Improved estimation of air-sea CO_2 fluxes from satellite microwave backscatter

Darek Bogucki

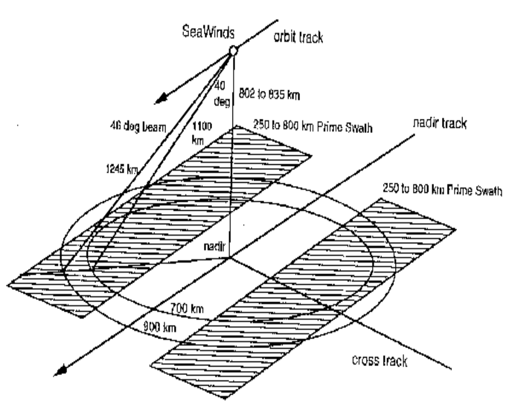
Texas A&M, Corpus Christi, TX, USA

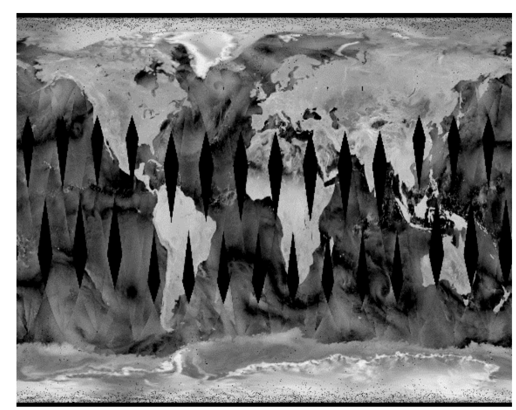
QuikSCAT

- Microwave scatterometer.
- Ku-band radar (13.46 GHz h- and v- pol).
- 90% daily global coverage follow-up: XOVWM, expected launch late 2014.
- QuikSCAT senses surface wave slopes, band-passed around Bragg wavenumber:

$$\boldsymbol{2k_{QS} \sin(\theta_0)}$$

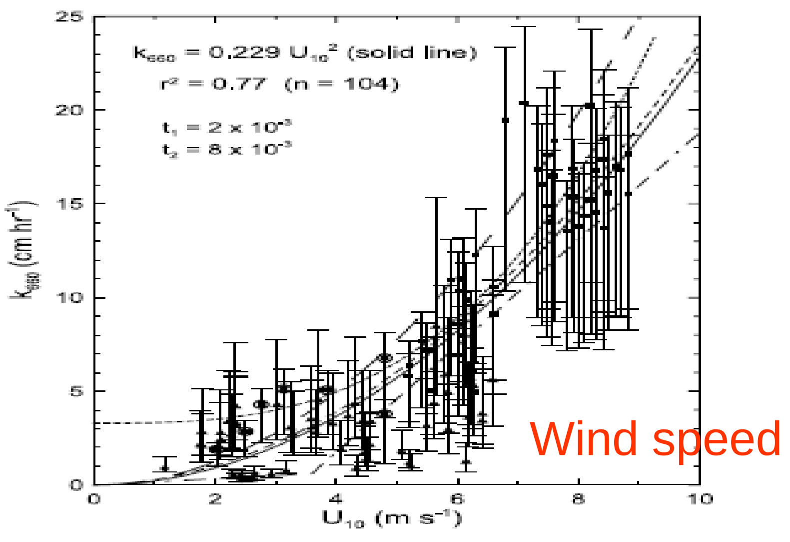
- The bands are centered at: λ=1.2 and 1.8 cm or 360 and 510 rad/m.

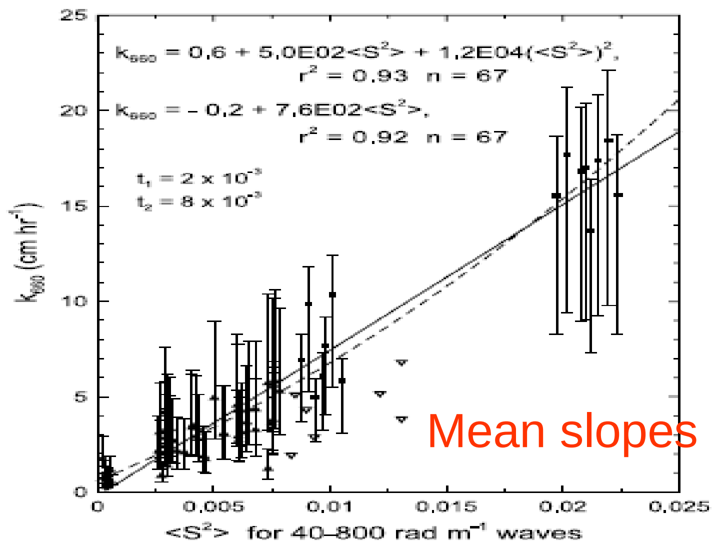




Question:

