIS can not detect

e.g., lidar scattering profiles for clear skies



Color scale: 10^x

Identifying absorbing aerosols

Clustering analysis (trained with AERONET data) for identifying absorbing aerosols

1. Aerosol layer backscatter: CALIPSO 532nm
2. Aerosol layer backscatter: CALIPSO 1064nm
3. Depolarization of the aerosol layer
4. Aerosol layer optical depths at 532nm and 1064nm

How do we obtain the optical depths?

Estimating aerosol optical depth

1. Adopting AMSR wind speed

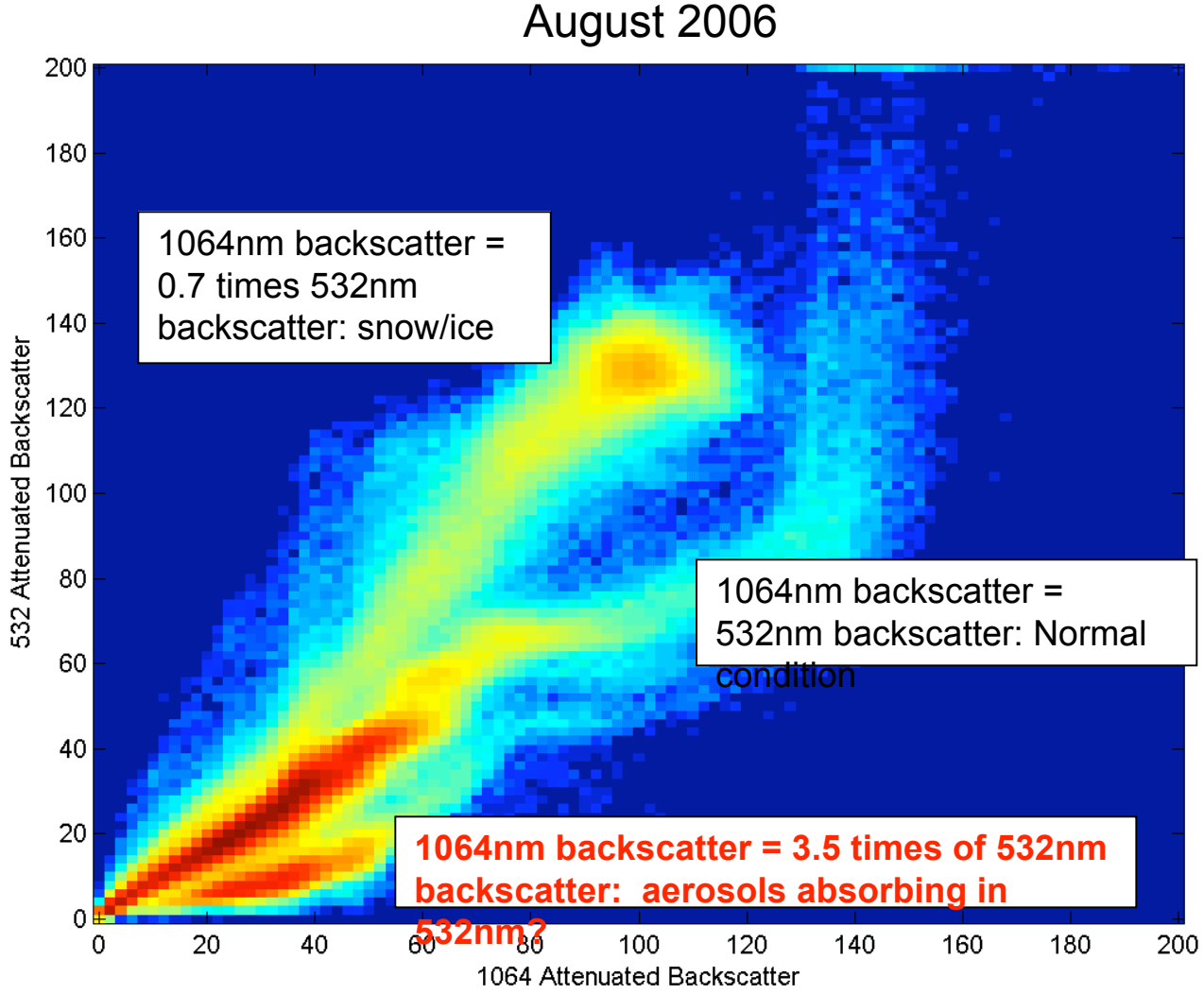
2. Estimating aerosol-free ocean surface lidar reflectance, $\mathbf{R_T}$,

3. $$\tau_{aerosol} = -0.5 \ln (R_C / R_T)$$

   (Rc is the measured lidar ocean surface reflectance)

