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

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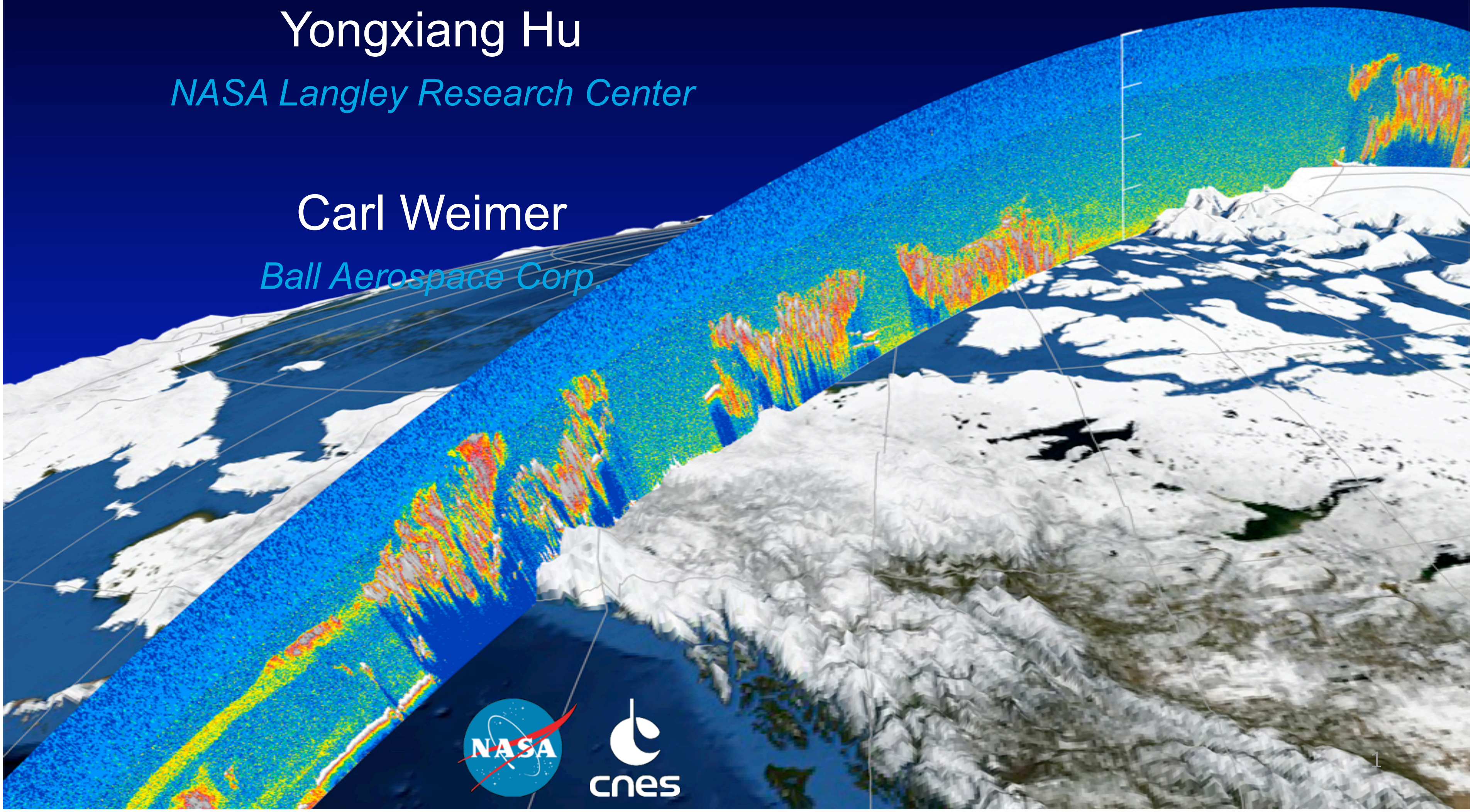


CALIPSO Mission Overview

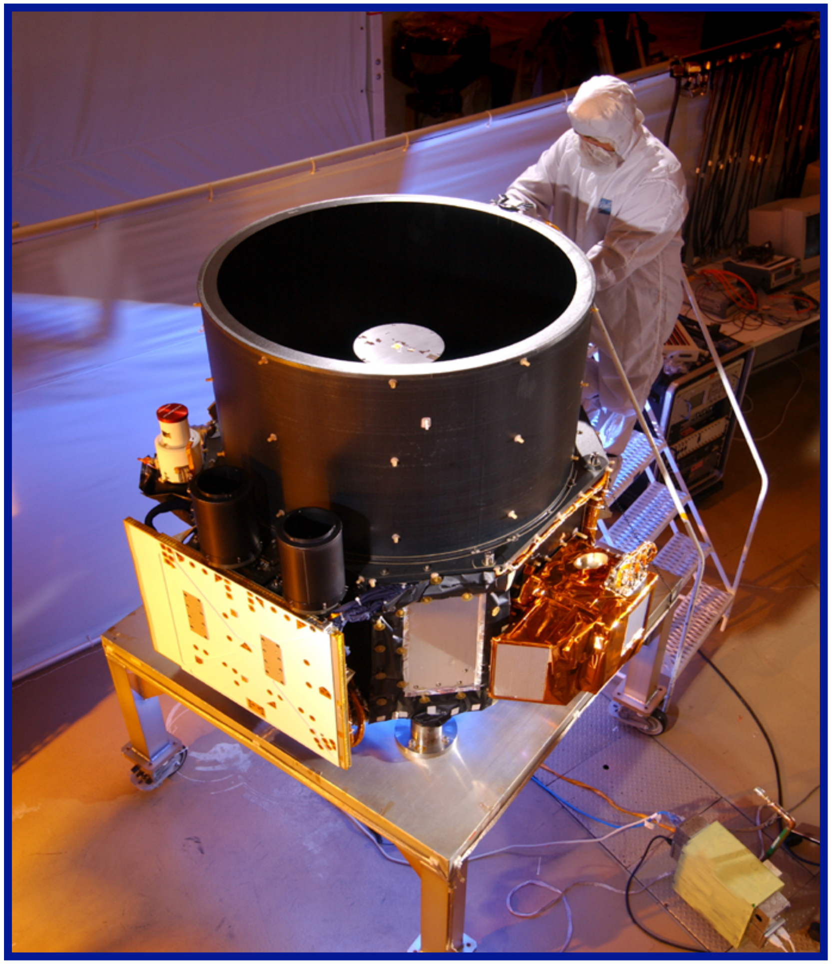
CALIPSO seeks to improve our understanding of the effects of aerosol and clouds on Earth's climate

Launched: April 28, 2006

Operational Achievements:

