Improved Estimates of Gas Transfer Rates from Dual-Frequency Altimeter Backscatter

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ABSTRACT

Global and regional estimates of ocean-atmosphere gas fluxes are limited by the uncertainties in current gas transfer velocity parameterizations. These model functions use wind as the sole forcing factor. However, many other factors, including boundary layer stability, variable fetch and surfactant films strongly affect exchange rates. We describe improvements to an algorithm for estimation of transfer velocity using altimeter backscatter, including improved data filtering, optimization with field data, and initial estimates of the accompanying error field.

PROJECT OVERVIEW

The goal of this project is to develop an algorithm for estimating air-sea gas exchange rates using the dual-frequency TOPEX/Poseidon 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 mean square surface slope for waves in the gravity-capillary region of the slope spectrum is a robust predictor of transfer velocity. Mean square slope can be estimated from nadir-looking microwave altimeters using a geometric optics specular scattering model and is inversely related to the normalized backscatter [Jackson *et al.*, 1992]. The differential scattering of the Ku-band and C-band pulses allows us to isolate the contribution of small-scale waves to mean square slope and gas transfer. A mean square slope for the nominal wavenumber range 40-100 rad/m is derived and combined with an empirical relationship between mean square slope and transfer velocity to yield our estimates of *k* as

$$k = C_0 + C_1 \left[\frac{r'_{Ku}}{s^o_{Ku}} - \frac{r'_C}{\left(s^o_C + a\right)} \right] \quad \textbf{(1)}$$

where r'_{Ku} and r'_C are effective reflectivities, $s_{Ku}{}^o$ and $s_C{}^o$ are Ku-band and C-band normalized backscatter coefficients, a is an *ad hoc* adjustment to $s_C{}^o$ and $\boldsymbol{C_0}$ and $\boldsymbol{C_1}$ are constants evaluated from the relation between gas transfer velocity and differenced mean square slope. The parameters for estimating the differenced mean square slope are optimized using *in situ* optical slope estimates. The empirical relation between gas transfer velocity and differenced mean square slope is derived from field and laboratory measurements of gas flux and optical slope. The algorithm is used to construct monthly global maps of CO_2 transfer velocity and to estimate seasonal transfer velocity variations.

METHODOLOGY

- Extract $s_{Ku}{}^o$ and $s_C{}^o$ from TOPEX/Poseidon MGDR-B using standard data quality flags and correct for atmospheric attenuation [PO.DAAC, 1997].
- Apply rain flag criterion of Tournadre and Morland [1997] to eliminate data impacted by rain events.
- Apply land and ice filters using high resolution elevation data and monthly average SSM/I 0% ice coverage.
- Compute k from Equation 1, taking $r'_{Ku} = 0.38$, $r'_C = 0.48$ $a = +0.6$. The constants $\boldsymbol{C_1} = 7 \times 10^3$ and $\boldsymbol{C_0} = 0.0$ were estimated from wind-wave tank data [*Bock* et al., 1999].
- Bin data spatially into 2.5°x2.5° grid cells and average to give monthly mean values.

(Ku - C) MEAN SQUARE SLOPE

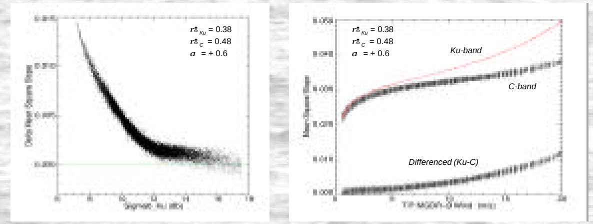
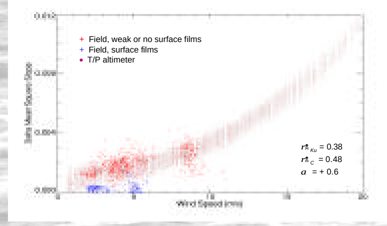


FIGURE 1. The differenced altimeter response ($r'_{Ku}/s_{Ku}{}^o$ - $r'_C/s_C{}^o$) was assumed to be proportional to the mean square slope computed over the wavenumber interval 40-100 rad/m, corresponding to the specular scattering cutoff wavenumbers for Ku- and C-band. Model parameters were adjusted to satisfy the condition that the differenced mean square slope should approach zero for total calm or glassy sea conditions ('sigma0 bloom' conditions, $s_{Ku}{}^o$ > ~17 dB; Hancock, 1999).