4. Identifying absorbing aerosols: clustering analysis with aerosol optical depths, and aerosol lidar backscatter signal

Method 2: Using lidar ocean surface backscatter color ratio to identify absorbing aerosols



Summary

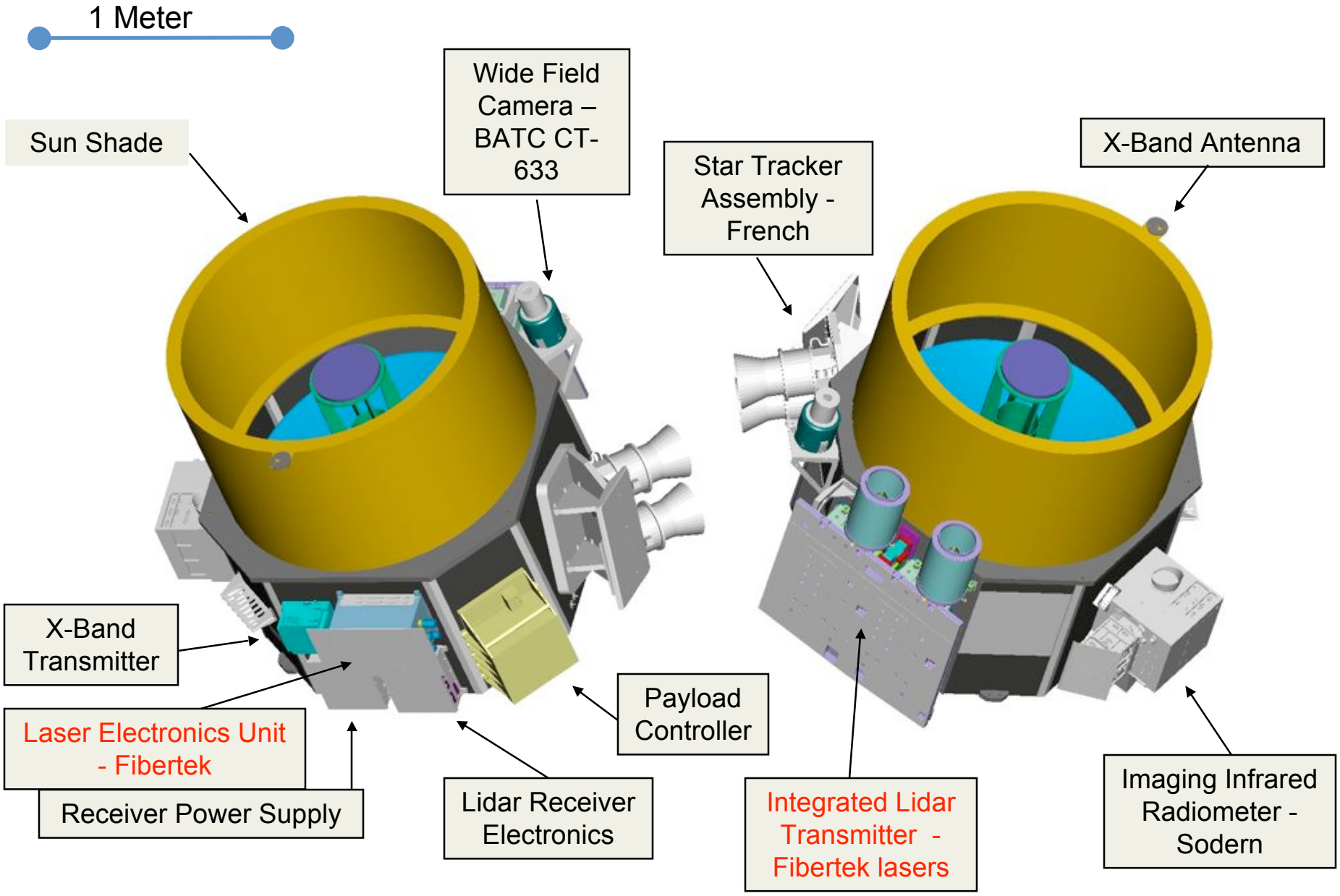
CALIPSO provides new information on….

- Ocean particle distributions
- Depth of particle maxima?
- Absorbing aerosols for correcting passive data
- Cloud droplet number density and distribution
- Ocean surface wind speed