- How do we improve satellite based parameterization of CO_2 flux estimates?
  - Correlation between gas transfer velocity and mean square slope stronger than correlation between gas transfer velocity and wind speed (Frew et al. 2004)





Overview

- Motivation
- Scatterometer estimates of gas transfer –Gasex2001
- Mean Square Slope (mss) parameterization of CO_2 gas transfer velocity
- Ongoing work: IPY CFL Study
  - Laser wave slope gauge
  - QuikSCAT
- Conclusions

Motivation

$$F = \mathbf{k}_{660} \cdot \alpha \cdot \left[\left(pCO_{2sw} \right) - \left(pCO_{2air} \right) \right]$$

- Conventional parameterizations of gas transfer velocity, $\boldsymbol{k_{660}}$, in terms of: *wind speed, whitecap coverage,* contain large uncertainty.

- The gas exchange processes are in fundamental way related to the nearsurface turbulence**:**
  $\boldsymbol{k_{660}} \sim S_c^{-1/2} [\boldsymbol{\varepsilon(0^-)} \nu]^{1/4}$ (Kitajgorodski, Donellan 1984),
  where $\boldsymbol{\varepsilon(0^-)}$ – near surface TKE dissipation.

- but $\boldsymbol{\varepsilon(0^-)}$ - difficult to measure …

Motivation

- An ***ε(0⁻)*** proxy: capillary waves energy of λ=1.5–3 cm (fastest growing): $E_{capillary} \sim T(\nabla\zeta)^2$

where: T, ζ -surface tension and displacement respectively

- ***mss***=over QuikSCAT wavebands (centered at: λ=1.2 and 1.8 cm or 360 and 510 rad/m).

Gas transfer velocity from QuikSCAT

- Conventional remote sensing gas transfer estimates:
  - NRCS (σ_0) => wind speed => gas transfer velocity
- *(Bogucki et al. 2010):*
  - NRCS => mss => gas transfer velocity, k_{660}
  - GasEx2001
    - Small set of collocated data points in tropical Pacific:
      - Gas transfer - ASIS
      - mss (laser slope gauge)
      - NRCS - QuikSCAT

