Using satellite altimetry to measure air-sea gas transfer velocity

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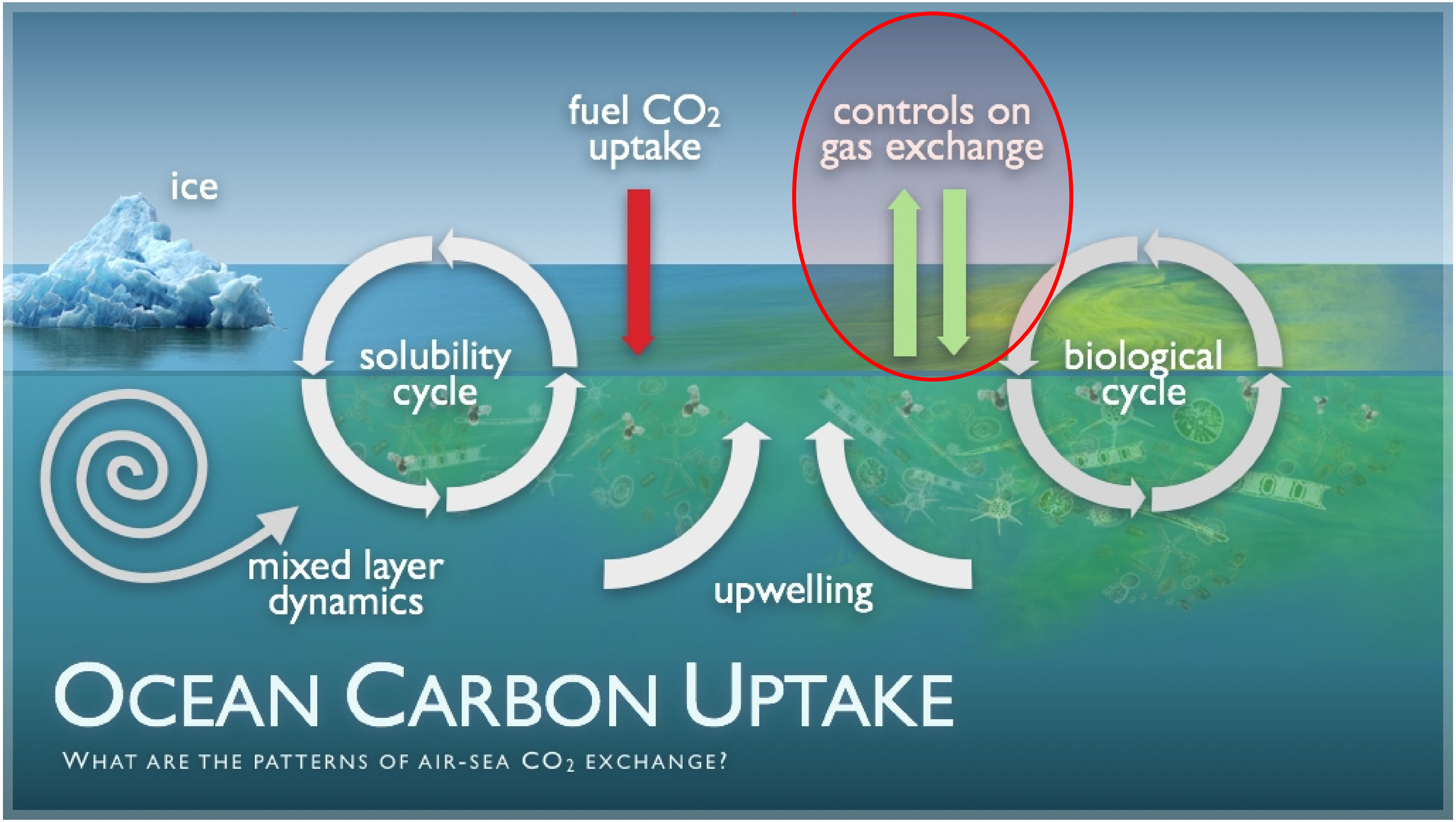
oceanflux ghg
support to science element

OceanFlux GHG is funded by: esa and affiliated to: solas

Using satellite altimetry to measure air-sea gas transfer velocity

1) Air-sea gas transfer and satellite altimetry

2) Apply our calibration for DMS to any other gas



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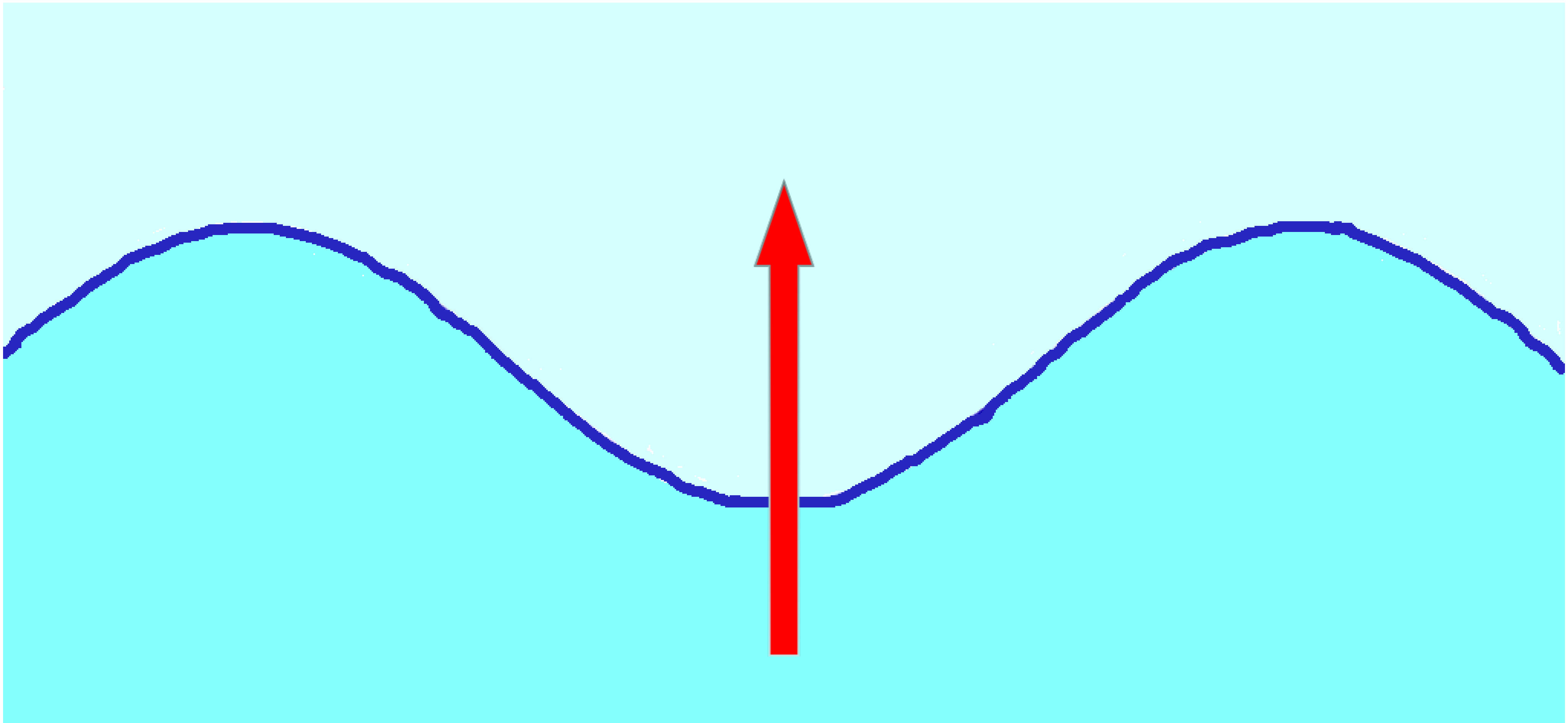
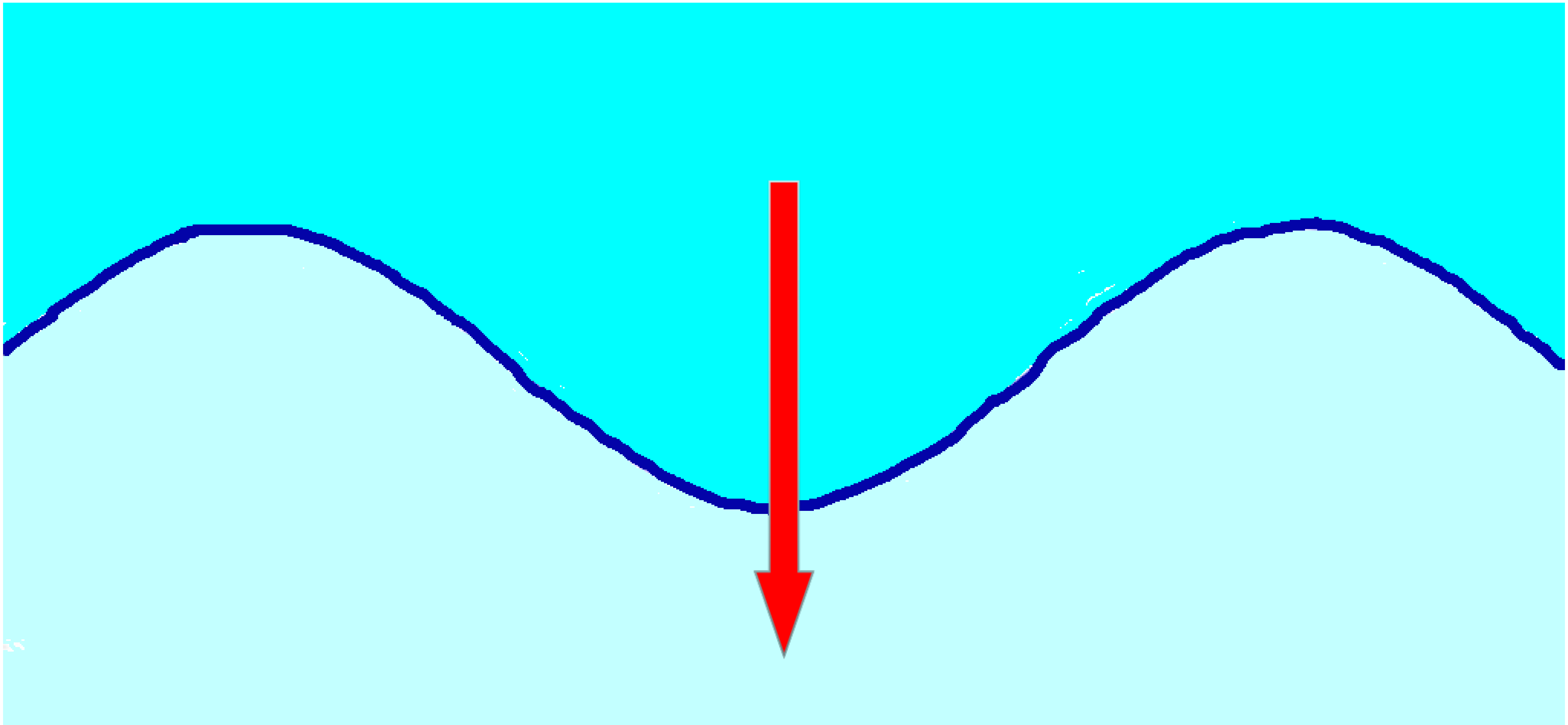
Gas Flux