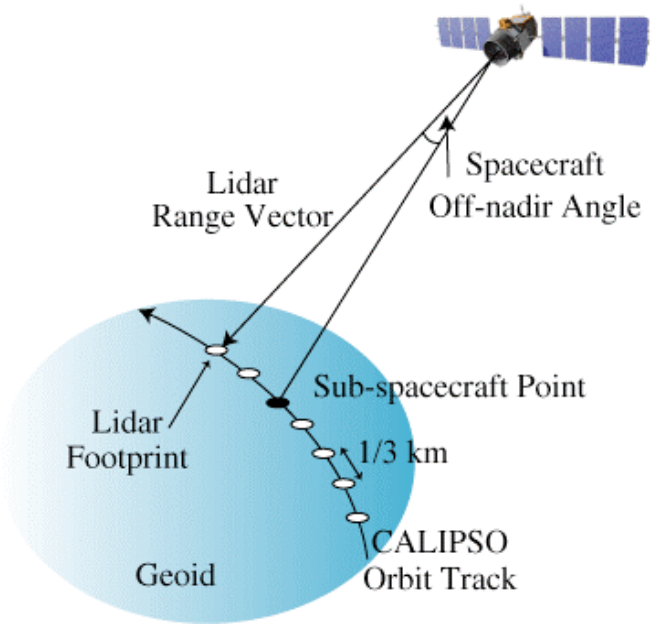
…all of which evidence the value of a joint aerosol-cloud-ocean ecosystem mission for understanding the Earth system, its functioning and feedbacks.

Backup Slides

Different Views of Payload



CALIPSO



CALIPSO Satellite

Proteus Spacecraft from (CNES/Alcatel)
Payload (NASA/CNES/Ball Aerospace)

CALIPSO Payload Instruments

CALIOP – Rayleigh-Mie Lidar (laser radar) for clouds, aerosols, air (and now Plankton?)
Wide Field Camera – Cloud Camera matched to MODIS (645 nm, **125 m pixel**)
Infrared Imaging Radiometer – Three band Thermal Images (8.65, 10.6, 12.05 μm)

CALIOP

Two Wavelengths (**532 nm** and **1064 nm**)
Polarization Channel at 532 nm (Detectors aligned Parallel and Perpendicular to laser linear polarization)
Laser Footprint on Ocean **70 m**

CALIPSO

CALIPSO Satellite

Proteus Spacecraft from (CNES/Alcatel)
Payload (NASA/CNES/Ball Aerospace)

CALIPSO Payload Instruments

Wide Field Camera – Cloud Camera matched to MODIS (645 nm, 125 m pixel)
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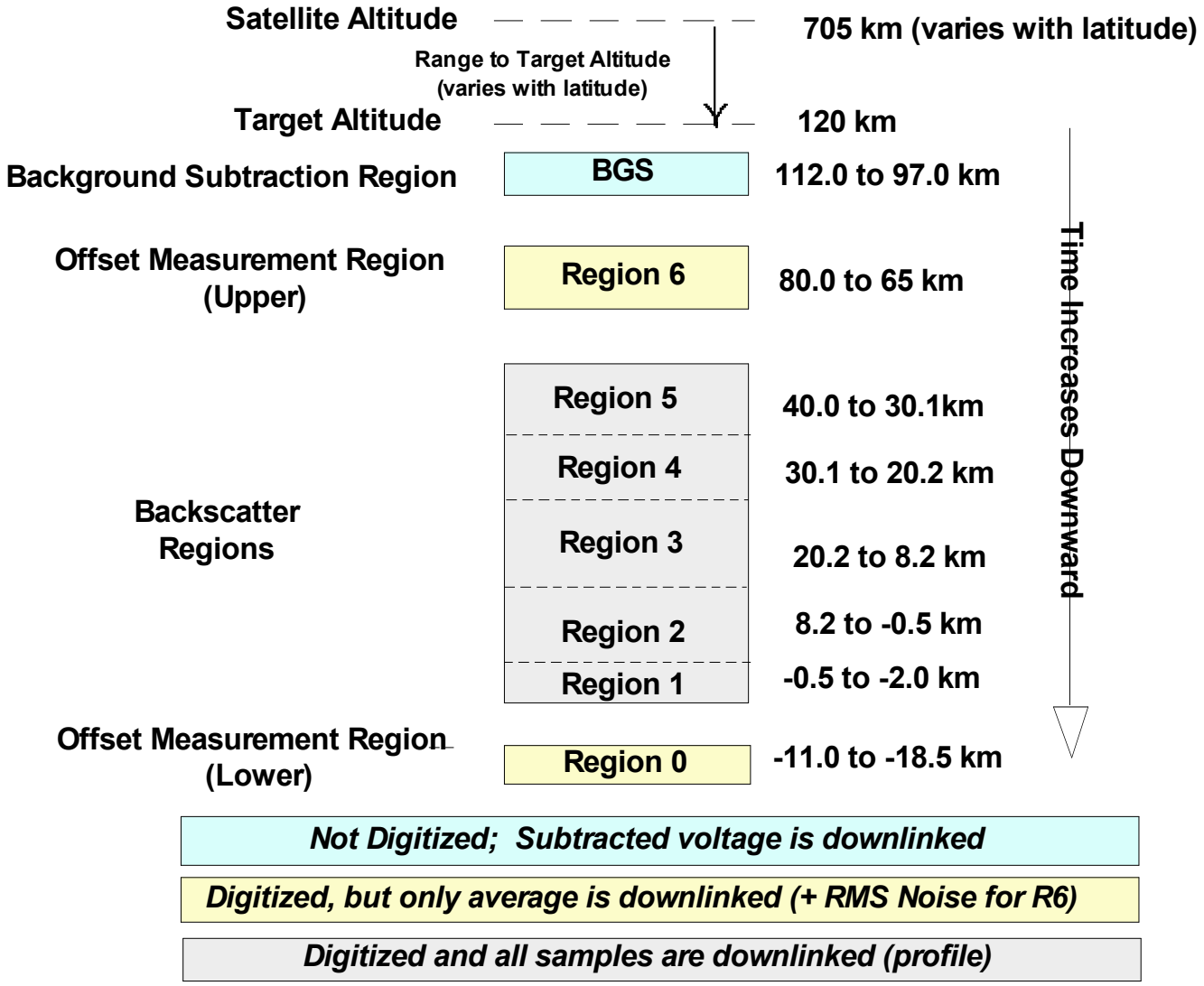
CALIOP – Rayleigh-Mie Lidar (laser radar) for clouds, aerosols, air (and now Plankton?)