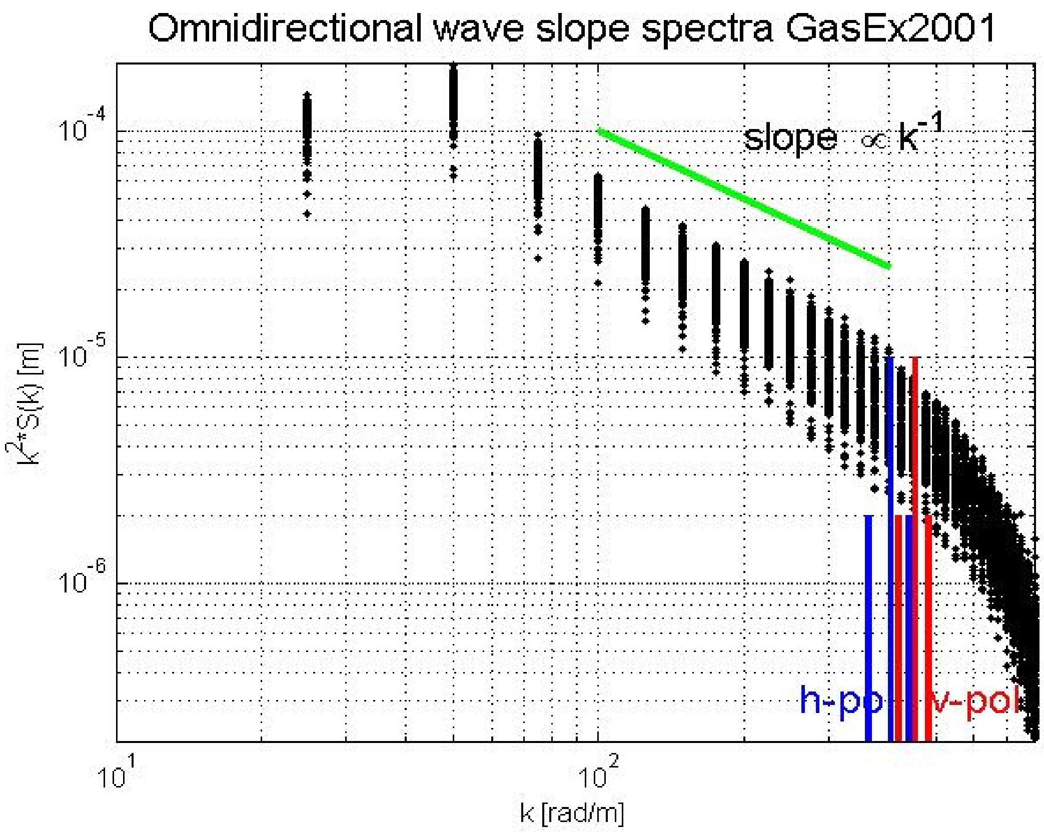
Gasex2001-surface wave spectra

•The absence of significant surfactant concentrations.
•No significant quantities of bubbles and sea spray present at wind speeds encountered during GasEx 2001.
•Measured in situ omnidirectional wave slope spectra *$k^2S(k)$:*

Define:

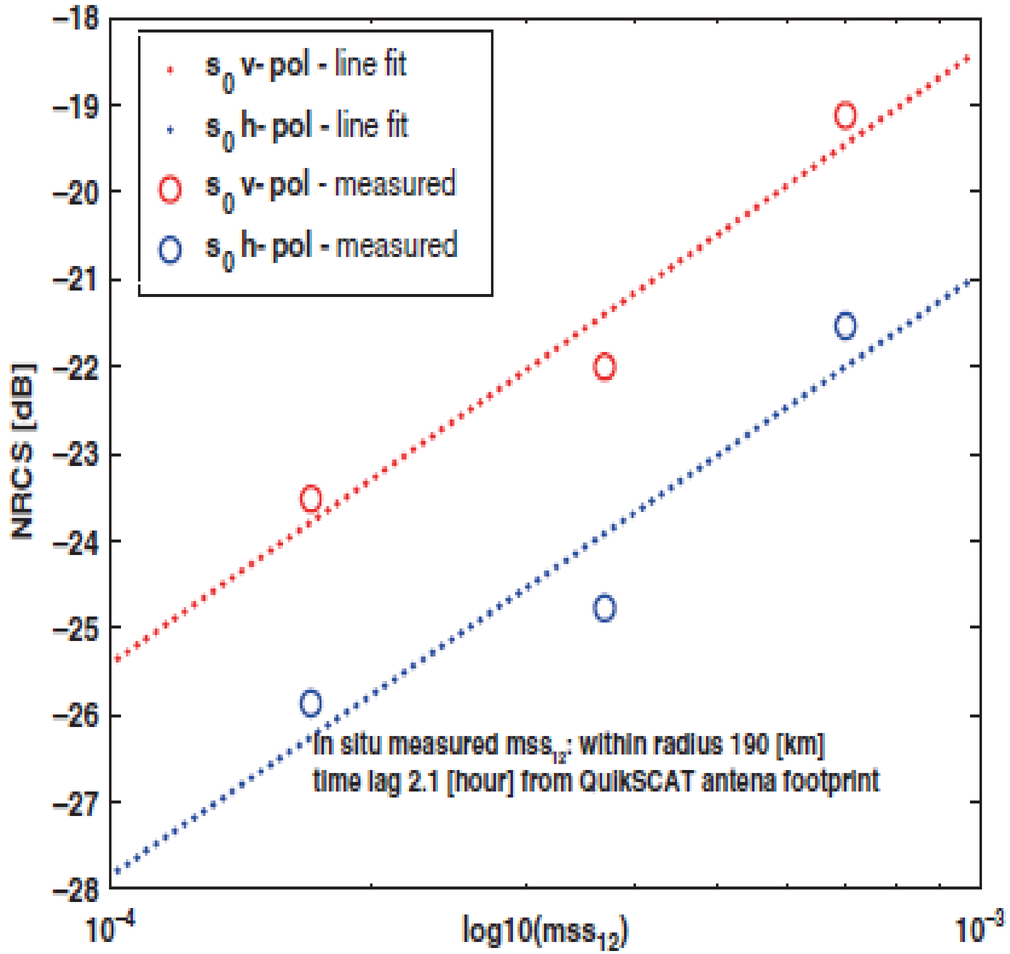
$$\bullet <\zeta^2>=\int_0^\infty S(k)dk$$

$$\bullet mss_{12} =<(\nabla\zeta)^2>= \int_{k_1}^{k_2} S(k)k^2dk$$



QuikSCAT upwind NRCS vs. shipboard mss:

$$\log\left(NRCS\left(\theta_o\right)\right) =$$
$$A\log\left(mss_{12}\right) + B\left(\theta_o\right)$$

