High Resolution Sea Surface Roughness and Wind Speed with Space Lidar (CALIPSO)

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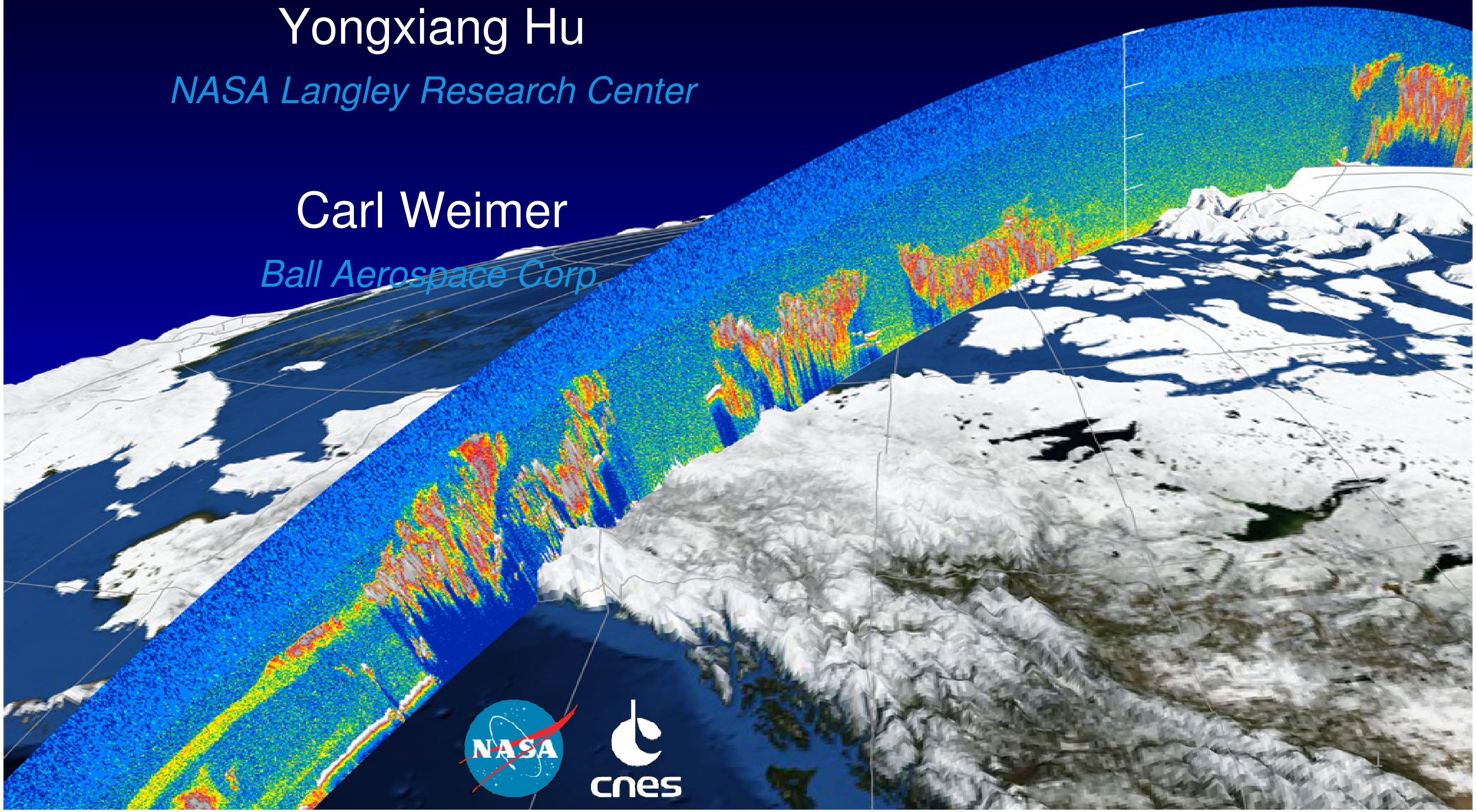


CALIPSO Mission Overview

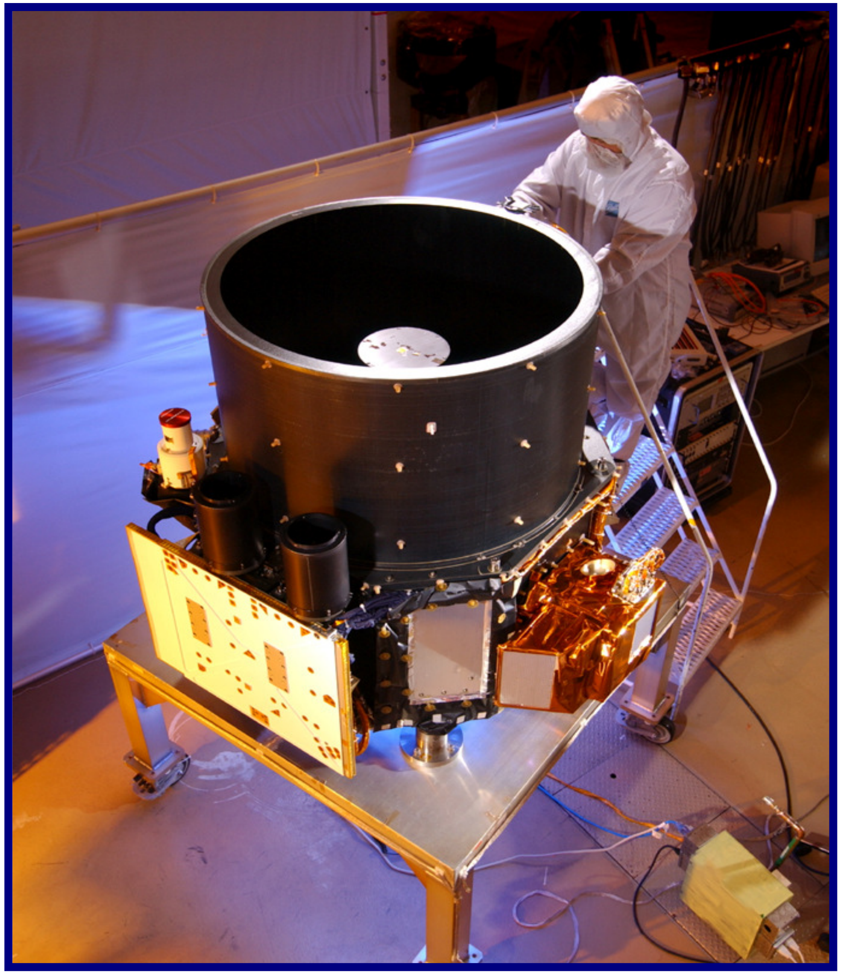
CALIPSO seeks to improve our understanding of the effects of aerosol and clouds on Earth's climate

Launched: April 28, 2006

Operational Achievements:

- Collected > 1.9 billion laser shots
- Observations during day/night and for all seasons
- Data publicly available

CALIPSO Lidar

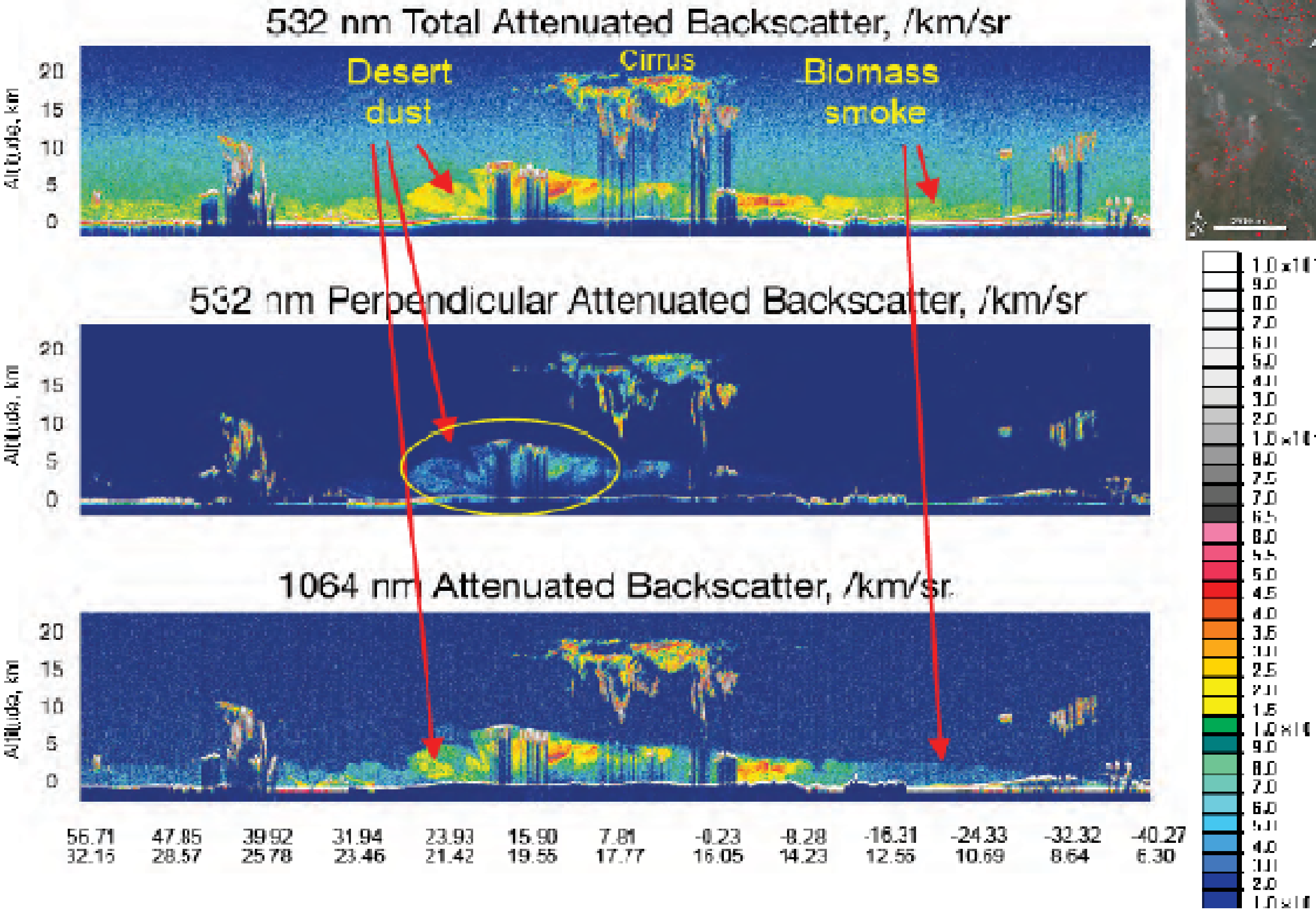


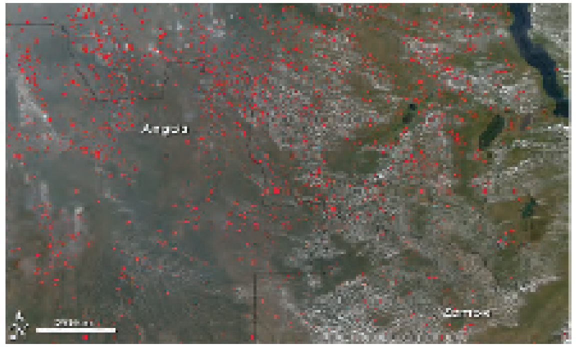
Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP)