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

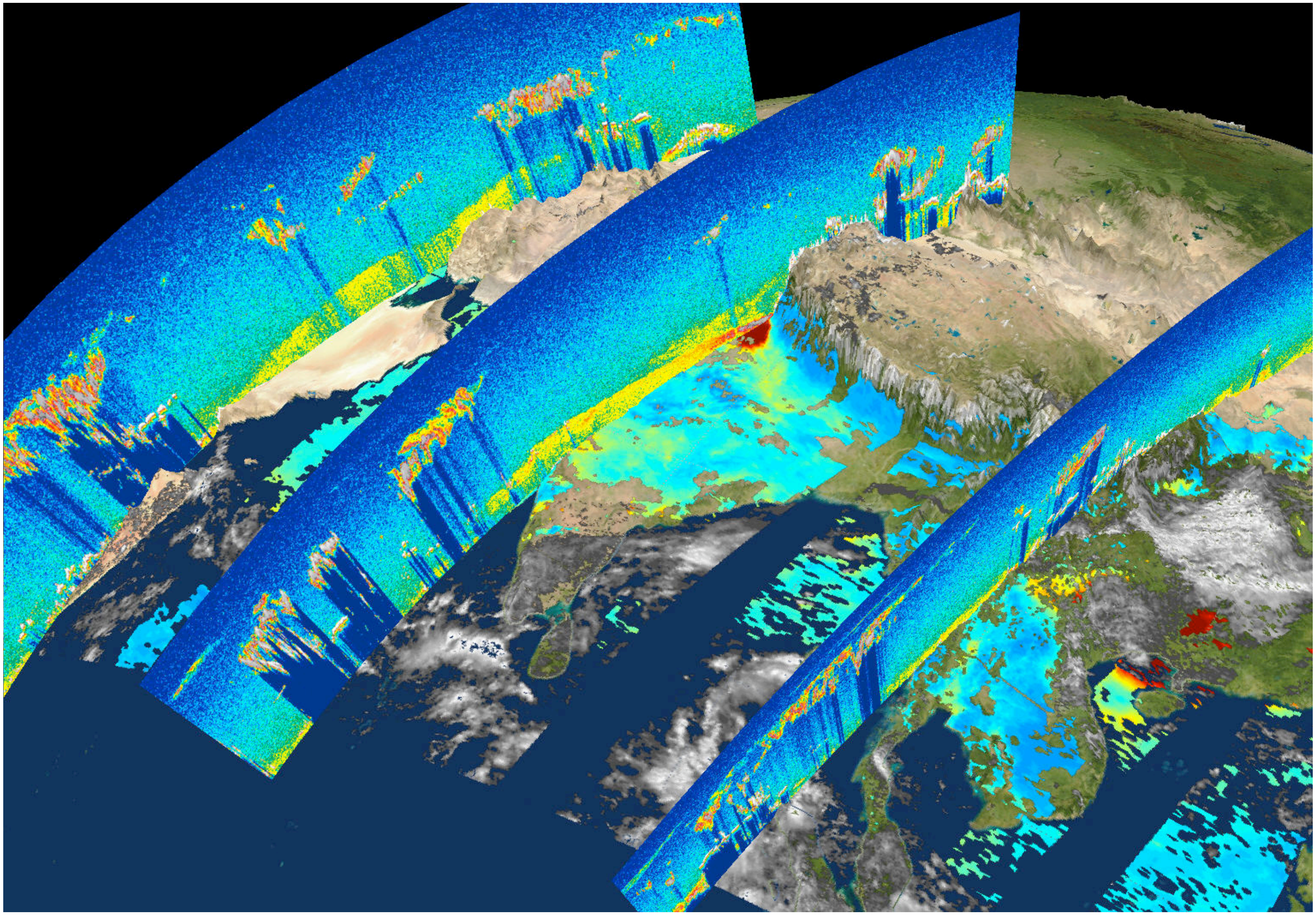
CALIPSO Lidar



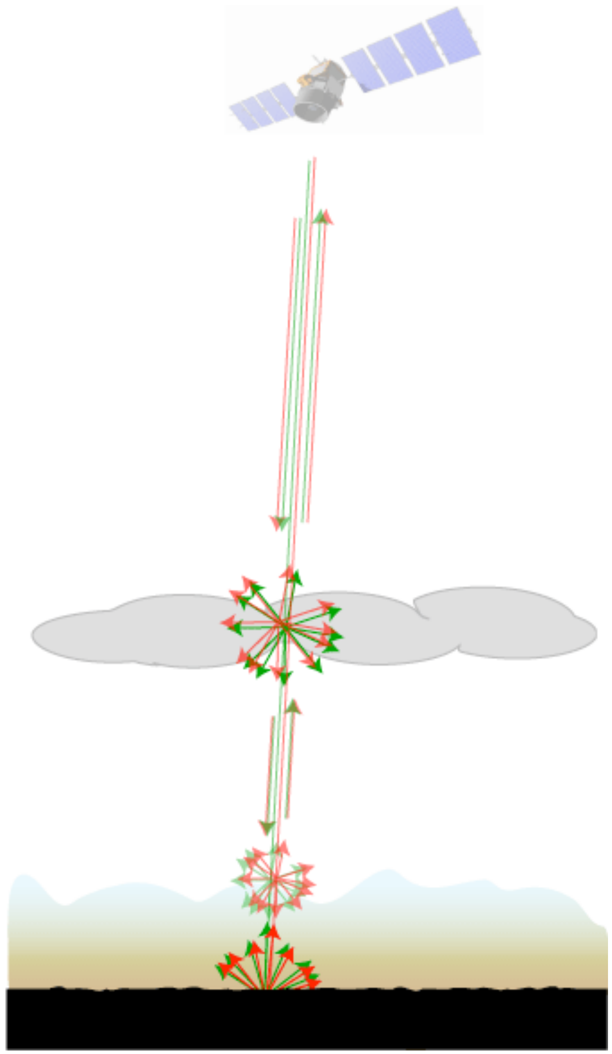
Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP)

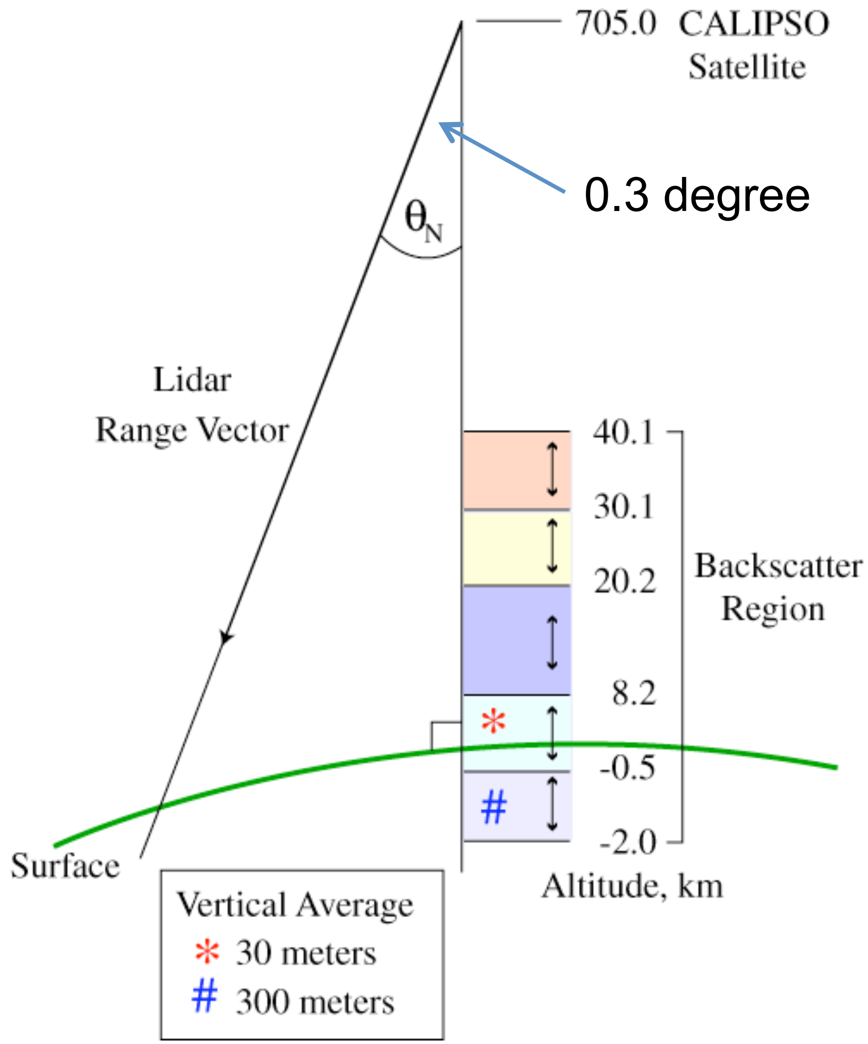
- **Surface Laser Spot Size: 70 m**
- **Vertical profiles of atmosphere**
- **2 wavelength polarization sensitive lidar: 1064 nm, 532 nm (parallel and perpendicular)**

CALIPSO Adds the Vertical Dimension



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





Lidar Backscatter Measurements of Ocean Surface: What can it do

1. Direct measurements of mean surface roughness (transfer velocity estimates not sensitive to surfactants, fetch, …)

2. High spatial resolution (70 m) wind speed

3. Unambiguous separation of liquid / solid surface

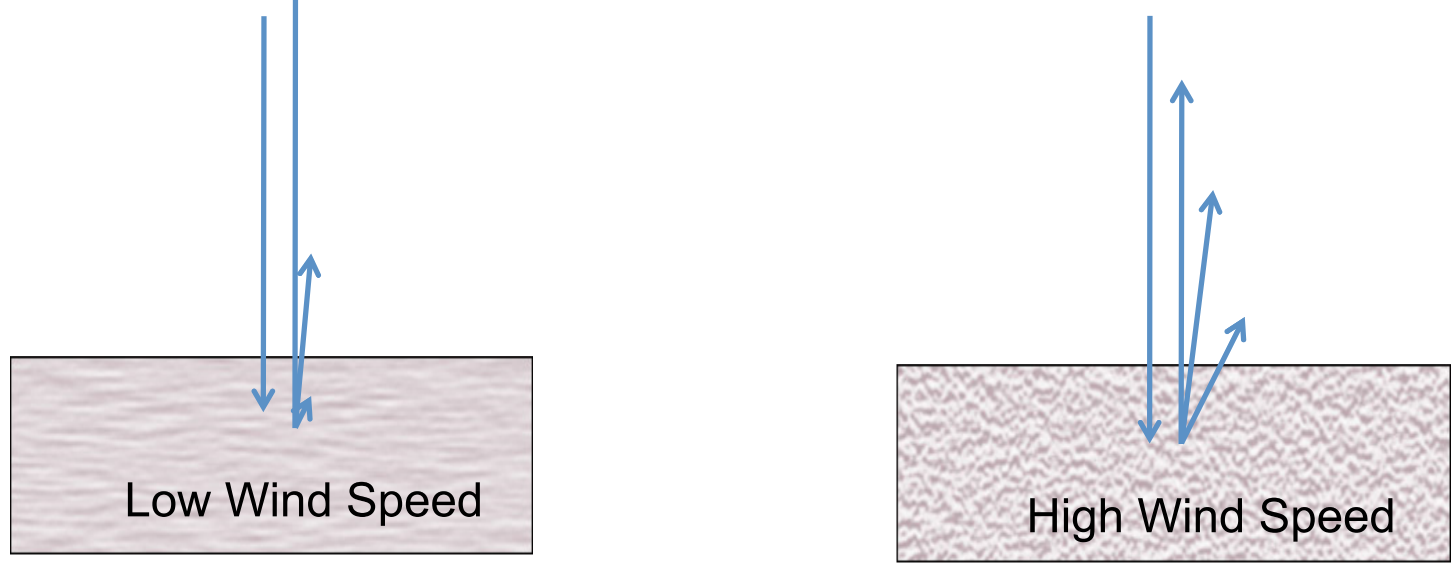
4. Estimate of Bubbles

5. Excellent long term calibration stability

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)

