Estimation of air-sea gas transfer using Jason-1 dual-frequency normalized backscatter

N.M. Frew [1], D.M. Glover [1], E.J. Bock [2]
[1] (Woods Hole Oceanographic Institution, USA)
[2] (University of Heidelberg, Germany)

The exchange rates of climatically important gases between the ocean and the atmosphere are determined from altimeter estimates of the roughness of the ocean surface. The intensity of backscattered microwave, radiation at two different wavelengths is used to measure the slope or steepness of the small-scale ocean waves that promote gas exchange and to derive monthly global maps of air-sea exchange rates and a multiyear climatology.

Introduction

Gas exchange flux is calculated from the product of a concentration gradient across the air-water interface and the exchange coefficient or transfer velocity representing a parameterization of a combination of important near surface exchange mechanisms. We refer to *k* as the transfer velocity (cm/h) and this is the parameter discribing the important near surface exchange mechanisms. Transfer velocity fields are predicted by various parameterizations based on wind speed [Liss and Merlivat, 1986; Wanninkhof, 1992; Nightingale et al., 2000] and lead to widely varying estimates of zonal and global net CO_2 flux. These are not sufficiently constrained to validate global climate change models, which suggest a global uptake of 2±0.8 GtC/yr, or to shed light on the apparent “missing sink” for anthropogenic CO_2 (1.6 GtC/yr). The uncertainty is a significant fraction of the total annual 3.5 GtC uptake by non-atmospheric sinks [Johnson, 1995]. Thus, the Intergovernmental Panel on Climate Change (IPCC, 1996) has identified uncertainty in the gas exchange coefficient as a significant limitation in assessing the role of the ocean in absorbing anthropogenic CO_2 and has called for increased study of its global spatial and temporal variations in order to help close the global carbon budget. What is needed, then, is a direct measurement of the surface roughness expressed by the small gravity-capillary wave portion (the gas-exchange-active portion) of the surface wave spectrum.

The goal of this project is to develop an algorithm for estimating air-sea gas transfer velocities using the dual-frequency Jason-1 altimeter. The approach is based on parameterization of the gas transfer velocity (*k*) using normalized radar backscatter as a direct measure of sea surface roughness due to small-scale waves. The small scale waves (order of 6 to 16 cm wavelength) have an overall average slope (mean square slope: $\langle s^2 \rangle$) that is a robust predictor of *k*. This mean square slope can be estimated from nadir-looking microwave backscatter, such as that returned by altimeters like the instrument on Jason-1. Since k is linearly related to $\langle s^2 \rangle$ and $\langle s^2 \rangle$ is inversely related to backscatter, we have a basis for an algorithm to derive *k* from the backscatter measured by altimeters. The differential scattering of the dual frequency altimeter (Ku- and C-band) allows us to isolate the contribution of small-scale waves to mean square slope and gas transfer. The algorithm is used to construct monthly global maps of CO_2 transfer velocity, to estimate seasonal transfer velocity variations, and from a lengthly time series of satellite data produce a climatology of *k*.

Results

Our work prior to the Jason-1 launch has focused on development of the algorithm using the extended

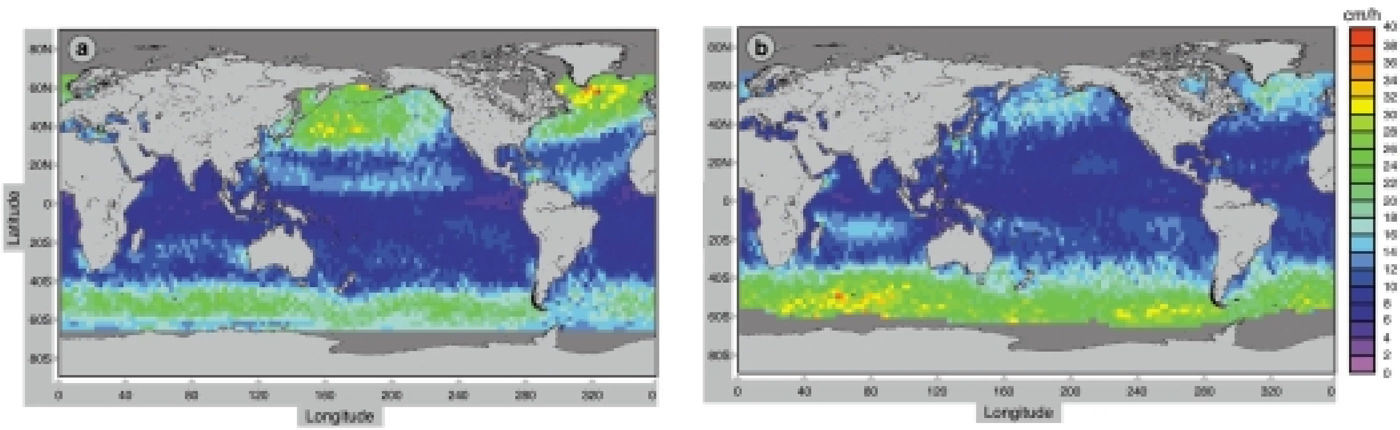

Figure 1: Averaged global monthly maps of gas transfer velocity (k_{660}) in cm/h for the six year period January, 1993 – December, 1998, computed on a 2.5 x 2.5 degree grid from the TOPEX/POSEIDON Merged GDR Gen. B: a) February and b) September.