- **Surface Laser Spot Size: 70 m**
- **Vertical profiles of atmosphere**
- **2 wavelength polarization sensitive lidar: 1064 nm, 532 nm (parallel and perpendicular)**

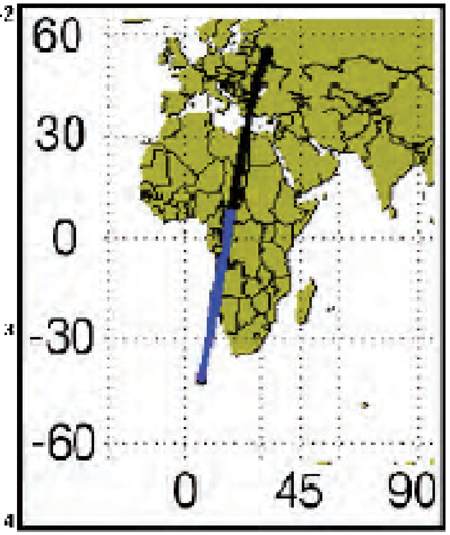
CALIPSO First Light Observations

June 9, 2006

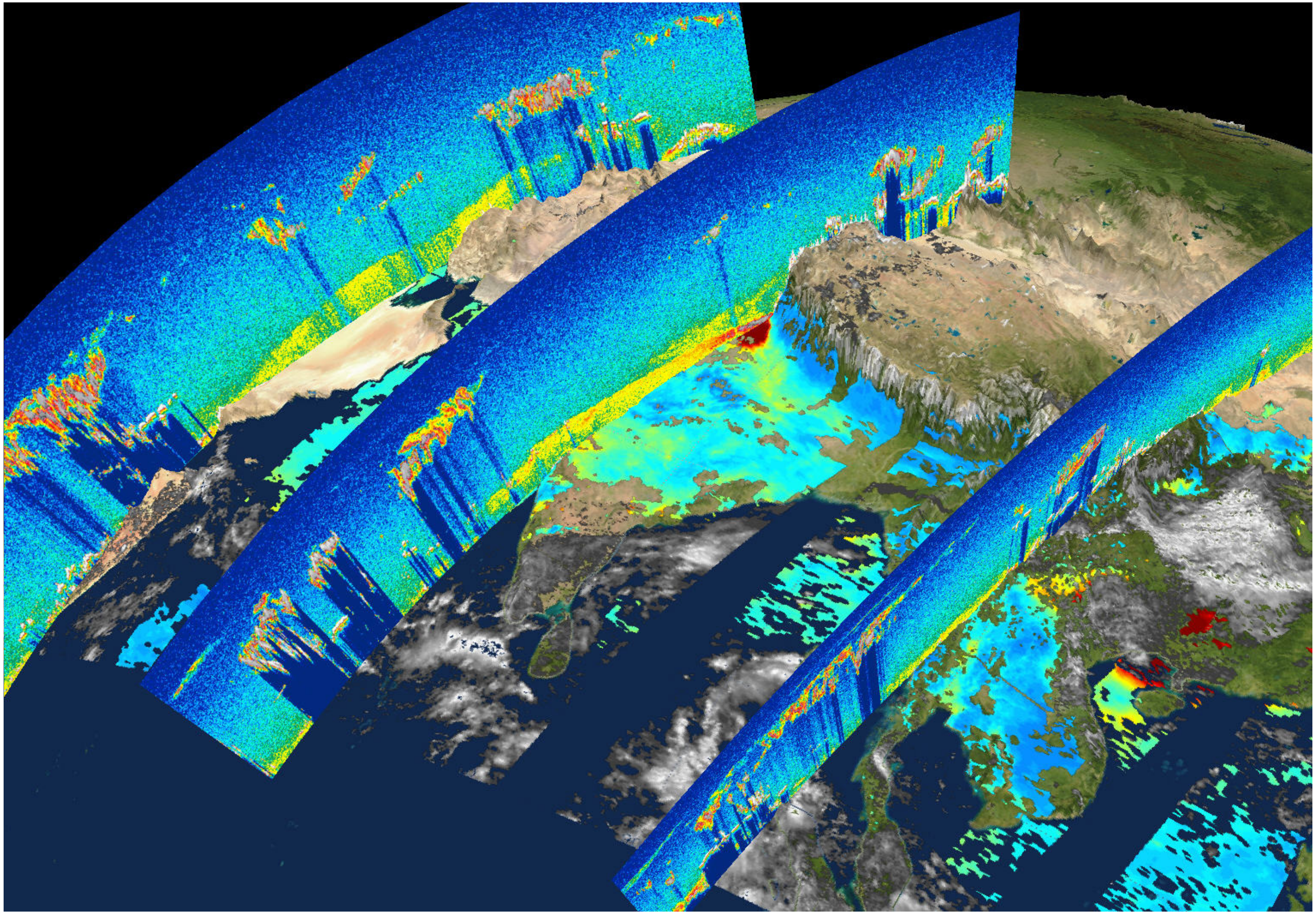




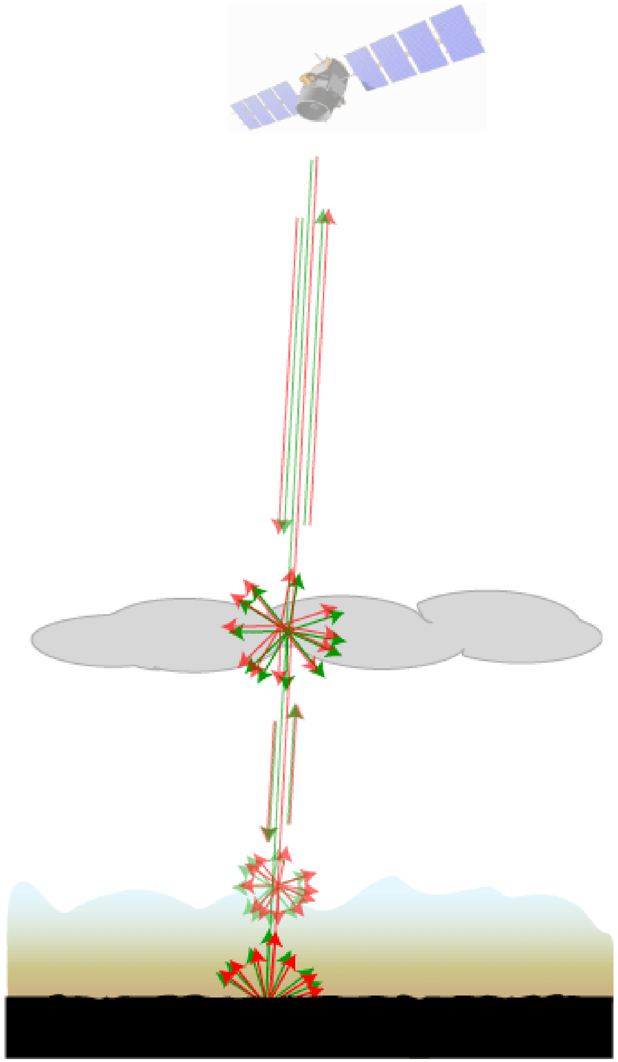
Fire locations in southern Africa from MODIS, 6/10/06

