An Innovative Concept for Spacebased Lidar Measurement of Ocean Carbon Biomass

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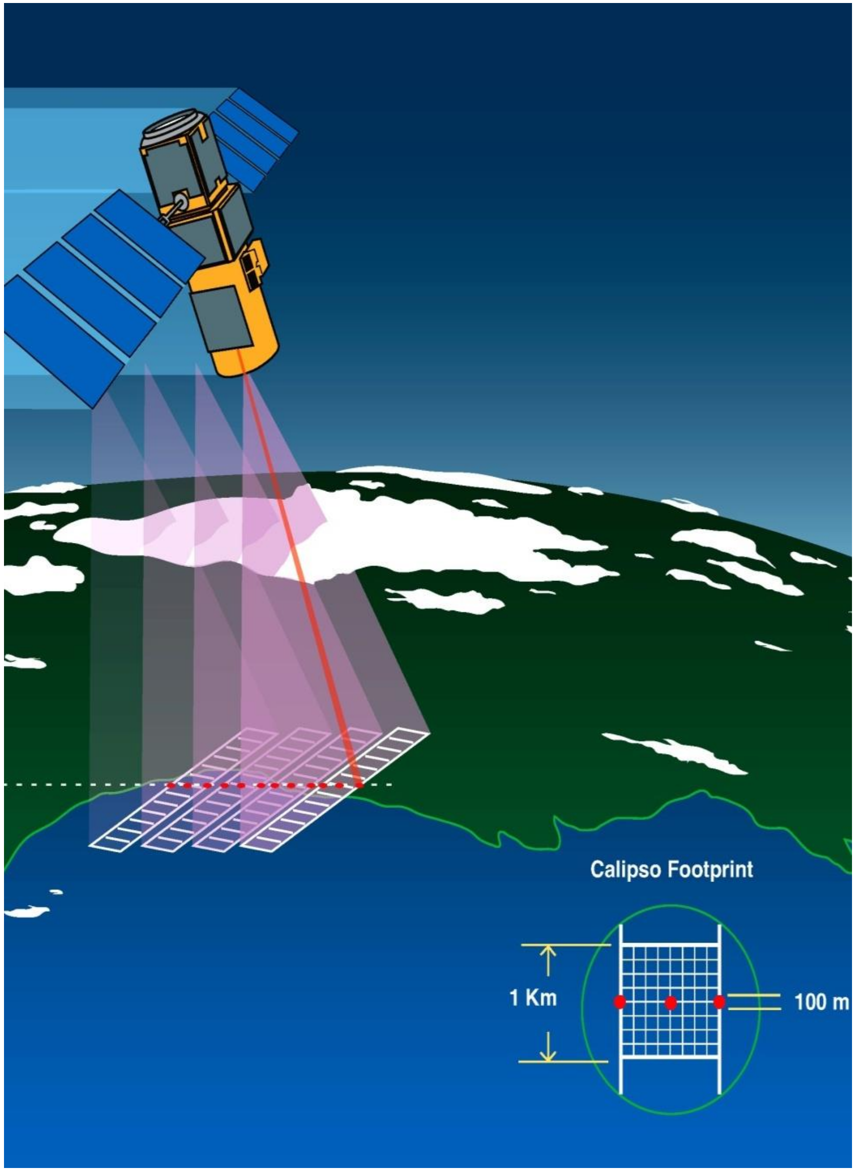
