

A study of potential links between ocean and cloud properties from CALIPSO observation record

Yongxiang Hu

CALIPSO for Climate Studies

Launched: April 28, 2006; Collected **11 years of data** with more than 7 billion laser shots; **may last a few more months (or longer)**

Unique climate change measurements:

- **Vertical dimension of clouds**
- **Backscatter of clouds and phytoplankton with very stable calibration (uncertainty within 1%)**



CALIPSO for Climate Studies

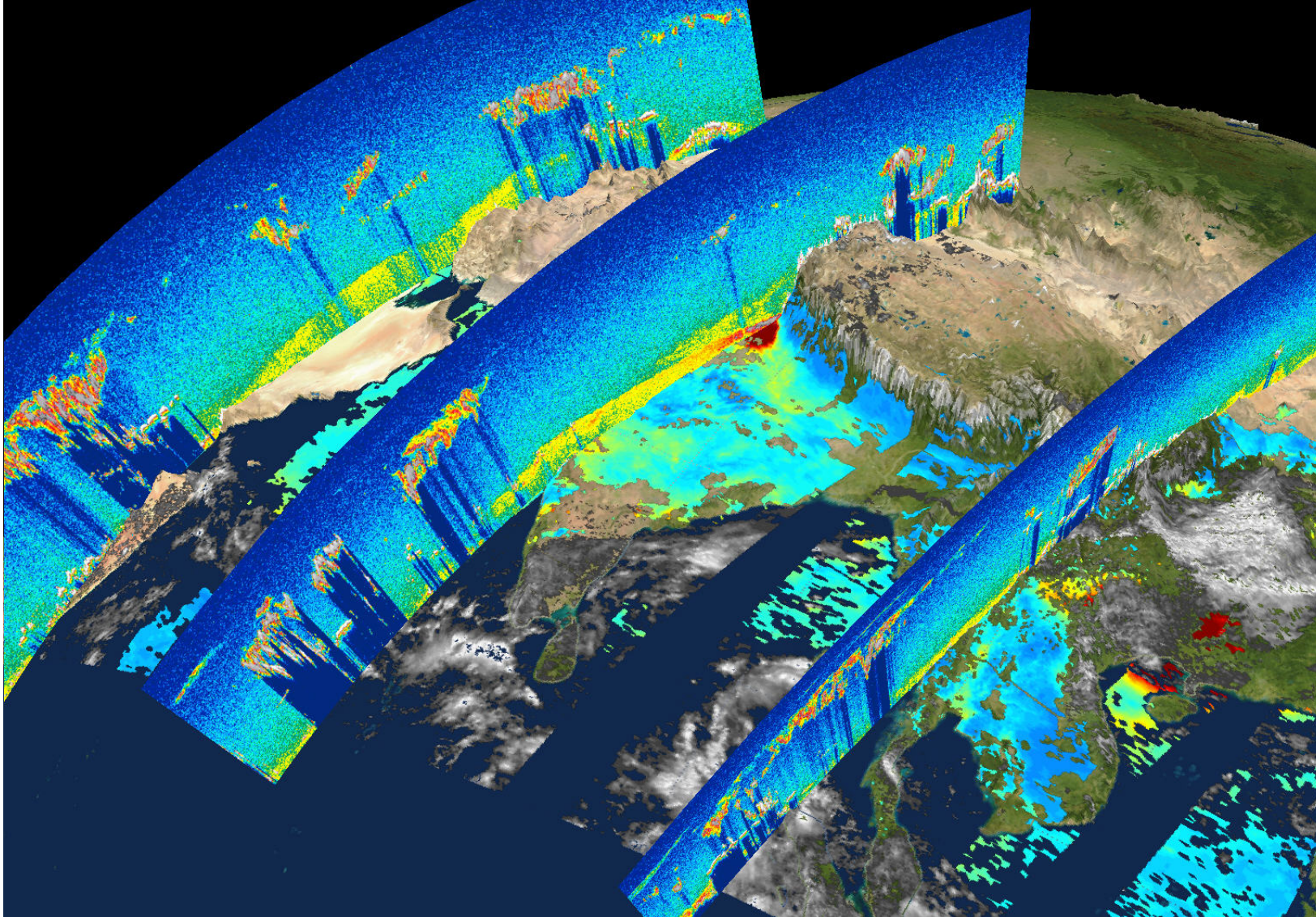
Launched: April 28, 2006; Collected **11 years of data** with more than 7 billion laser shots; **may last a few more months (or longer)**

Unique climate change measurements:

- **Vertical dimension of clouds**
- **Backscatter of clouds and phytoplankton with very stable calibration (uncertainty within 1%)**



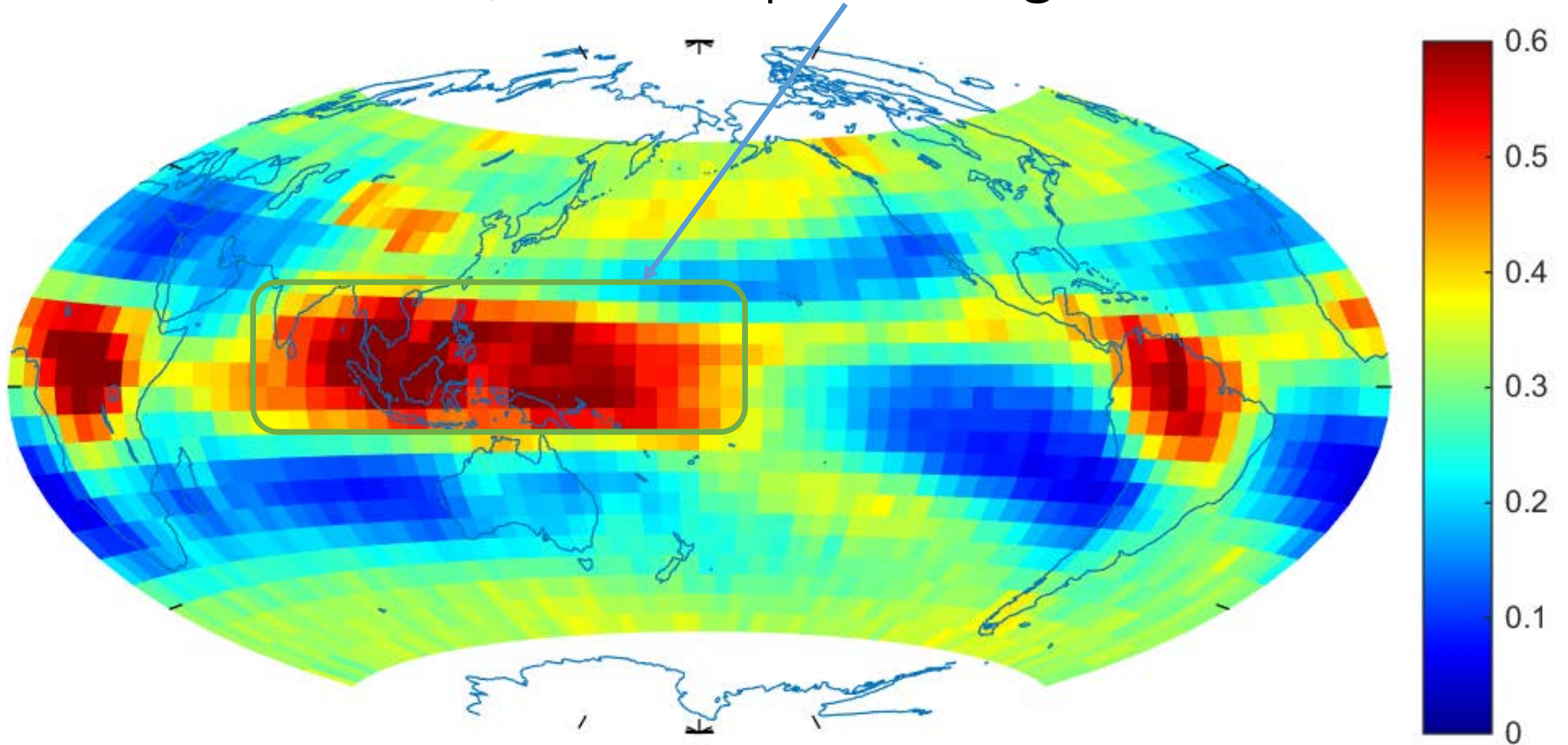
CALIPSO Adds the **Vertical** Dimension



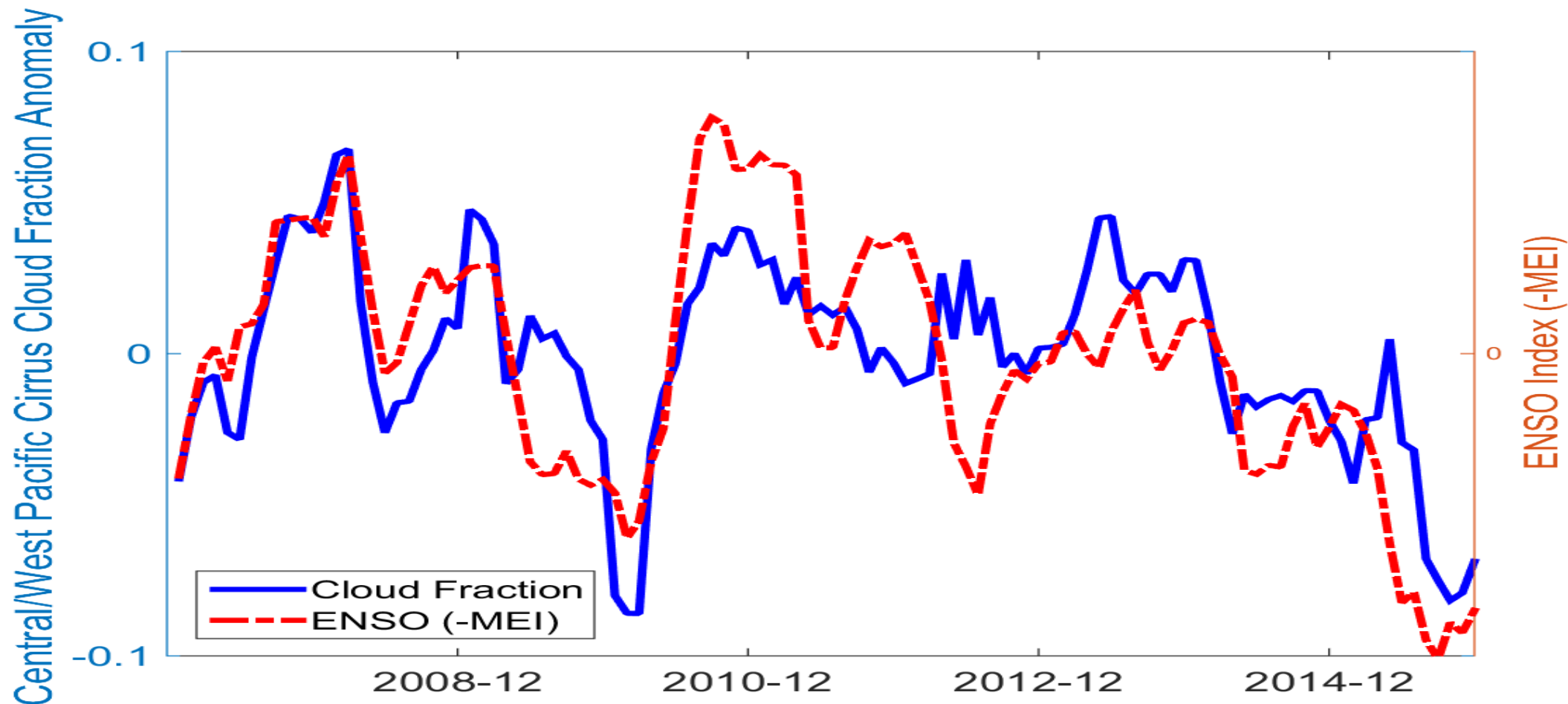
A few examples demonstrating the climate quality of CALIPSO cloud record