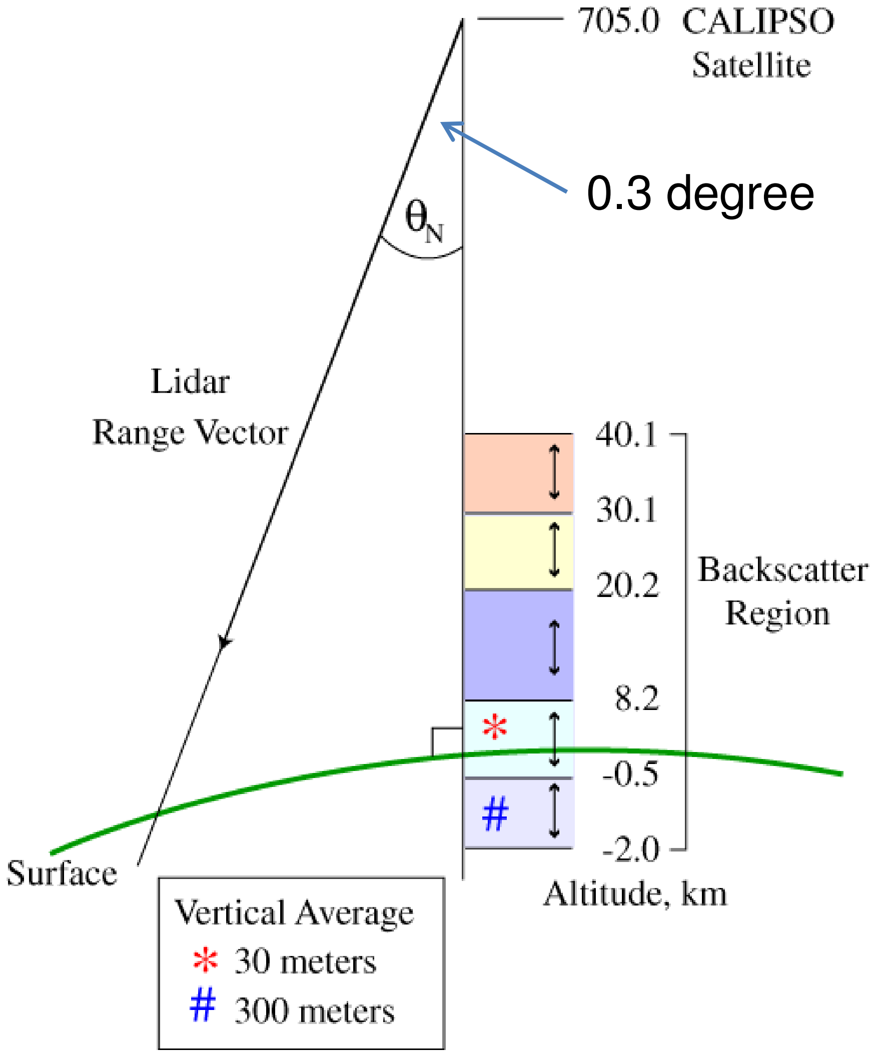


CALIPSO Adds the Vertical Dimension



Vertical Profiling of atmosphere, ocean surface and ocean sub-surface





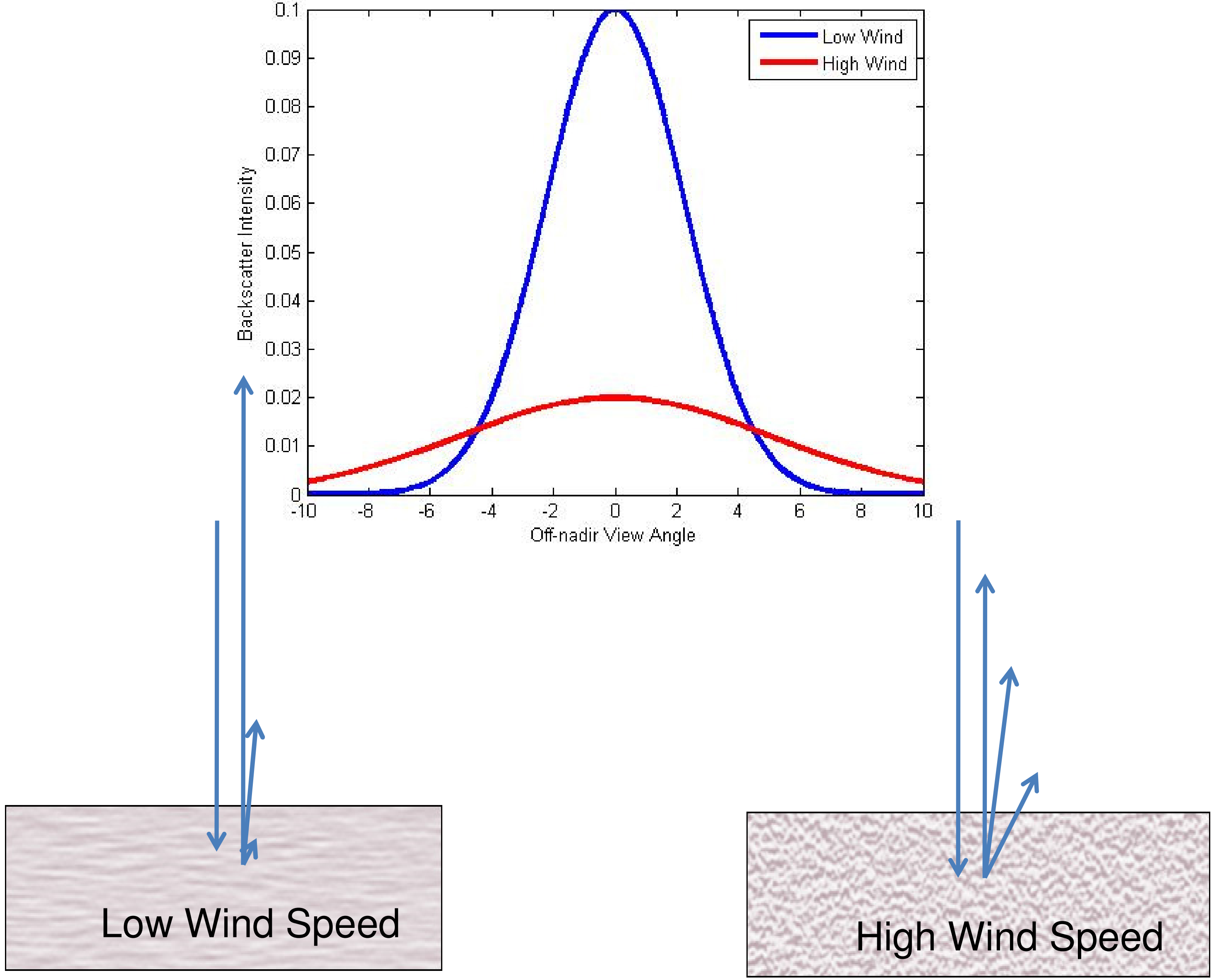
Sea surface wind speed from CALIPSO: Introduction

- The signal: ocean surface lidar backscatter signal from specular reflection

- The physics:

  higher wind → rougher surface → lower backscatter

  (nadir pointing laser; 2% sea surface reflection at 1064nm wavelength; higher probability of laser beam normal to sea surface at lower wind speed, thus more chance of specular return back to the lidar system)

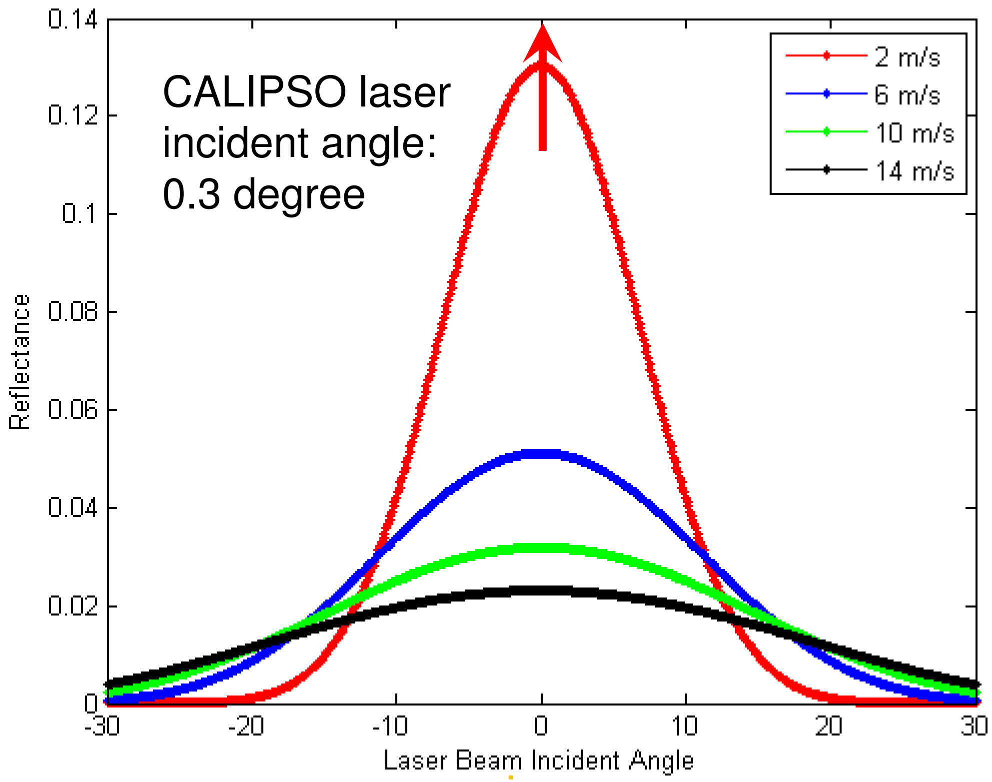

Low Wind
High Wind
Backscatter Intensity
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
-10
-8
-6
-4
-2
0
2
4
6
8
10
Off-nadir View Angle
Low Wind Speed
High Wind Speed

near surface wind speed from CALIPSO lidar backscatter

Sea surface lidar backscatter (after a few corrections) = c / [$<s^2>$]

Linear relation between wind speed and wave slope variance [$<s^2>$] (Cox-Munk):

Lidar backscatter = c/(a+b*wind)



$$P(s)ds = \frac{c}{< s^2 >} e^{-\frac{s^2}{2< s^2 >}} ds^2$$

$$< s^2 >= a * Wind + b;$$

CALIPSO high resolution wind speed and what it is for

What's new about CALIPSO sea surface wind speed:

Global statistics of high resolution wind (70 meter)

(Hu et al. 2008, ACP, p3593-3601)

Application: Improvement of air-sea turbulence exchange

CO_2 Uptake = turbulence transport * solubility * $\Delta(PCO_2)$

= f(V^n) * solubility * $\Delta(Pco_2)$

n: 1-3 (e.g., Liss & Merlivat, 86; Wanninkhof, 92, 99; Nightingale, 00)

While the mean value statistics of V for CALIPSO (70m) and AMSR-E (21km) are nearly the same, the mean value of V^3 from CALIPSO is about 30% higher than AMSR-E