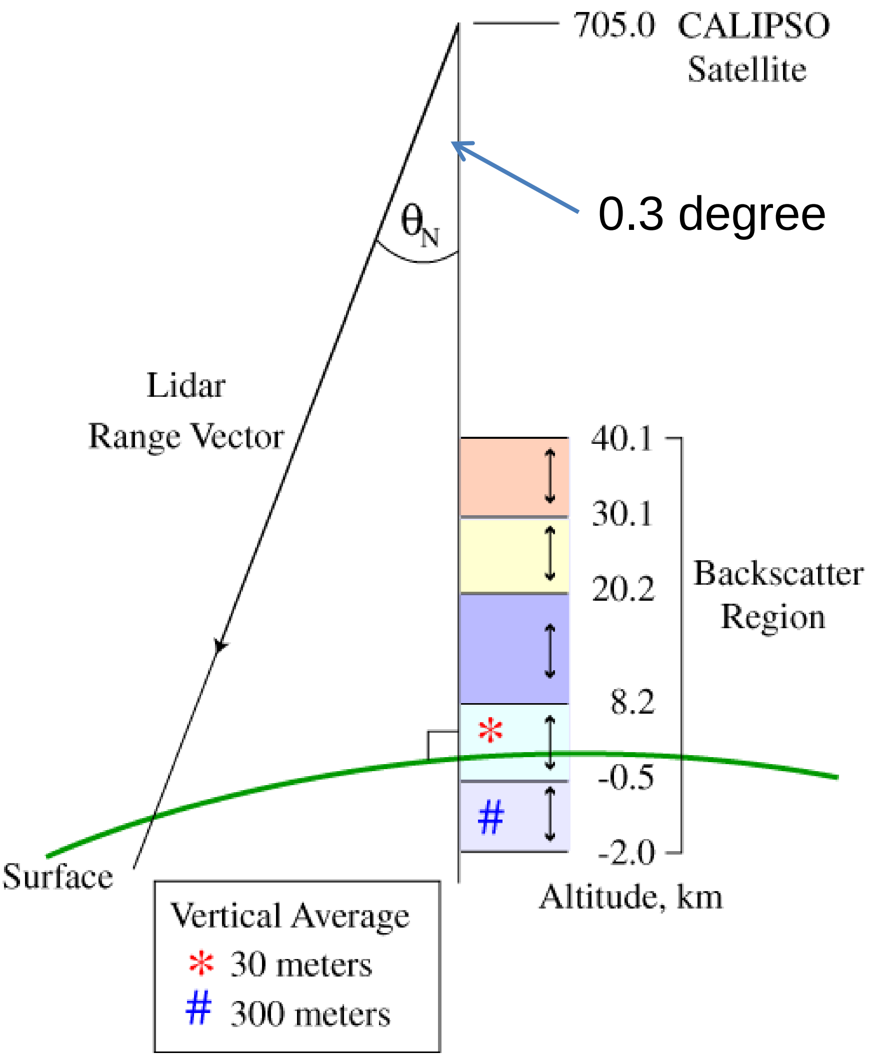
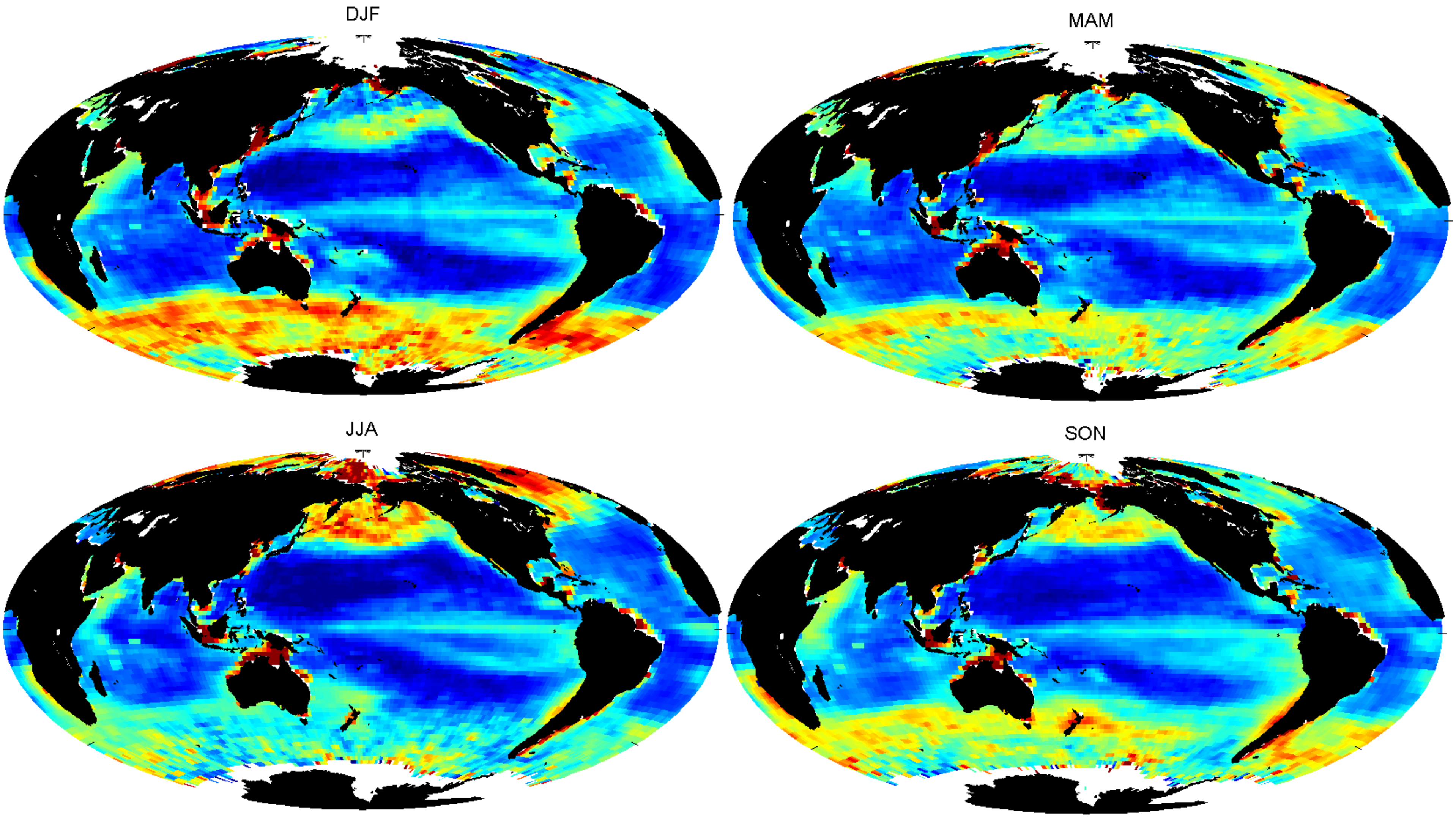
Altitude Region and CALIOP ocean subsurface range bins