1. Clear correlation between central/western pacific tropical cirrus cloud fraction and ENSO index
2. The clear link between QBO and tropical cirrus cloud height and fraction
3. Decreasing trend of arctic water cloud depolarization ratios and supercooled liquid water cloud fraction

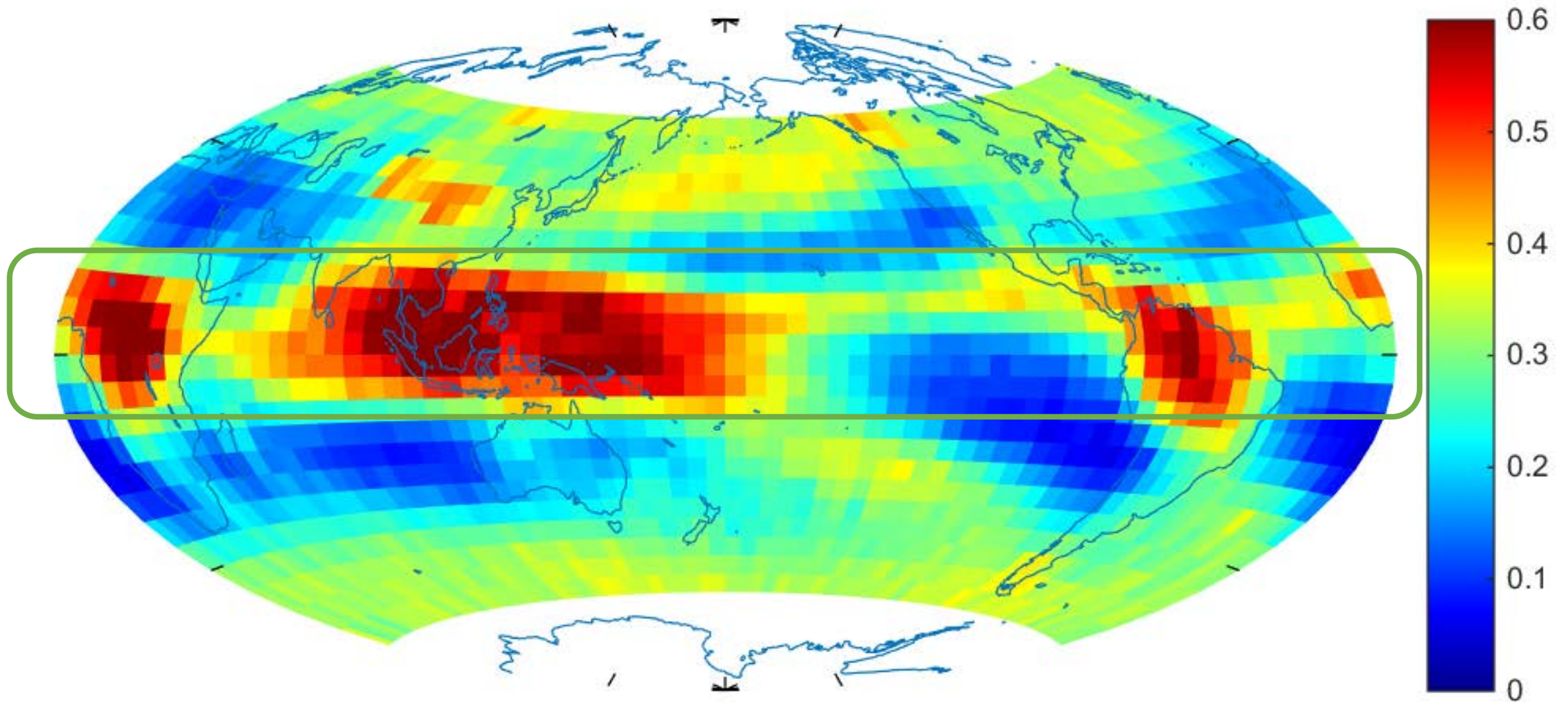
CALIPSO cirrus cloud fraction of central/western pacific region



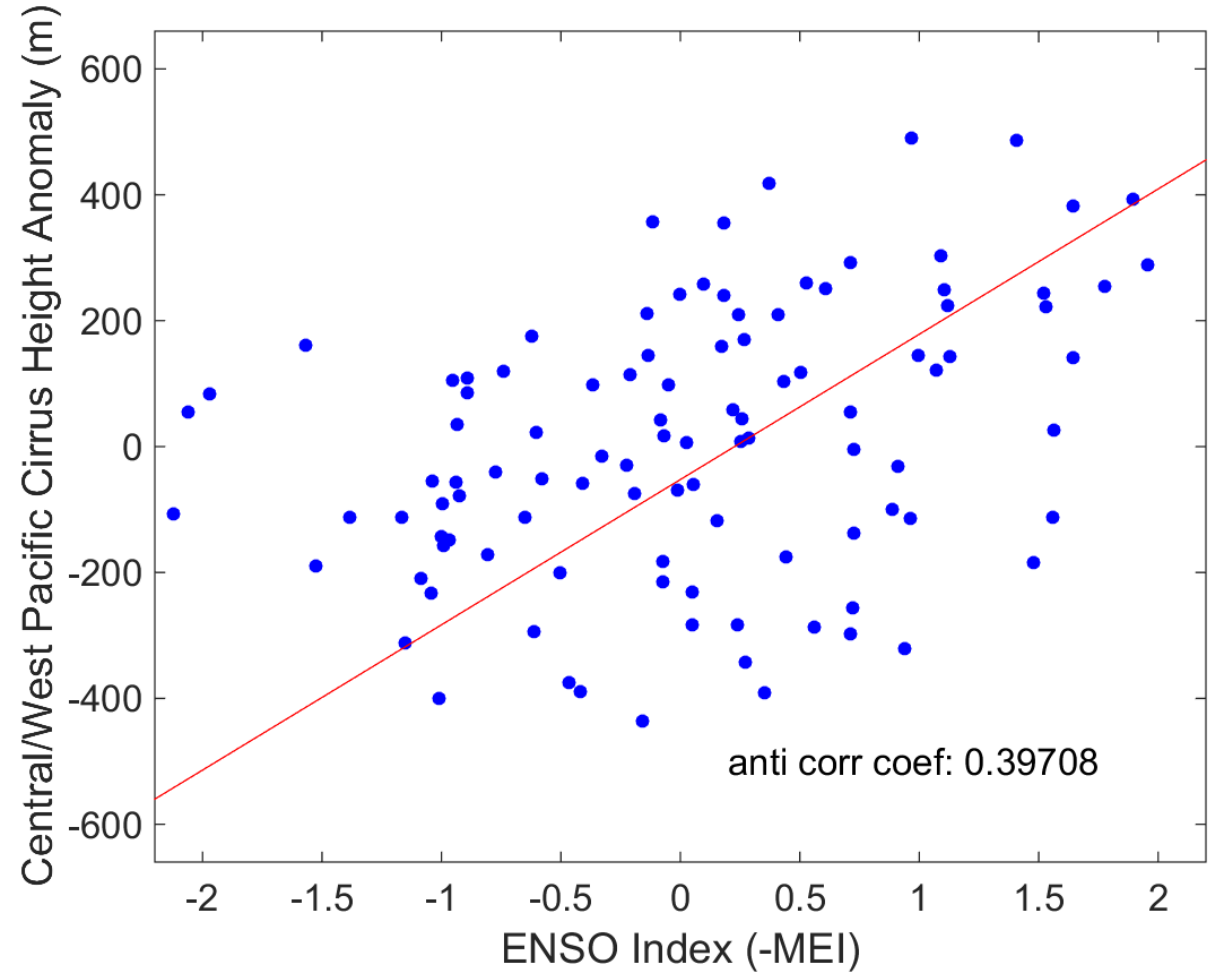
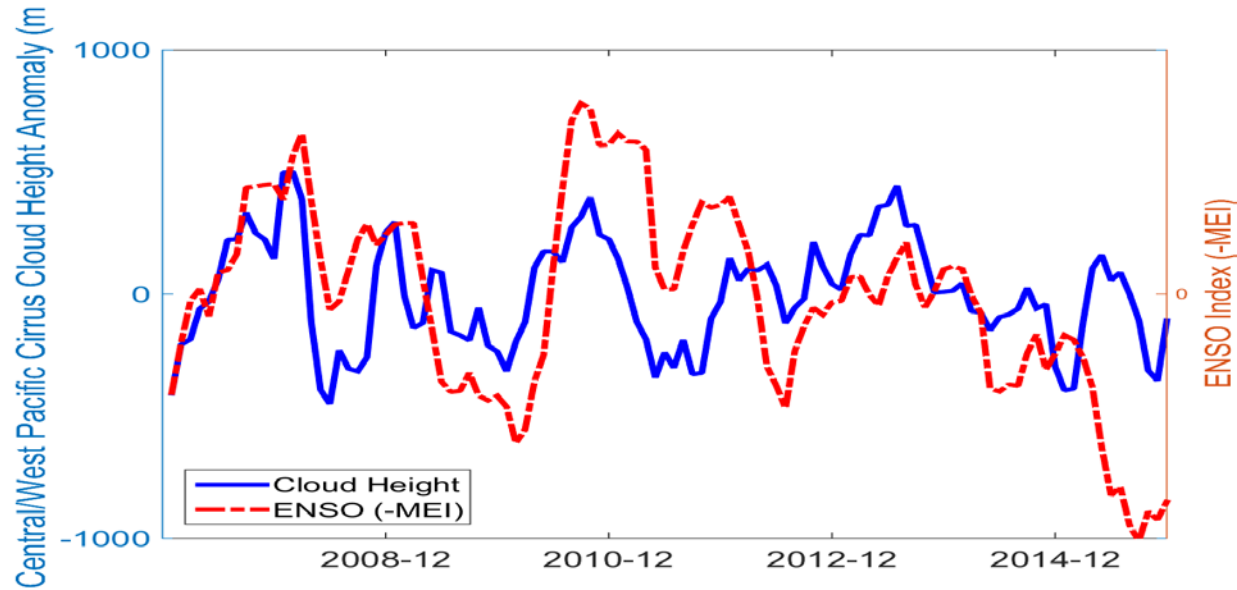
CALIPSO cirrus cloud fraction of central/western pacific region: highly correlated with ENSO index