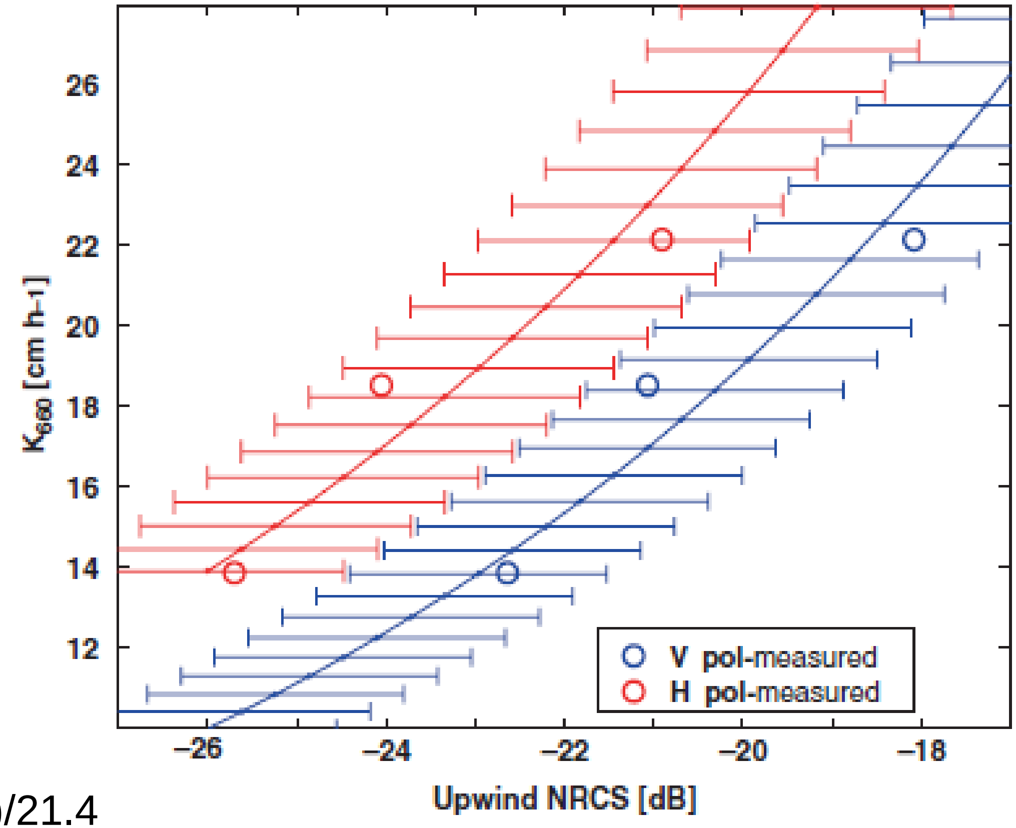


- *A*, *B* are polarization dependent constants

(Bogucki et al. 2010)

Gas transfer velocity from QuikSCAT

Bogucki et al. 2010



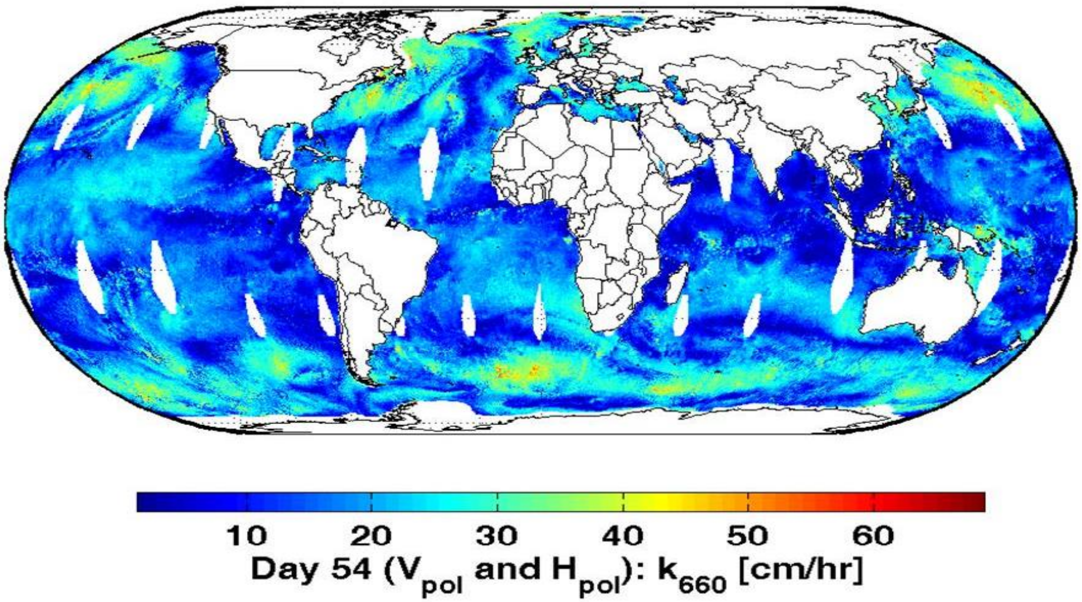
•v-pol:

$k660(cm\ h^{-1})=10^{(\sigma 0v+47.4)/21.4}$

•h-pol:

$k660(cm\ h\text{-}1)=10^{(\sigma 0h+51.7)/22.5}$; where upwind σ in [dB]

QuikSCAT global distribution of k_{660}

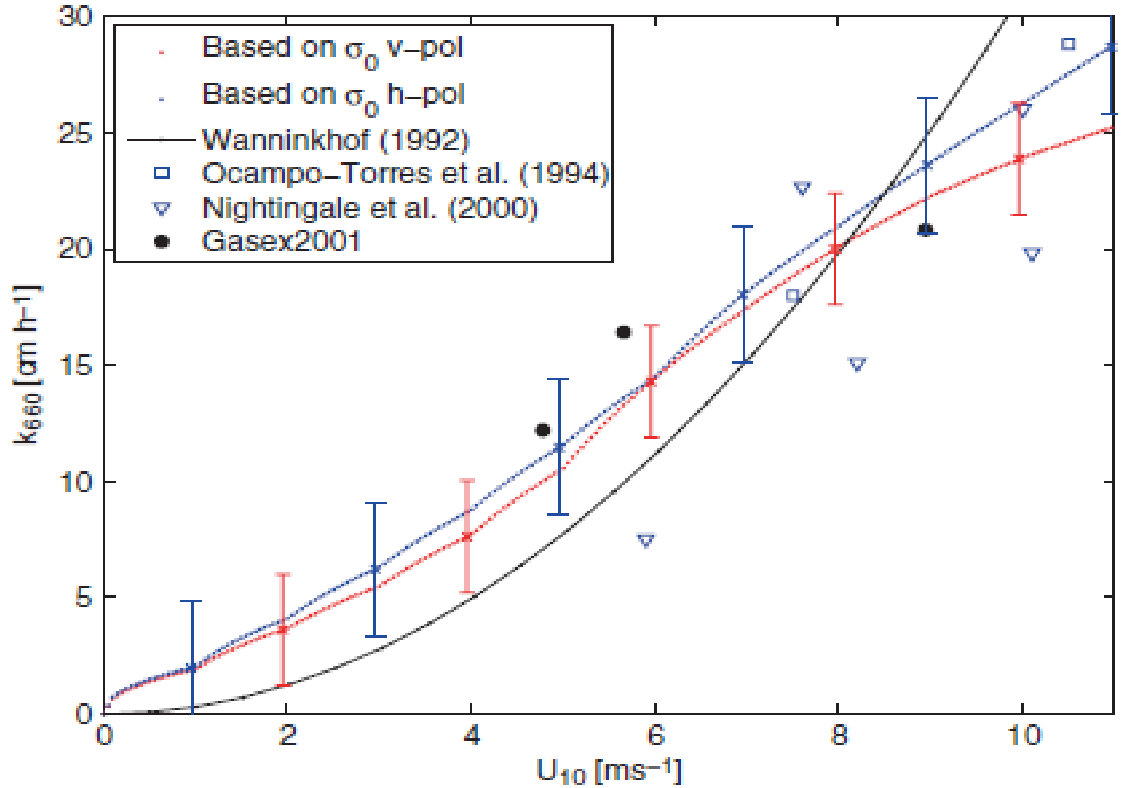


The global distribution of CO_2 transfer velocity obtained from QuikSCAT data for day 54 of 2001 using the matchup derived in the GasEx 2001 region. (based on *Bogucki et. al. 2010*)

- How does this k_{660} compares to 'classic' wind u_{10} based one ?
- Calculate *k660* based on σ and plot it as a function of the wind speed..

Gas transfer velocity from QuikSCAT

Bogucki et al. 2010



- Gas transfer velocity- k_{660} , with associated error bars, obtained from QuikSCAT surface roughness for day 54 of 2001 as a function of concurrent QuikSCAT observations of wind speed u_{10}.