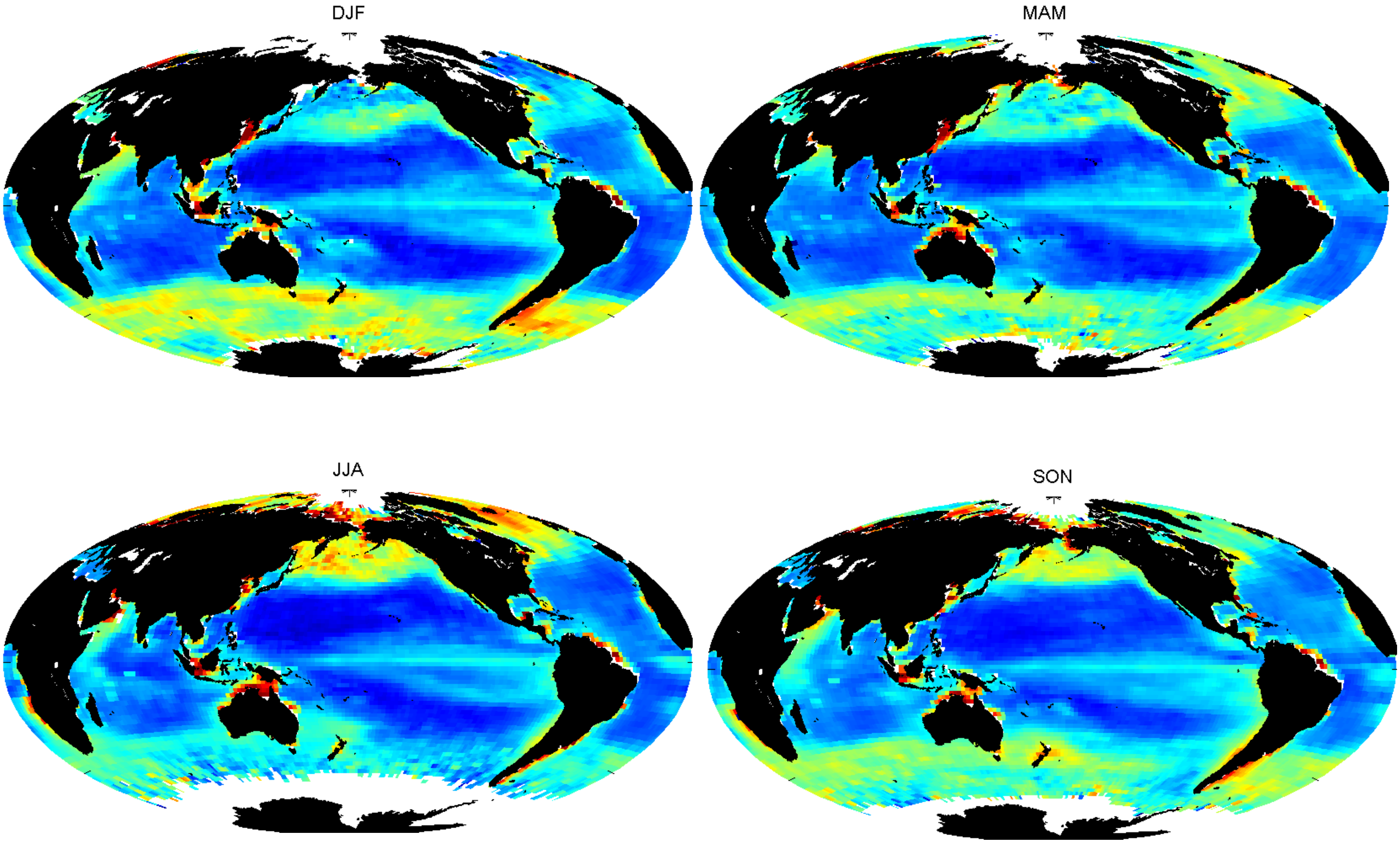




Seasonal Variations of CALIPSO Ocean Cross Polarization Measurements of Phytoplankton Backscatter

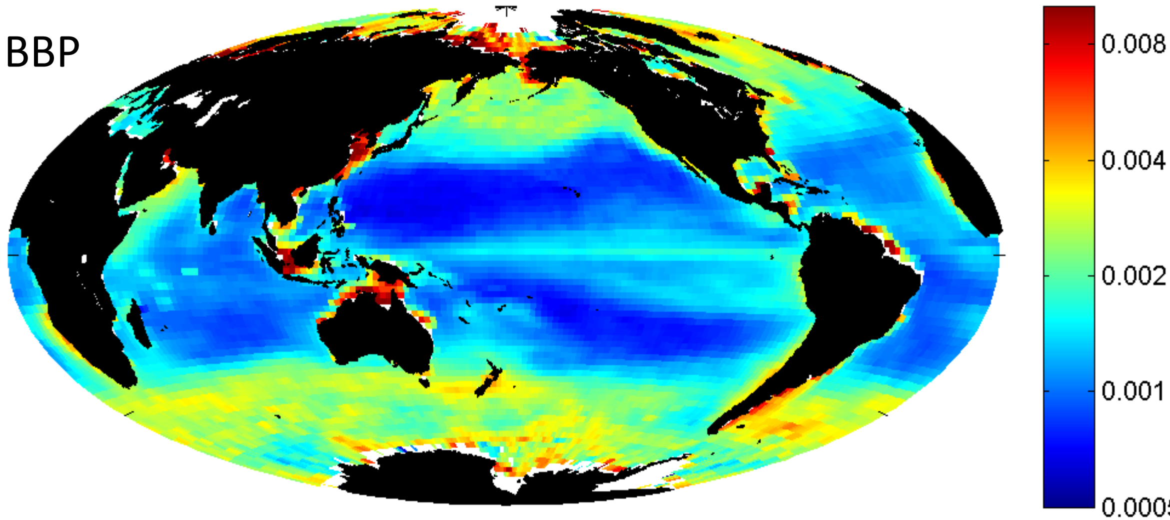


Seasonal Variations of CALIPSO BBP

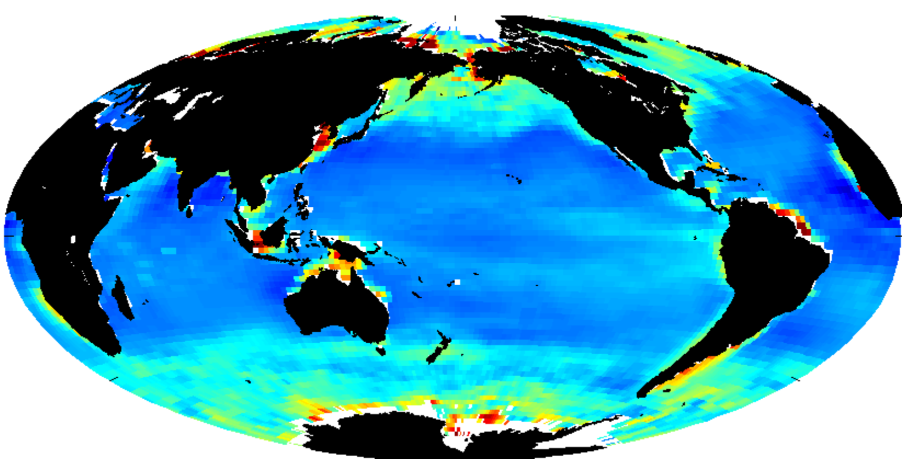


Phytoplankton particulate backscatter coefficient (1/m) estimate from CALIPSO, and comparisons with MODIS

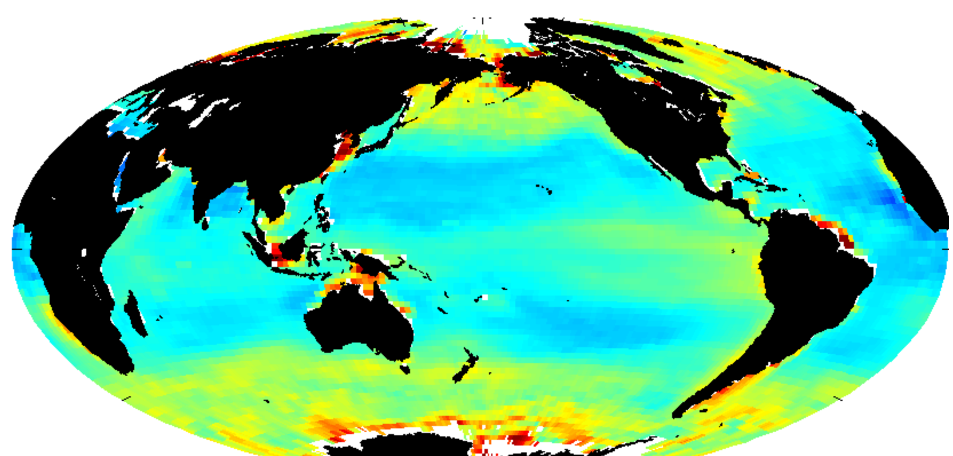
CALIPSO BBP



MODIS BBP: GSM Product



MODIS BBP: QAA Product



Current Methods for Ocean Carbon Biomass Estimate

Carbon biomass is proportional to beam attenuation coefficient C of particulates in water.