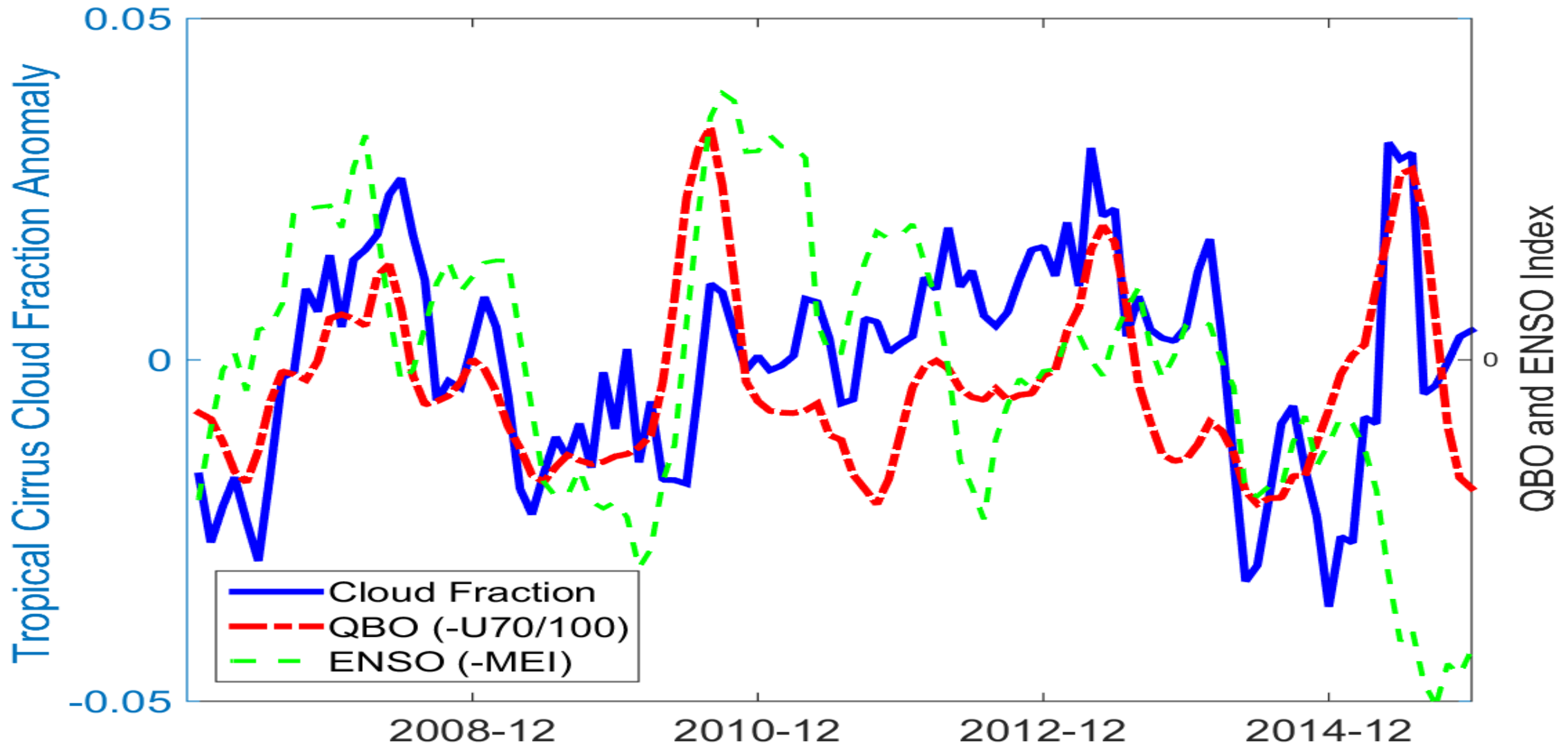
Tropical cirrus cloud fraction



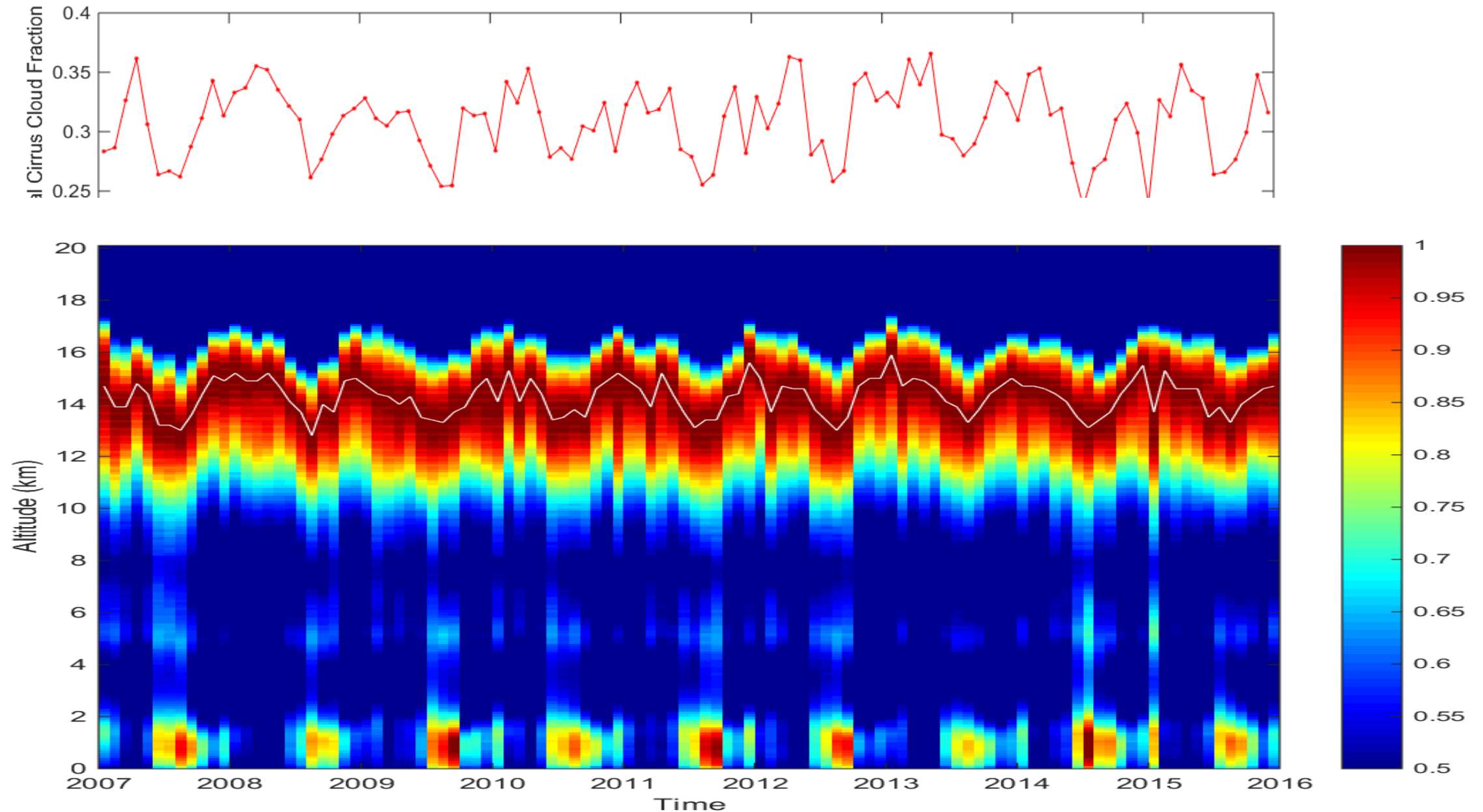
CALIPSO cirrus cloud height of central/western pacific region: less correlated with ENSO comparing with cloud fraction