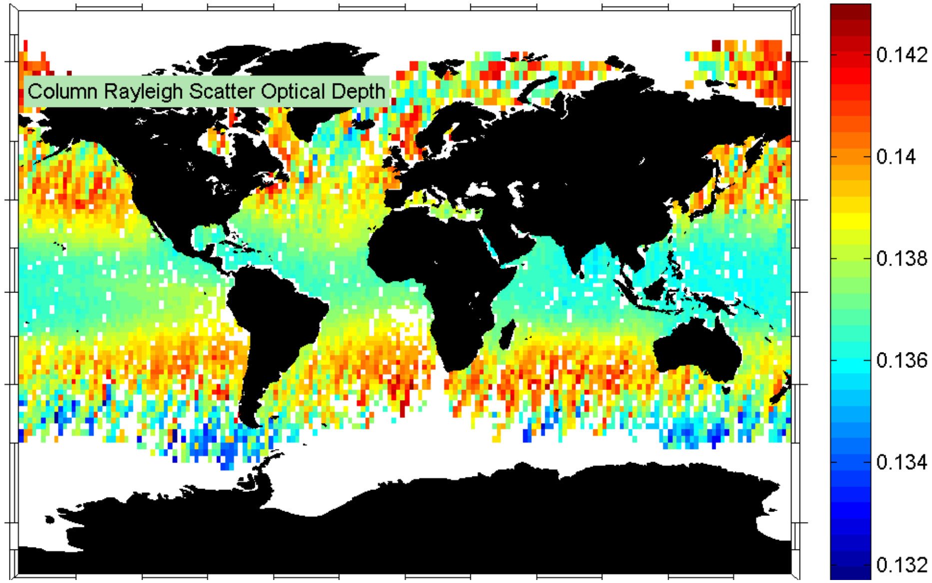
Estimating wind speed from CALIPSO: procedures

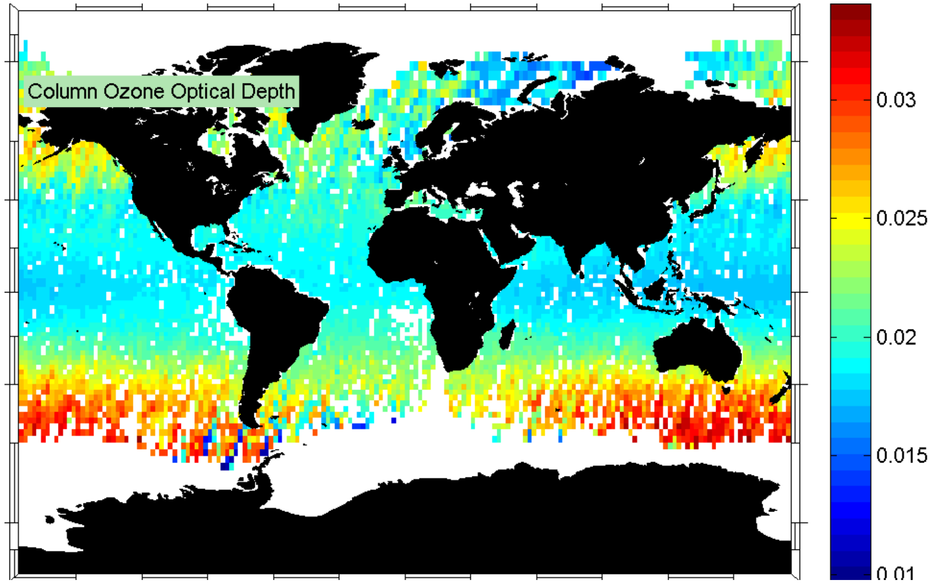
- Calibrating backscatter intensity
- Correcting for atmospheric two-way transmittance
- Correcting for backscatter from bubbles, water and particulates in water
- Estimating mean square wave slope =

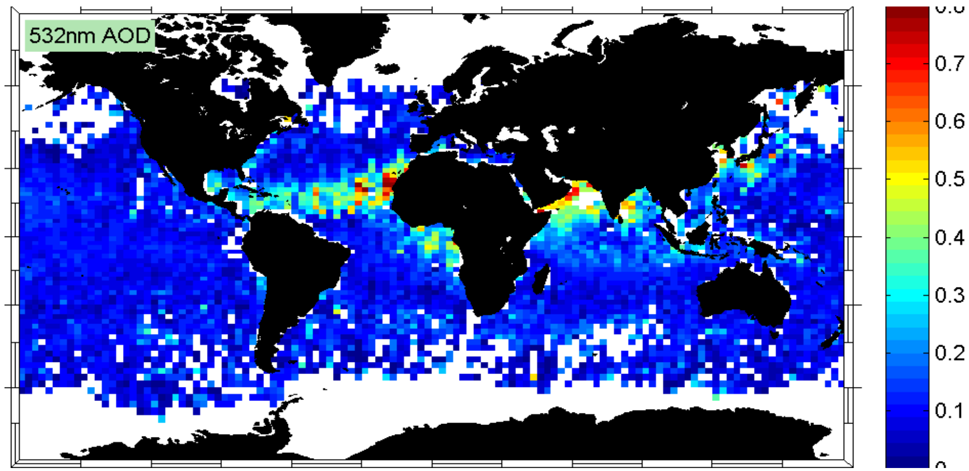
$$0.02 / [4\pi \text{ corrected sea surface lidar backscatter}]$$

Then we can estimate wind speed from the

Estimating wave slope variance from CALIPSO: Correction for atmospheric attenuation (molecular scatter, absorption and aerosol/cloud scattering)





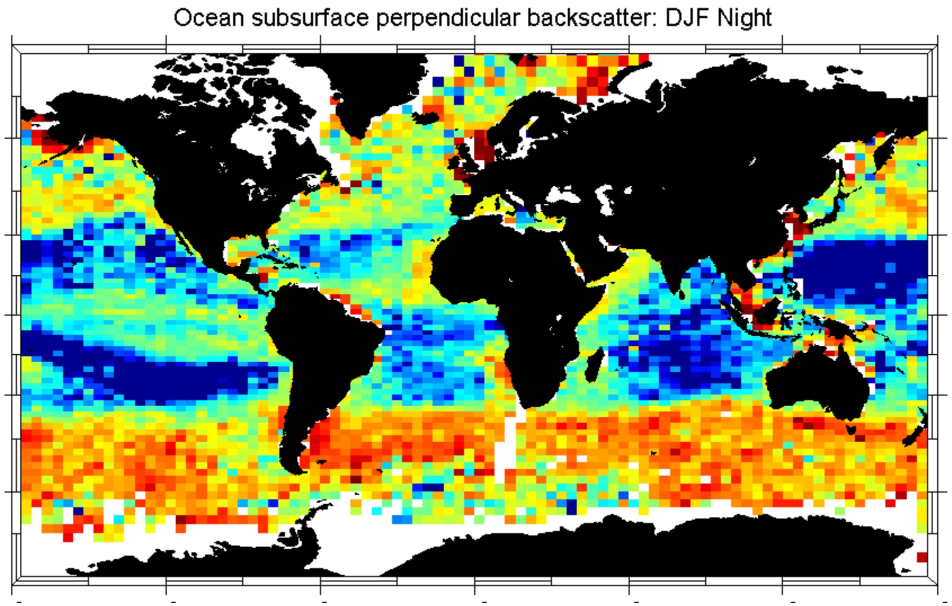


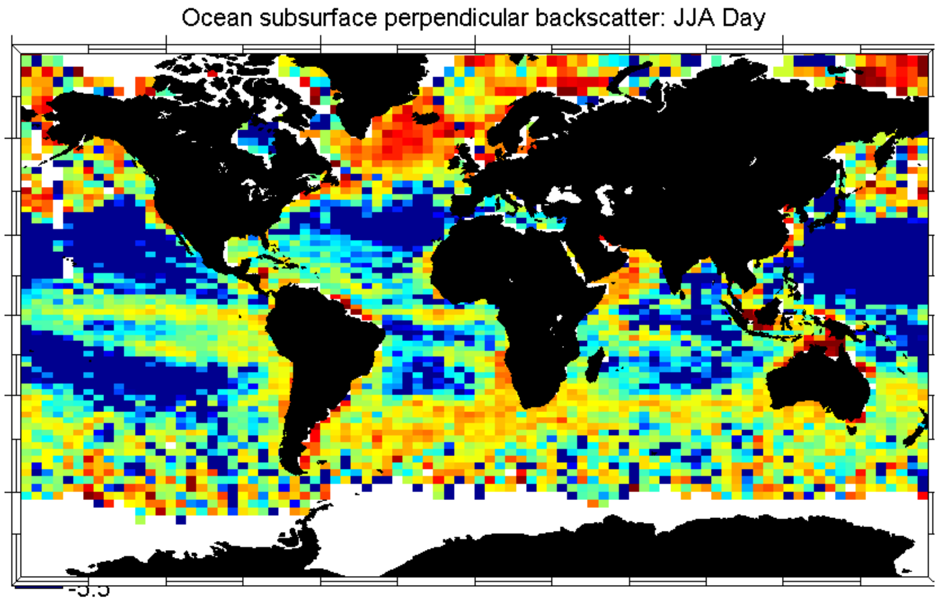
Estimating wave slope variance from CALIPSO: Correction for other backscatter (in water particulates and Rayleigh, and Bubbles)

Difference between specular reflection from waves vs other backscatter: backscatter from waves does not change state of polarization (cross-polarization backscatter = 0)

A simple algorithm (Hu et al., 2008):