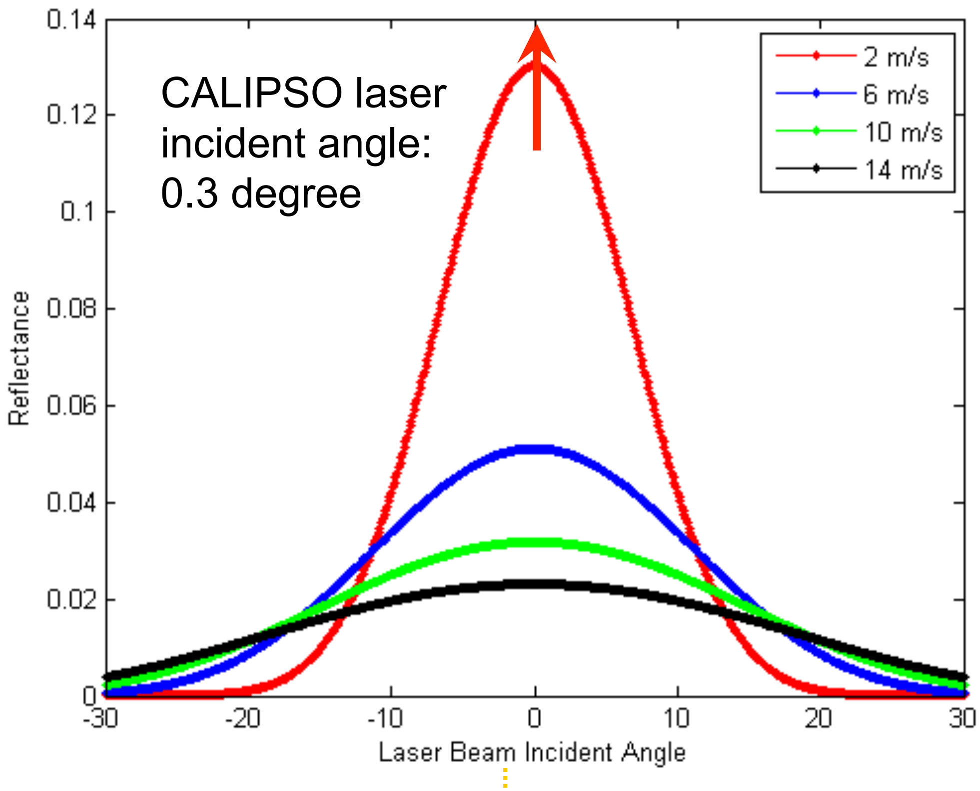


near surface wind speed from CALIPSO lidar backscatter

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)



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

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

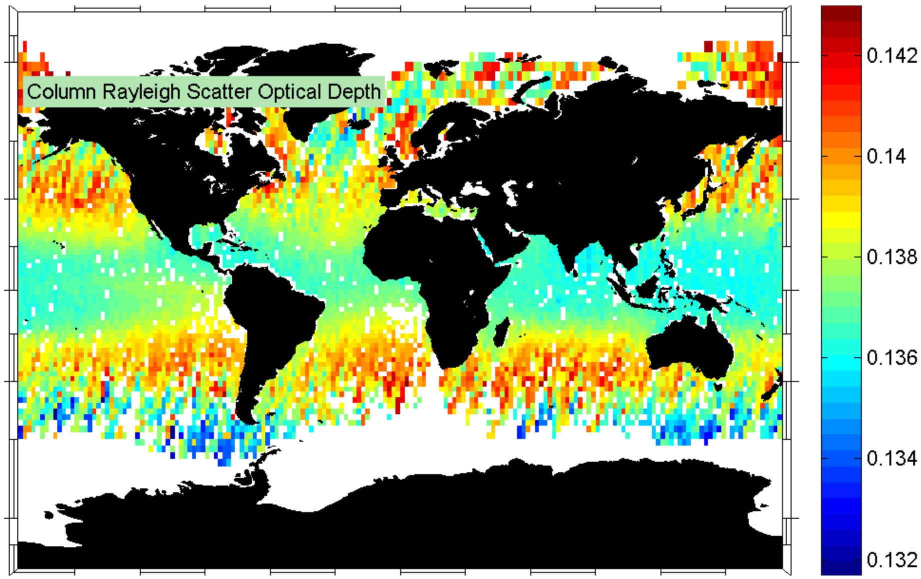
Estimating wind speed from CALIPSO: procedures

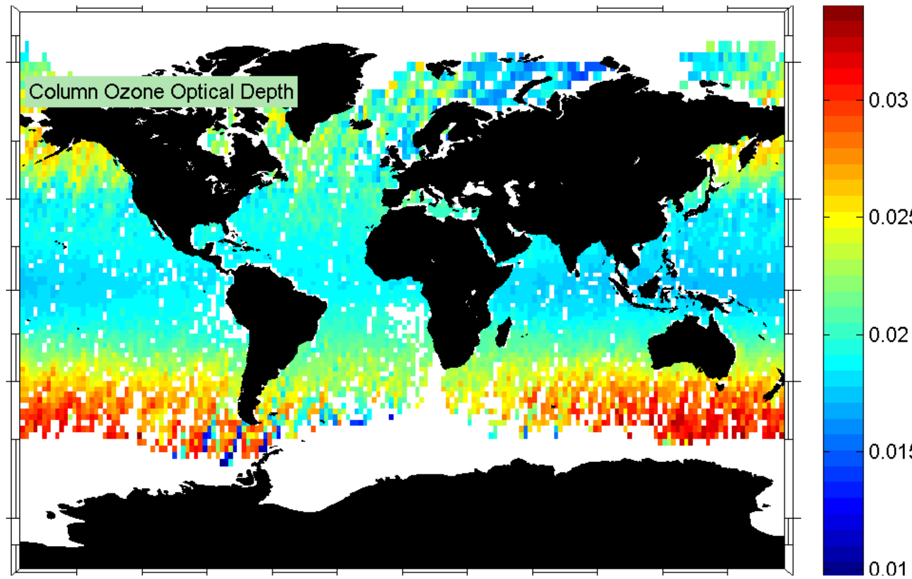
- Calibrating backscatter intensity
- Correcting for atmospheric two-way transmittance
- Correcting for backscatter from bubbles, water and particulates in water
- Estimating mean square wave slope =

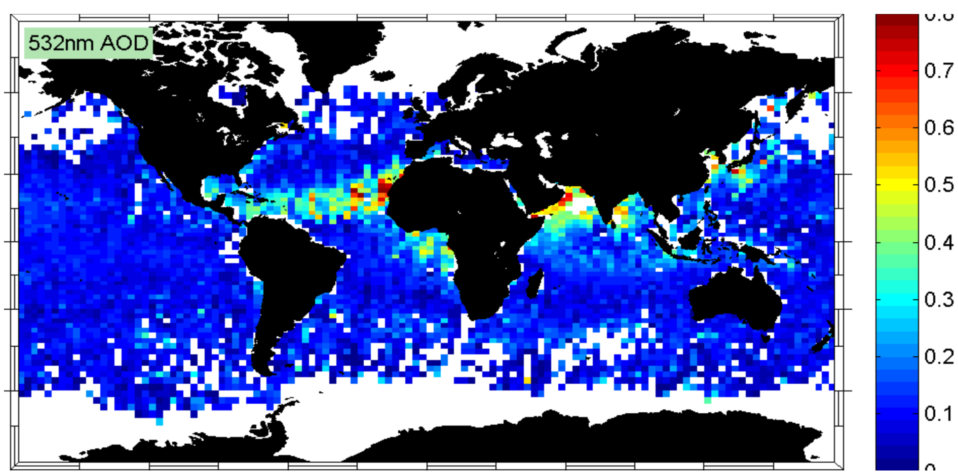
$$0.02 / [4\pi \text{ corrected sea surface lidar backscatter}]$$