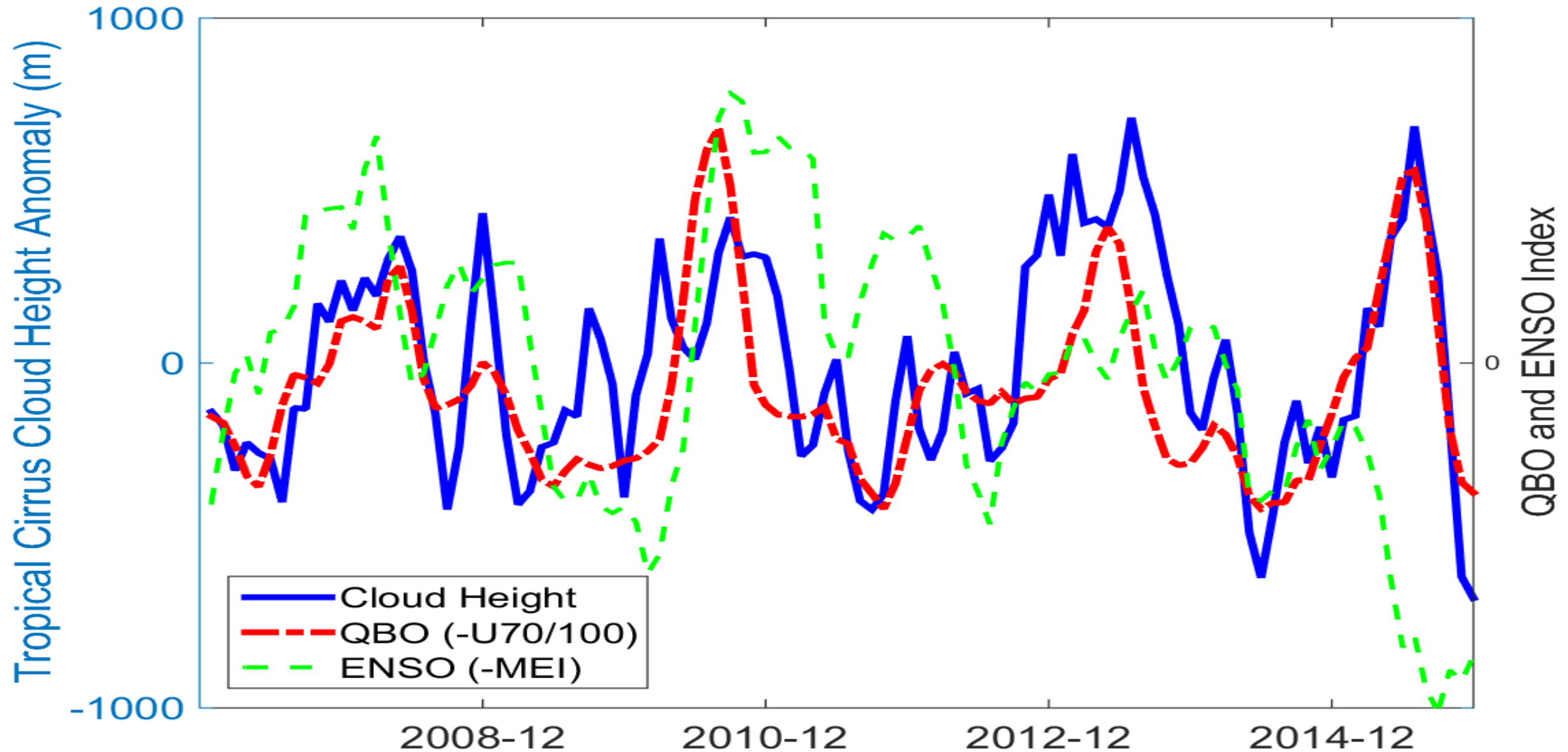
CALIPSO tropical cirrus cloud fraction correlates better with 70 mb QBO index



Time series of tropical cloud fraction and cloud height from CALIPSO



CALIPSO tropical cirrus cloud height highly correlates with 70 mb QBO index



stratospheric water vapor $\Leftrightarrow$ QBO $\Leftrightarrow$ upper tropospheric clouds

CALIPSO cloud observation record shows strong evidence of the link between tropical cirrus clouds to QBO, and thus the clear link between tropical cirrus clouds and stratospheric water vapor

CALIPSO for Climate Studies

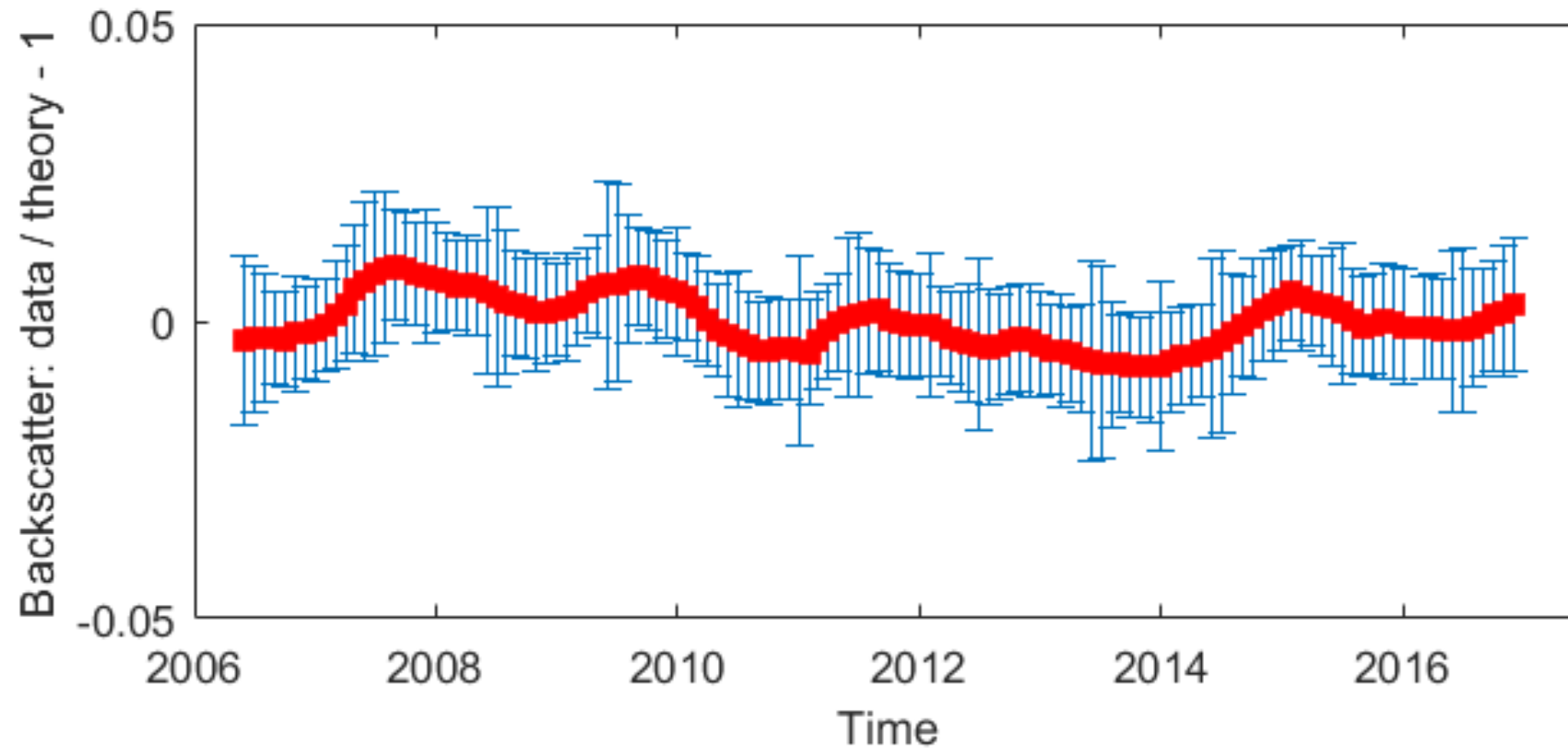
Launched: April 28, 2006; Collected **11 years of data** with more than 7 billion laser shots; **may last a few more months (or longer)**

Unique climate change measurements:

- **Vertical dimension of clouds**
- **Backscatter of clouds and phytoplankton with very stable calibration (uncertainty within 1%)**

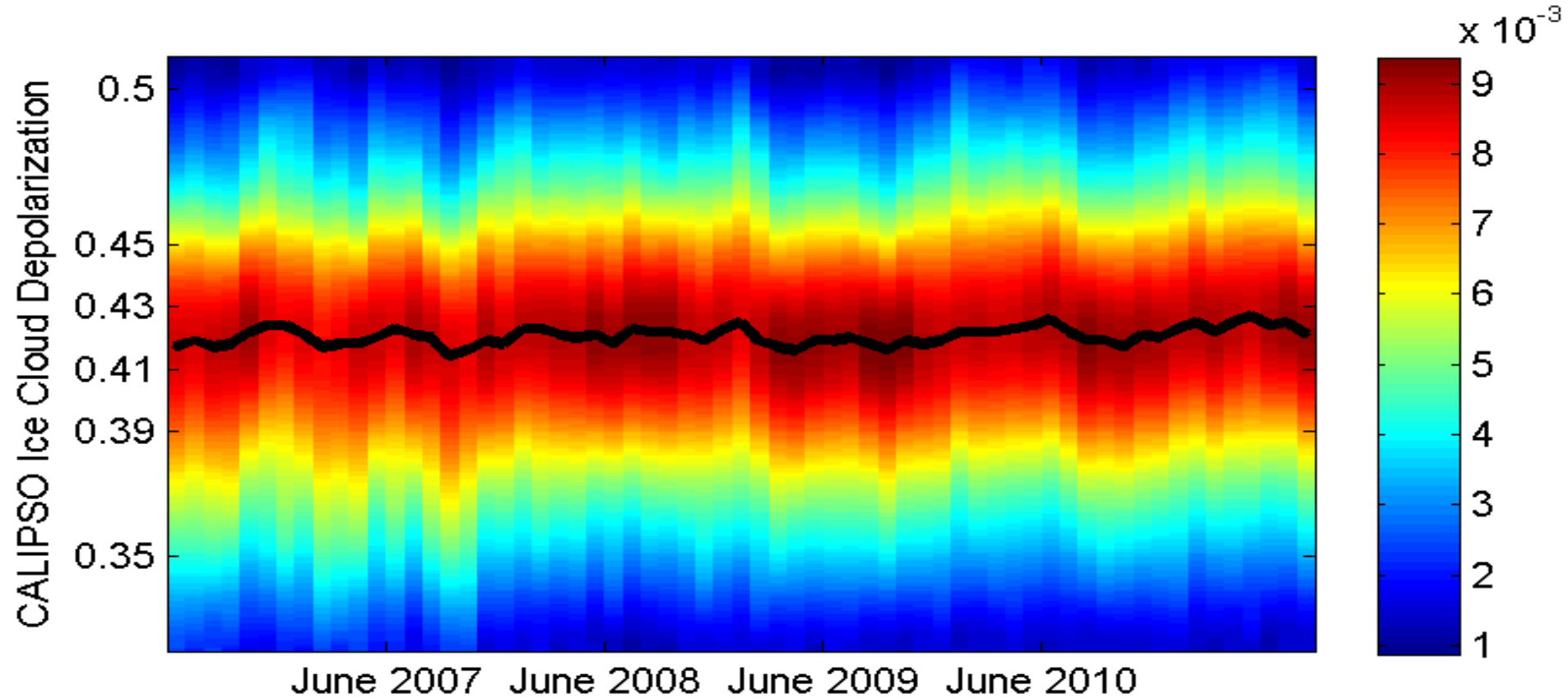


High quality cloud and phytoplankton climate record with best long term calibration stability: 532 nm backscatter within 1%