CALIOP

Two Wavelengths (532 nm and 1064 nm)
Polarization sensitive at 532 nm (Detectors aligned Parallel and Perpendicular to laser linear polarization)
Laser Footprint on Ocean 70 m
Sensitive to single photons at 532 nm
Laser pulse emitted at 20 Hz repetition (330 m spacing between laser pulses)

Vertical Resolution 30 m fixed by Analog-to-Converter clock (increases in steps to 300 m in stratosphere)
Data collected for altitudes -2 km to +40 km

Altitude Region

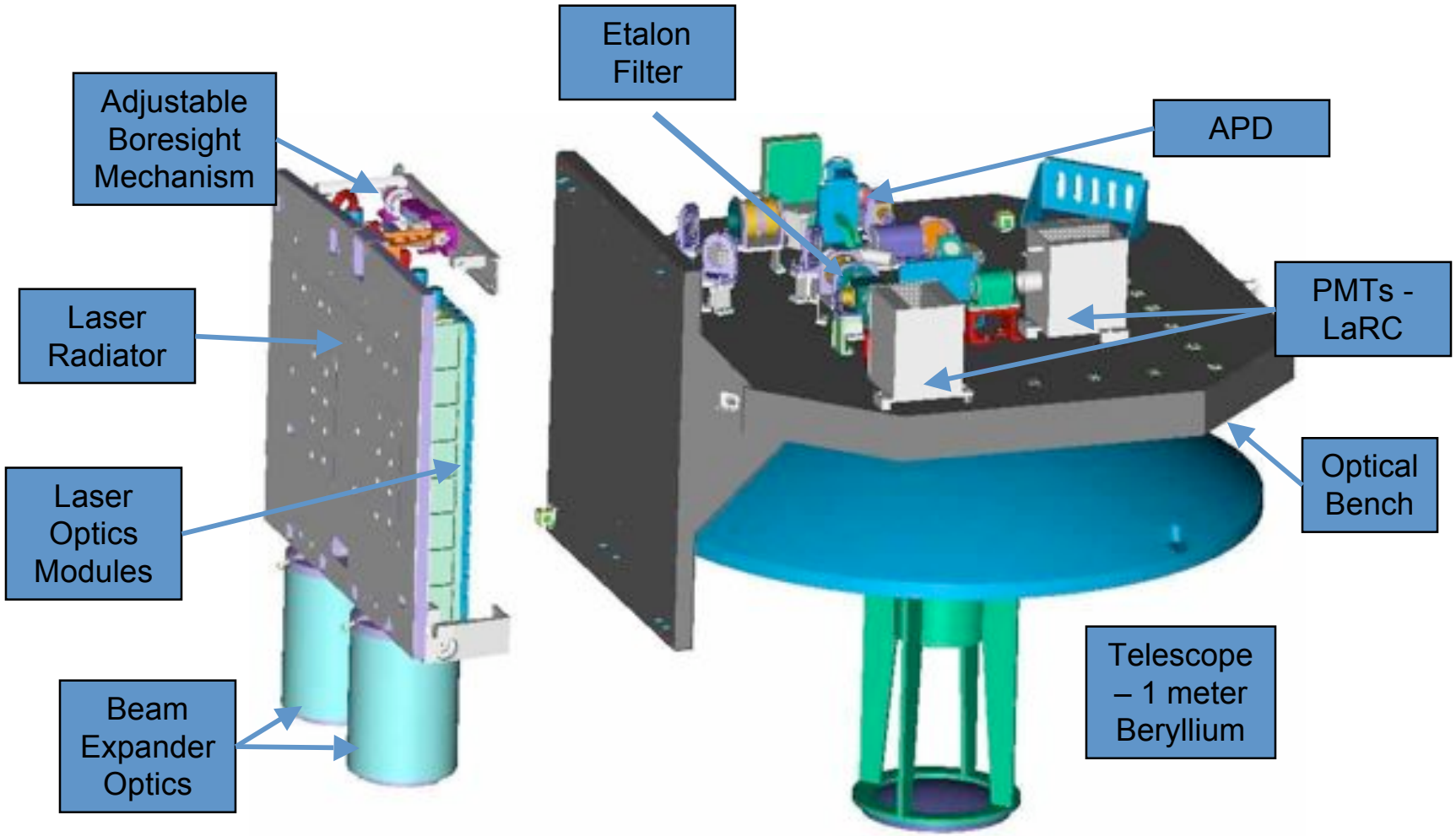


Instrument Clock runs at 10 MHz, giving 15 meter vertical bin size set by digitizer

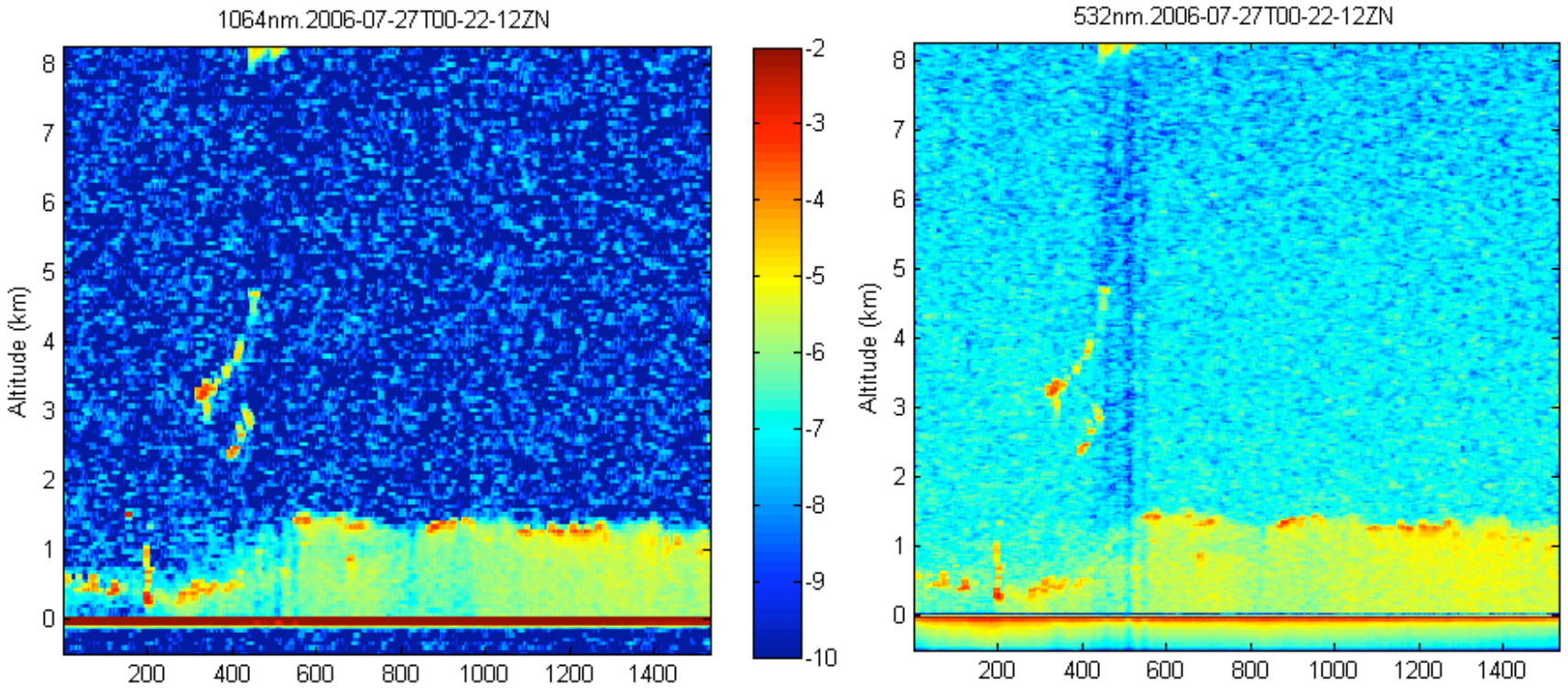
Bins are averaged to reduce downlink size