Then we can estimate wind speed from mean square slope

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





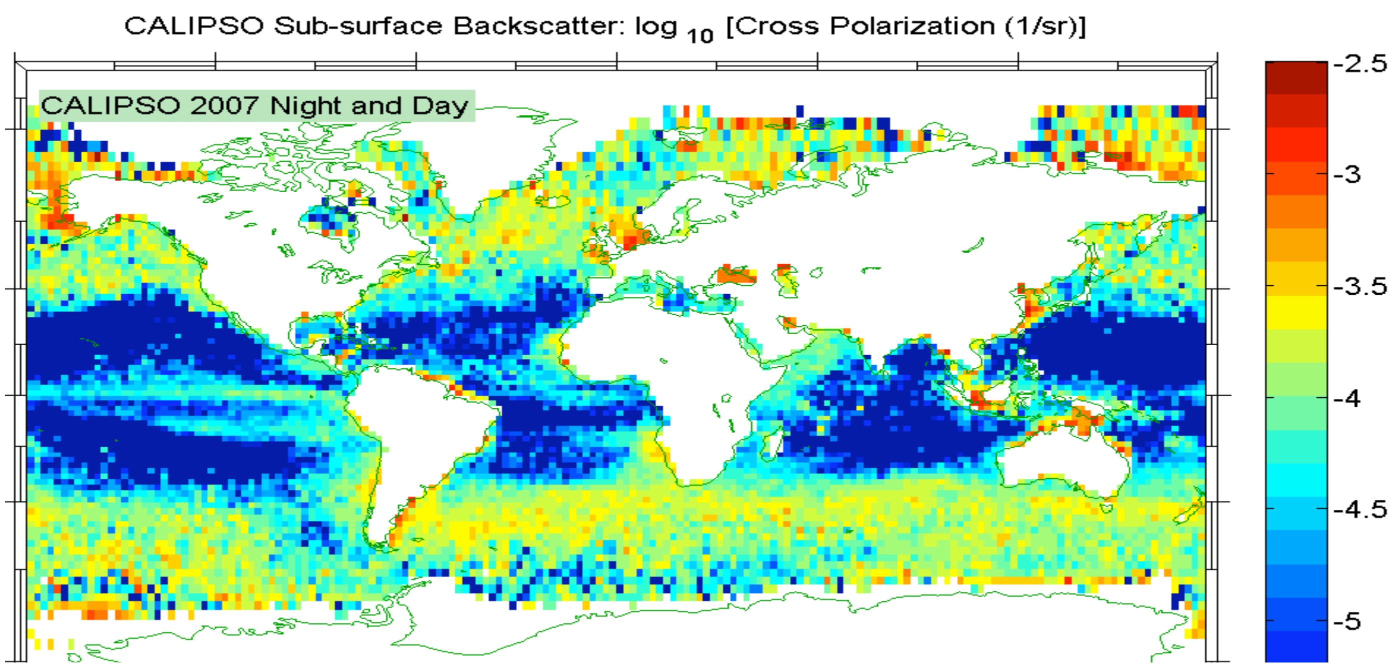


Estimating wave slope variance from CALIPSO: Correction for other backscatter (in water particulates and Rayleigh, and Bubbles)

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

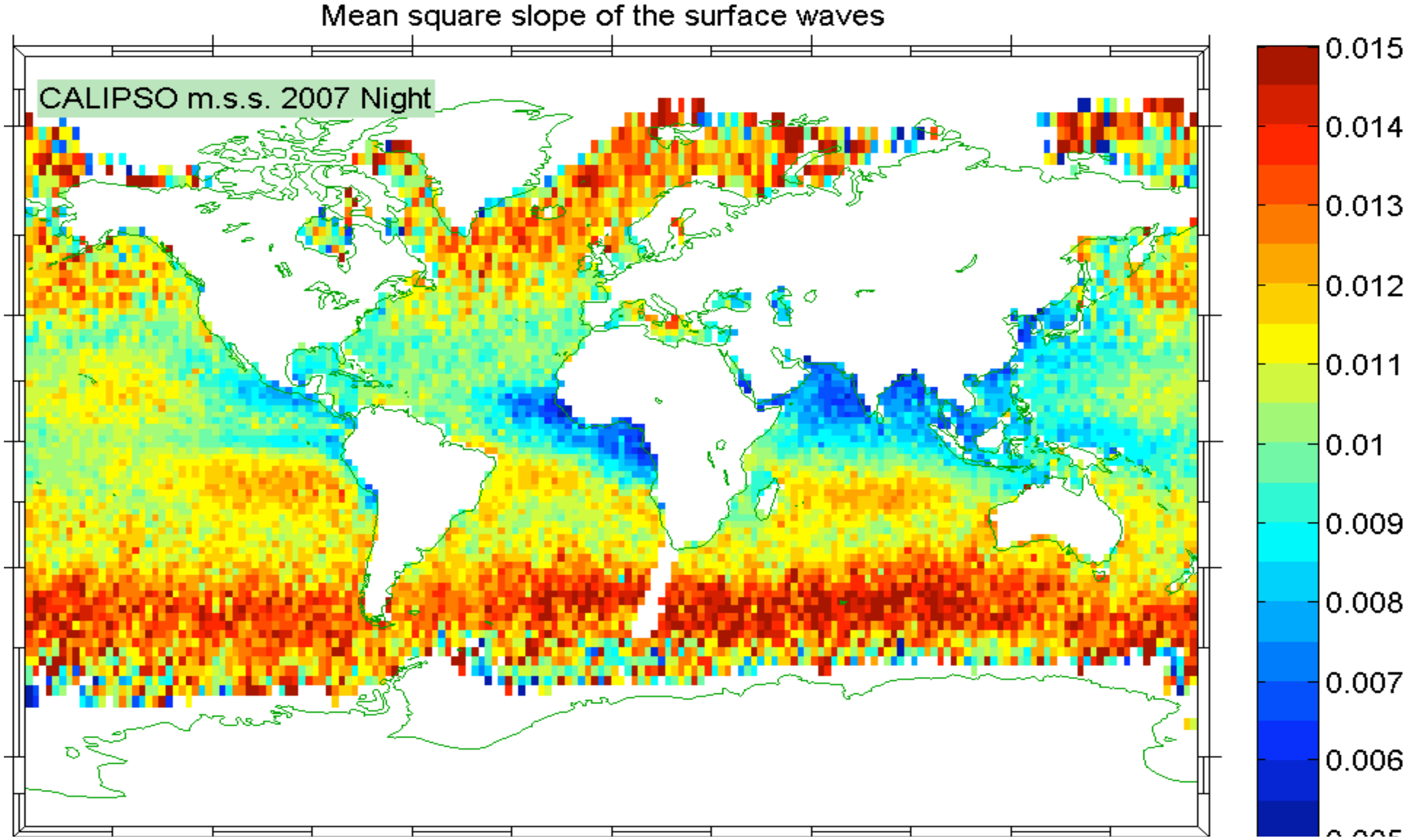
A simple algorithm (Hu et al., 2008):

other backscatter = cross-polarization / 0.15



Wave Slope Variance from CALIPSO

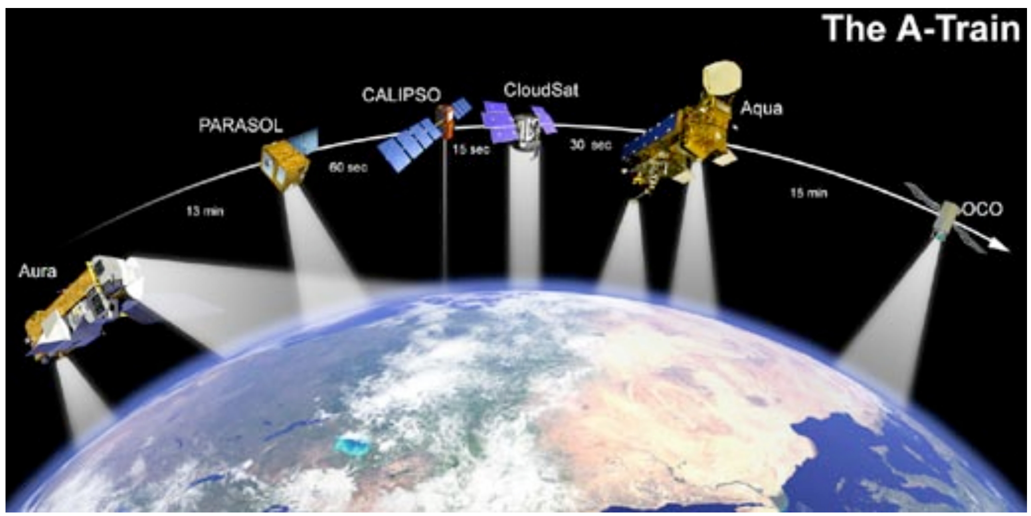
Wave slope variance = 0.02 / [4π * sea surface lidar backscatter]