Existing methods:

1. Chlorophyll based algorithm (Voss, 1992): C = f(Chl)
   Problem: C does not always co-vary with Chl (e.g., sunlight, nutriciean can affect Chl)
2. BBP based algorithm: C=f(BBP)
   Better than Chl based algorithm

An Innovative Methods for Ocean Carbon Biomass Estimate

New method:

linking beam attenuation and diffuse attenuation with depolarization ratios

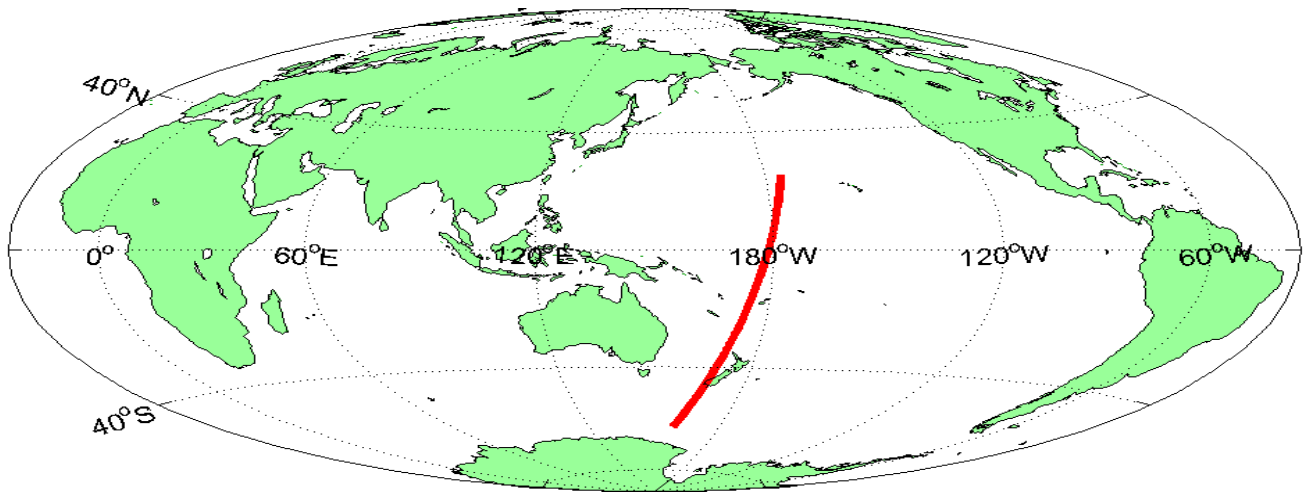
C = diffuse attenuation Kd / multiple scattering factor η

$$\eta = [(\omega^2-\delta)/(\omega^2+\delta)]^2$$

ω is single scatter albedo and δ is depolarization ratio

The multiple scattering – depolarization relation is based on Monte Carlo simulation

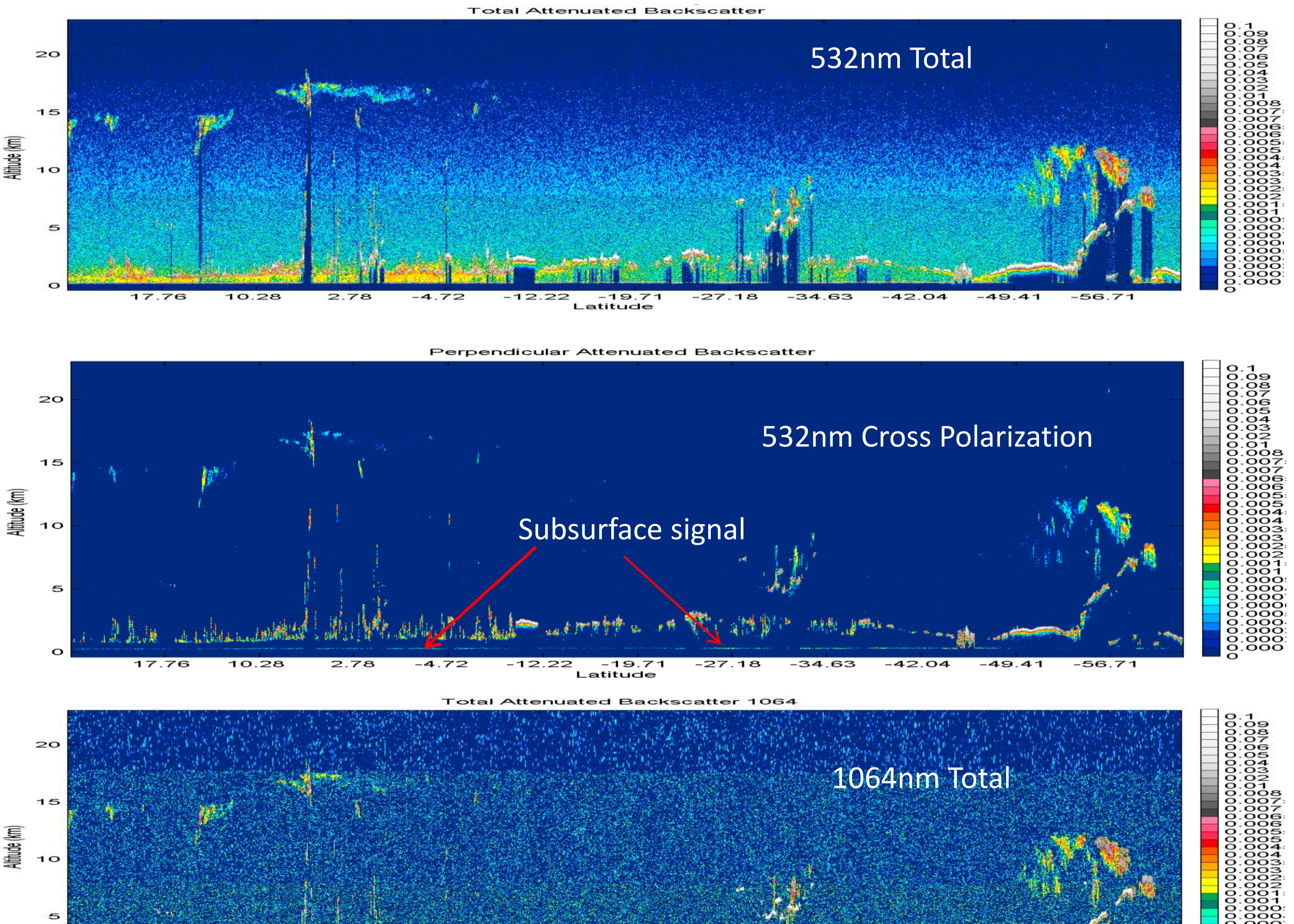
30 degree off-nadir measurement of ocean subsurface depolarization ratios