Vertical Resolution of Region 2: 30m in the air; 23m in water

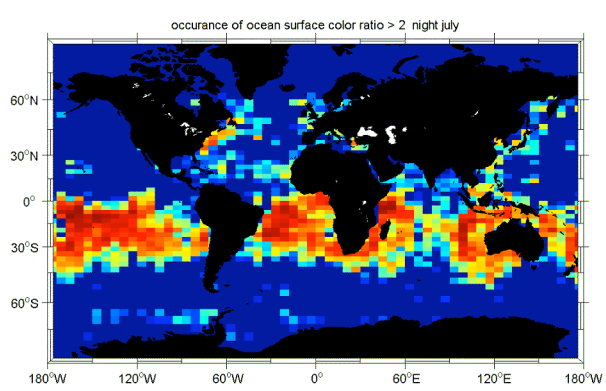
Lidar Core – Transmitter and Receiver

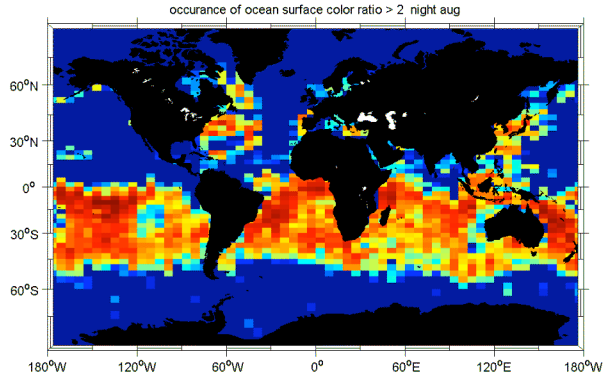


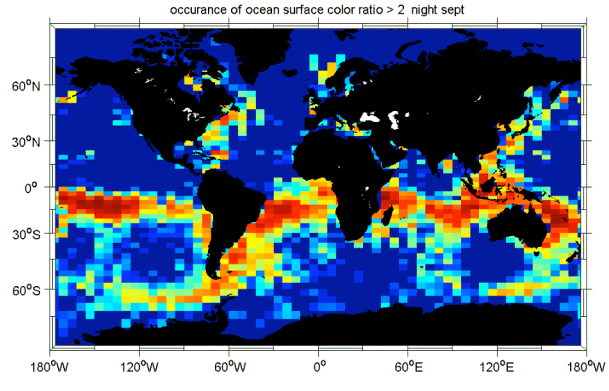
What does the absorbing aerosols look like from CALIPSO?