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

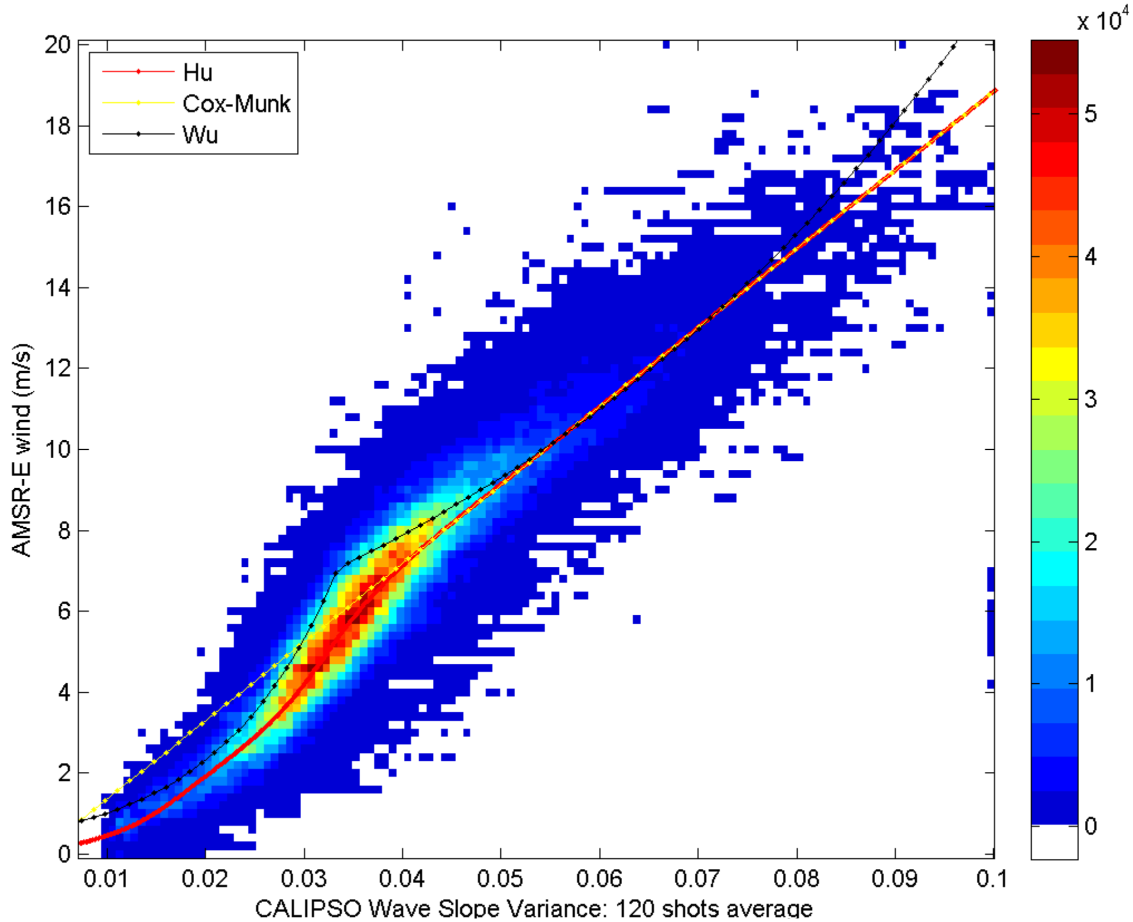
AMSR-E wind speed: derived from AMSR-E instrument (12 microwave channels, 6.92 to 89 GHz), 0.25 X 0.25 degree resolution



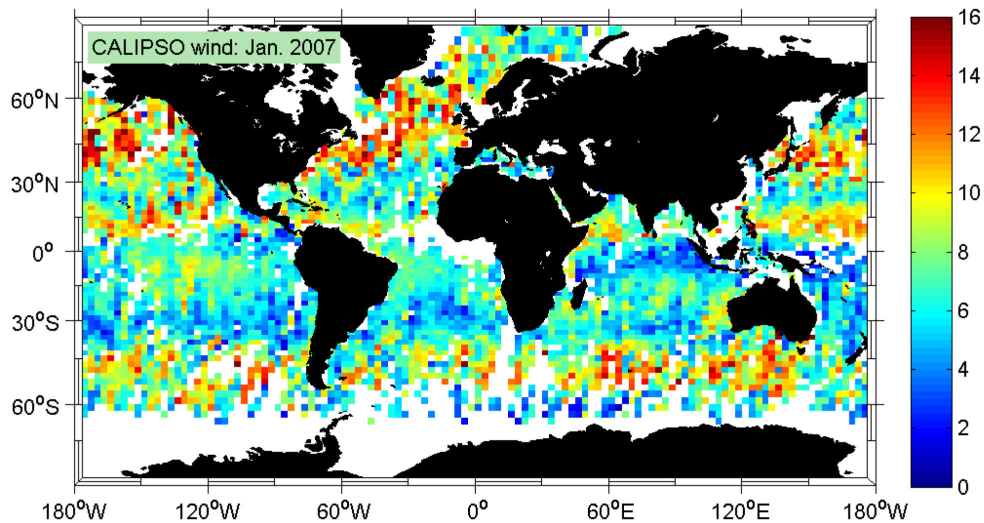
89th AMS, Jan 10-16, 2009
Phoenix, AZ.

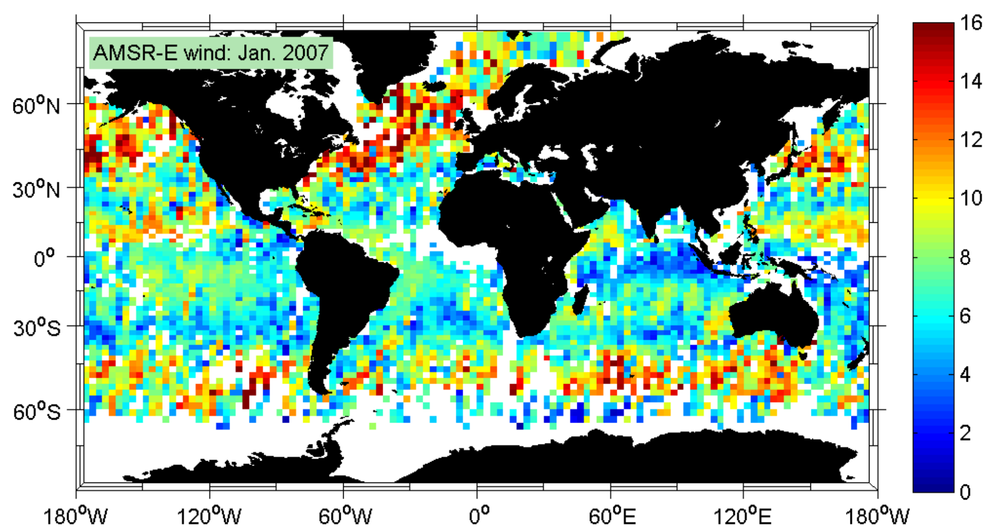
CALIPSO wave slope variance vs AMSR-E wind speed