FIELD OBSERVATIONS OF SMALL-SCALE WAVES

FIGURE 2. Field measurements of small-scale waves were made during the July, 1997 NSF-CoOP experiment southeast of Cape Cod. The study area covered a wide range of biological productivity as shown by the July climatological CZCS chlorophyll distribution (left). The air-sea interaction research catamaran LADAS (center) carried a suite of instruments to measure wind stress, wave slope, and surface chemical enrichments. A scanning laser slope gauge (right) recorded 3-D frequency-wavenumber spectra (25-1200 rad/m).

FIGURE 3. Comparison of field mean square slope estimates (40-100 rad/m) with a typical one-month block of T/P differenced (Ku-C) mean square slope as a function of wind speed with model constants r'_{Ku}= 0.38, r'_C = 0.48 and a =0.6. Field data are plotted against shipboard wind speeds. T/P differenced mean square slope is plotted as a function of altimeter wind speed



[Witter and Chelton, 1991]. Red crosses represent slope measurements at stations where surface films were weak or absent. Blue crosses represent areas with significant surface film enrichments or coherent slicks. The bulk of the 'clean water' values, representing a variety of surface conditions in low to moderate winds, overlie the T/P data reasonably well. The 'filmed' cases do not, emphasizing the discrepancy between anemometer and 'roughness' winds.

GAS TRANSFER VELOCITY FIELDS

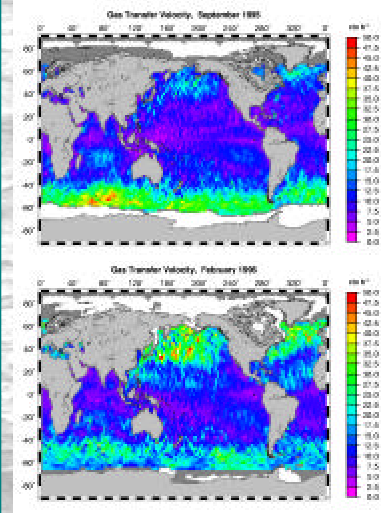


FIGURE 4. Global monthly fields of gas transfer velocity (*k*) on a 2.5° x 2.5° grid for September, 1995 (upper) and February, 1996 (lower) derived from the improved T/P algorithm. Values in units of cm/hr for Schmidt number, Sc = 660. (Sc = 660 for CO_2 in seawater at 20°C).

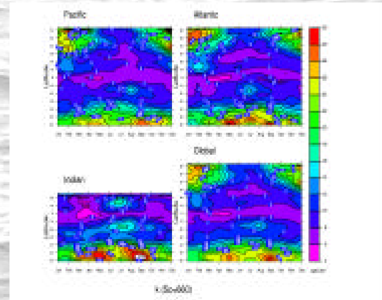


FIGURE 5. Zonally-averaged seasonal variations in gas transfer velocity (k_{660}) for the Pacific, Atlantic, and Indian Oceans, and the global ocean over an annual cycle with linear interpolation between months. Strong seasonal variations are observed in the N. Pacific, N. Atlantic, and northern Indian Oceans. Pronounced seasonal fluctuations are also observed in the south central Indian Ocean and in the southern ocean. The highest zonal average transfer velocities occur between 45°-60° in both hemi-spheres, attaining values > 32 cm/hr. The lowest zonal averages (4-8 cm/hr) are observed in the equatorial regions throughout the year and particularly during March-May.

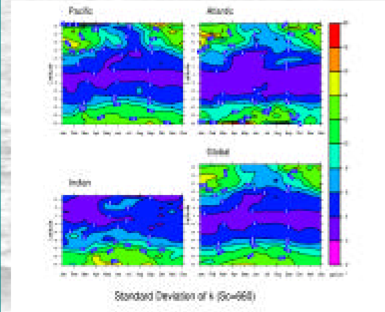


FIGURE 6. Estimated error fields for k_{660} shown as the square root of the zonally-averaged, seasonal variances in cm/hr. Error is determined mainly by binning on the 2.5° x 2.5° grid. Individual grid cells typically contain 100-300 data points, with extremes as low as 25 in the equatorial regions and as high as 500 in polar regions. The tropical to subtropical regions have consistently low relative standard deviations while the subpolar regions have the highest.

CONCLUSIONS

- T/P estimates of mean square slope in the wavenumber range 40-100 rad/m are in close agreement with field measurements.
- The adjusted model produces *k* fields generally consistent with the Liss and Merlivat [1986] formulation but lower than that of Wanninkhof [1992].
- The revised algorithm produces lower, more realistic gas transfer estimates in equatorial regions than the previous version.
- Previously observed anomalously high transfer velocities due to precipitation are effectively eliminated by use of the Tournadre-Morland rain flag.
- The largest source of error is uncertainty arising from the data binning scheme dictated by altimeter spatial and temporal coverage.

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