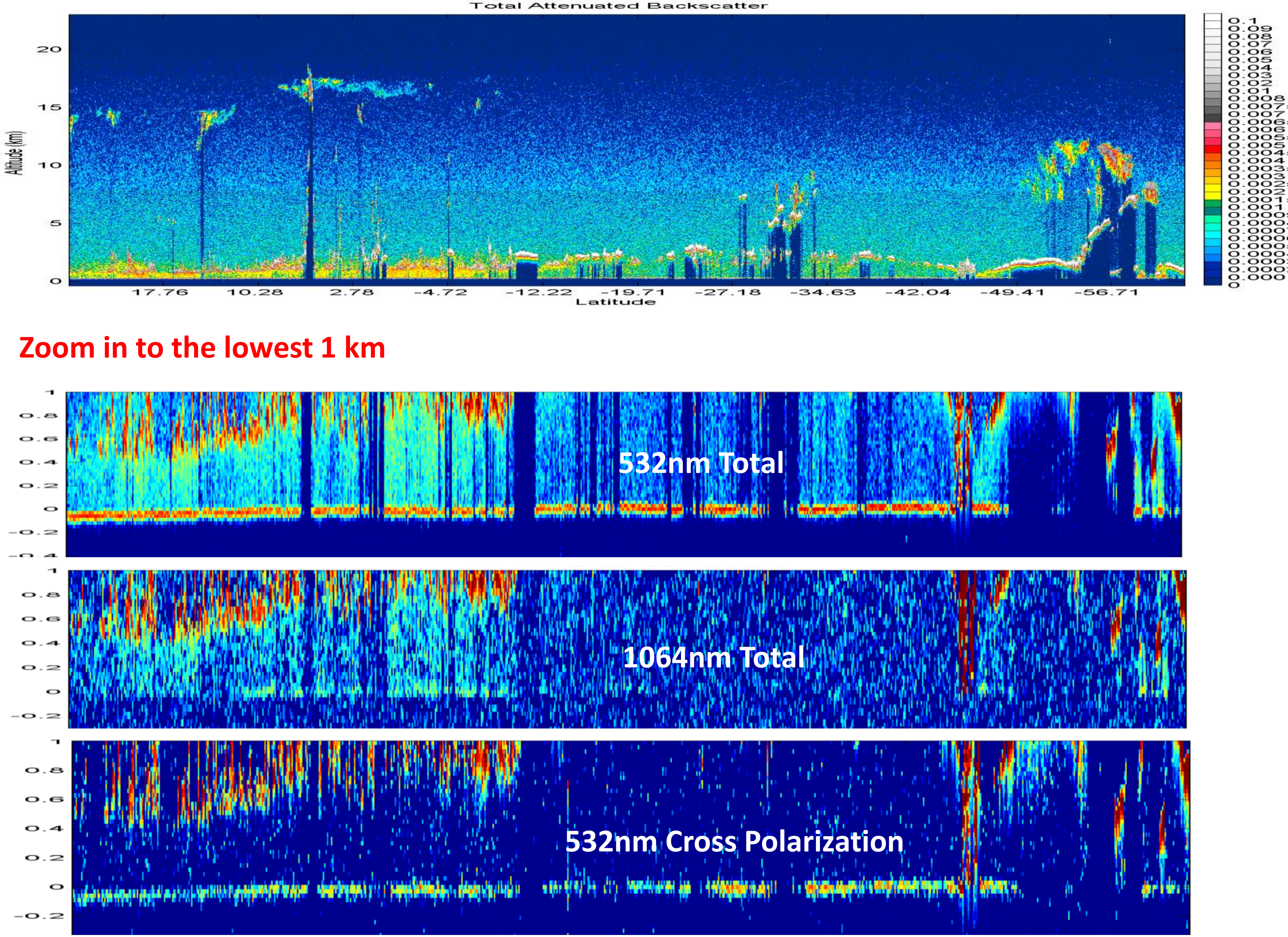


Why pointing CALIPSO 30 degree off-nadir: avoid ocean surface backscatter

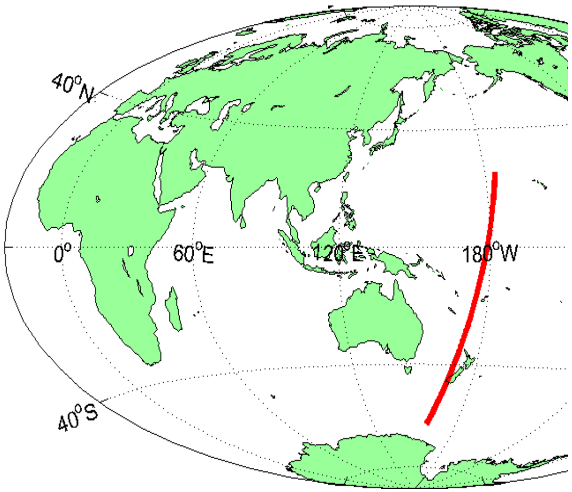
1. Direct demonstration of CALIPSO ocean subsurface signals in both co-polarization and cross-polarization to convince the community that CALIOP can measure phytoplankton backscatter
2. Direct measurements of depolarization ratios of phytoplankton backscatter to improve CALIOP estimate of phytoplankton backscatter and biomass estimate