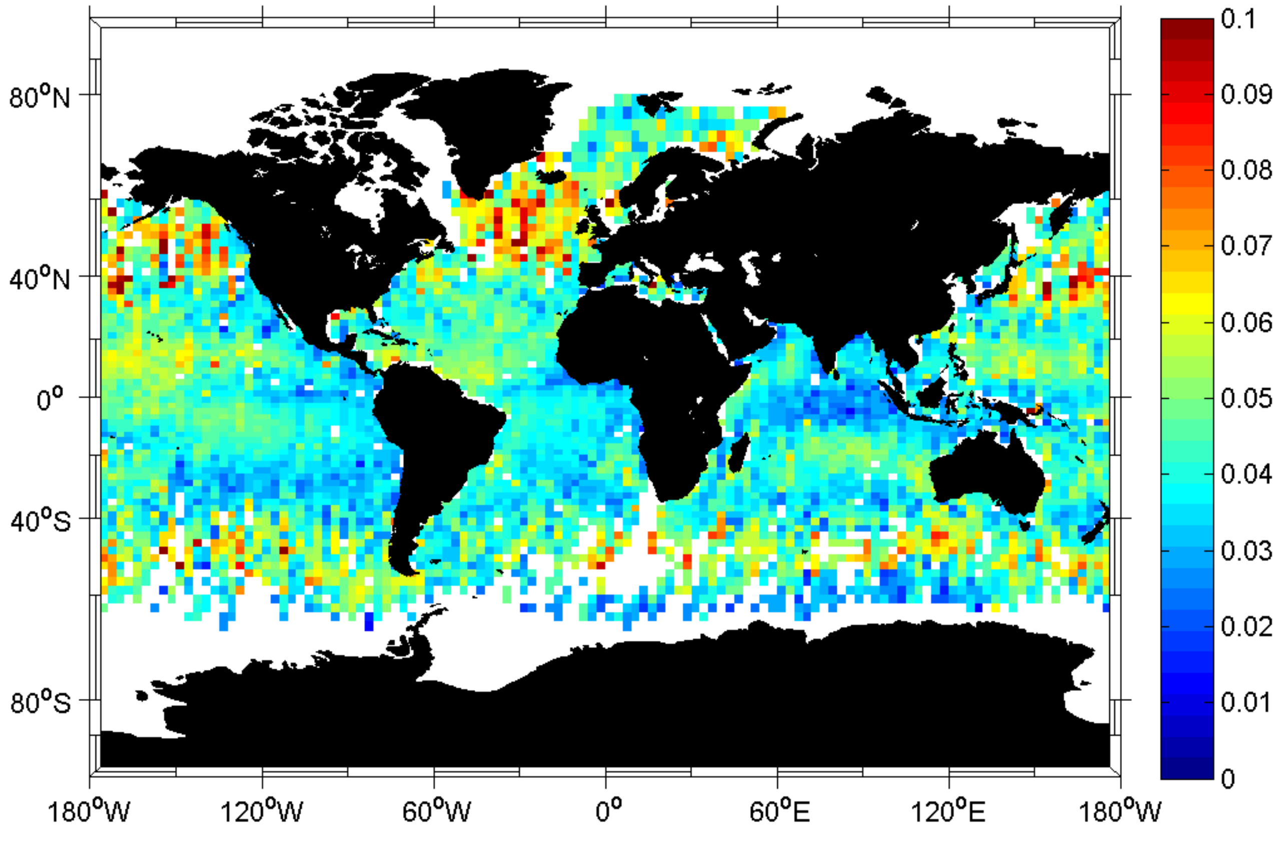
other backscatter = cross-polarization / 0.15





Wave Slope Variance from CALIPSO

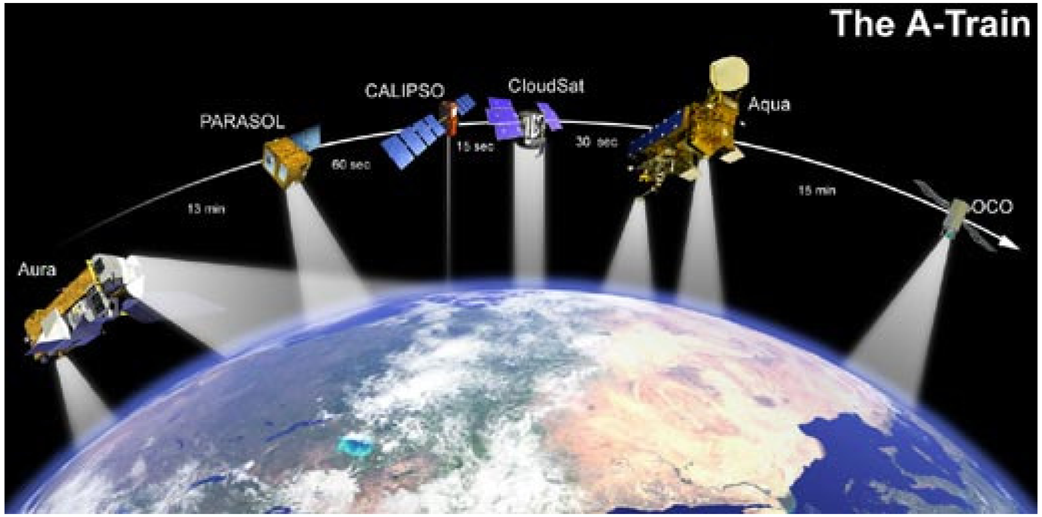
Wave slope variance = 0.02 / [4π * sea surface lidar backscatter]



Studying wave slope variance – wind speed relation Using collocated CALIPSO wave slope and AMSR-E wind measurements

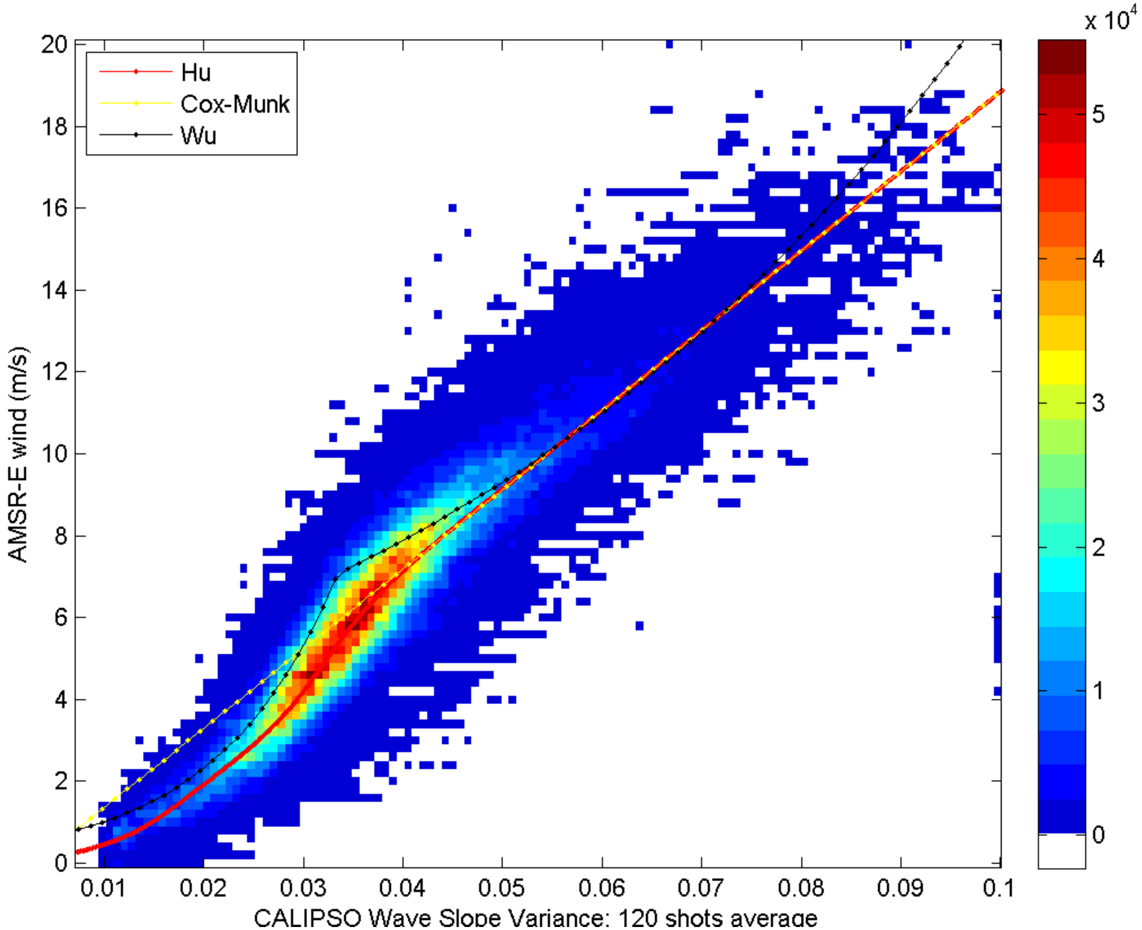
Advanced Microwave Scanning Radiometer - Earth Observing System (AMSR-E) is on Aqua satellite: 75 seconds ahead of CALIPSO

AMSR-E wind speed: derived from AMSR-E instrument (12 microwave channels, 6.92 to 89 GHz), 0.25 X 0.25 degree resolution

