Satellite Estimation of Air-Sea Gas Transfer Velocity during GasEx-3 using QuikSCAT and Jason-1 Microwave Radar Backscatter

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Introduction

During this project we are advancing our scatterometer-based algorithm for estimating air-sea gas transfer velocity (k) from QuikSCAT normalized radar backscatter ($\sigma°$) at 25 km and one day resolution using field data from the GasEx-3 expedition to the Southern Ocean. Our algorithm calculates k from a field-determined, quadratic function of the small-scale wave mean square slope ($\langle s^2 \rangle$). The $\langle s^2 \rangle$, in turn, is calculated from an empirical function of QuikSCAT normalized radar backscatter ($\sigma°$). Our algorithm is calibrated with an altimeter-based $\langle s^2 \rangle - \sigma°$ relationship using co-located QuikSCAT–altimeter $\sigma°$ (Frew *et al.*, 2007). In this phase of our study we seek to fulfill the following objectives: (1) carry out a regional analysis of the spatial and temporal variability of k in the proposed study area, (2) calculate regional, diurnal resolution (four times a day) remote-sensing estimates of k during the field campaign, and (3) use GasEx-3 field measurements of k and surface roughness collected during QuikSCAT (and less frequently, Jason-1) overflights to better constrain the algorithm parameters. An overarching objective of this study is to compare model function parameters optimized with Southern Ocean GasEx field data with those derived from the altimeter-QuikSCAT match-ups in order to strengthen the calibration obtained from the co-located TOPEX and Jason-1 $\sigma°$ and then extend this improvement into the seven-plus years of data overlap between the three satellites. With this internally consistent, wind speed independent, field calibrated time series we will be able to examine the seven-plus year record for evidence of trends and expressions of basin to global scale phenomena (climatic oscillation indices, e.g. ENSO, NAO, *etc.*).

Algorithm

Mean square slope can be estimated from nadir looking altimeters using a geometric optics (specular) scattering model (Brown, 1990; Jackson *et al.*, 1992). We combined estimates of Ku-band (13.6 GHz) and C-band (5.3 GHz) mean square slope to make an estimate of the mean square slope of only a portion (40 ≤ κ ≤ 100 rads/m) of the wavenumber spectrum thought to be intimately linked to gas exchange (Frew *et al.*, 2004) as shown in Eqn 1. Definitions of the symbols used in this poster are given in Table 1.

$$\langle s^2 \rangle_{40}^{100} \approx \Delta\langle s_n^2 \rangle = \langle s_n^2 \rangle_{Ku} - \langle s_n^2 \rangle_C = \frac{\rho_n^{\prime Ku}}{\sigma_{Ku}^{\circ}} - \frac{\rho_n^{\prime C}}{\sigma_C^{\circ} + \alpha}, \quad (1)$$

For each day, on a swath-by-swath basis, we map all of the TOPEX 1 Hz radar returns that fall inside a QuikSCAT wind vector cell (WVC) restricted to be to within ±30 min of each other. Five parameters are estimated from a nonlinear least squares performed with the TOPEX $\sigma°$ providing the $\Delta\langle s^2 \rangle$ information (from Eqn 1) and QuikSCAT providing the $\sigma°$ and φ information of the right hand side of Eqn 2. The resultant parameters are given in Table 2.

$$\Delta\langle s^2 \rangle = p_1 \left(10^{\sigma^{\circ}}\right)^{p_2} [1 + p_3 \cos\varphi + p_4 \cos 2\varphi] + p_5. \quad (2)$$

$\Delta\langle s^2 \rangle$ is then used in Eqn 3 to produce estimates of gas transfer velocity normalized to a Schmidt number of 660 (the Schmidt number of CO_2 dissolved in seawater at 20°C). Frew *et al.* (2004) determined the values of the quadratic relationship parameters C_0 and C_1.

$$k_{CO_2}[T] = \left(\frac{Sc_{CO_2}[T]}{660}\right)^{-0.5} \left(C_0 + C_1(\Delta\langle s_n^2 \rangle)^2\right) \qquad (3)$$