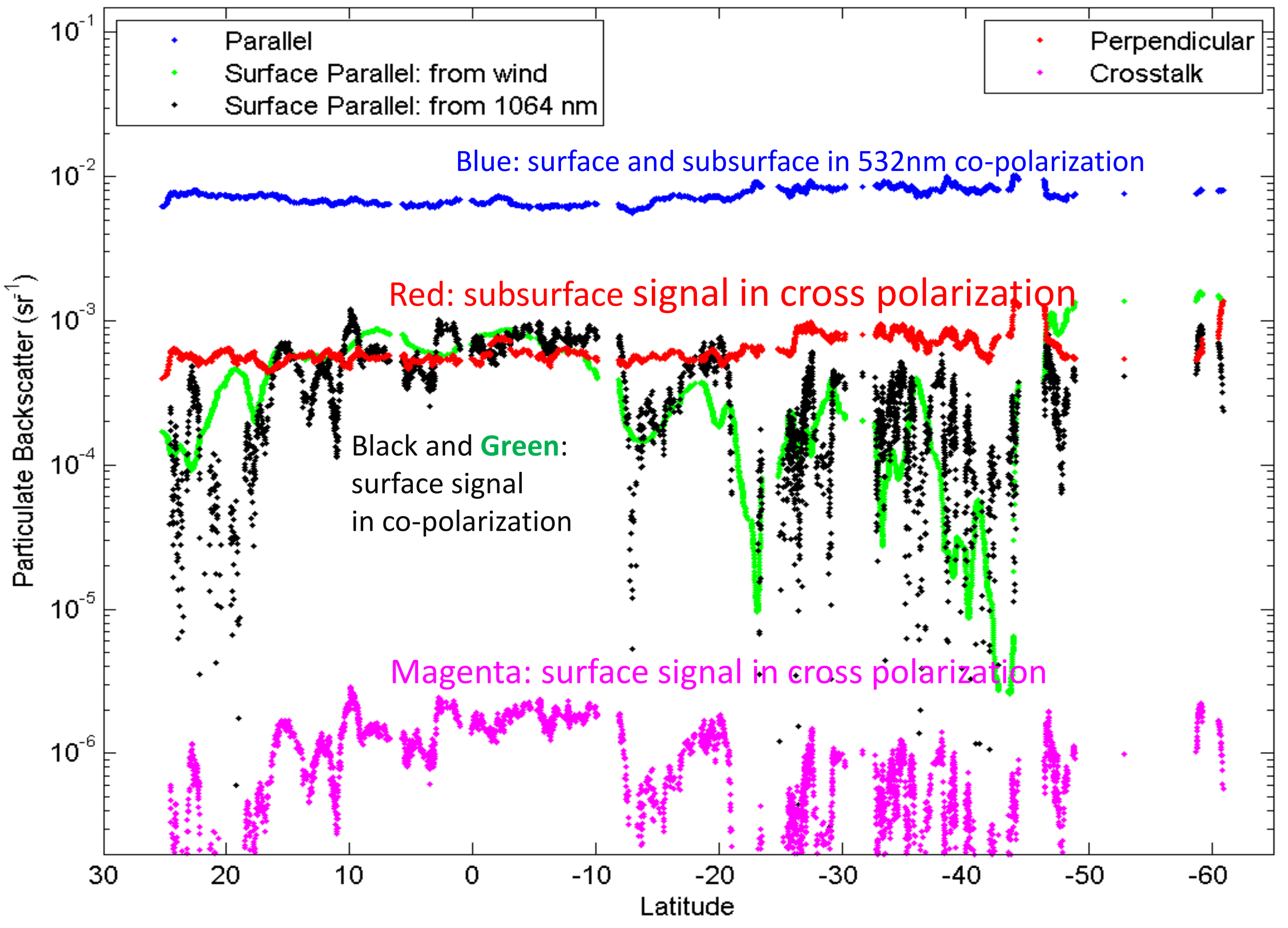
Behrenfeld, Hu, Hostetler, Dall'Olmo, Rodier, Hair, Trepte(2013), Space-based lidar measurements of global ocean carbon stocks, **Geophys. Res. Lett**., 40, 4355–4360, doi:10.1002/grl.50816.
Lu., Hu, Trepte, Zeng, and Churnside (2014), Ocean subsurface studies with the CALIPSO spaceborne lidar, **J. Geophys. Res. Oceans**, 119, 4305–4317, doi:10.1002/2014JC009970.


Total Attenuated Backscatter
532nm Total
Altitude (km)
Latitude
Perpendicular Attenuated Backscatter
532nm Cross Polarization
Subsurface signal
Total Attenuated Backscatter 1064
1064nm Total


Total Attenuated Backscatter
Altitude (km)
Latitude
17.76
10.28
2.78
-4.72
-12.22
-19.71
-27.18
-34.63
-42.04
-49.41
-56.71
Zoom in to the lowest 1 km
532nm Total
1064nm Total
532nm Cross Polarization

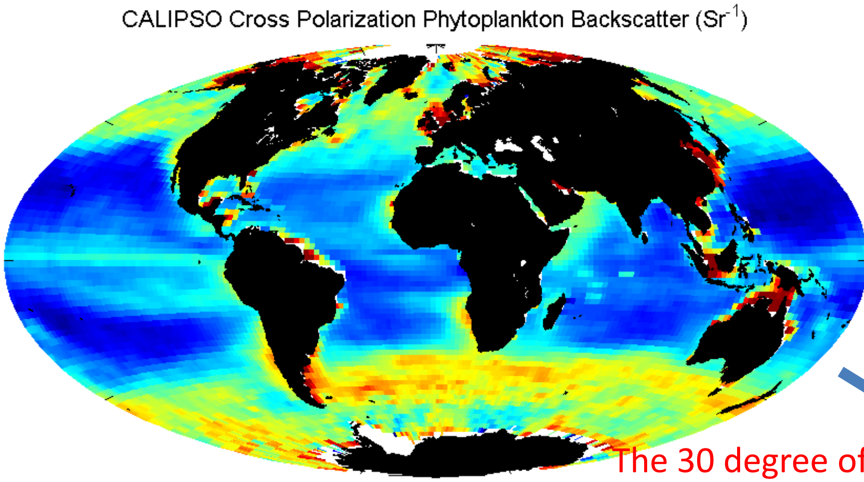
Surface signals are much weaker than subsurface signals and can be corrected using 1064nm measurements





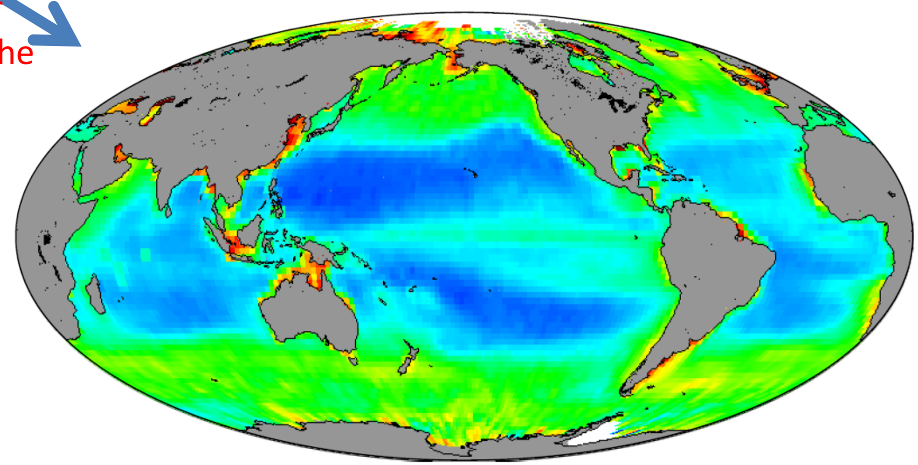
Thus, at 30 degree off-nadir, we can accurately measure depolarization ratio of ocean subsurface backscatter