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

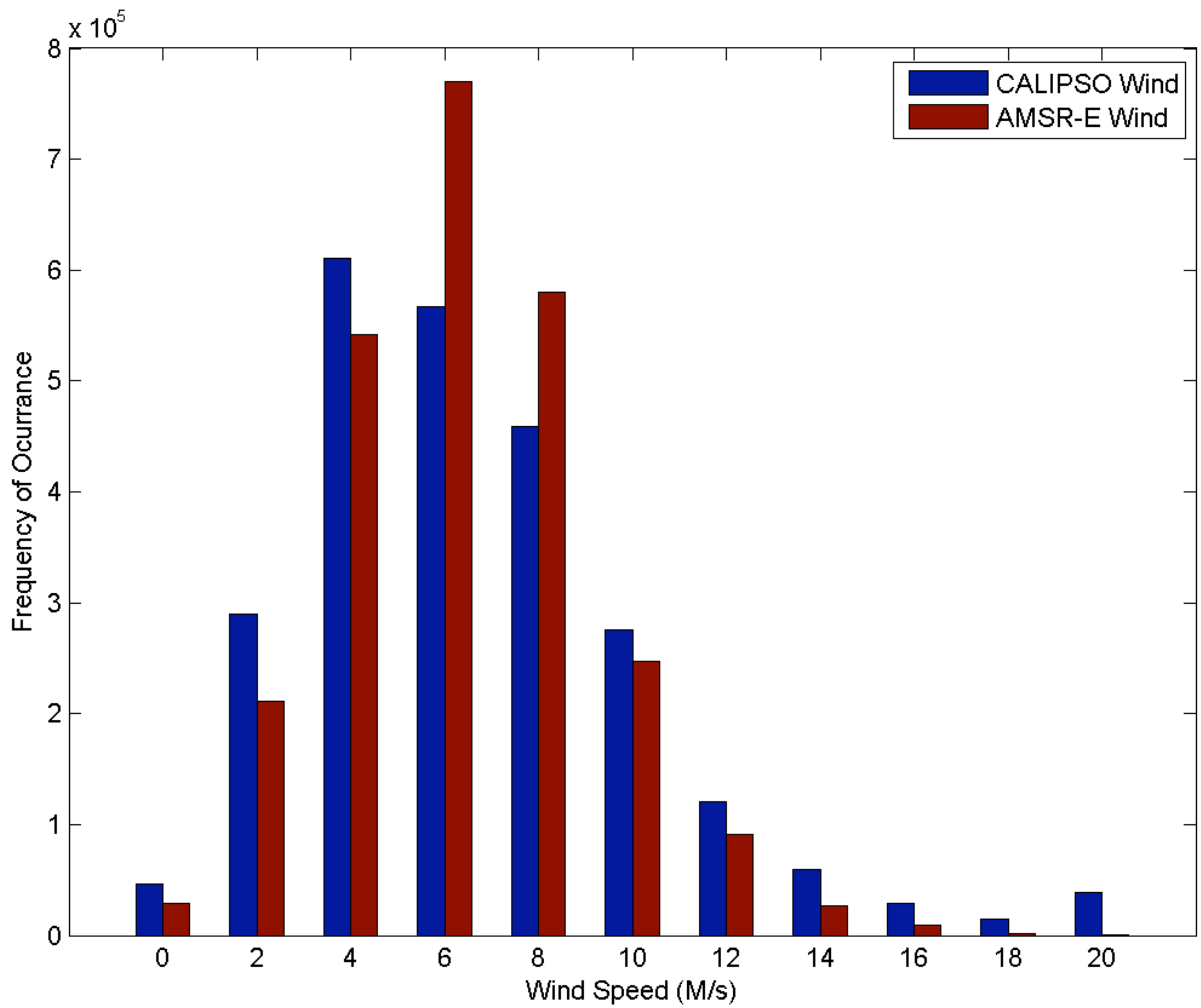


Comparison with CALIPSO wind speed from AMSR-E: Monthly mean





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



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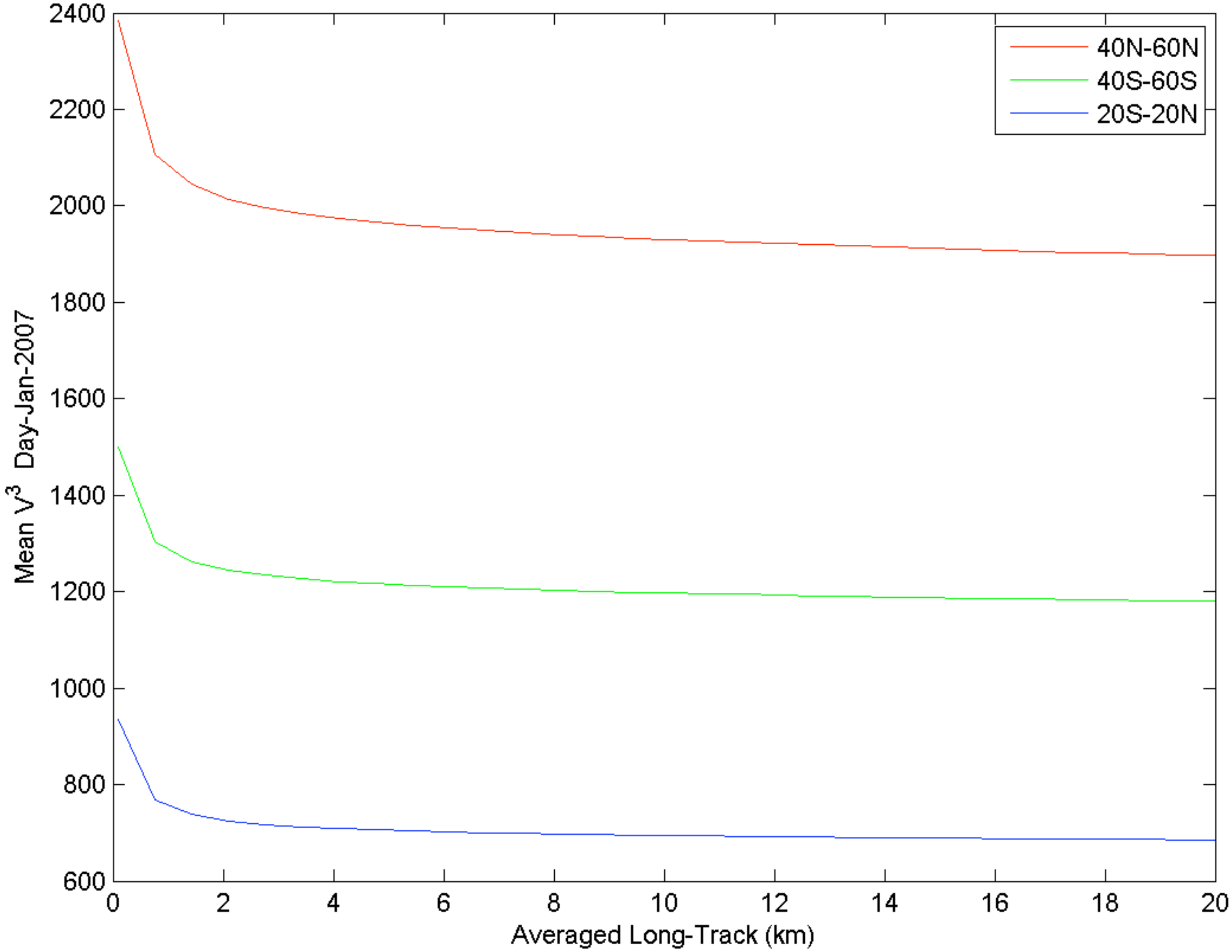
$\langle V^3 \rangle$ vs wind speed spatial averaging

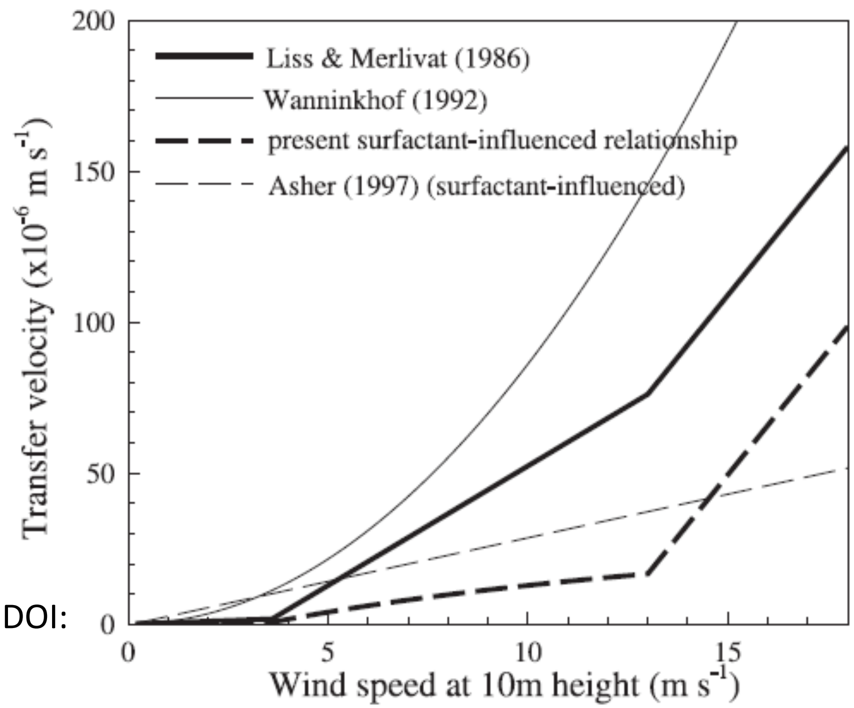


Deriving turbulence transfer velocity from wind speed: issues that lead to uncertainty

1. **Nonlinearity of the gas transfer velocity – wind speed relation**: makes it hard to use spatial/temporal averaged wind speeds:

$$(W_1^2+W_2^2)/2 > [(W_1+W_2)/2]^2$$

2. **Sea state dependence**: e.g., for the same wind speed, gas transfer velocity reduces when surfactant (such as degraded planktons) presents.