Table 1: Symbol Definitions

Symbol	Definition
Sc	Schmidt number (ratio of kinematic viscosity to molecular diffusivity)
k	Transfer velocity (cm/hr) at Sc=660 (CO_2 in seawater at 20°C)
$\langle s^2 \rangle$	Mean square slope
$\langle s_n^2 \rangle$	Mean square slope derived from nadir looking altimeter
Ku	Designates Ku-band altimeter
C	Designates C-band altimeter
$\langle s^2 \rangle_{40}^{100}$	Mean square slope of the 40–100 rad/m waveslope spectra
$\Delta\langle s^2 \rangle$	Delta mean square slope ($40 \le \kappa \le 100$ rad/m)
$\rho_n^{\prime Ku}$	Effecive Fresnel reflectivity coefficient at Ku-band wavelengths
$\rho_n^{\prime C}$	Effecive Fresnel reflectivity coefficient at C-band wavelengths
σ_{Ku}°	Normalized radar cross section at Ku-band wavelenths (2.1 cm)
σ_C°	Normalized radar cross section at C-band wavelenths (5.5 cm)
α	*ad hoc* calibration adjustment to C-band $\sigma°$ (Chapron *et al.*, 1995)
θ	Angle of incidence (at nadir $\theta = 0°$)
φ	Relative scatterometer azimuth (difference between look and wind directions)
p_i	Parameters of non-linear least square regression of QuikSCAT $\sigma°$ ($i = 1, \ldots, 5$)
C_0, C_1	Coefficients of field determined $k = f(\langle s^2 \rangle^2)$ (Frew *et al.*, 2004)
T	Sea surface temperature (°C)

Table 2: Summary of parameter values QSv1.4.1

	p_1	p_2	p_3	p_4	p_5	n^a	m^b
$\theta = 46°$							
2000	0.11	0.69	0.16	-0.26	1.8e-3	166,763	255
2001	0.11	0.69	0.16	-0.26	1.8e-3	179,167	279
2002	0.10	0.68	0.17	-0.26	1.8e-3	145,214	253
2003	0.10	0.68	0.17	-0.26	1.8e-3	155,735	284
mean[c]/total	0.10	0.68	0.17	-0.26	1.8e-3	646,879	1071
std dev[d]	0.04	0.10	0.05	0.05	4e-4		
$\theta = 54°$							
2000	0.22	0.93	0.10	-0.40	2.3e-3	155,354	249
2001	0.20	0.91	0.09	-0.40	2.2e-3	172,902	269
2002	0.20	0.90	0.10	-0.40	2.3e-3	147,045	267
2003	0.20	0.90	0.10	-0.39	2.2e-3	145,923	271
mean/total	0.20	0.91	0.10	-0.40	2.2e-3	621,224	1056
std dev	0.13	0.18	0.06	0.07	4e-4		

[a] Number of matched pairs
[b] Number of days
[c] There may be some round-off in the least significant digit
[d] Means and standard deviations are based on the entire 4 yr daily time series

Results

All of these results are preliminary as the field data has just returned from the Southern Ocean. However, we present here some highlights to stimulate discussion.

Figure 1 shows one days worth of the global, 25 km transfer velocities. These maps and data will be available at: http://w3eos.whoi.edu/~david/qstrans/QSv1.4.1/daily_img.html

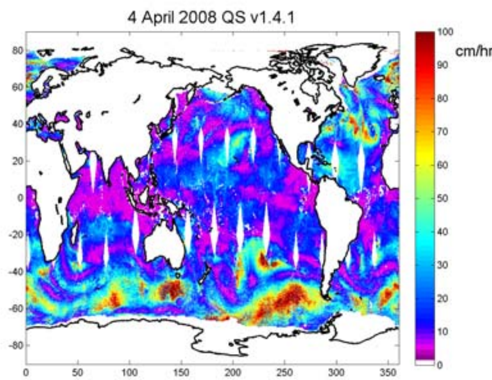

Figure 1: Geographic distribution of a single day (4 Apr 2008) of 25 km, QuikSCAT-derived transfer velocities.