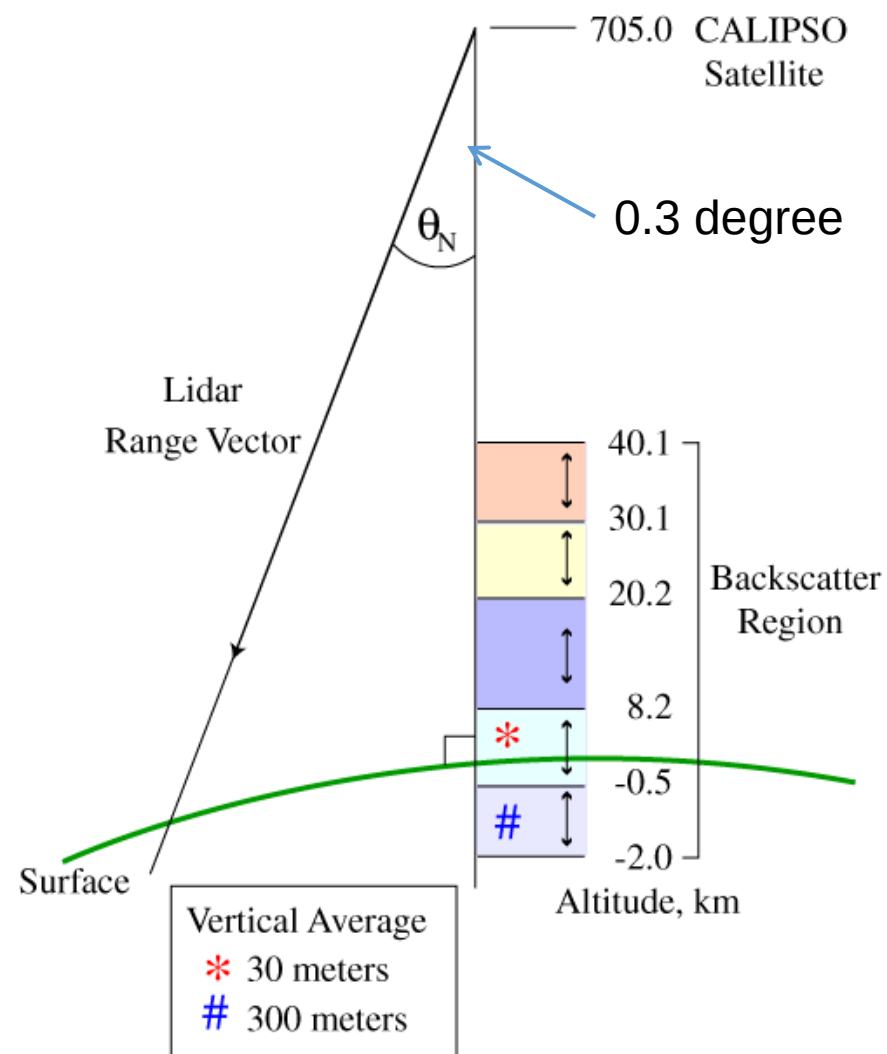
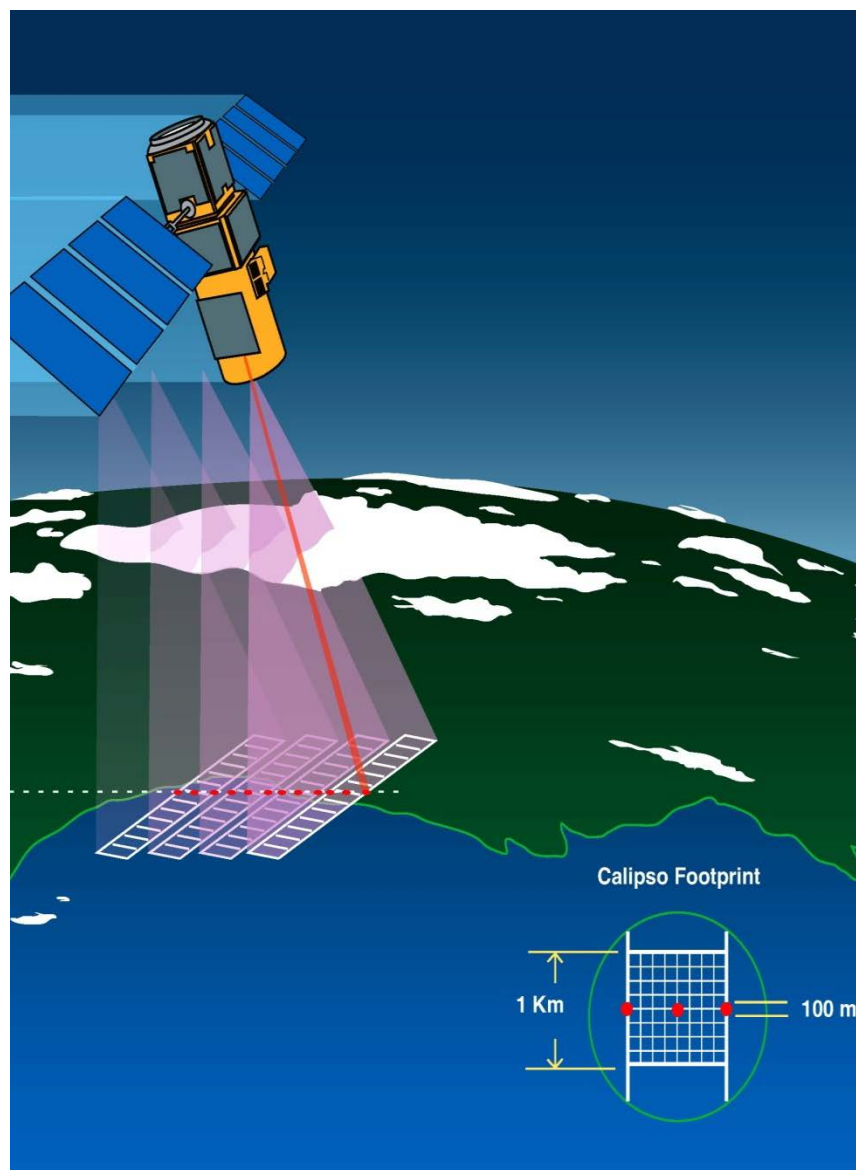


CALIPSO measurements of clear sky atmospheric backscatter: measurement vs theory

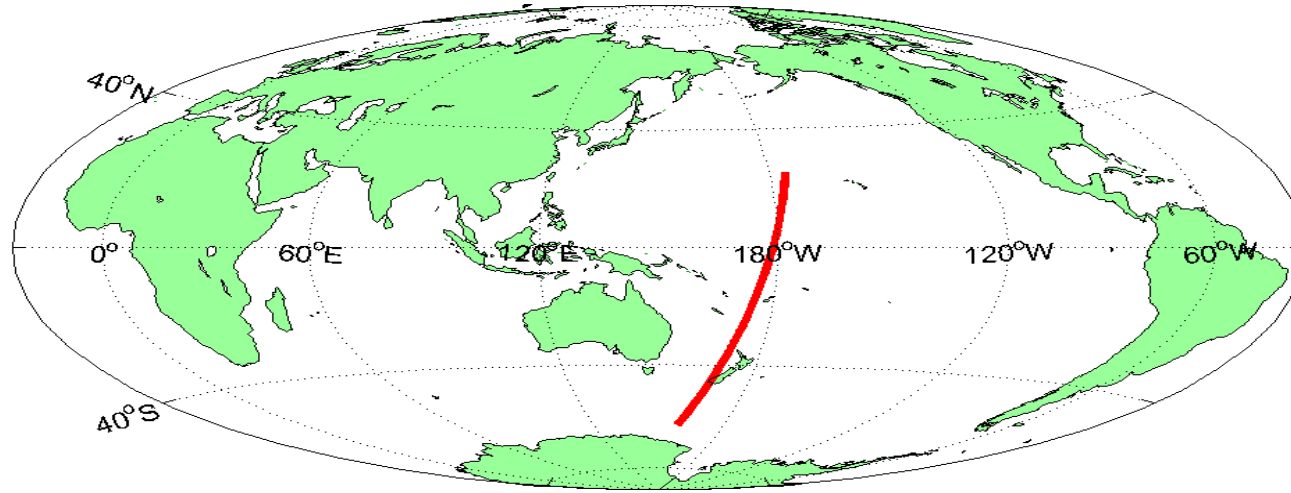
Highly stable 532 nm cross polarization calibration as well