Current work: DOGEE 2007

Collocated measurements of:

- Surface roughness from QuikSCAT and Surface roughness and air-sea CO_2 flux in DOGEE 2007

- DOGEE project was one of the efforts from the Surface Ocean–Lower Atmosphere Study (SOLAS) to quantitative understanding of the key biogeochemical–physical interactions and feedbacks between the ocean and the atmosphere, and of how this coupled system affects and is affected by climate and environmental change.

- During the DOGEE field campaign were conducted the widest-ranging measurements of the three programs, focused around a dual-tracer (3He and SF6) release for measuring kw (Watson et al. 1991). Multiple simultaneous direct flux measurements were also made: CO2 fluxes by AutoFlux and from two air–sea interaction spar (ASIS) buoys (Graber et al. 2000) deployed within the tracer patches and a DMS flux system with inlet and sonic anemometer collocated at the top of the foremast extension. The campaigns occurred during june-july 2007 in the northeast Atlantic region.

DOGEE 2007 – study area

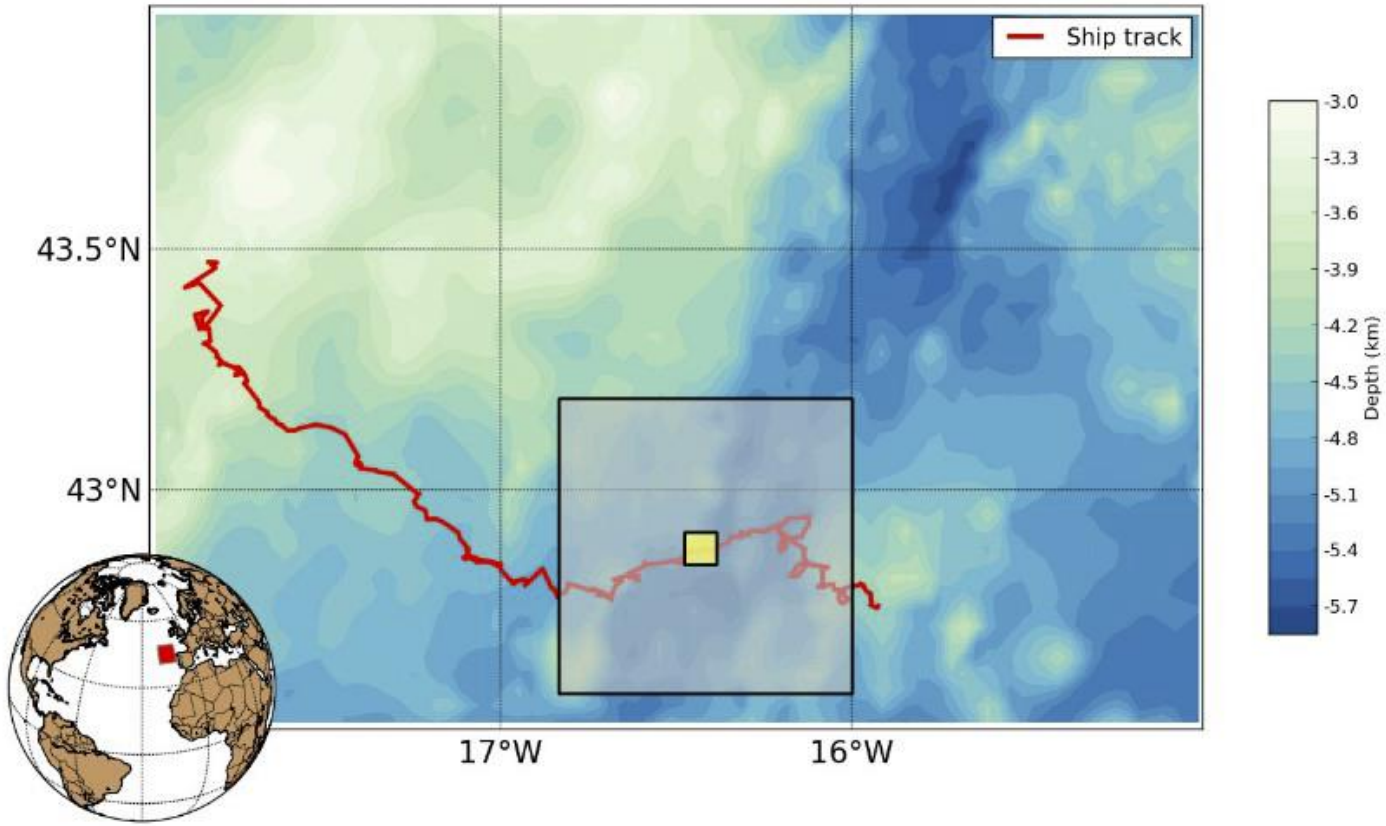


Figure shows our study region and the moving windows implemented. The yellow square represents the first moving windows with 5 x 5 km used to obtain the k660 values derived from the scatterometer. The biggest window (gray color) was used to evaluate the sigma-zero patterns during DOGEE experiment. Additionally, the gray window (spatial resolution: 25 x 25 km), was used to evaluate the wind distribution over our study region. The DOGEE campaign occurred during June 29 to July 11, 2007.

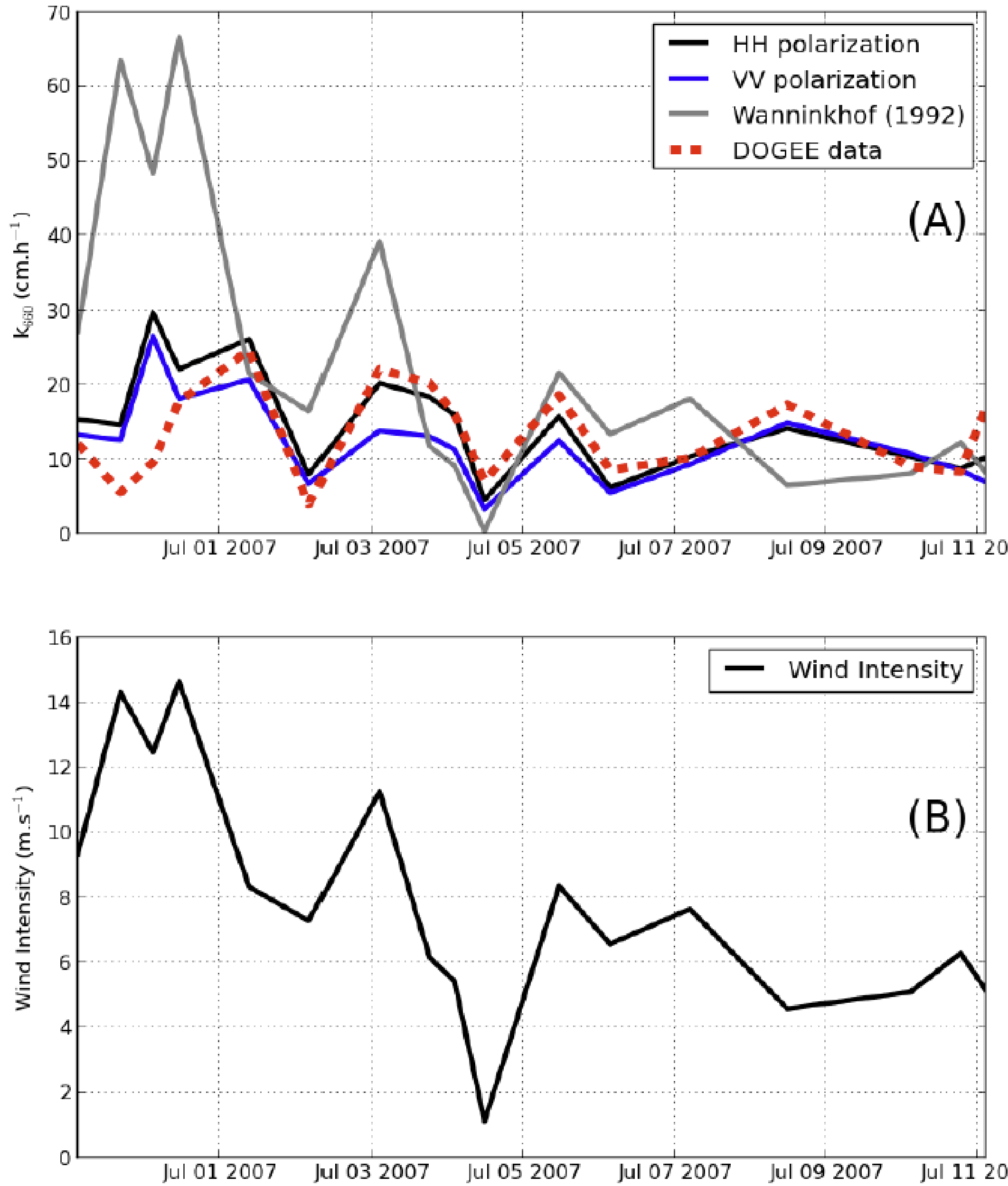
Results DOGEE 2007

$$k_{660} = \frac{F_{CO_2}}{\Delta p_{CO_2}} \cdot L \left(\frac{Sc}{660} \right)^{1/2}$$ → **DOGEE DATA**