Higher gas concentration in the ocean

Gas Flux



Higher gas concentration in the atmosphere

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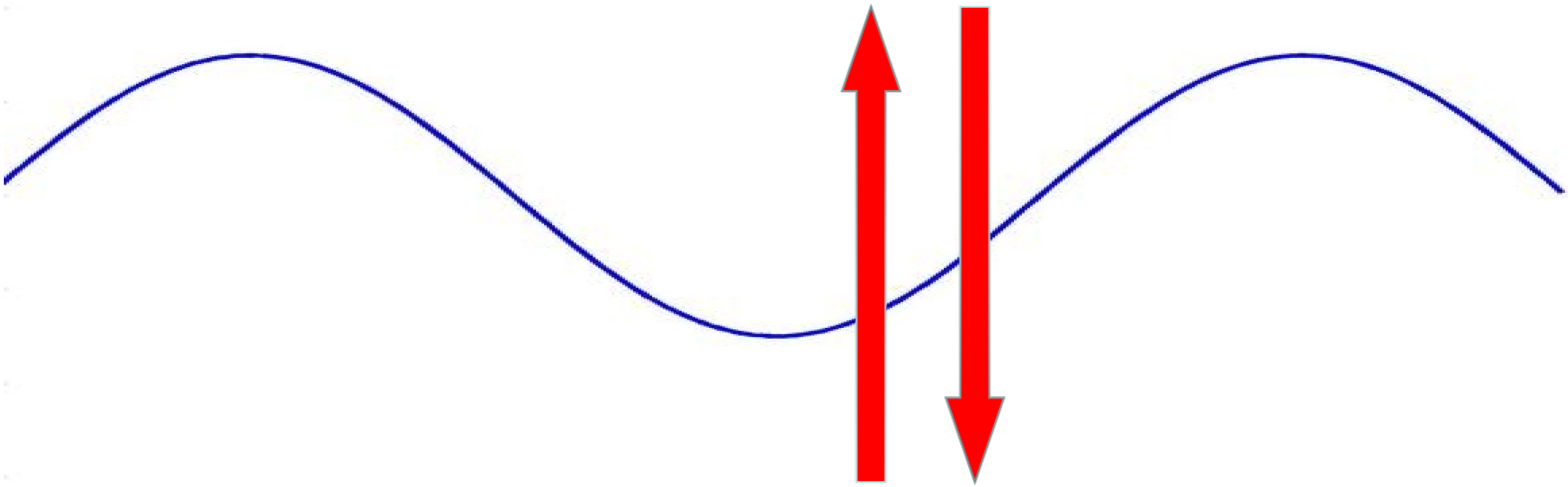
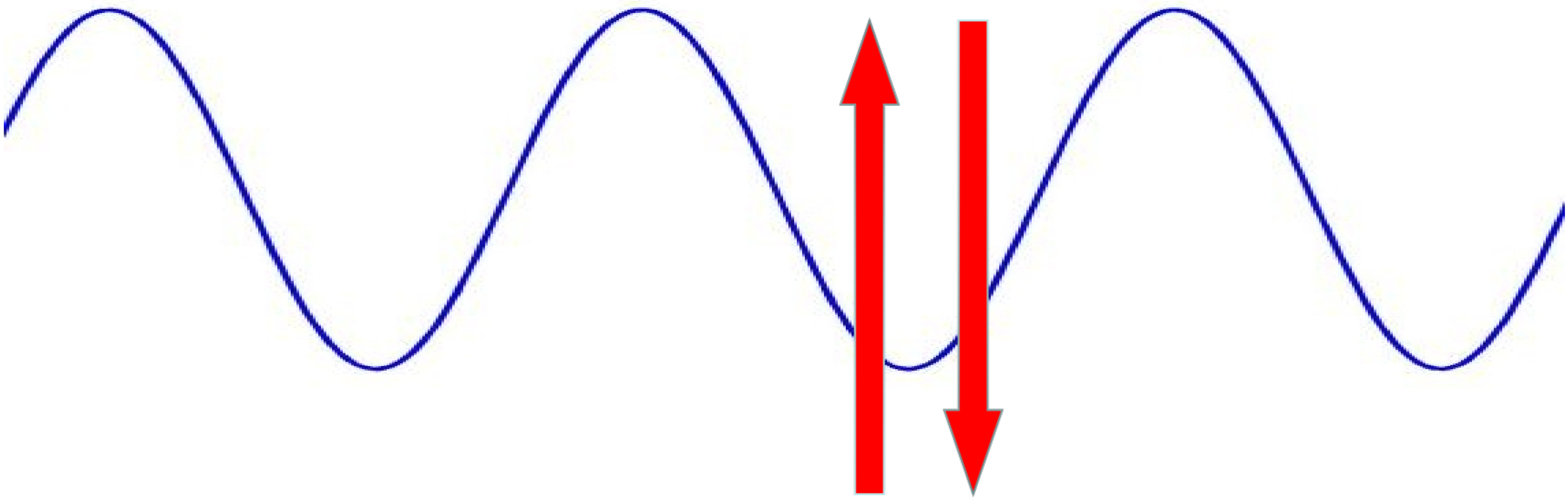
$$Gas\ Flux = \Delta C \times K$$



$\Delta C = C(\text{air}) - C(\text{ocean})$

K = gas transfer velocity (cm/hr)

$$Gas\ Flux = \Delta C \times K$$



Bigger wave slope gives bigger gas transfer velocity, *K*

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Traditional wind speed parameterizations of *K*

Wind speed, U_{10} (m/s)

↓

Short wind waves

↓

Gas transfer velocity, *K* (cm/hr)

Traditional wind speed parameterizations of *K*

Wind speed, U_{10} (m/s)