Altitude Region and CALIOP ocean subsurface range bins



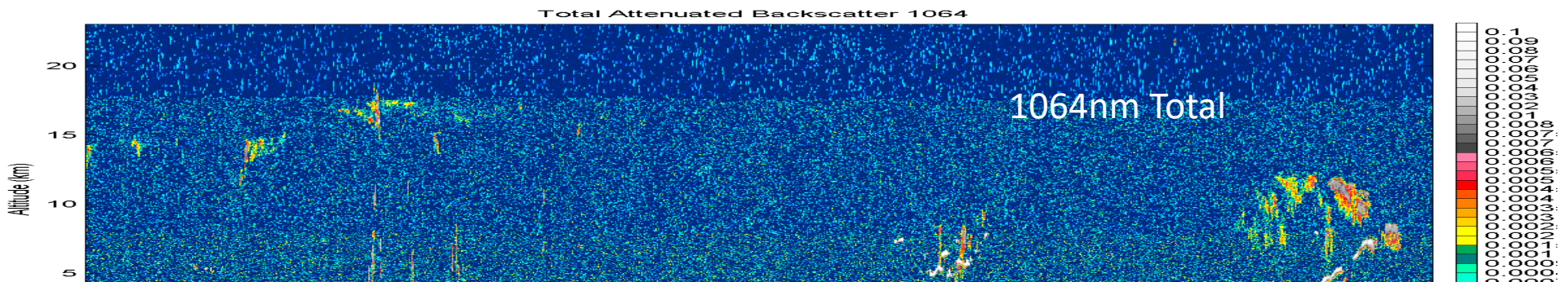
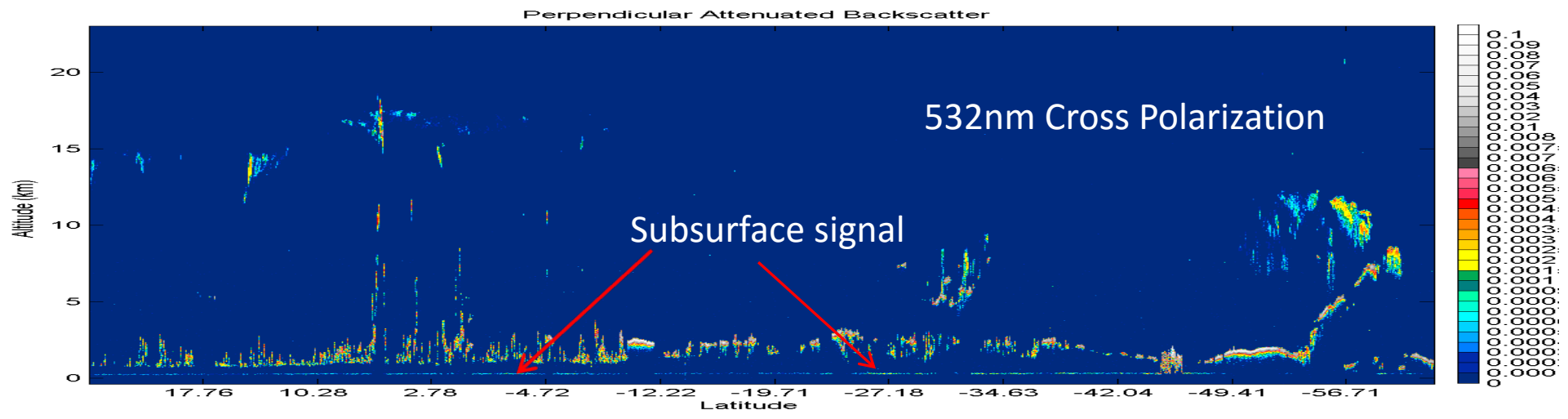
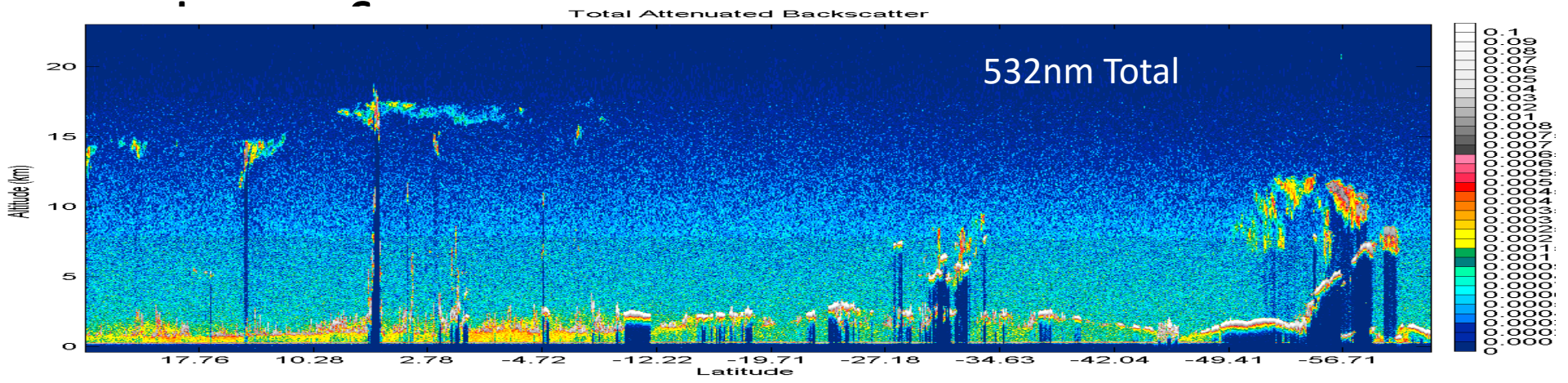
30 degree tilt of CALIPSO satellite: ocean subsurface signal

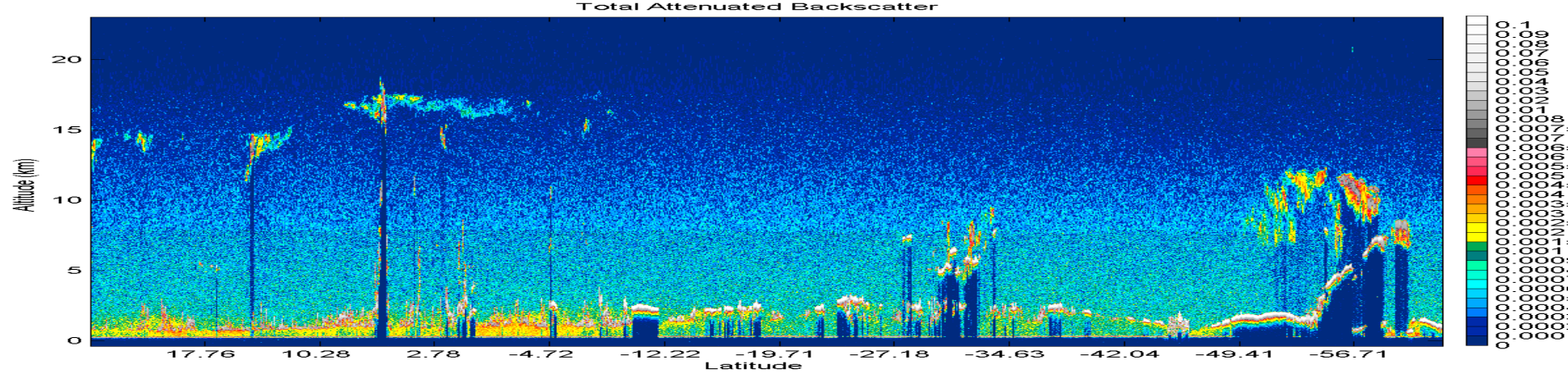


One orbit out of every two weeks since Sept. 2015, CALIPSO satellite tilts 30° off-nadir.