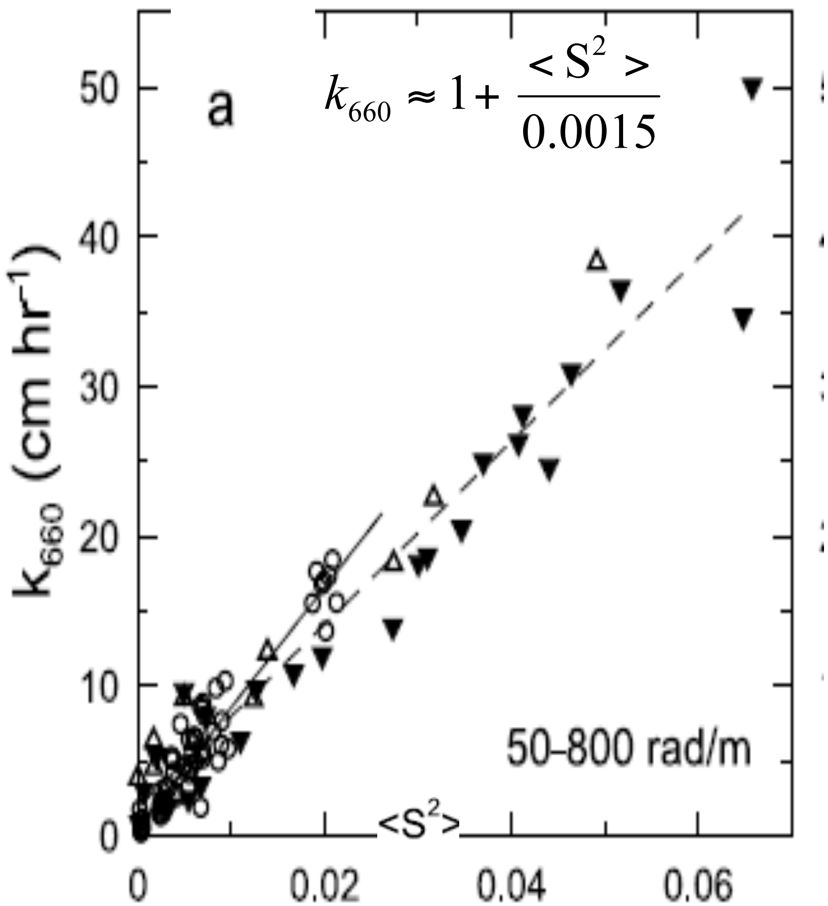


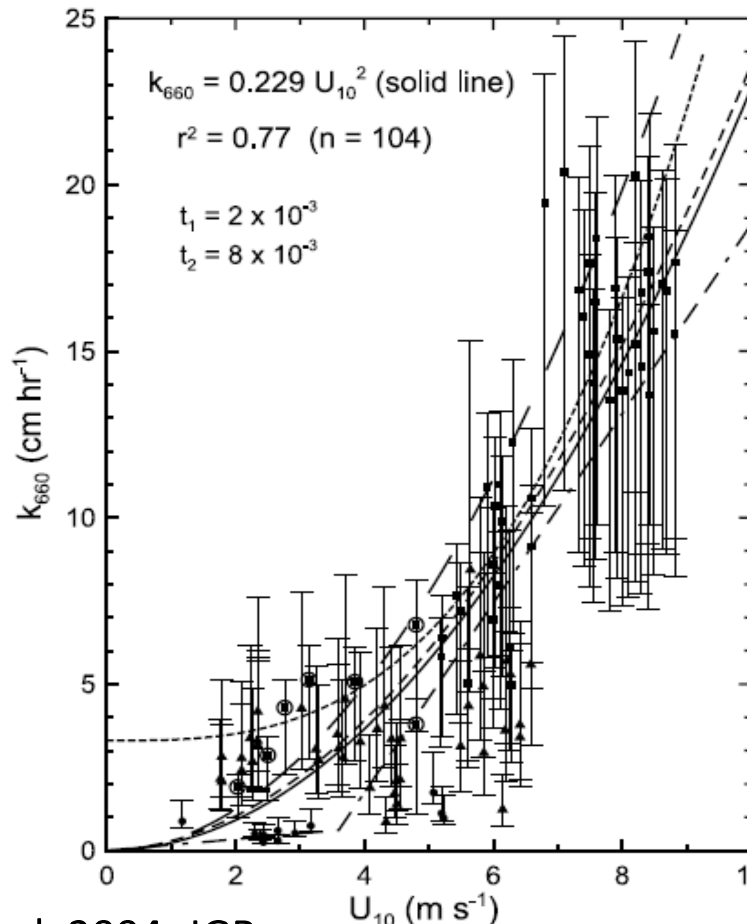
Tsai & Liu, 2003: JGR, 108, C4, DOI: 10.1029/2000JC000740.

Air-sea gas exchange improves with direct mean square wave slope measurements

(Jahne et al 1984; Hara et al 1995; Bock et al 1999; Frew et al 2004, ...)

Vertical gas transfer velocity correlates with wave slope variance better than wind speed