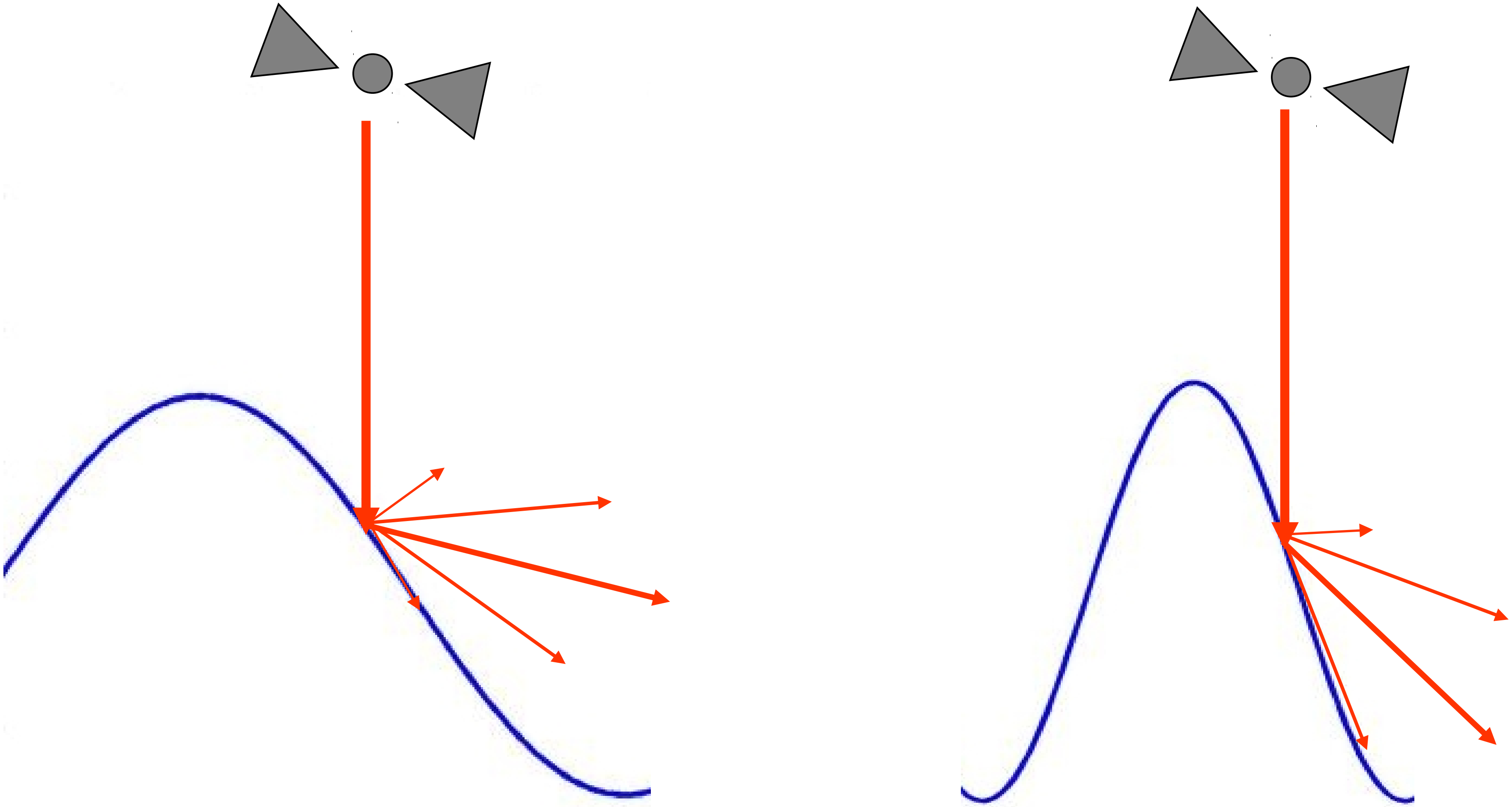
↓

Short wind waves, mean square slope (mss)

↓

Gas transfer velocity, *K* (cm/hr)

measured over the open ocean using satellite altimeters



Gas transfer velocity is inversely related to backscatter coefficient, σ

Data Sources

Ku-band observations from altimeters on board 7 satellites:

ERS-1

ERS-2

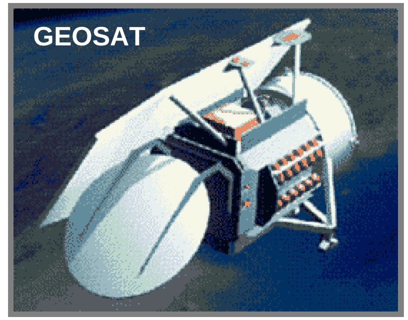
TOPEX-Poseidon

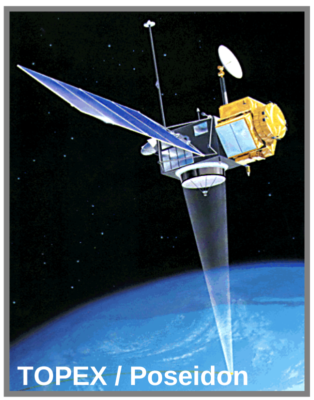
GEOSAT Follow-On

JASON-1

JASON-2

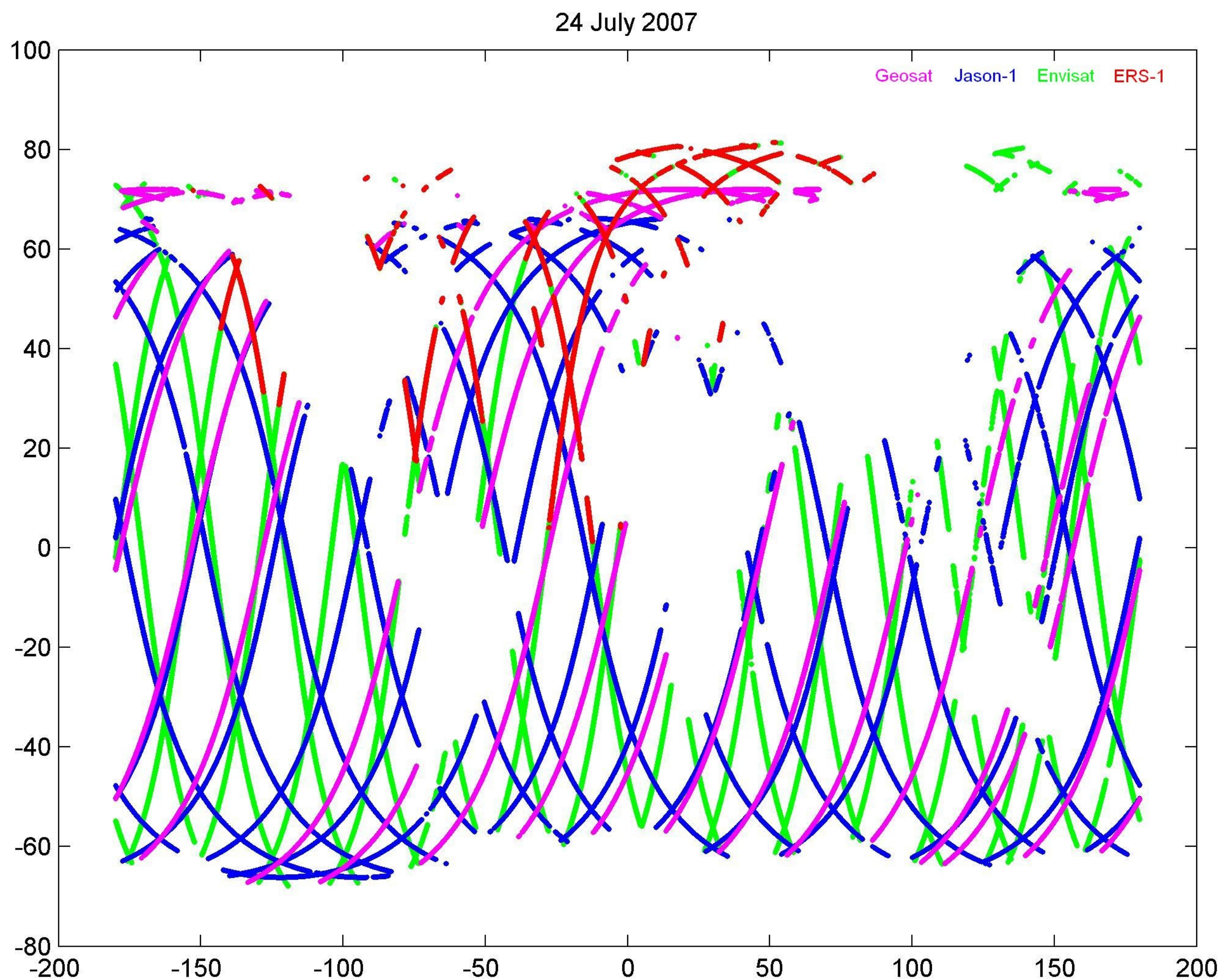
ENVISAT





ftp://ftp.ifremer.fr/ifremer/cersat/products/swath/altimeters/waves

Data Sources



ftp://ftp.ifremer.fr/ifremer/cersat/products/swath/altimeters/waves

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Data Sources

1347 Dimethyl Sulfide (DMS) gas transfer velocity, ***K*** (cm/hr) measurements

UCI

PHASE1

Knorr_06,

Knorr_07

UH

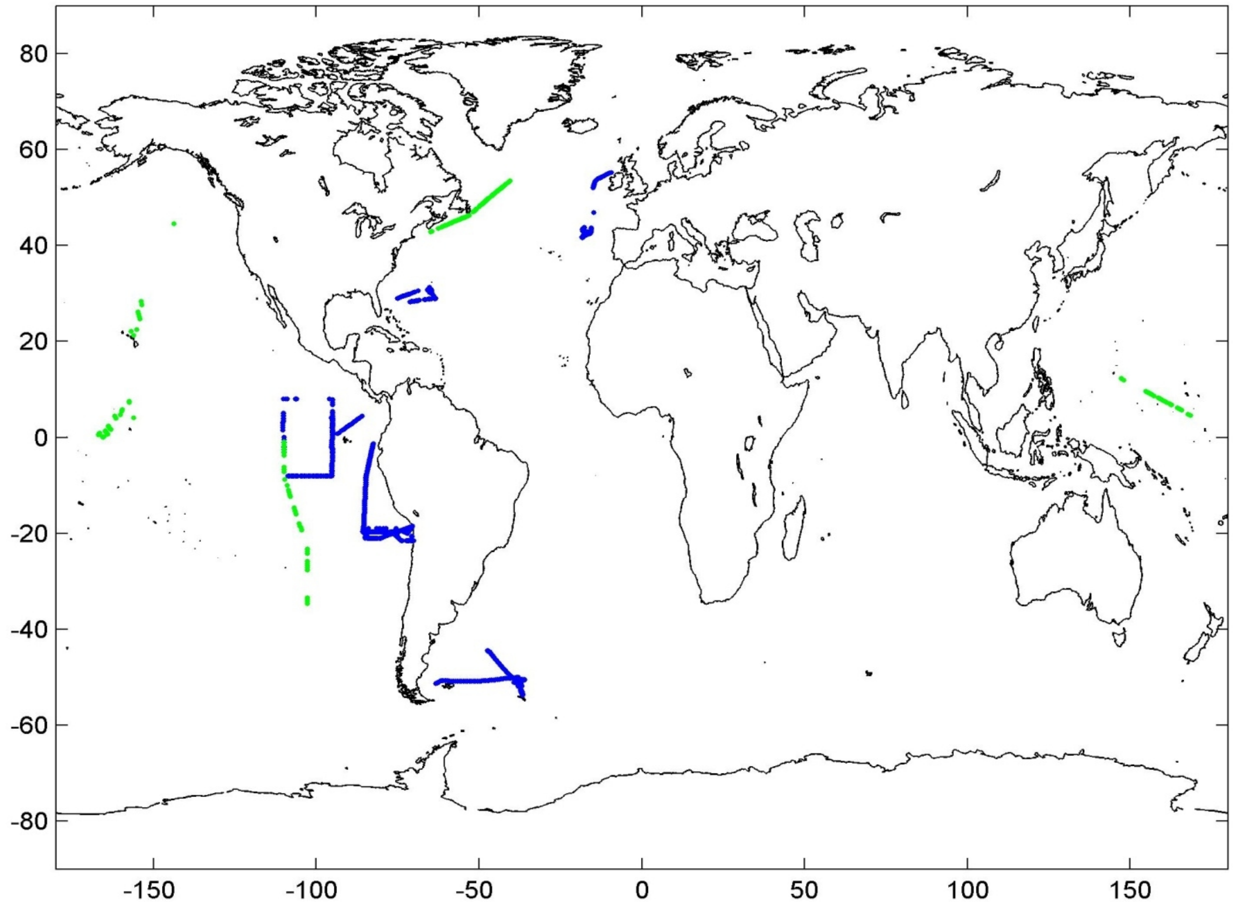
TAO,

BIO,

DOGEE,

SO-GasEx

VOCALS-Rex



Data Sources

179 Matches between altimeter over passes and sample locations

UCI

PHASE1

Knorr_06,

Knorr_07

UH

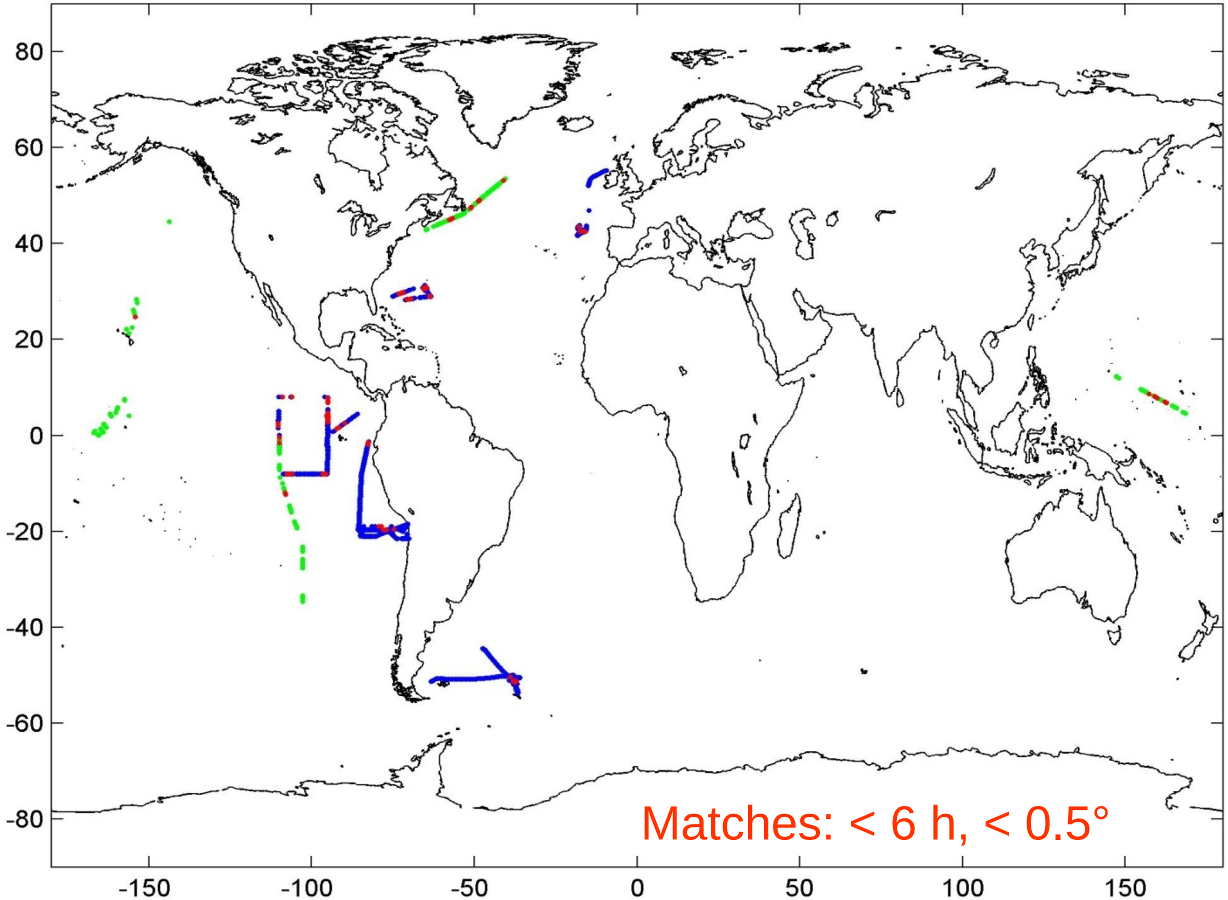
TAO,

BIO,

DOGEE,

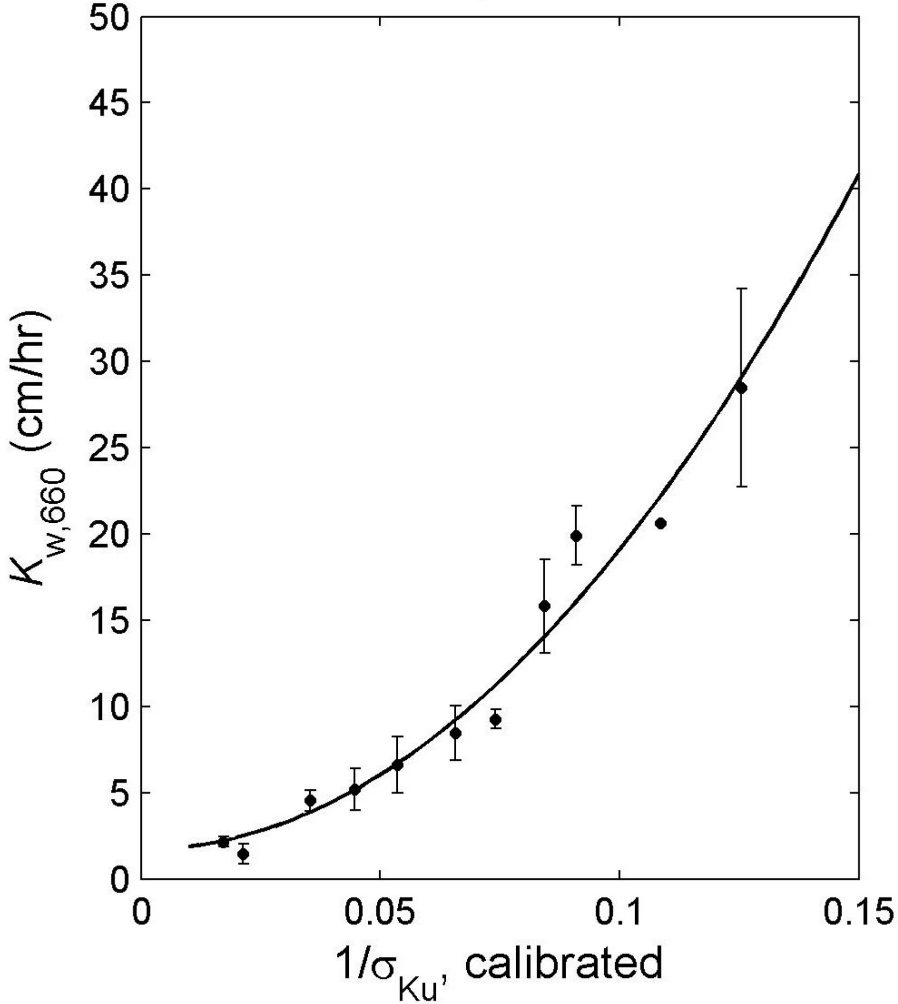
SO-GasEx

VOCALS-Rex



Results

measured in the open ocean



$$K_{w,660} = 0.4 + \frac{1.9 \cdot 10^3}{\sigma_{Ku}^2}$$

(R^2 = 0.52; *RMSE* = 5.0)