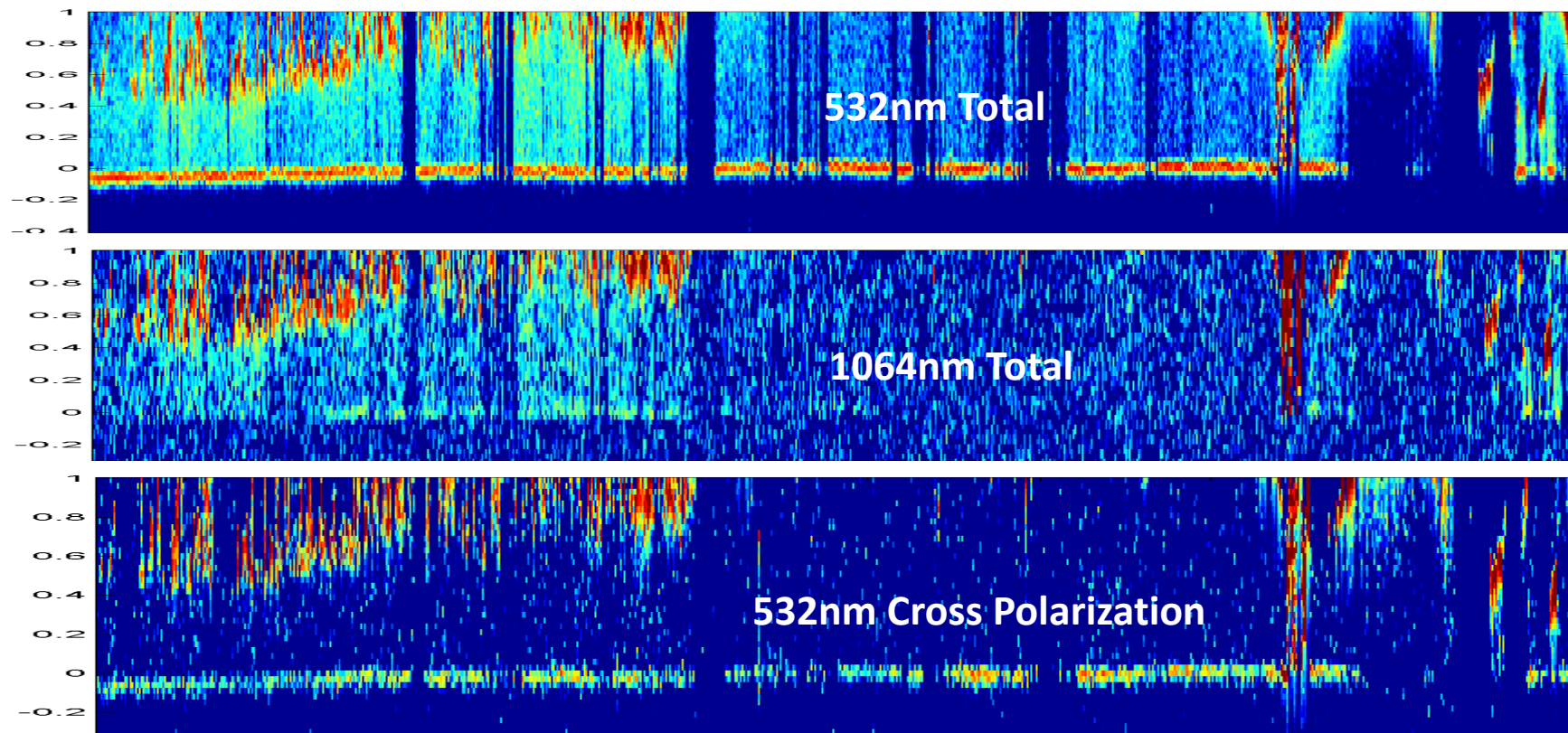
Why? avoid ocean surface backscatter

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

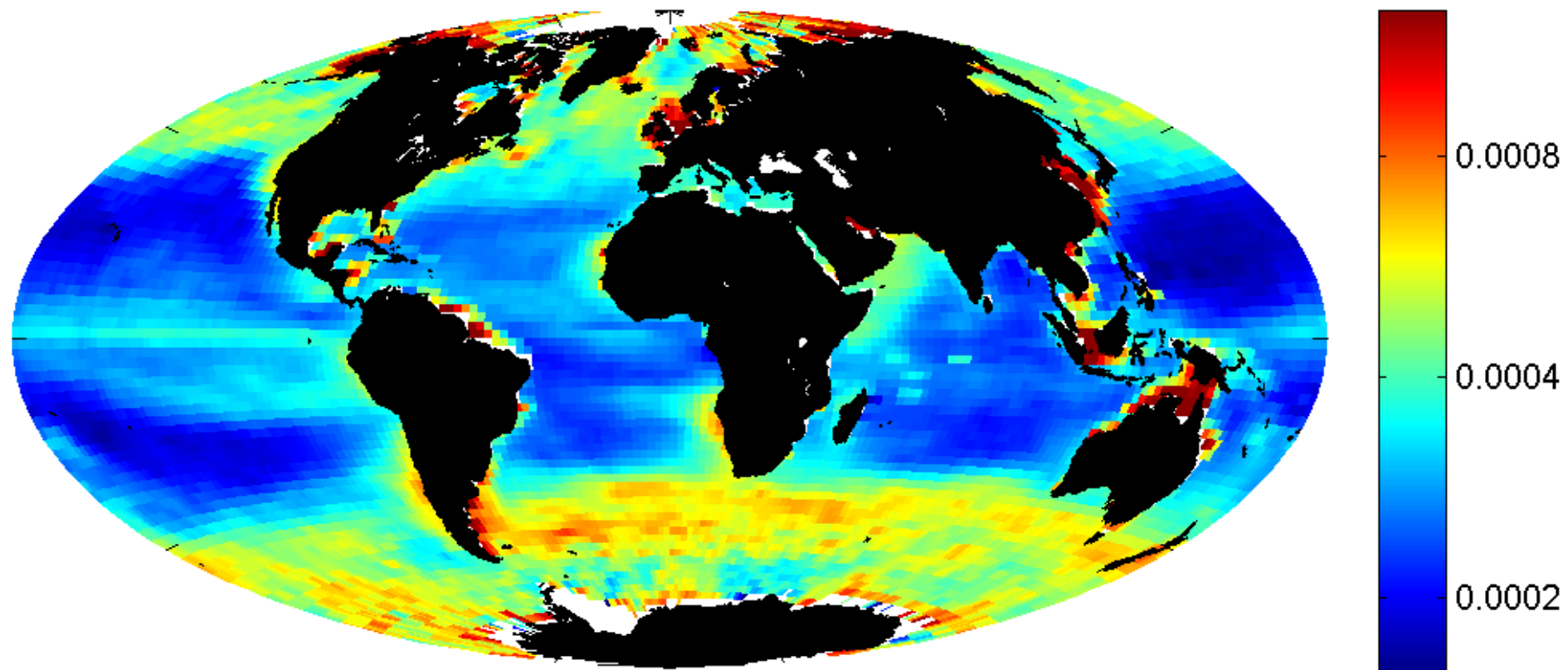




Zoom in to the lowest 1 km

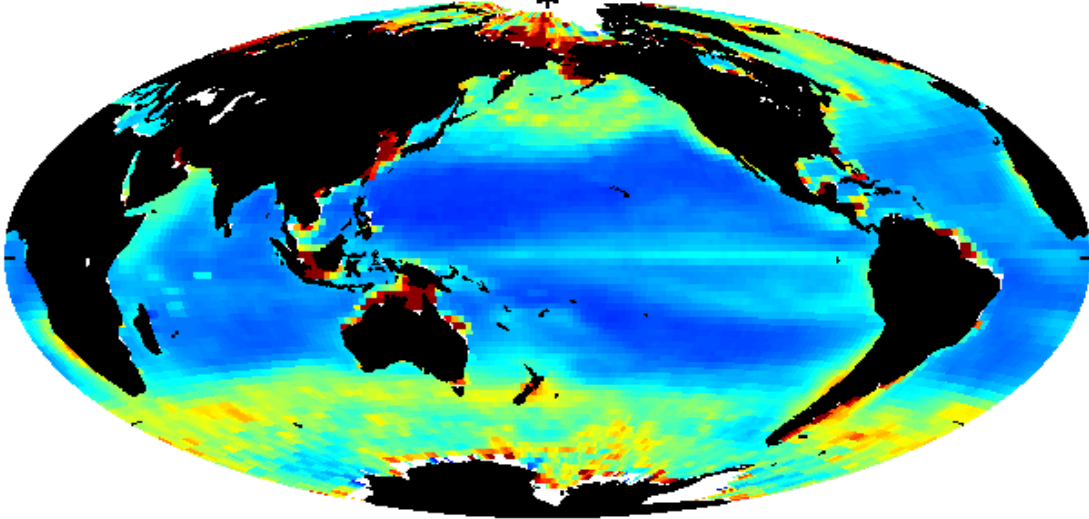


CALIPSO Cross Polarization Phytoplankton Backscatter (Sr^{-1})

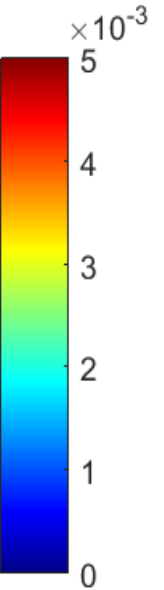
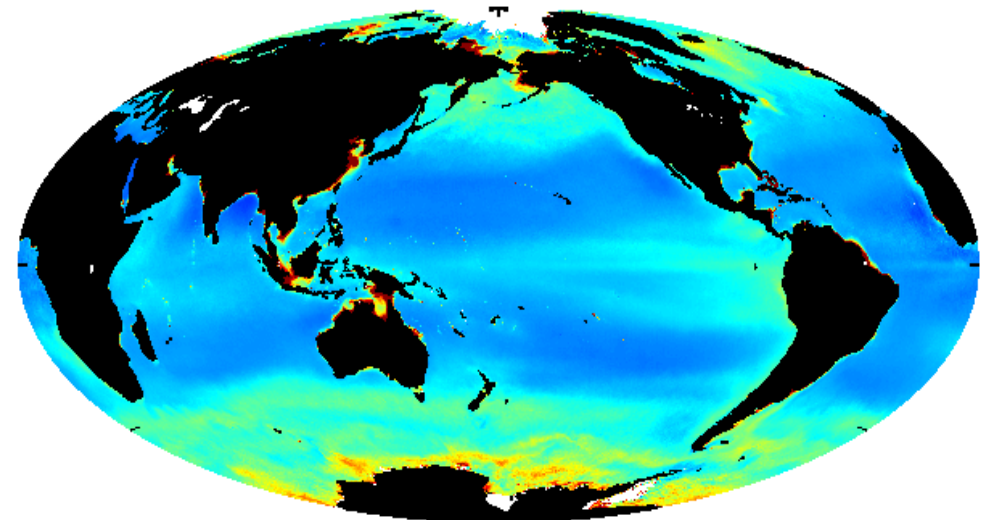


Difference between CALIPSO and MODIS: CALIPSO is more sensitive to changes in phytoplankton particles

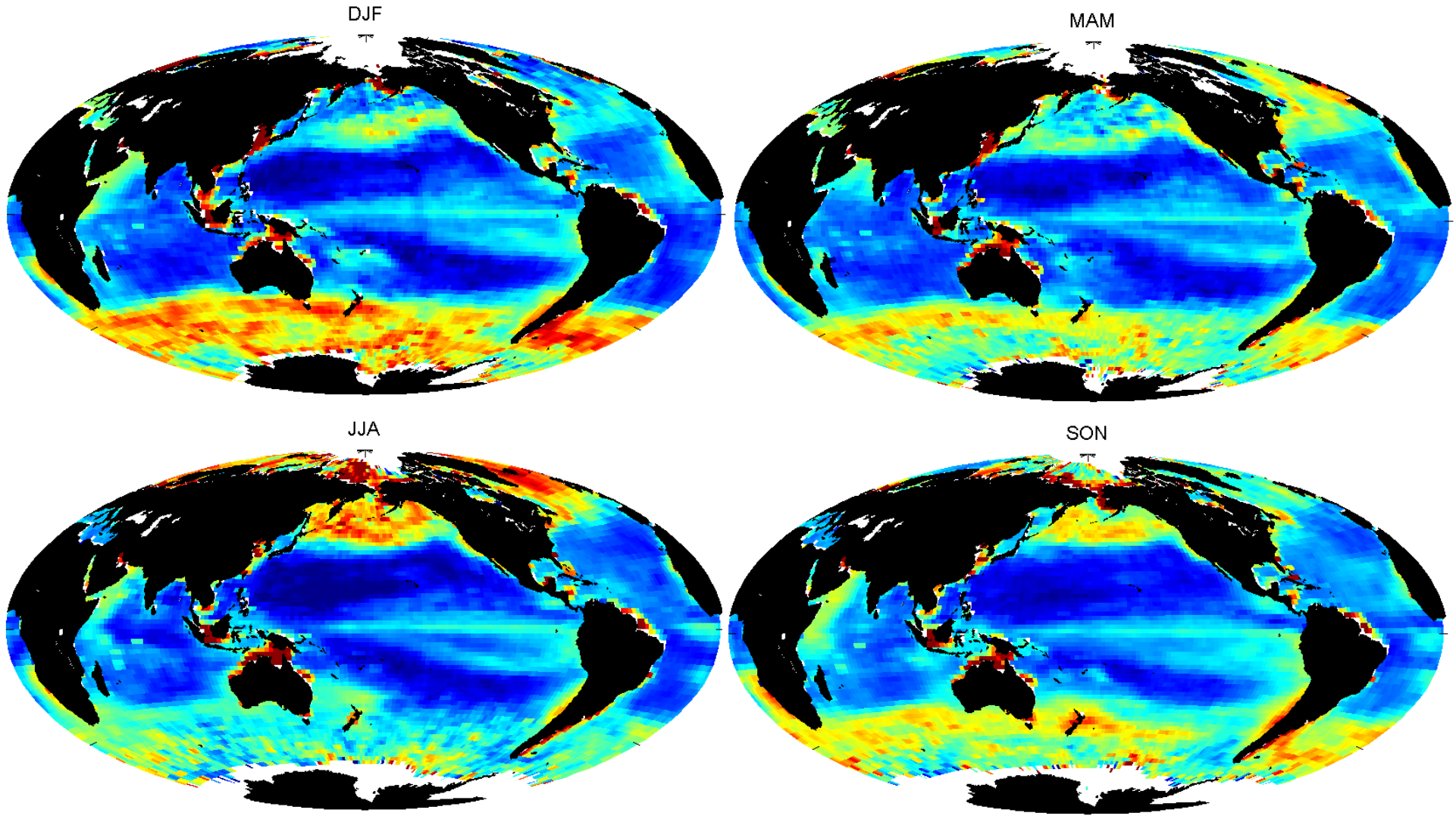
CALIPSO Cross Polarization Backscatter (Sr^{-1})