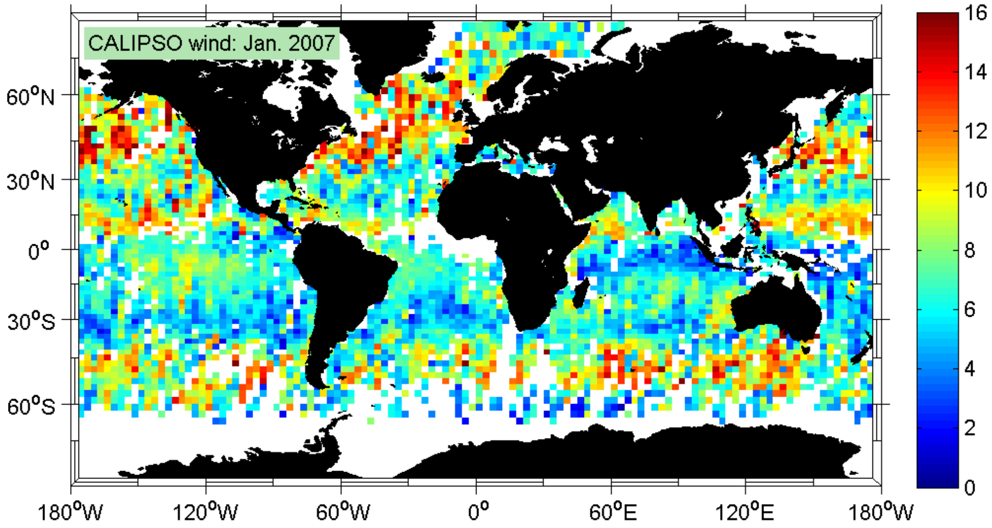


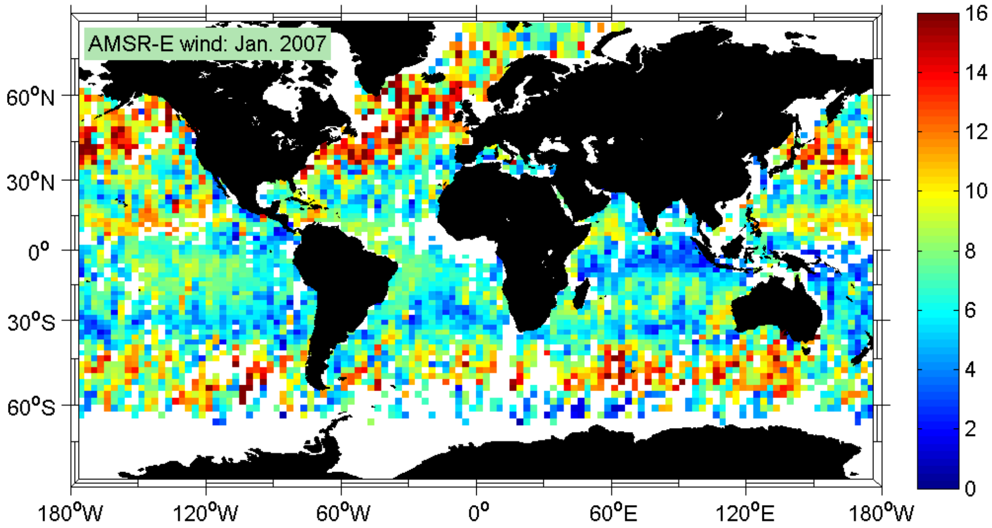
CALIPSO wave slope variance vs AMSR-E wind speed

$$\text{'Wave Slope Variance'} = \begin{cases} a\,V^{0.5} & (V < 7 \text{ m/s}) \\ c\,V + b & (V > 7\text{m/s}) \end{cases}$$