Goddijn-Murphy, L., D. K. Woolf, C. Marandino (2012), Space-based measurements of air-sea gas transfer velocities using altimeters.,117(C08028), *J. Geophys. Res*. doi:10.1029/2011JC007535

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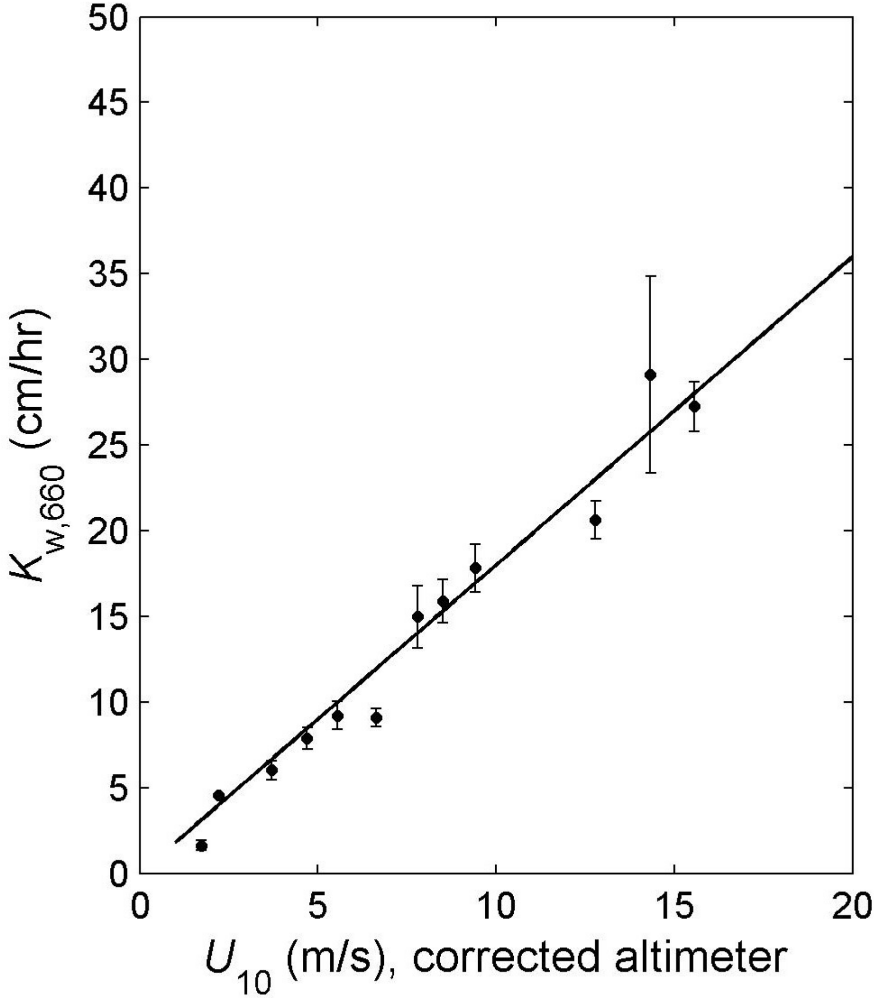
Results

measured in the open ocean



$$K_{w,660} = 2.1 \cdot U_{10,al} - 2.8$$

(R^2 = 0.53; *RMSE* = 4.9)

Goddijn-Murphy, L., D. K. Woolf, C. Marandino (2012), Space-based measurements of air-sea gas transfer velocities using altimeters.,117(C08028), *J. Geophys. Res*. doi:10.1029/2011JC007535

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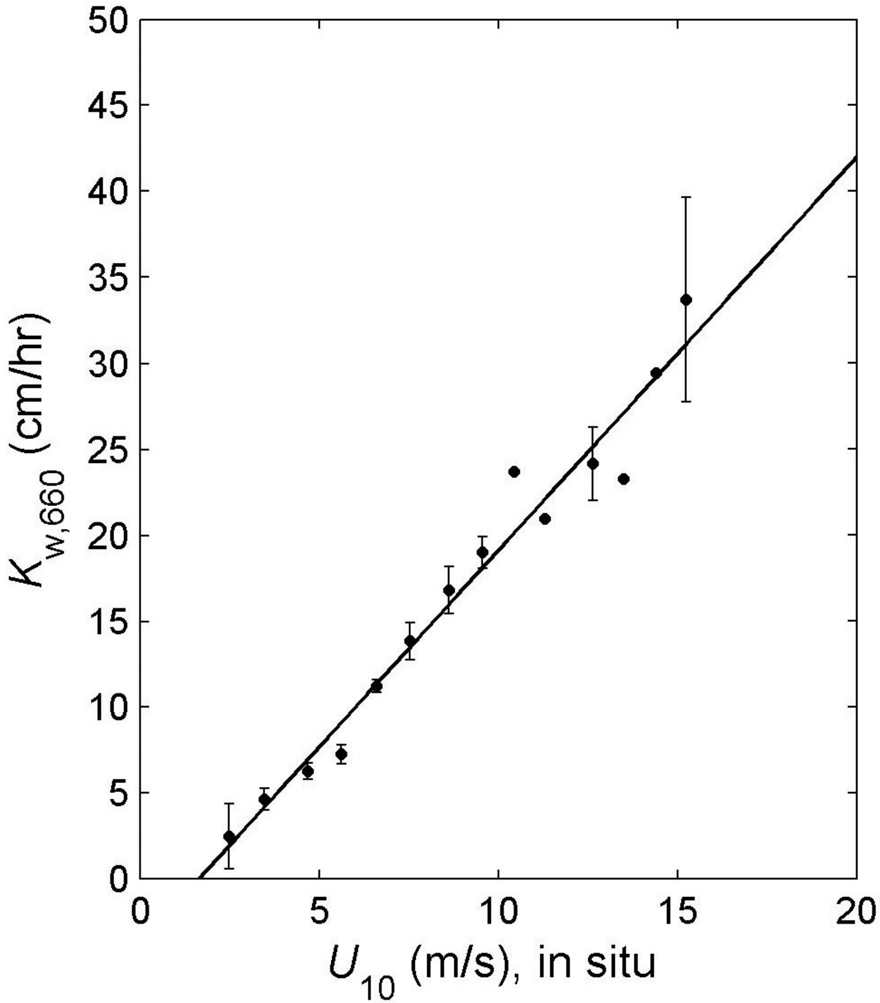
Results

measured in the open ocean



$$K_{w,660} = 2.4 \cdot U_{10,is} - 5.0$$

(R^2 = 0.73; *RMSE* = 3.7)

Goddijn-Murphy, L., D. K. Woolf, C. Marandino (2012), Space-based measurements of air-sea gas transfer velocities using altimeters.,117(C08028), *J. Geophys. Res*. doi:10.1029/2011JC007535