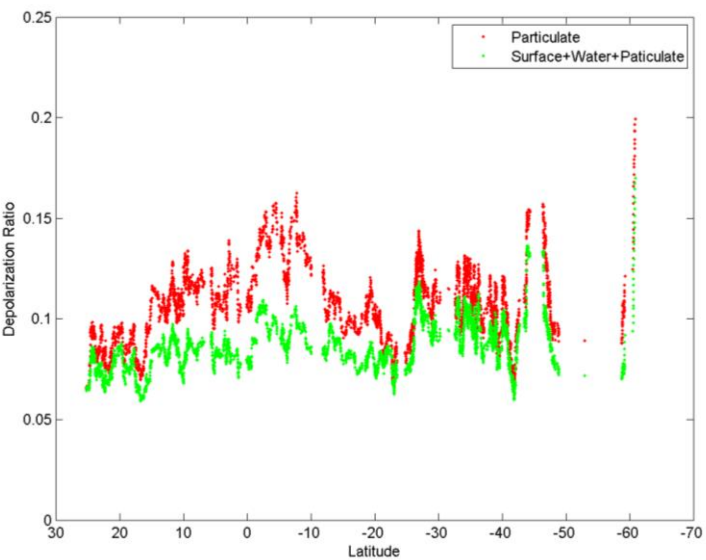
Applications: Improving Phytoplankton Particulate Organic Carbon (POC) Estimate from CALIPSO



The 30 degree off-nadir measurement verifies the assumption about depolarization ratio

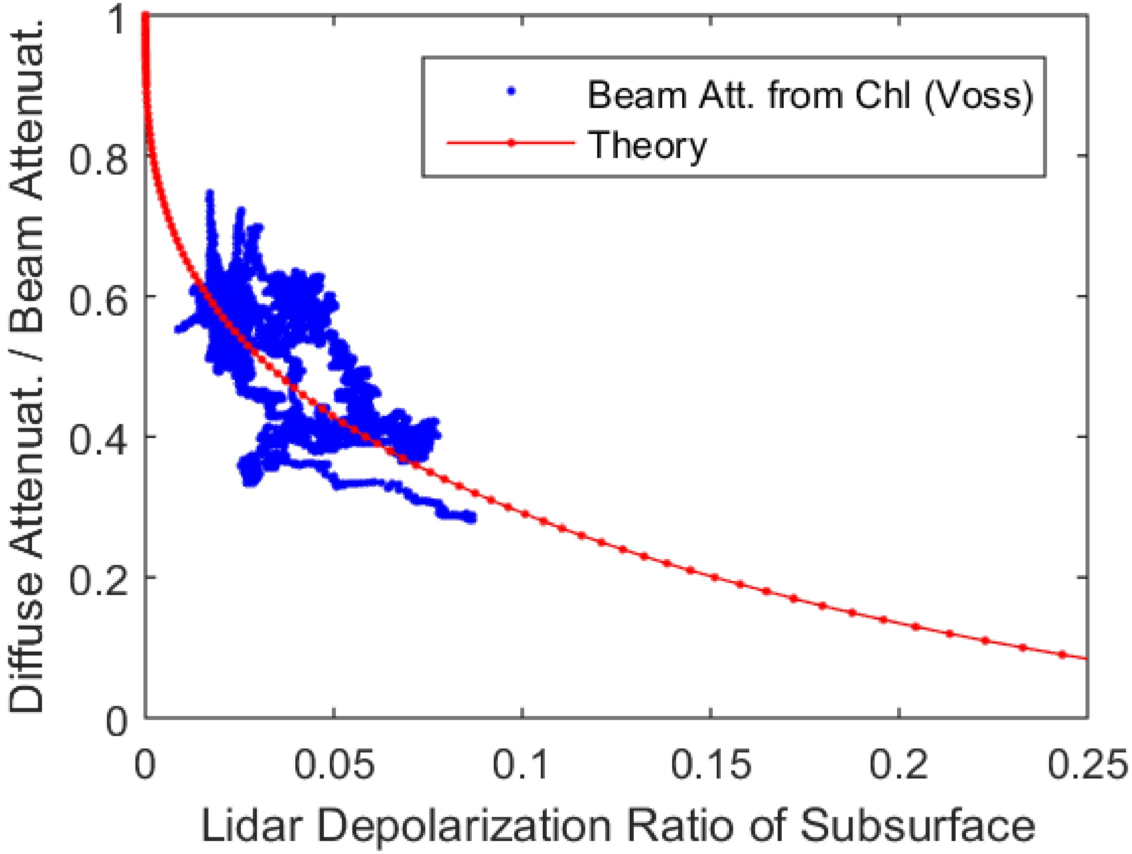
Particulate Organic Carbon (mg m^{-3}) from CALIPSO