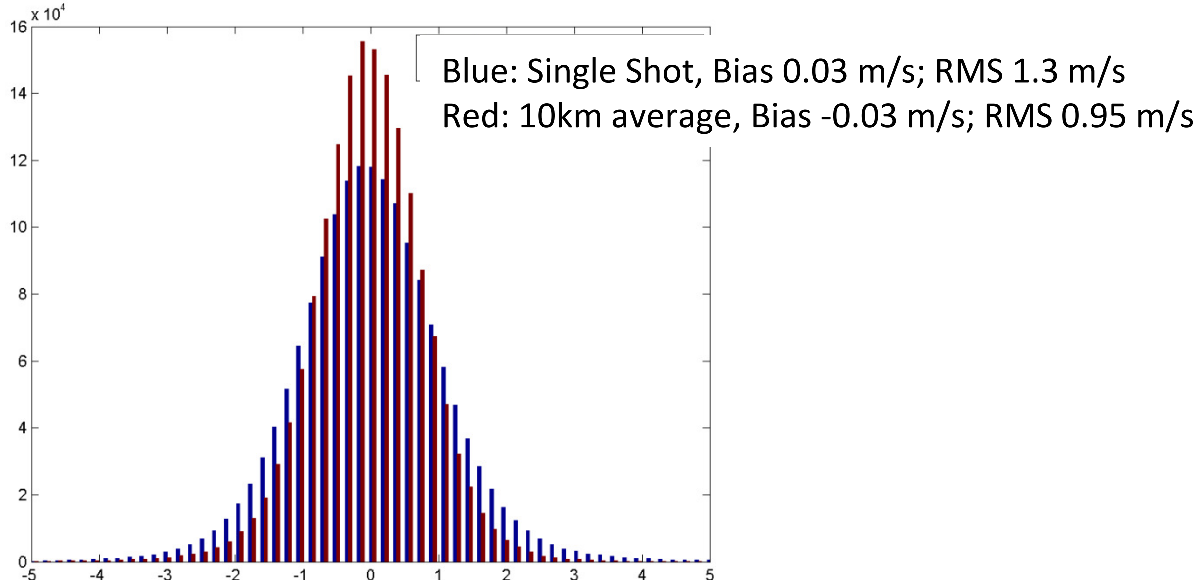


Comparison with CALIPSO wind speed from AMSR-E



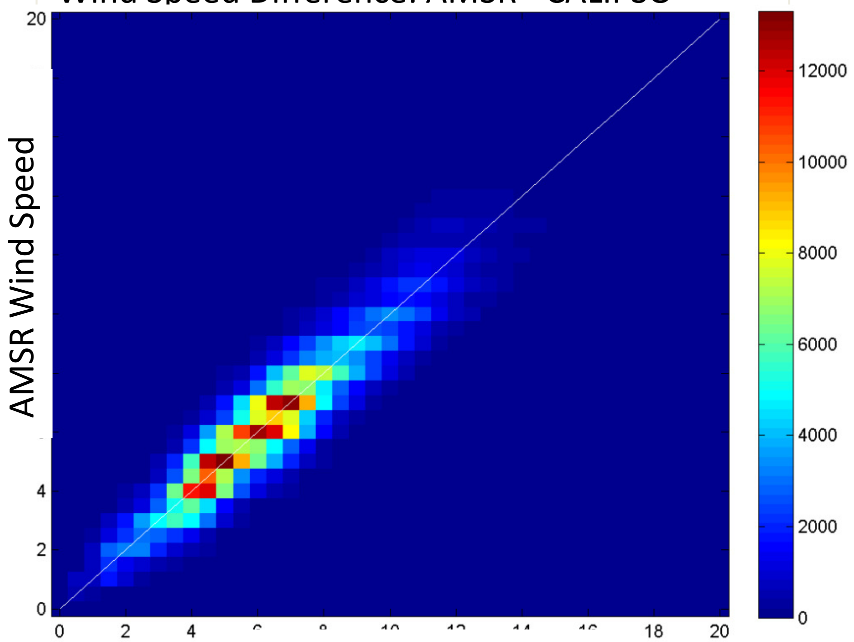


Wind Speed Comparison: CALIPSO vs AMSR-E

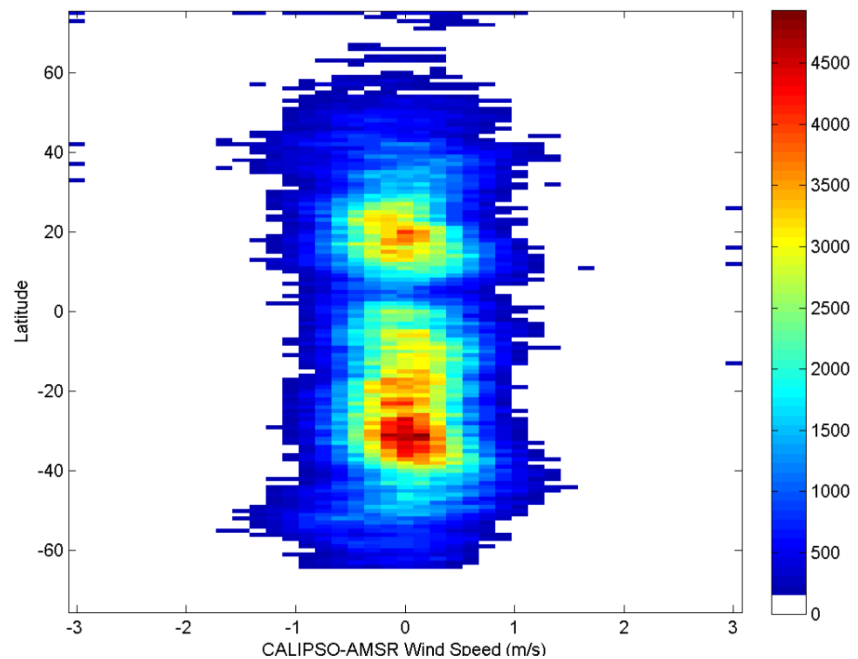


CALIPSO wind Speed – AMSR wind speed

Wind Speed Difference: AMSR - CALIPSO

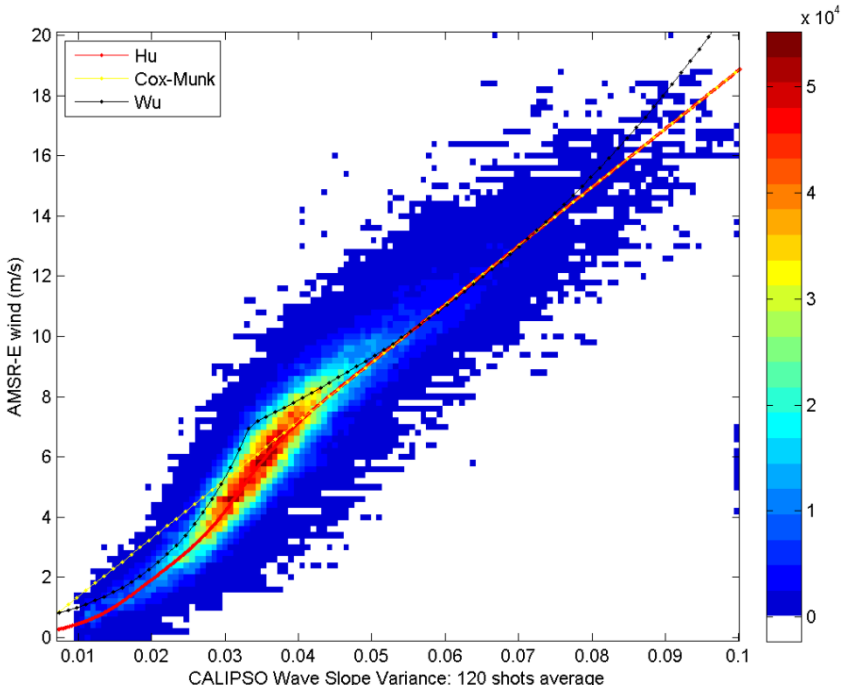


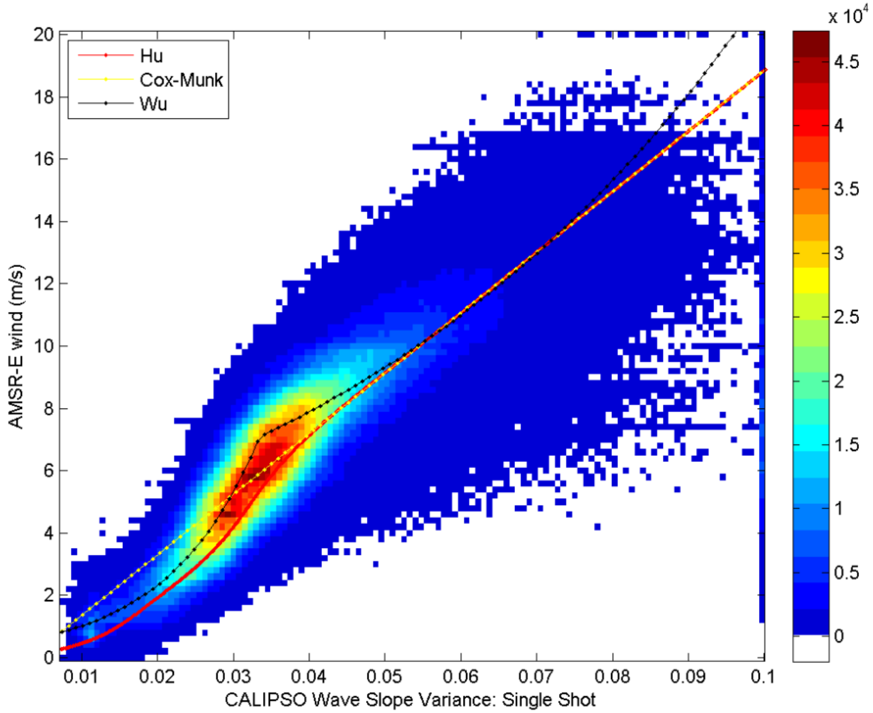
CALIPSO Wind Speed



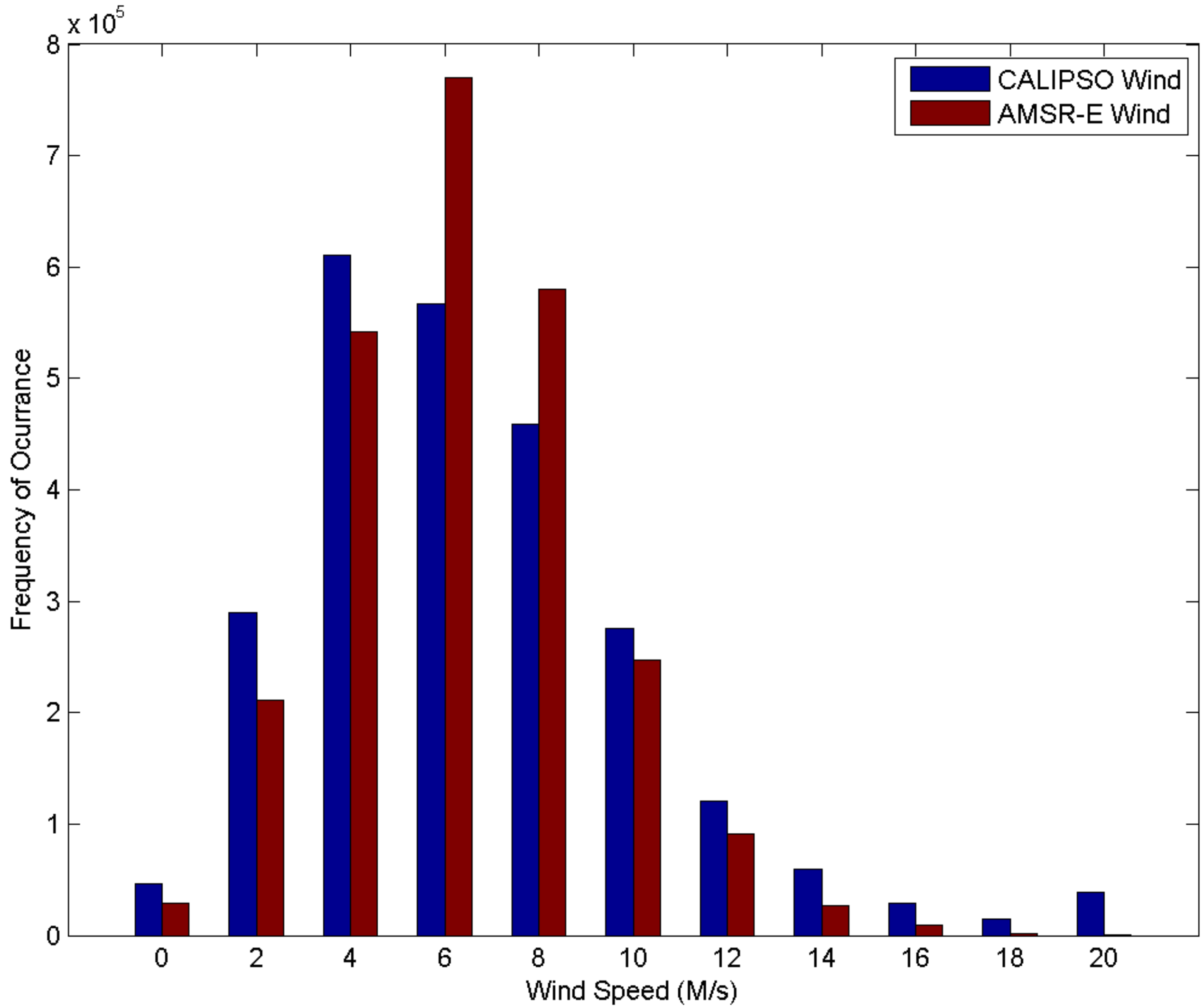
Wind Speed Difference: AMSR - CALIPSO

CALIPSO wave slope variance vs AMSR-E wind speed

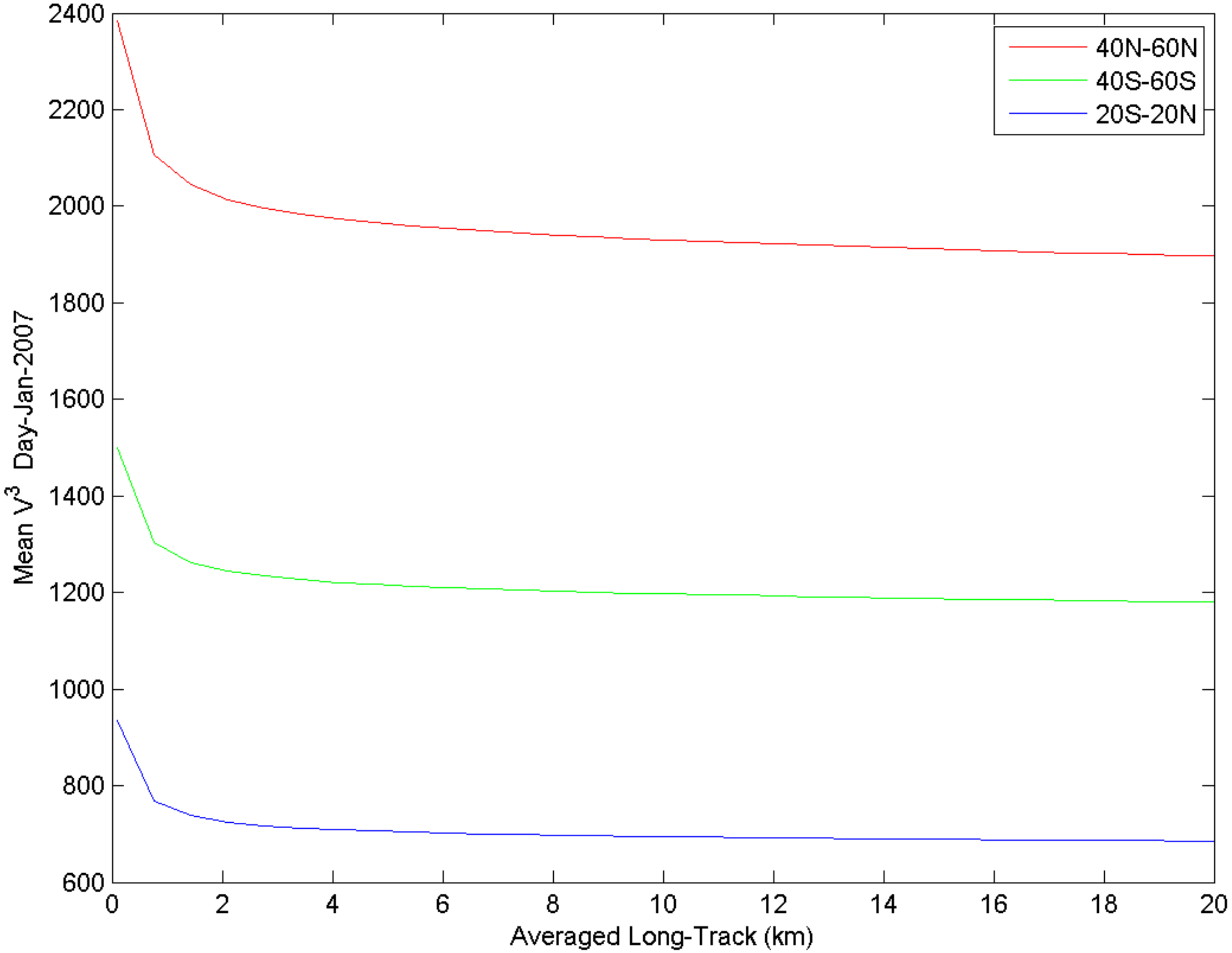




CALIPSO high resolution wind speed:
Broader distribution, equal mean value, larger higher order moments