MODIS 531 $R_{rs} - bb_w / [2 * 2\pi * m_w^2 K_d] (\text{Sr}^{-1})$



Seasonal Variations of CALIPSO Ocean Cross Polarization Measurements of Phytoplankton Backscatter



CALIPSO Ocean Subsurface Backscatter: accurately calibrated using Ocean Surface Wind

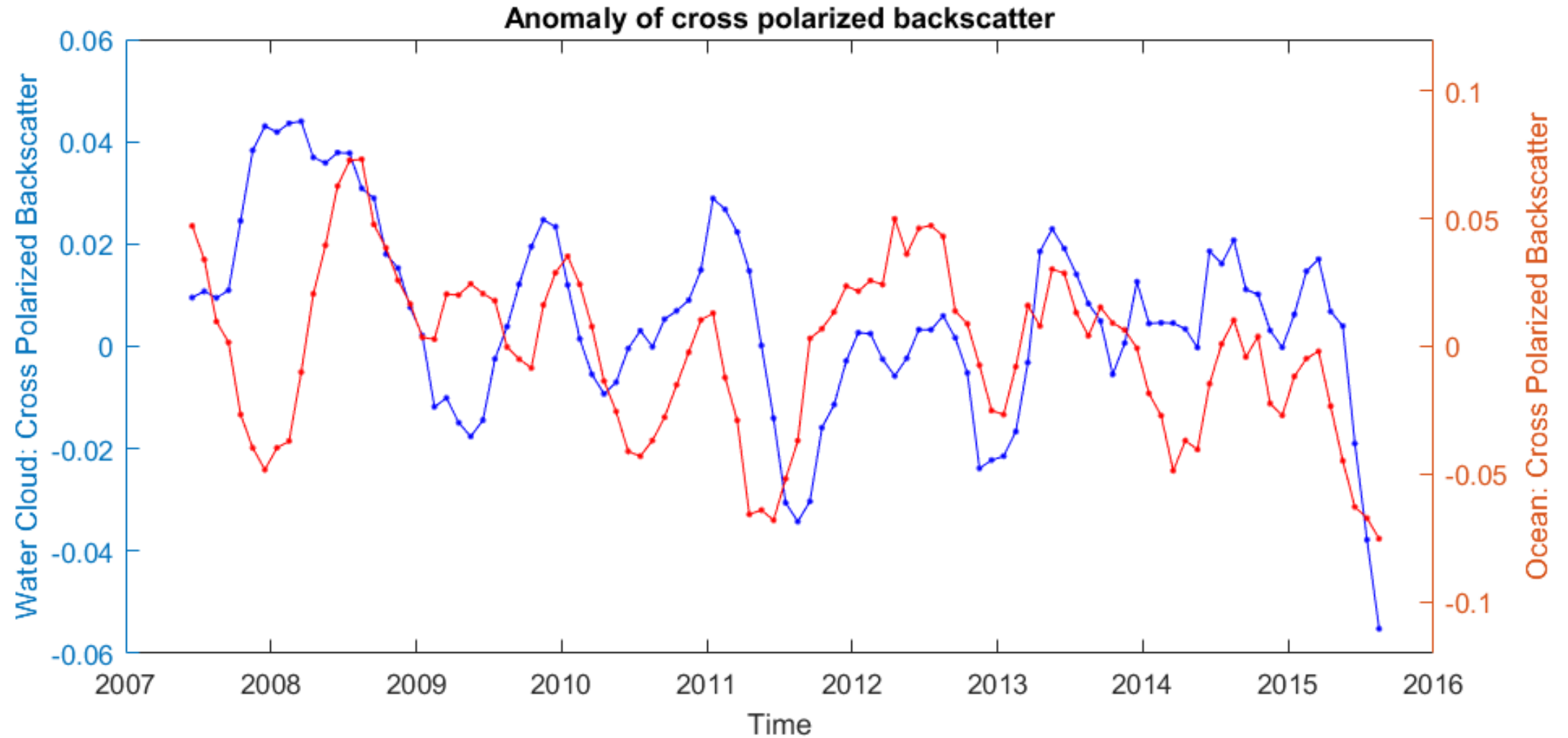
$$\beta_{sub} = \beta_{surf} \frac{\beta'_{sub}}{\beta'_{surf}}$$

- β_{sub} : calibrated cross polarization component of **CALIPSO ocean subsurface backscatter** coefficient
- β'_{sub} : uncalibrated cross polarization column integrated ocean subsurface backscatter **signal**
- β'_{surf} : uncalibrated ocean surface backscatter **signal**
- β_{surf} : **theoretical** ocean surface backscatter cross section $c/(0.003+0.00512*Wind)$

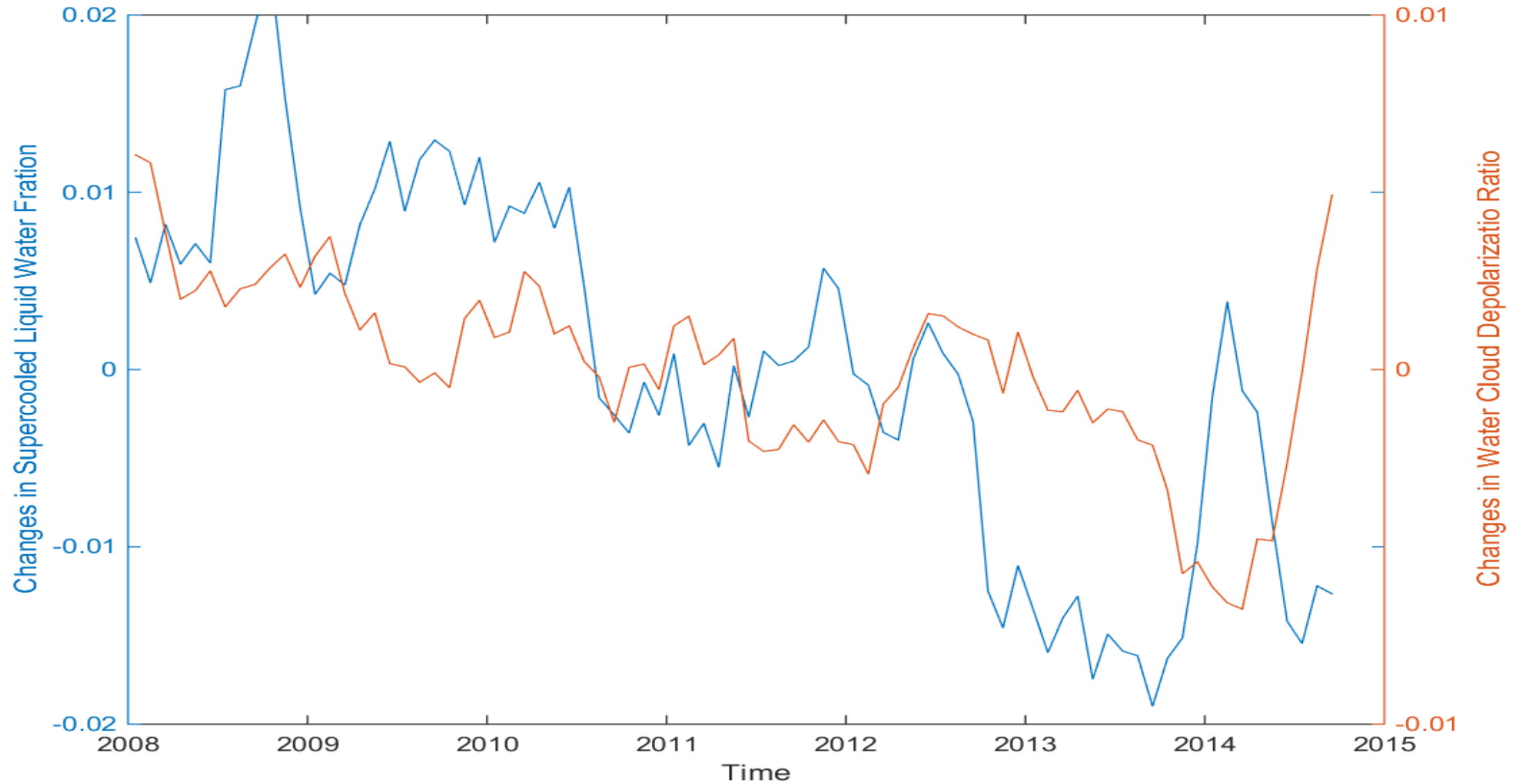
Climate change signal in CALIPSO

- Correlation of phytoplankton biomass and water clouds in the Southern Ocean
- Reduction in supercooled liquid water cloud fraction and thinner clouds in the Arctic

Anomaly of Phytoplankton Backscatter and Water Cloud Droplet Number Density: Southern Oceans



Trends in Arctic water cloud observation: decreasing depolarization ratio and cloud fraction



Anomaly of Tropical Phytoplankton Backscatter and Tropical Water Clouds: no clear relation



Summary

CALIPSO provide a unique 11 year active remote sensing climate record of clouds/phytoplankton backscatter and their vertical distribution. Here are what we find using the data:

- Central/western pacific cirrus cloud fraction (and height, to a less degree) is highly anti-correlated with ENSO index.
- Over the whole tropics, cirrus cloud height (and fraction, to a less degree) is strongly anti-correlates with 70 mb QBO index
- Arctic water clouds: reduction in cloud fraction and depolarization
- Cross polarization backscatter measurements suggest good correlation between water clouds and phytoplankton in the Southern Ocean region