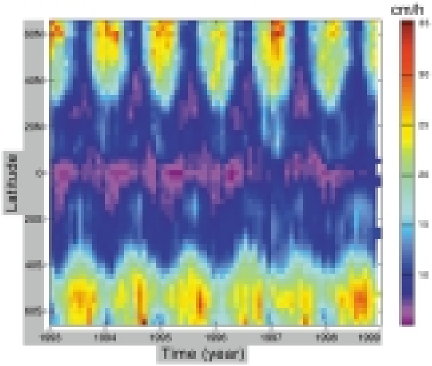

Figure 2: Monthly zonal average time-series for the period January, 1993 – December, 1998 (cycles 11-232) of TOPEX-derived gas transfer velocity (k_{660}) computed on a 2.5 x 2.5 degree grid. Values are in units of cm/h for Schmidt number S*c*=660 (S*c*=660 for CO_2 at 20°C in seawater). The minimum value (the darkest purple) is approximately 5 cm/h.

TOPEX/POSEIDON altimeter record. The feasibility of calculating gas transfer velocity directly from altimeter estimates of sea surface roughness presents a unique opportunity to look at seasonal and interannual variability in the transfer velocity field. Using the extended TOPEX/POSEIDON MGDR-B data set, we have produced a six year time series (1993-1998) of TOPEX data processed into gas transfer velocity and have examined the variability of these results in space and time. The seasonal and interannual variability of the regional patterns yield insight into the sensitivity of the altimeter-based gas transfer velocity to phenomena such as ENSO. We have also compared the results of this time series to similar time series created through the application of more traditional wind speed-gas transfer velocity parameterizations to the wind speed estimates made by the National Center for Environmental Prediction reanalysis project for the same period.

From Jan. 1993 to Dec 1998, we have computed gas transfer velocity k_{660}. The transfer velocities are normalized to Schmidt number S*c* = 660, the value for CO_2 in seawater at 20°C, in order to remove temperature effects and facilitate comparison with other parameterizations. Global climatological gas transfer velocity fields for the months of February and September are shown in figure 1, representing the seasonal extremes in the Northern and Southern Hemispheres.
The backscatter-derived k_{660} fields are shown in figure 2 as the zonal averages. The overall pattern of seasonal variation is clearly seen in figure 2, with the maximum transfer velocities in each hemisphere's corresponding wintertime. Additionally there is an anti-correlated period of low to very low transfer velocities along the equator. At mid-latitudes (20° - 40°N) there is a period of low transfer velocities developing each year in summertime. A similarly low austral summertime low, zonally averaged, transfer velocity does not appear in any year in the 20° - 40°S zone. Additionally, early 1997 has the highest zonally averaged transfer velocities in the northern subpolar region.
The extremely low zonal averages along the equator are interrupted during two periods: late winter-early spring in 1997 (El Niño) and in late autumn-early winter in 1998. Except in the eastern equatorial Pacific, the El Niño signal is not apparent over most of the globe in the zonal averages.

The data of figure 2 have been collapsed into a time series climatology, shown in figure 3a. Averaged over the six years, the pattern of higher transfer velocities poleward displays an asymmetry, highest between 50° - 60°S. This is not surprising since at those latitudes the fetch is greatest. To the north, land intervenes, and to the south the seasonal ice-pack covers the air-sea interface. We have further processed the data to produce a time series of the monthly global average transfer velocities shown in figure 3b. Treating both hemispheres together smooths out the seasonal pattern mentioned in figure 2. However, starting in mid-1996 there is a distinct increase in the global average transfer velocity peaking in January, 1997, approximately two to three months before the generally recognized beginning of the last El Niño.
After decreasing later in 1997, the transfer velocities in 1998 return to a value higher than the average obtained from the 1993-1995 period.

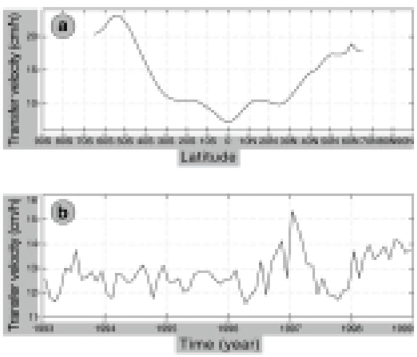

Figure 3: Recomputing figure 2 as a global climatology yields in a) the average zonal transfer velocities over the time series 1993-1998 and b) the global monthly average transfer velocities. Note that in b) both hemispheres are averaged together, thus smoothing out the seasonal cycle.

References

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**Corresponding author:
Nelson M. Frew
Department of Marine Chemistry and Geochemistry
Woods Hole Oceanographic Institution
360 Woods Hole Rd. Mail Stop 4, Woods Hole, MA 02543-1543 - USA
E-mail: nfrew@whoi.edu**