$\langle V^3 \rangle$ vs wind speed spatial averaging



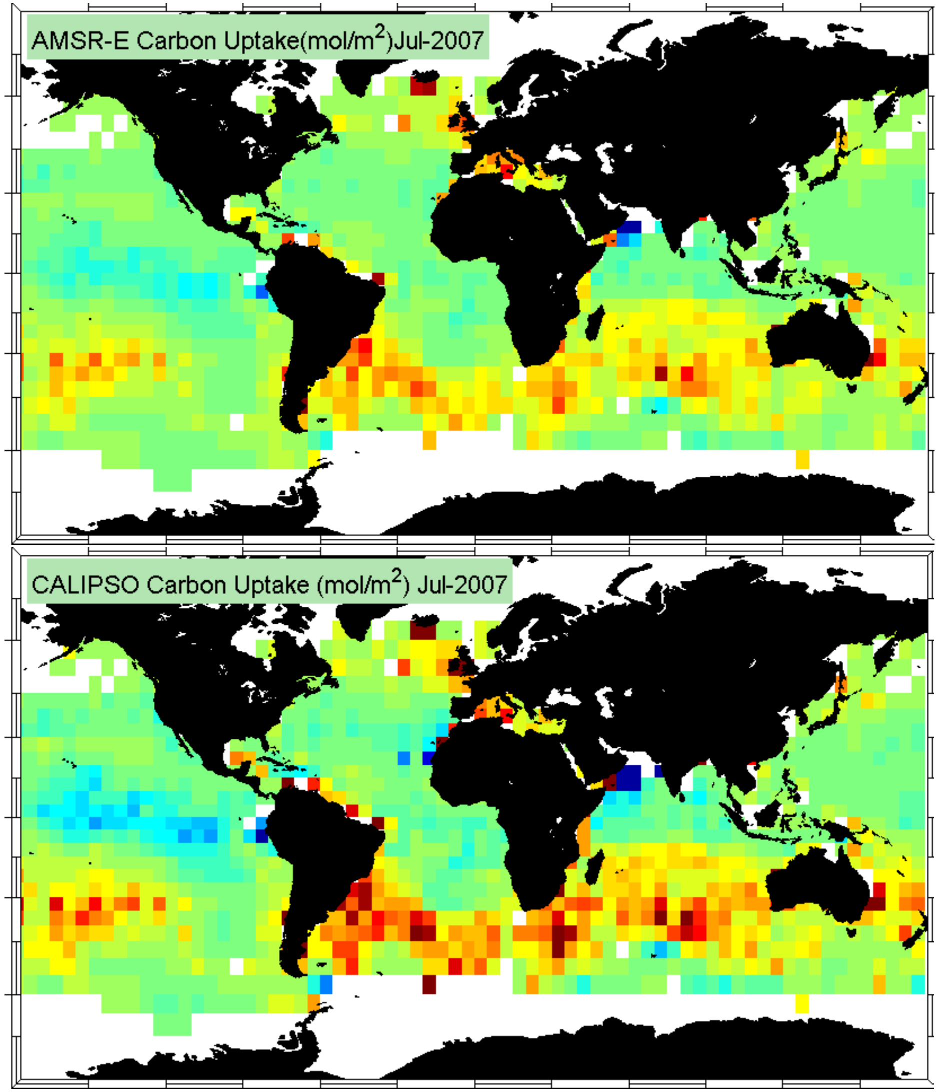
Air-sea Exchange

CO_2 Uptake

= turbulence transport

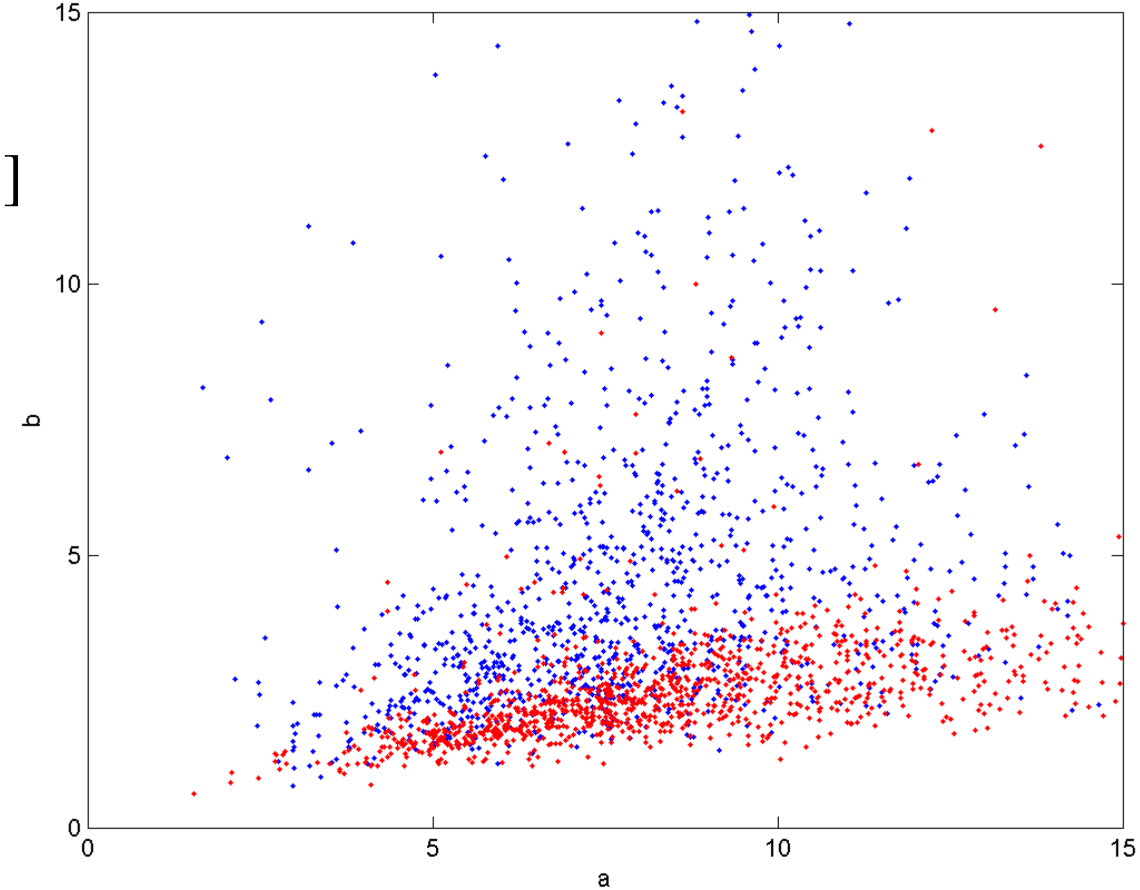
* solubility * $\Delta(PCO_2)$

= f(V^n) * solubility * $\Delta(Pco_2)$



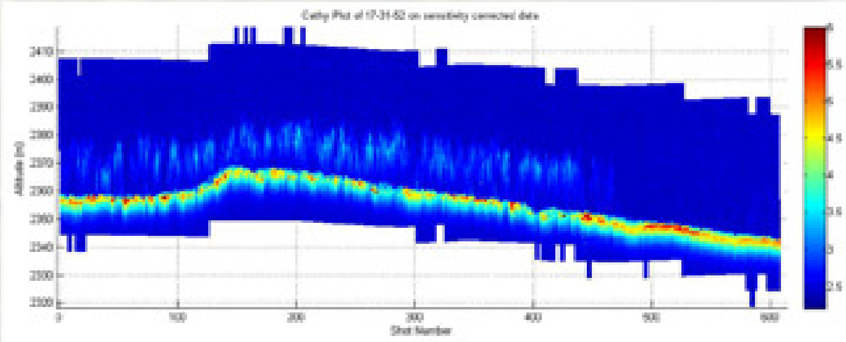
Shape Factor of Weibull Wind Distribution: CALIPSO (red) vs AMSR-E (blue)

$$P(x) = \frac{b}{a}\left(\frac{x}{a}\right)^{b-1} \exp\left[-\left(\frac{x}{a}\right)^{b}\right]$$

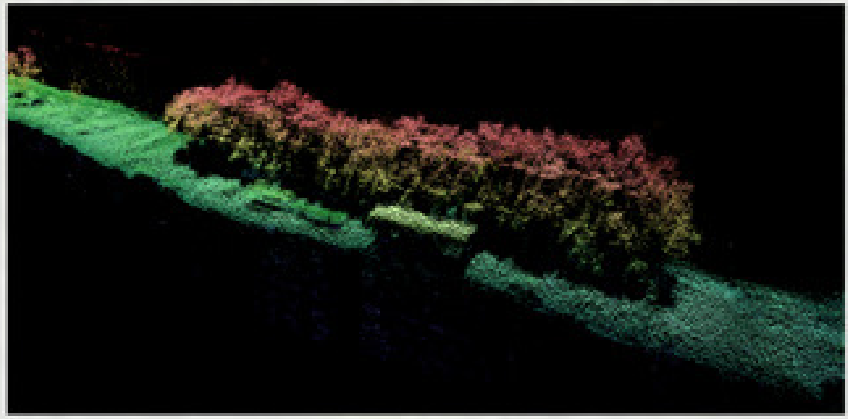


The relation between a and b of Weibull distributions from AMSR-E (blue) and CALIPSO (red). Rayleigh distribution (b=2) is a good approximation for wind speed around 7 m/s when CALIPSO high spatial resolution wind speed is used.

Potential use of flash lidar (3D laser imaging) for AMV?



ESFL data showing tree and ground returns as a 'side view (looking across-track). Data has been summed across-track.



Black camera hits mode data regridding multiple frames into a single uniform grid to show an entire data swath.

Space-based Flash Lidar:

- Ball IIP Instrument (PI: Carl Weimer)
- Flash focal plane, 128X128 pixels
- Lidar images the entire FOV
- Scanning without moving parts

Question:

Is this type of measurements useful for AMV? Can this group provide letter of support?

Look for collaborators for future studies

Email: yongxiang.hu-1@nasa.gov
Phone: 757 864 9824

Summary

- Introduction of retrieving sea surface slope variance and wind speed from space-based lidar

- Lidar on CALIPSO provides the first global wind speed statistics at high spatial resolution (70m along-track), which can be useful for improvement of vertical turbulence exchange

- Three and half years of (June 2006 To Now) experimental CALIPSO wave slope variance and wind speed data will be available (yongxiang.hu-1@nasa.gov, 757-864-9824)

- Looking for collaboration with anyone interested (validation, algorithm improvement, applications, concept studies for future lidar missions…)