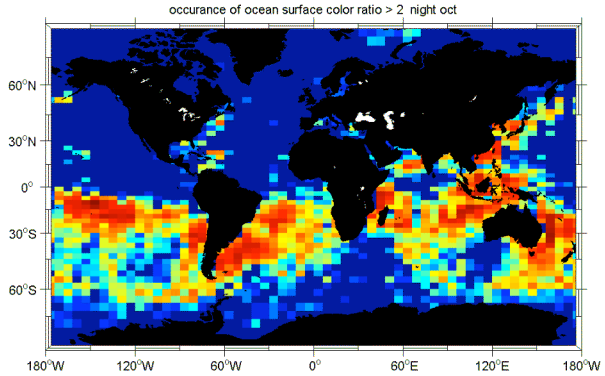


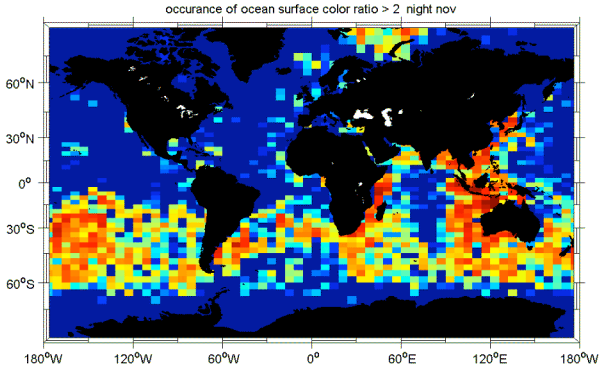
Where it happened

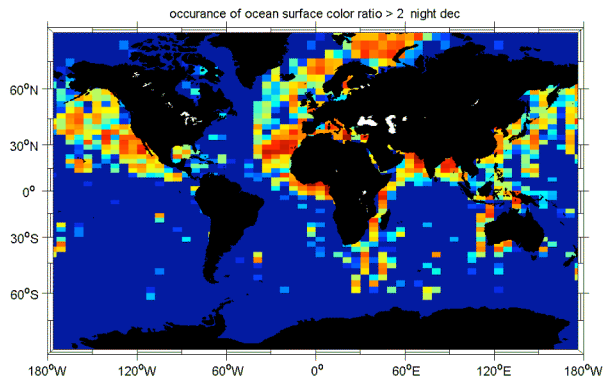


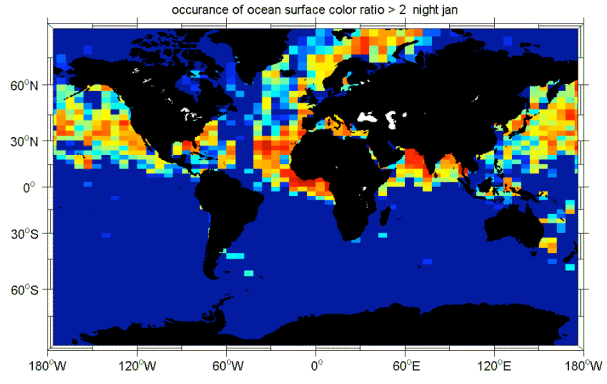


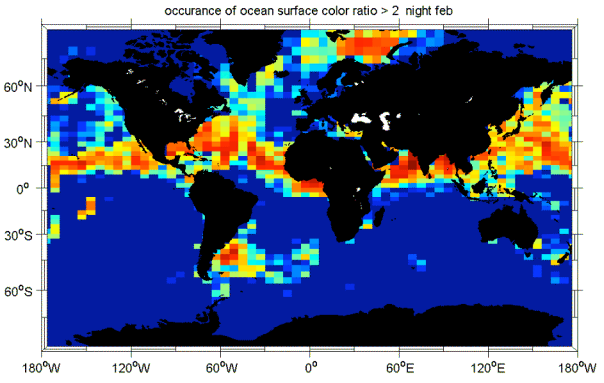


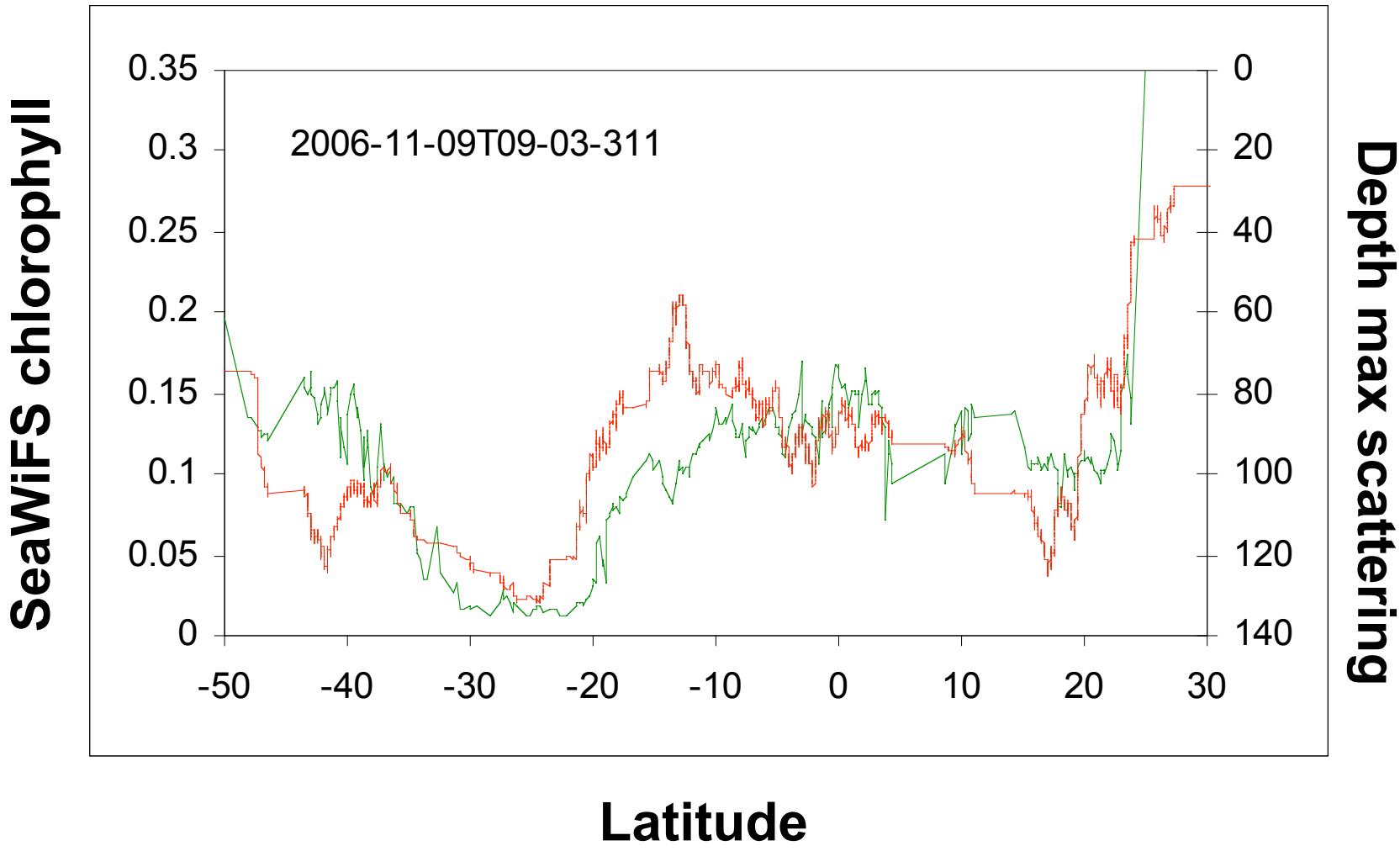











SeaWiFS chlorophyll
Depth max scattering
Latitude
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0.25
0.2
0.15
0.1
0.05
0
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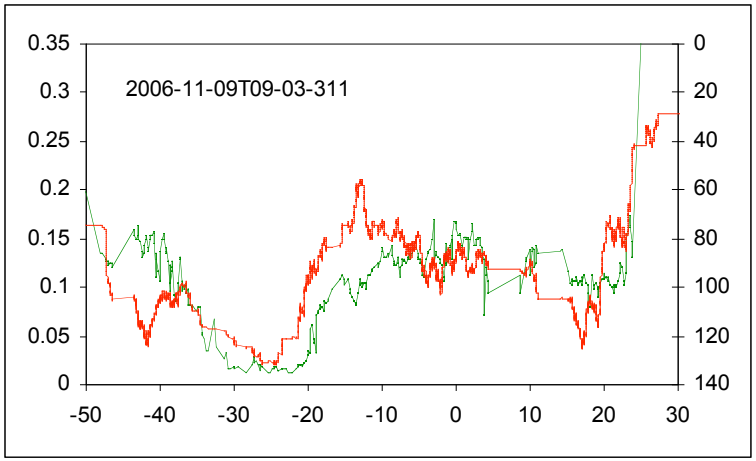
20
40
60
80
100
120