In Fig. 2 we show the four (sometimes five or six) views of the S.O. GasEx study area we are afforded by QuikSCAT in a single day. This level of replication will allow us to explore diurnal variability in k. And in Fig. 3 we present 38 daily images (centered on 1500 UTC) of the S.O. GasEx field experiment. This data will help us characterize the spatial variability of k in the S.O. GasEx study area.

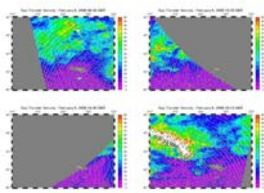

Figure 2: Four views of the GasEx-3 study area on 6 Feb 2008 (0850, 1029, 1836 and 2014).

In Fig. 4 we present the daily transfer velocities co-located with ship positions of the NOAA ship R.H. Brown provided by the NOAA ship tracker (http://shiptracker.noaa.gov/). Also provided at this web page is wind speed and direction, which we use as an index of convenience for plotting the QuikSCAT derived transfer velocities for comparison to Wanninkhof (1992) and Wanninkhof and McGillis (1999) two commonly used wind-speed parameterizations.

Daily Transfer Velocities during S.O. GasEx

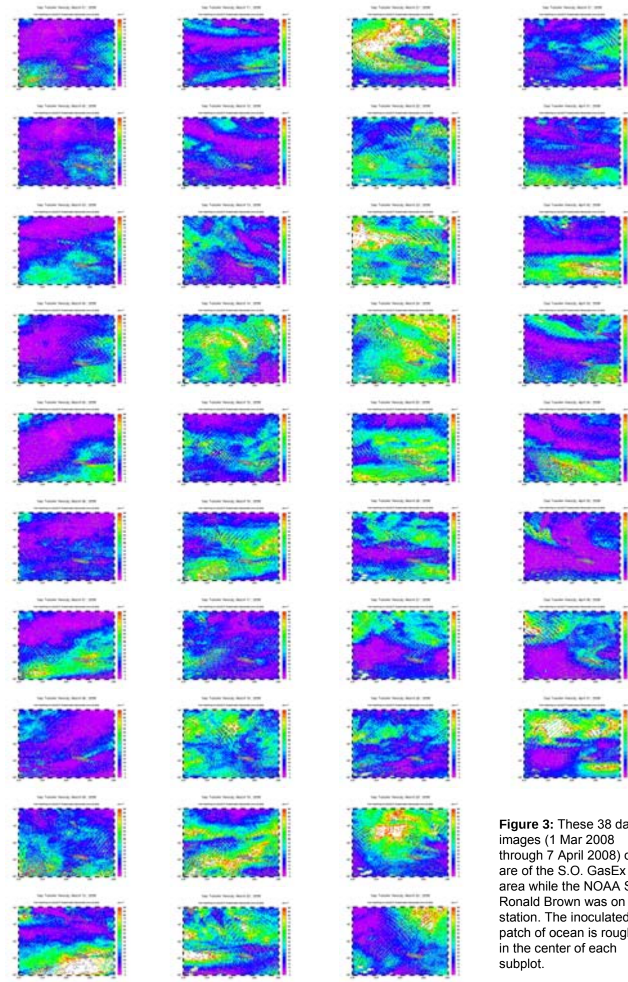

Figure 3: These 38 daily images (1 Mar 2008 through 7 April 2008) of k are of the S.O. GasEx field area while the NOAA Ship Ronald Brown was on station. The inoculated patch of ocean is roughly in the center of each subplot.

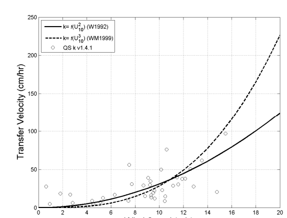

Figure 4

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