Frew et al, 2004, JGR

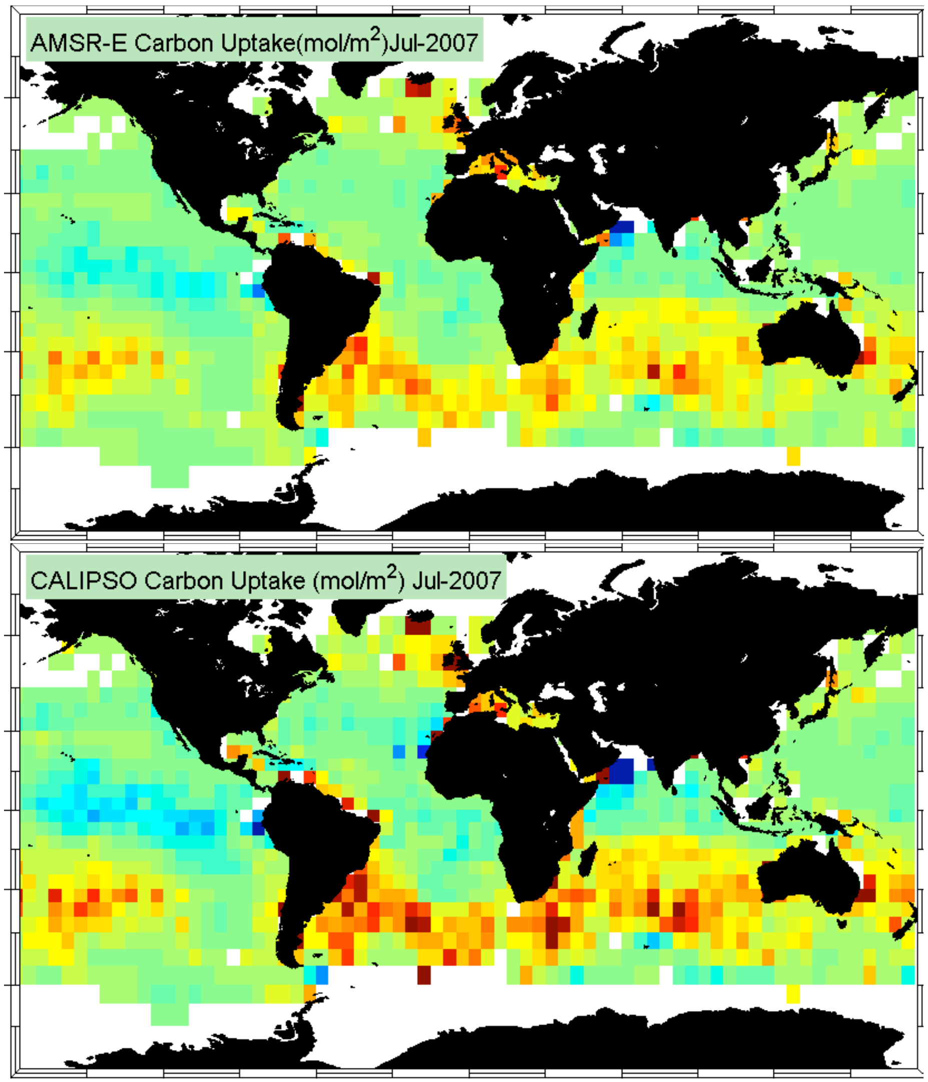
Air-sea Gas Exchange

CO_2 Uptake

= turbulence transport

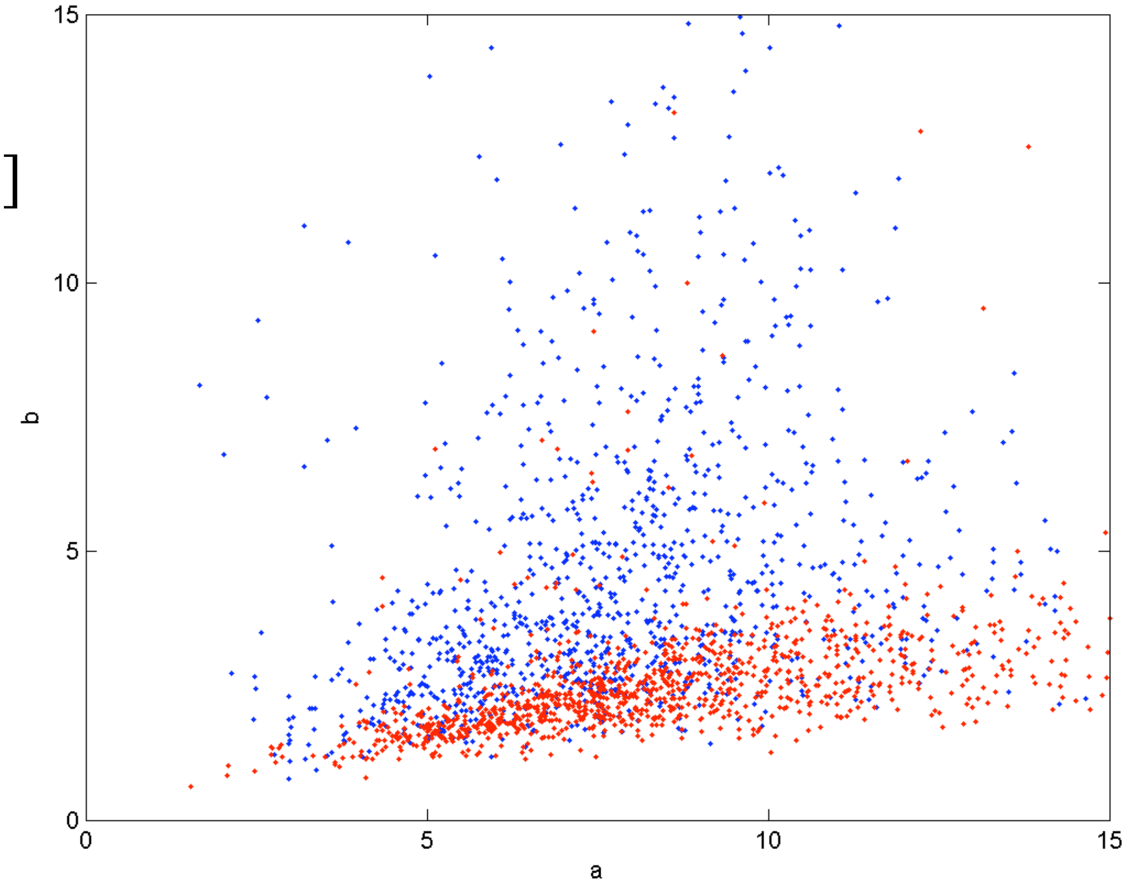
* solubility * $\Delta(PCO_2)$

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



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

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

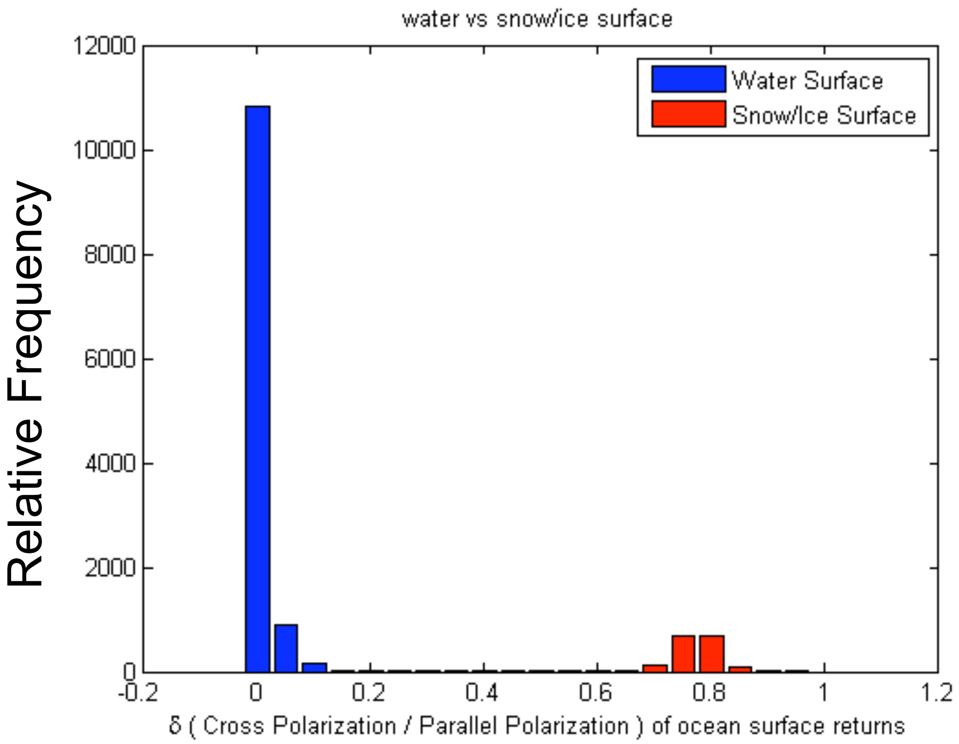


The relation between a and b of Weibull distributions from AMSR-E (blue) and CALIPSO (red). Rayleigh distribution (b=2) is a good approximation for wind speed around 7 m/s when CALIPSO high spatial resolution wind speed is used.

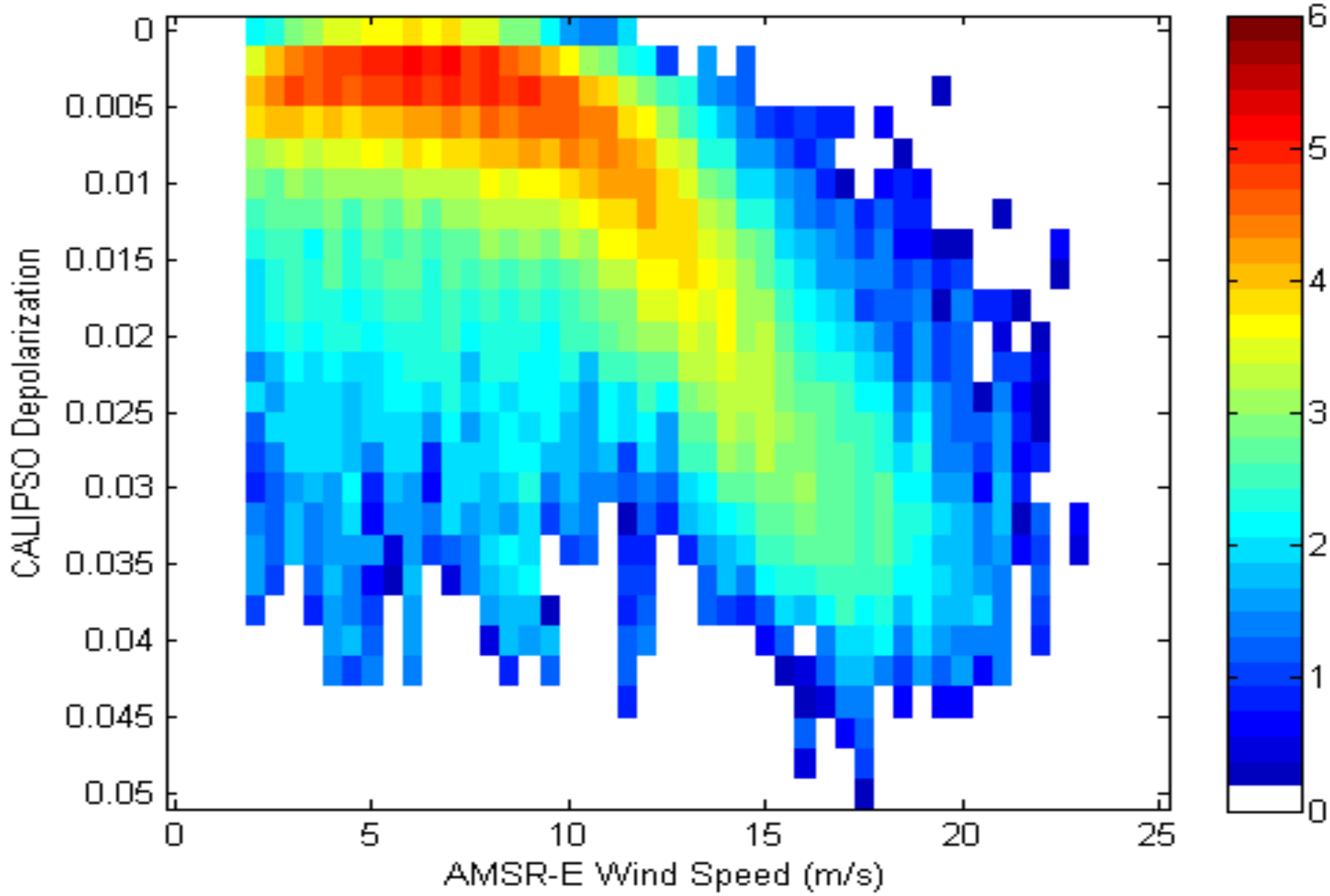
Improving observations at high latitudes: spotting open water at 70 m footprint size

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

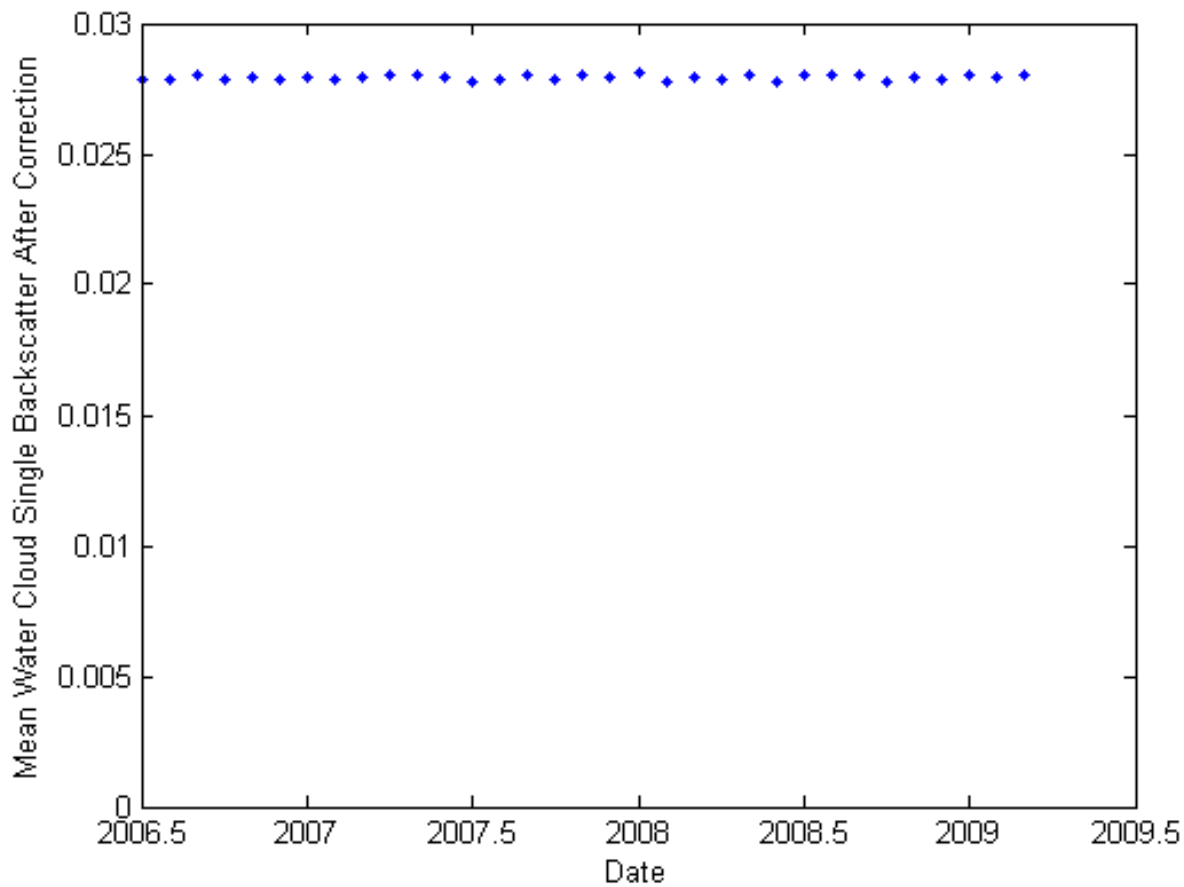
$$\delta = \frac{I_{cross\ polarization}}{I_{parallel\ polarization}}$$



CALIPSO depolarization measurements: Estimate of Bubbles



Stable Calibration: Good for Long Term Trend Analysis



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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…)