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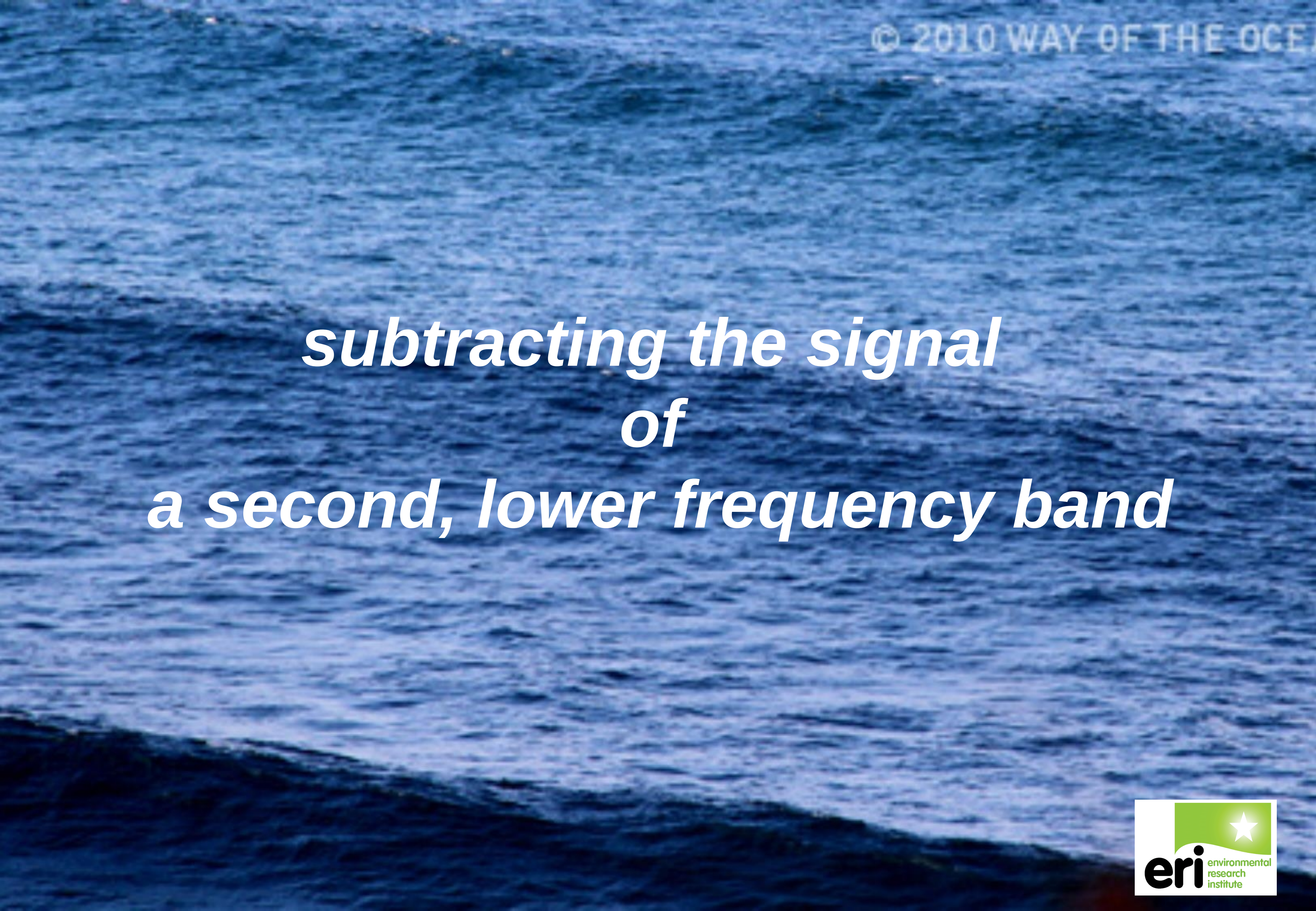
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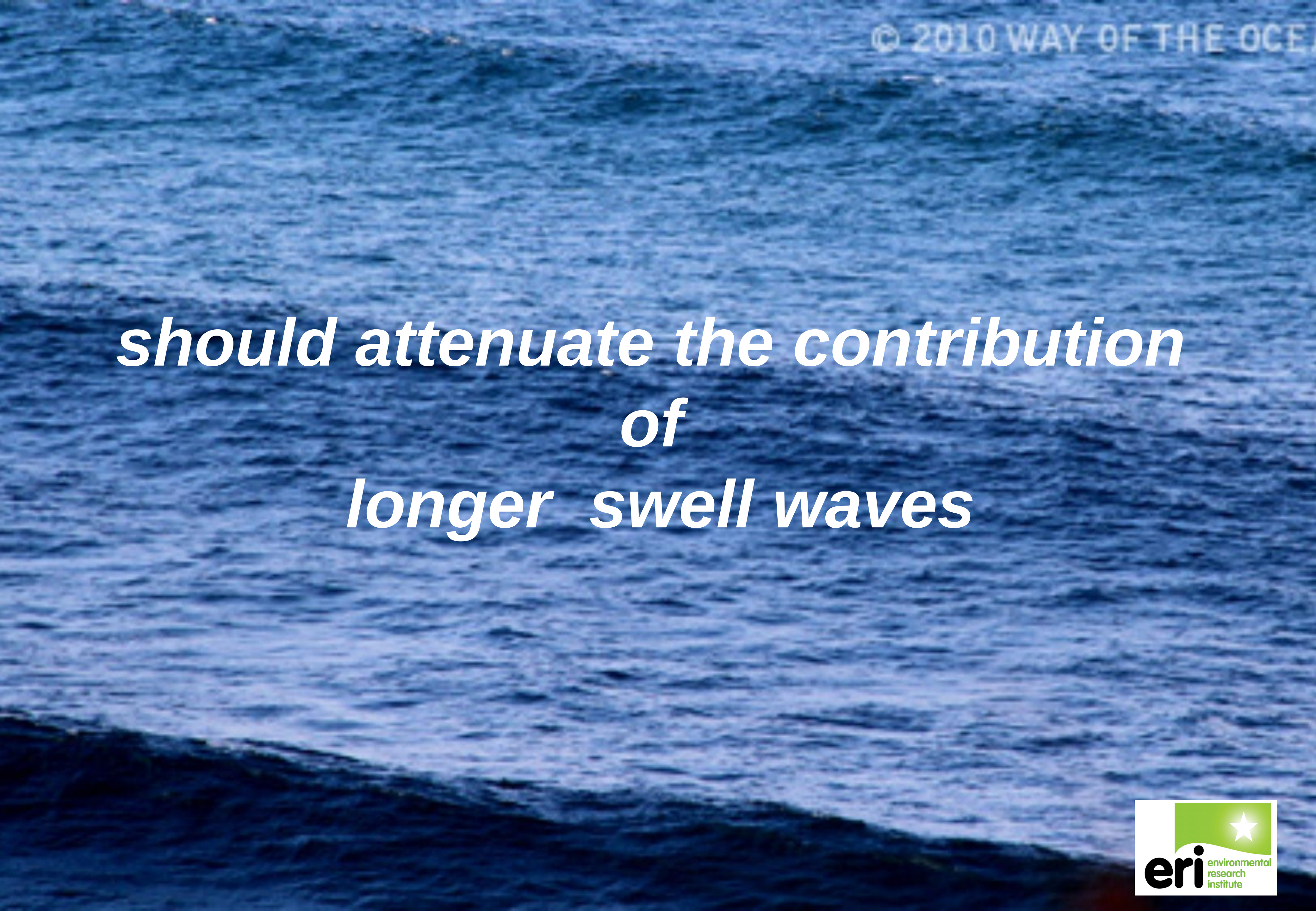
subtracting the signal
of
a second, lower frequency band



should attenuate the contribution of longer swell waves

Data Sources

Ku- and C- band observations from altimeters on board Jason-1 and Jason-2:

Recently C-band data have also become available for Jason 1 and Jason 2

We found 62 matches with DMS sample stations for *dt* <6 hr and *dx* < 0.5º

σ_{Ku}-band: 13.6 GHz; 2.1 cm;100 rad/m

σ_{C}-band: 5.3 GHz; 5.5 cm; 40 rad/m

ftp://ftp.ifremer.fr/ifremer/cersat/products/swath/altimeters/waves

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Parameterizations

Best wind speed	$K_{w,660} = C + AU_{10,is}$	(1)
Best single band	$K_{w,660} = C + \dfrac{A}{\sigma_{Ku}^{2}}$	(2)
Best dual band	$K_{w,660} = C + A\left(\dfrac{1}{\sigma_{Ku}} - \dfrac{B}{\sigma_{C}}\right)$	(3)

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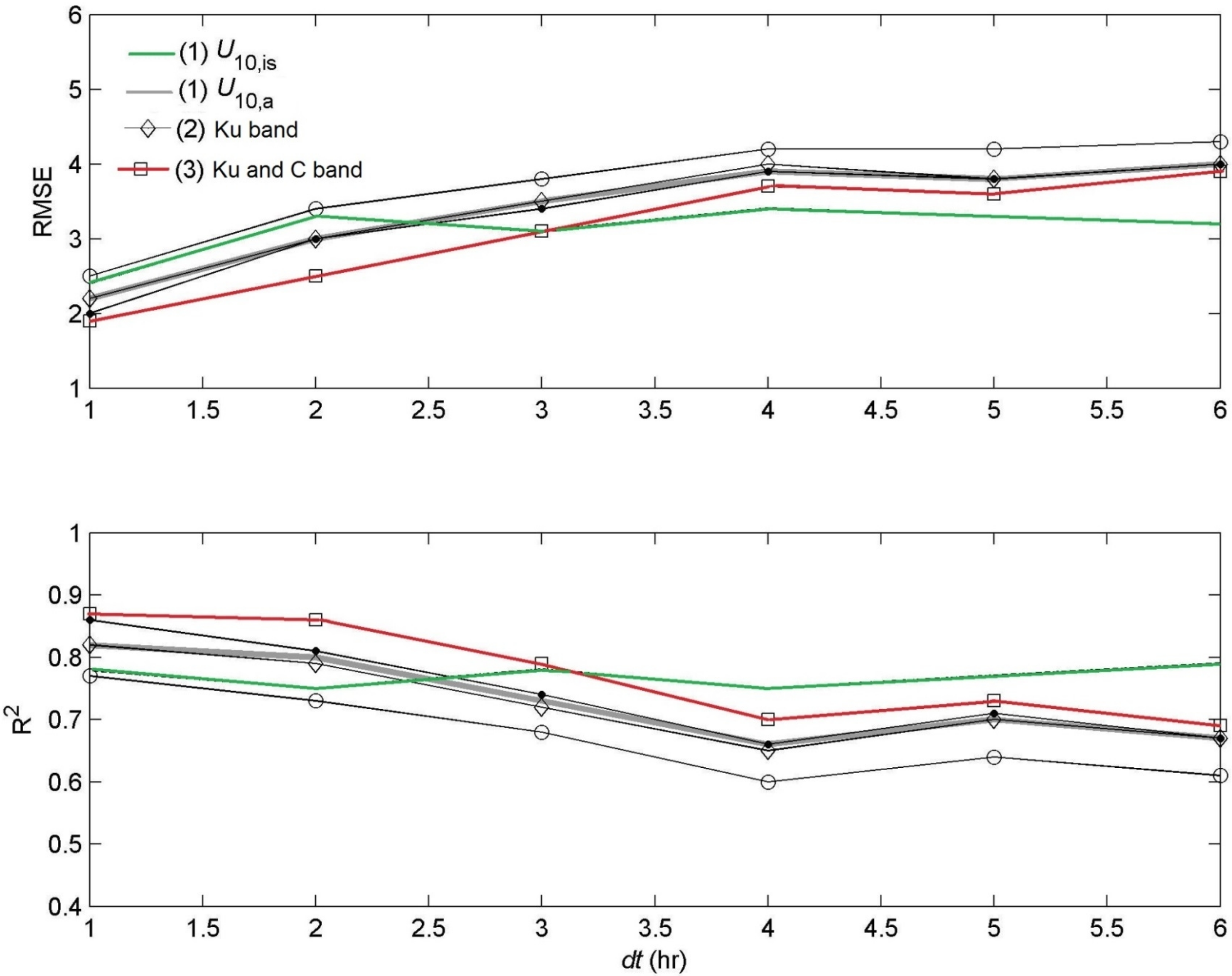
Parameterizations