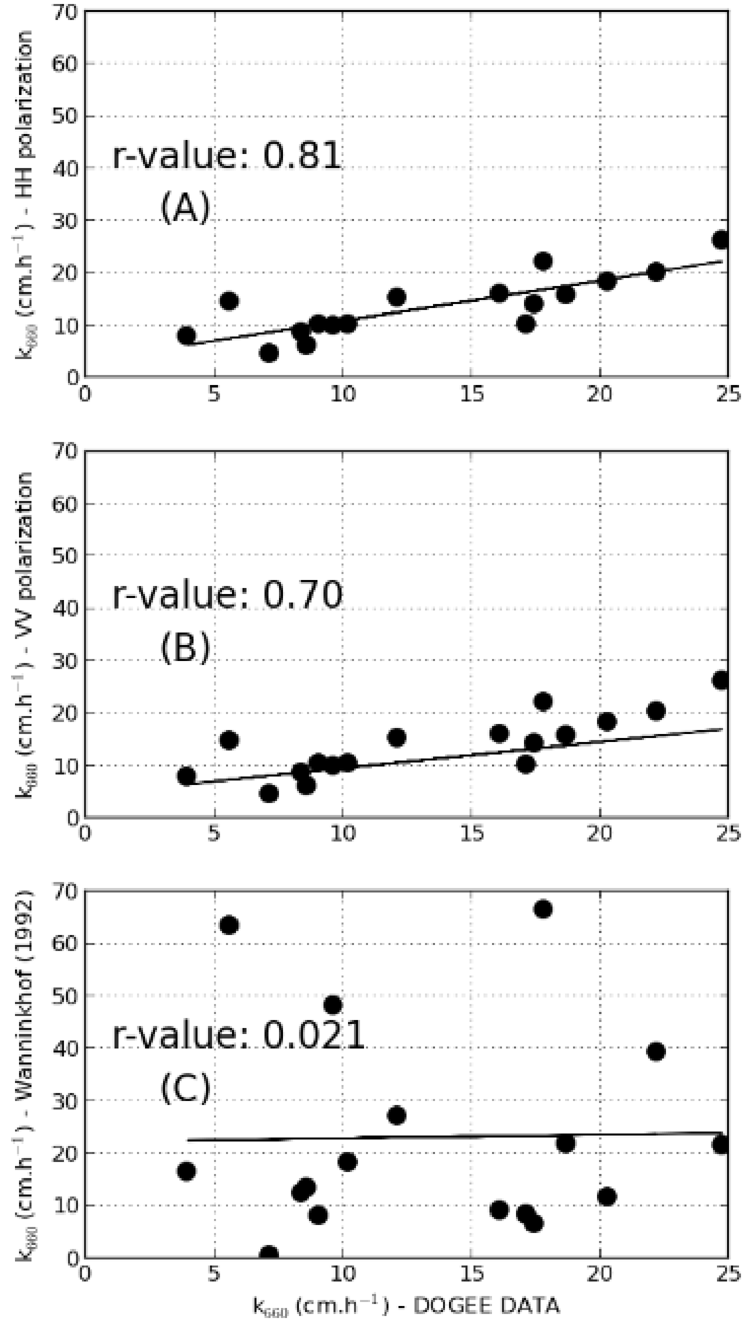
solubility

$$k_{660} = 0.31\,(u)^2\,(Sc/660)^{-1/2}$$ → **Wanninkhof (1992)**

$$k_{660}(\mathrm{cm\,h^{-1}}) = 10^{(\sigma_{0v}+47.4079)/21.4248}$$
$$k_{660}(\mathrm{cm\,h^{-1}}) = 10^{(\sigma_{0h}+51.7545)/22.5334}$$
Bogucki et al. (2010)



Results DOGEE 2007



r values obtained by the different algorithms:
(A) HH polarization and DOGEE project.
(B) VV polarization and DOGEE project.
(C) Wanninkhof (1992) algorithm and DOGEE project

Conclusions

- Conventional parameterizations of gas transfer velocity, k_{660}, are associated with large uncertainties

- k_{660} has been shown here correlate well with mean square slope obtain from satellite microwave backscatter measurements.

- The microwave backscatter permits for better then wind speed based characterization of the global oceanic CO_2