140
-50
-40
-30
-20
-10
0
10
20
30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120
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-50
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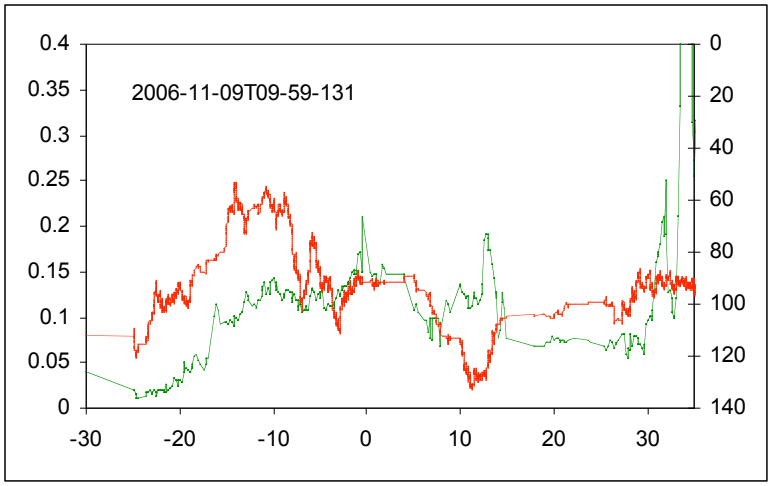
20
30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20
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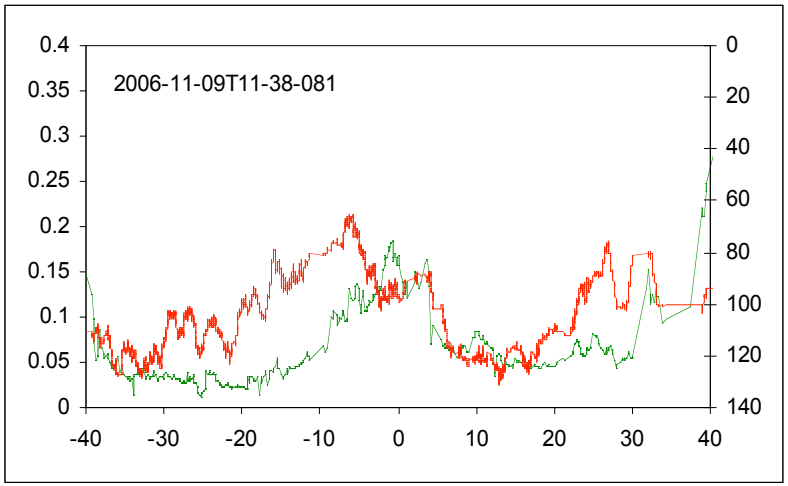
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-40
-30
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0
10
20
30
40