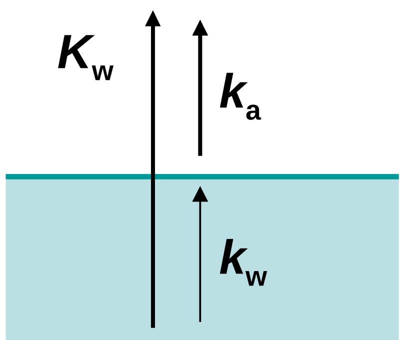


Goddijn-Murphy, L., D. K. Woolf, B. Chapron, P. Queffeulou (2013).” Improvements to estimating the air-sea gas transfer velocity by using dual-frequency, altimeter backscatter.” *Rem. Sens. Env*. 139 1–5, doi: 10.1016/j.rse.2013.07.026

Application to other gases

Measured $\boldsymbol{K_w}$ is total gas transfer velocity

$\boldsymbol{K_w}$ is composite of air-side and water-side gas transfer velocities, $\boldsymbol{k_a}$ and $\boldsymbol{k_w}$

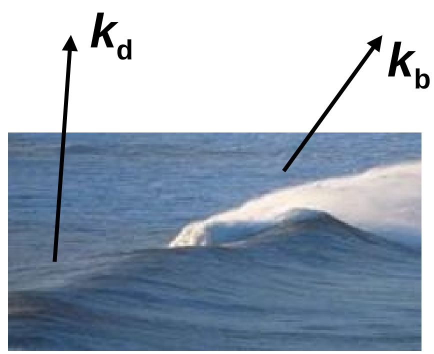


$$\frac{1}{K_w} = \frac{1}{k_w} + \frac{1}{H \cdot k_a}$$

Application to other gases

$\boldsymbol{k_w}$ is water side gas transfer velocity

$\boldsymbol{k_w}$ is the sum of direct and bubble mediated gas transfer, $\boldsymbol{k_d}$ and $\boldsymbol{k_b}$



$$k_w = k_d + k_b$$

Hybrid model (Woolf, 1997)

Application to other gases

Total gas transfer velocity, $\boldsymbol{K_w}$, for DMS

$$\frac{1}{K_w} = \frac{1}{k_w} + \frac{1}{H \cdot k_a}$$

Calculated for DMS
(Johnson, 2010)

$$k_w = k_d + k_b$$

DMS is sufficiently soluble

(Woolf, 1997)

Calibration for K_w for DMS can give us calibration for $k_{d,DMS}$

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Application to other gases

$k_{d,DMS}$ can be converted to k_d of any other gas with Schmidt number Sc

$$k_d = \left(\frac{Sc}{Sc_{DMS}} \right)^{-1/2} k_{d,DMS}$$

$$k_w = k_d + k_b$$

Calibration for k_d can give us calibration for k_w

Application to other gases

$k_{d,DMS}$ was normalized to gas with Schmidt number 660

$$k_d = \left(\frac{Sc}{660}\right)^{-1/2} k_{d,660}$$

$$k_w = k_d + 850 \cdot W$$ (Woolf, 1997)

W is fraction whitecap coverage

W can be derived from models and remote sensing

Application to other gases

For carbon dioxide, CO_2

$$k_w = \left(\frac{Sc}{660}\right)^{-1/2} k_{d,660} + 850 \cdot W$$

$$\frac{1}{K_w} = \frac{1}{k_w} + \frac{1}{H \cdot k_a}$$

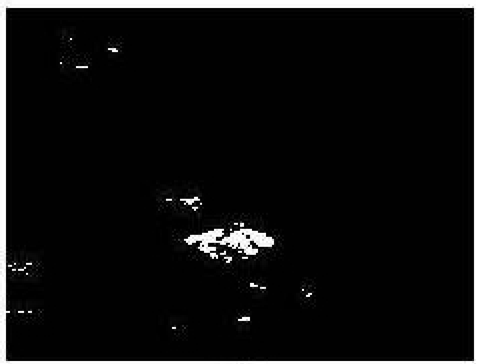
CO_2 is sufficiently insoluble

$K_w \sim k_w$ air-sea gas transfer of CO_2 is limited by water side

Comparison with other k parameterizations

17 — 28 June, 2006 Marine Aerosol Production (MAP) survey in the North East Atlantic

produced 107 fraction whitecap coverage, *W,* and U_{10} measurements



Callaghan, A., G. de Leeuw, L. Cohen, and C. D. O'Dowd, 2008: Relationship of oceanic whitecap coverage to wind speed and wind history. GRL, VOL. 35

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Comparison with other k parameterizations

Using the parameterization with in situ data for CO_2

$$k_d = \left(\frac{Sc}{660}\right)^{-1/2} (2.6 \cdot U_{10,is} - 5.7)$$

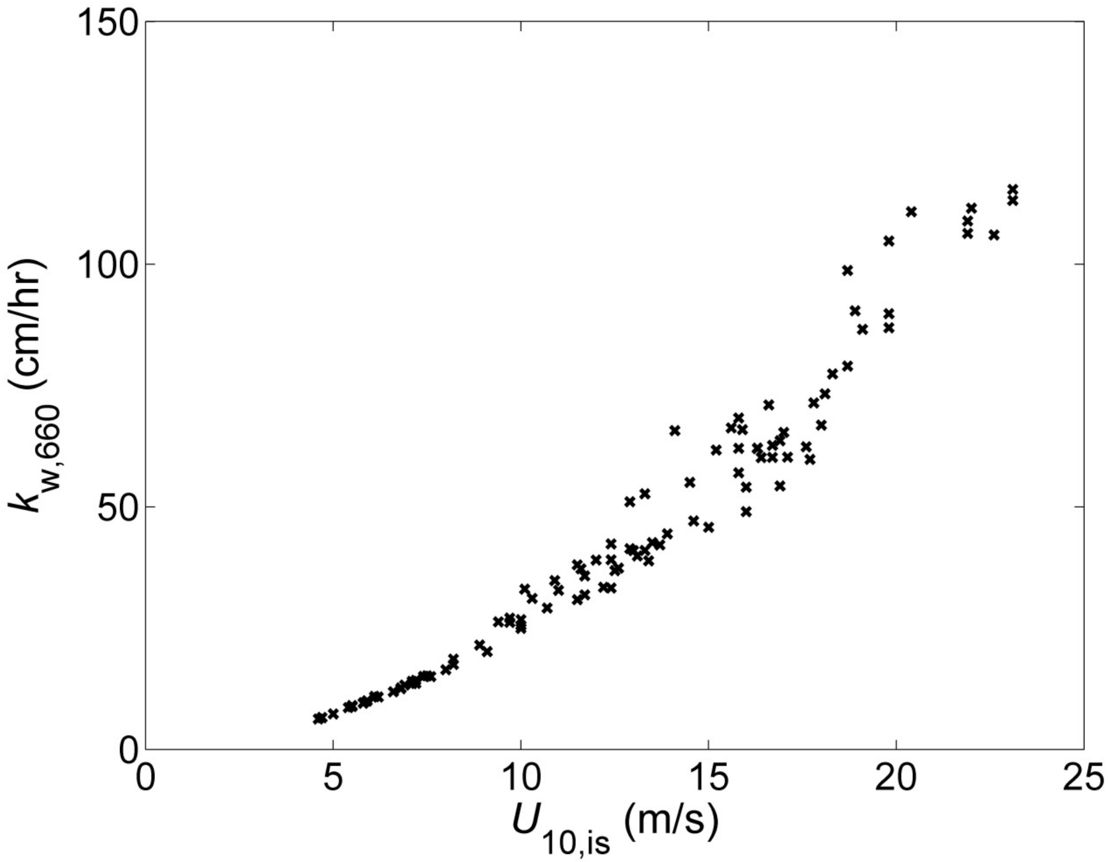
(Goddijn-Murphy et.al., 2012)

$$k_w = k_d + 850 \cdot W$$

(Woolf, 1997)