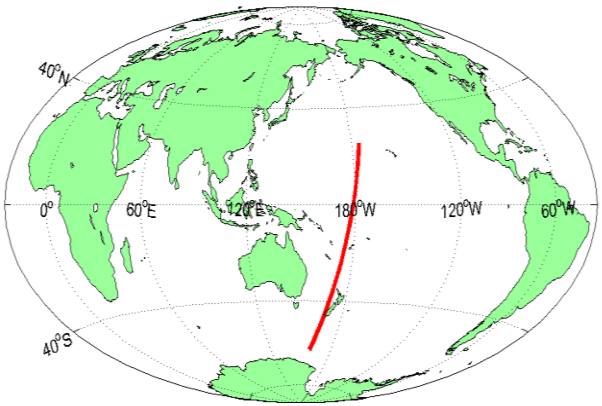


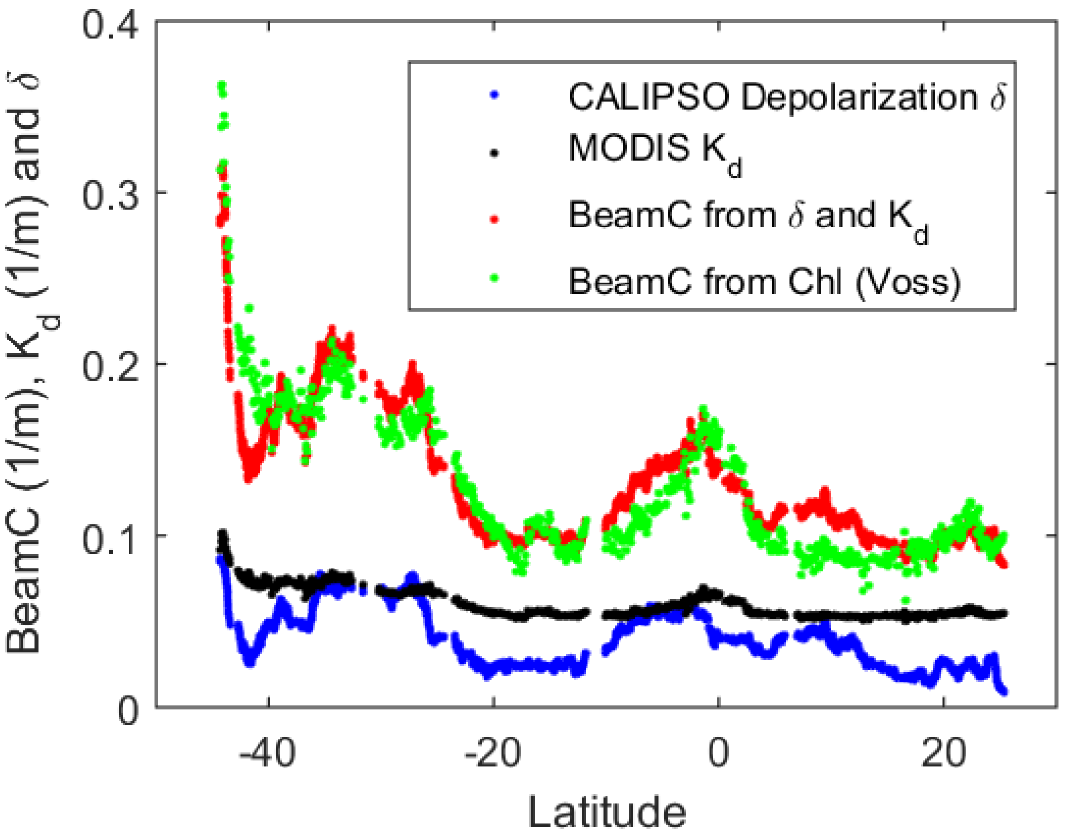
Behrenfeld, Hu, Hostetler, Dall'Olmo, Rodier, Hair, Trepte, GRL, 2013

Evaluation of the multiple scattering factor – depolarization ratio relation

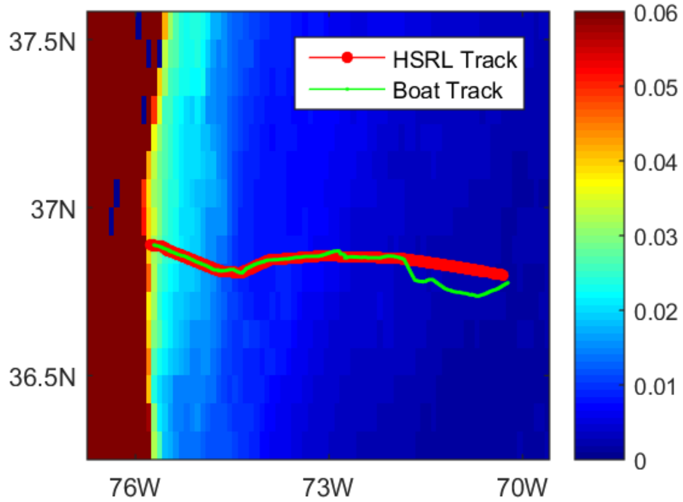


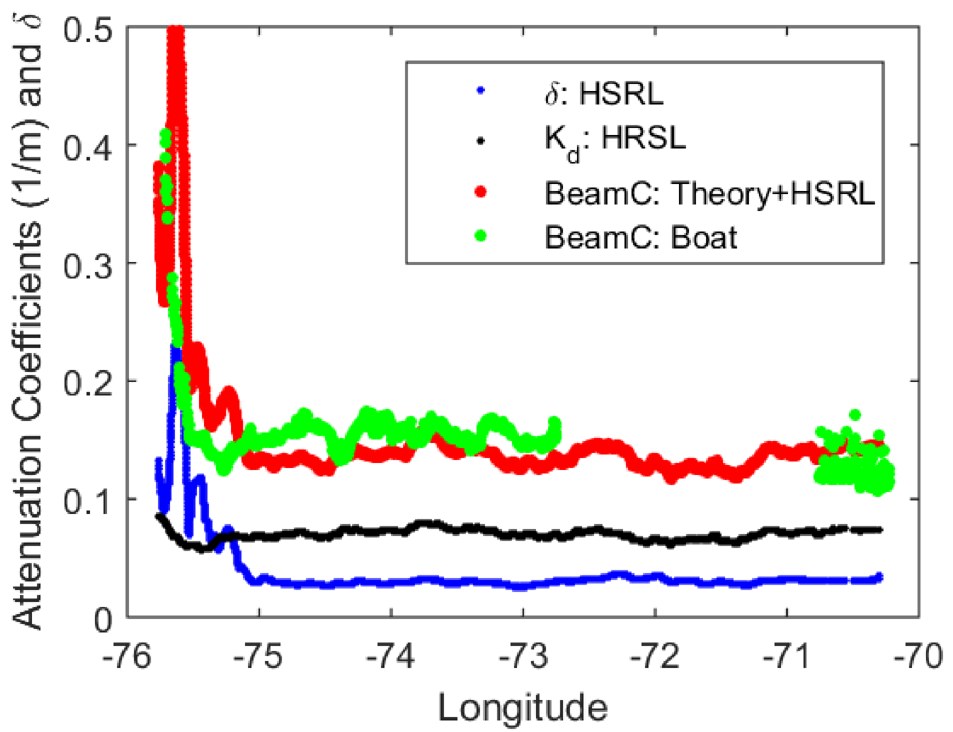
Comparisons of beam attenuation between CALIPSO and MODIS





Comparisons with shipbased measurements during SABOR campaign





Summary

- Ocean carbon biomass co-varies with phytoplankton beam attenuation coefficient

- Effective attenuation coefficient, which can be measured, is the product of beam attenuation and multiple scattering factor

- Multiple scattering factor can be accurately estimated from lidar depolarization ratio measurements

- Spaced-based lidars provide most direct measurements of ocean carbon biomass