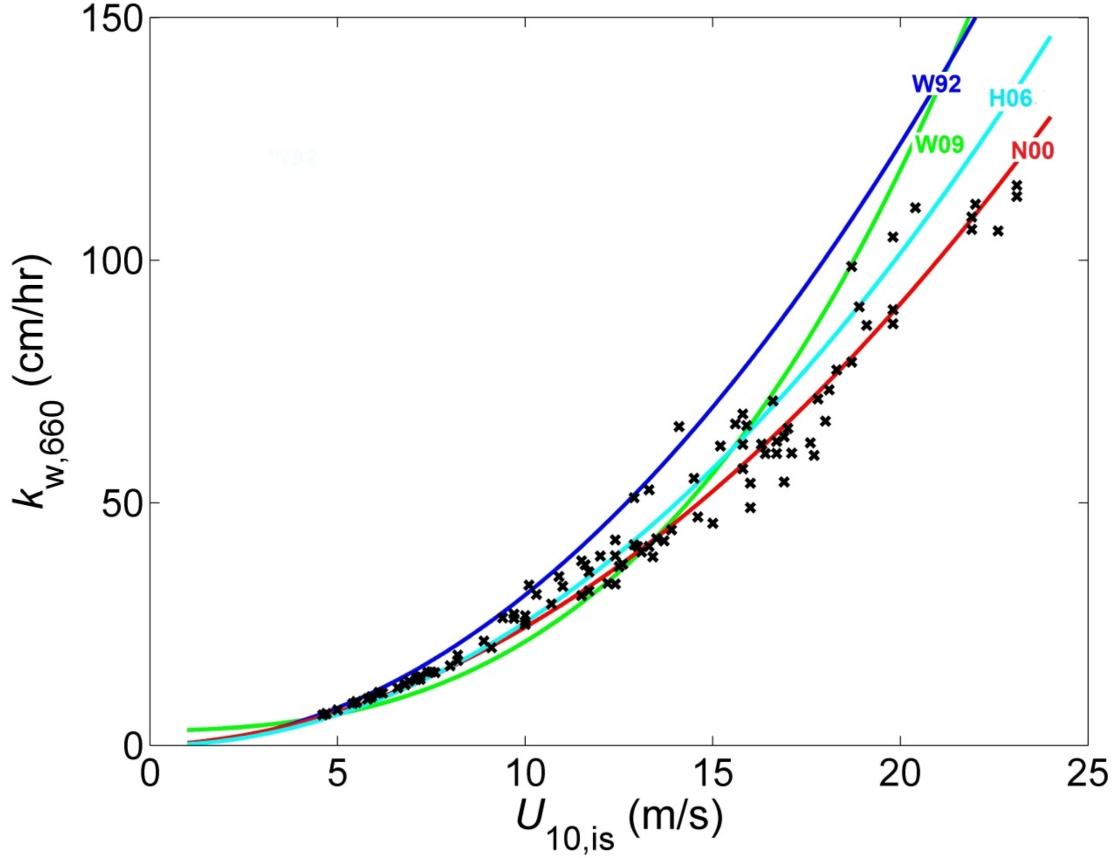
Comparison with other k parameterizations

Water side gas transfer velocity, $\boldsymbol{k}_w$, for CO_2 normalized to Sc = 660



Comparison with other k parameterizations

Water side gas transfer velocity, $\boldsymbol{k}_w$, for CO_2 normalized to Sc = 660



Advantages of measuring K of DMS

DMS is produced in ocean surfaces around the globe

Air-sea concentration difference of DMS is large relative to atmospheric background concentration

Air-sea gradient of DMS is always from the ocean to the atmosphere

All DMS gas transfer is presumably through the unbroken surface

DMS important gas in climate studies (related to cloud formation)

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Bootstrap method

To minimize separation errors, data points with short *dt* were analysed.

Because these data sets were small the **bootstrap method** was applied. The bootstrap method creates synthetic sets of data by random resampling from the original data with replacement.

We created 1000 synthetic data sets using

(a) 16 Data points for which *dt* < 1 hr

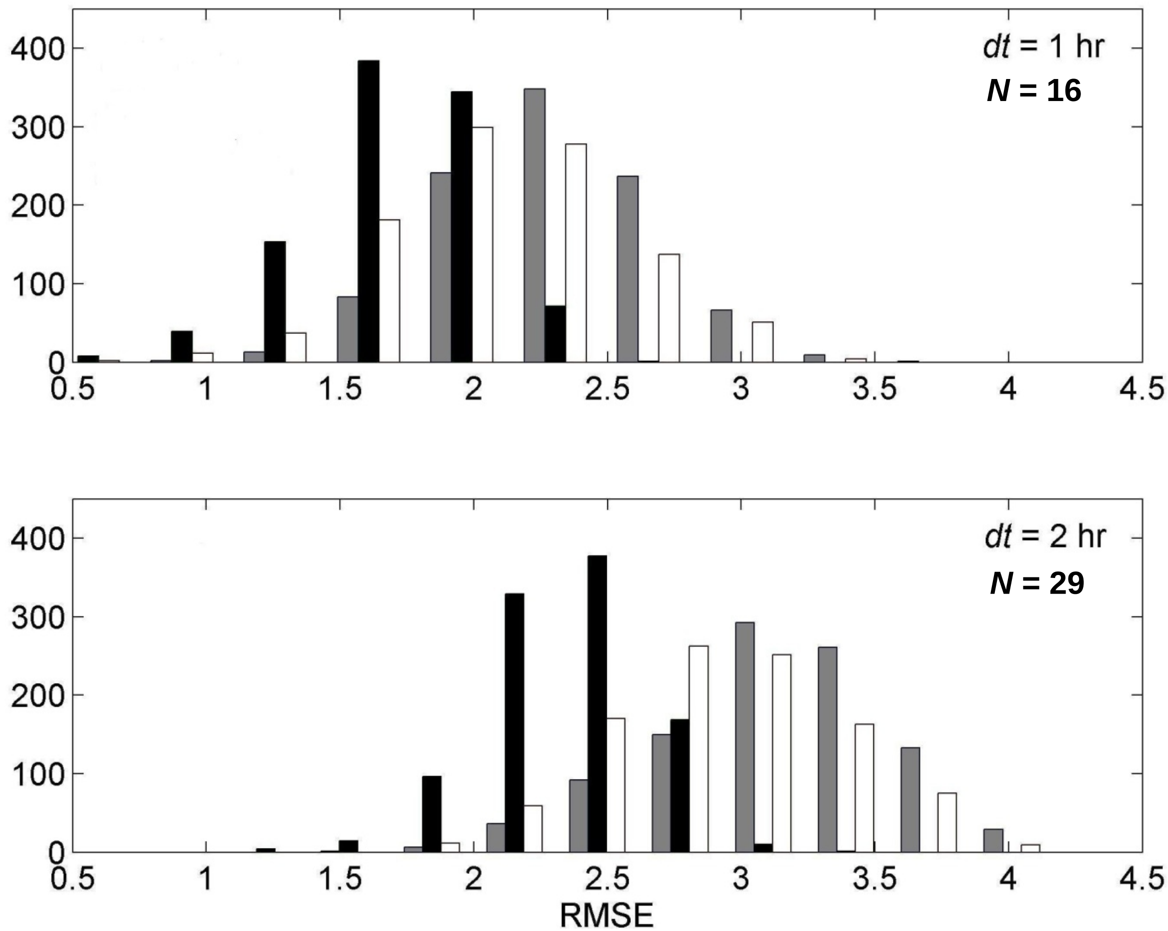
(b) 29 Data points for which *dt* < 2 hr

The RMSE values of the fits for each synthetic data set were calculated for Eqs. 1-3

For small separation errors

Using a 1000 bootstrapped data sets

Histograms of RMSE of the fits to Eqs. 1-3



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Results

Direct gas transfer velocity, $\boldsymbol{k}_{\mathbf{d,660}}$ (cm hr^{-1}), valid for **any gas**

Altimeter $\boldsymbol{\sigma}_{Ku}$

$$k_{d,660} = 2.1\times10^{3}\left(\frac{1}{\sigma_{Ku}}\right)^{2} + 0.1$$

(R^2 = 0.51; *RMSE* = 5.5)

Altimeter $\boldsymbol{U}_{\mathbf{10}}$

$$k_{d,660} = 2.2\cdot U_{10} - 3.2$$

(R^2 = 0.52; *RMSE* = 5.5)

In situ $\boldsymbol{U}_{\mathbf{10}}$

$$k_{d,660} = 2.6\cdot U_{10} - 5.7$$

(R^2 = 0.71; *RMSE* = 4.2)

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