AN EMPIRICAL ESTIMATE OF THE SOUTHERN OCEAN AIR-SEA CO_2 FLUX

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ABSTRACT

A discrepancy exists between current estimates of the Southern Ocean air-sea flux of CO_2. The most recent estimate using a combination of direct and climatologically-derived pCO_2 measurements [*Takahashi et al*., 2002] (herein referred to as T02) suggests a Southern Ocean CO_2 sink that is nearly two times greater that that suggested from general circulation models, atmospheric inverse models [*Gurney et al.,* 2002] and oceanic inverse models [*Gloor et al.*, 2003]. Here we employ an independent method to estimate the Southern ocean air-sea flux of CO_2. Our method exploits all available surface measurements for Dissolved Inorganic Carbon (DIC) and total alkalinity (ALK) from 1986 to 1996. We show that surface age-normalized DIC can be predicted to within ~8μmol/kg and ~10μmol/kg for ALK using standard hydrographic properties, independent of season. The predictive equations are used in conjunction with World Ocean Atlas (2001) climatologies to estimate an annual cycle of DIC and ALK, while the pCO_2 distribution is calculated using standard carbonate chemistry. For consistency we use the same gas transfer relationship and wind product from *Takahashi et al*, [2002] however, we include the effects of sea-ice. We estimate a Southern Ocean CO_2 sink (>40°S) of -0.19±0.26 Pg C for 1995. Our estimates are smaller than those estimated by *Takahashi et al,* [2002], but consistent with atmospheric / oceanic inverse methods, general circulation models and provides further evidence that the Southern Ocean CO_2 sink in relation to its oceanic surface area, is moderate on a global scale.

DATA AND METHODOLOGY

Our methodology to estimate the air-sea CO_2 flux in the Southern Ocean follows a stepwise procedure. We firstly develop a predictive empirical relationship for DIC and ALK that uses all available carbon measurements over the past two decades where DIC has been normalized to a common year (1995) using CFC measurements. A step-wise linear least squares regression for surface DIC and ALK was conducted using various independent parameters as predictors. The regression equation for DIC is represented by:

$DIC_{obs} = \alpha_0 + \sum_{i=1}^{n} \alpha_i P_i + \varepsilon$, where α_i are the partial regression coefficients for n number of independent parameters (P_i) and α_0 is the y-intercept. The independent parameters were varied to investigate the influence of each on the DIC prediction. Each regression was applied to the upper 20m of data south of 40°S. The final resulting fit for DIC uses 5 parameters (T, Sal, O_2, NO_3 and SiO_4) with a standard error of ~8.4μmol/kg and an adjusted R^2 of 0.97. We then exploit the predictive relationship by using all available hydrographic properties from the World Ocean Atlas 2001 in order to estimate an annual cycle of DIC and ALK for the year 1995. Using optimal dissociation constants, the annual cycle of pCO_2 for 1995 is then calculated. The final step was to use global wind products and gas exchange velocities to estimate a net uptake of CO_2 in the Southern Ocean and to quantify the effects of sea-ice. A careful uncertainty analysis using Monte-Carlo trials precludes a final estimate of CO_2 uptake in the Southern Ocean and a comparison to other independent results.

RESULTS

In general, our pCO_2 estimates are higher than those estimated from T02 (Fig. 1), with the only exception being within the sub-Antarctic Zone in winter. Spring, autumn and winter pCO_2 estimates within the SAZ are in good agreement within T02 when considering the uncertainties. Regions showing significant differences are north of 65°S in summer and south of 55°S in the winter. Overall our flux estimate (~ -0.2 Pg C /yr) implies a weaker Southern Ocean CO_2 sink than from T02 (~ -0.35 Pg C /yr). New pCO_2 measurements within the Indian sector of the Southern Ocean have also challenged the notion of a large Southern Ocean CO_2 sink [*Metzl et al.,* 2004]. Metzl et al., [2004] take seasonal pCO_2 measurements in the year 2000 and extrapolate using the 1-D biogeochemical model of Louanchi and Hoppema [2000] and find a considerably weaker CO_2 sink south of the Polar Front (~0.1 Pg C / yr). They suggest the weaker CO_2 sink in the Southern Ocean is due to the inclusion of direct winter-time pCO_2

measurements. Although this result is different to T02, it is consistent with our predictions and other independent estimates (Table 1).

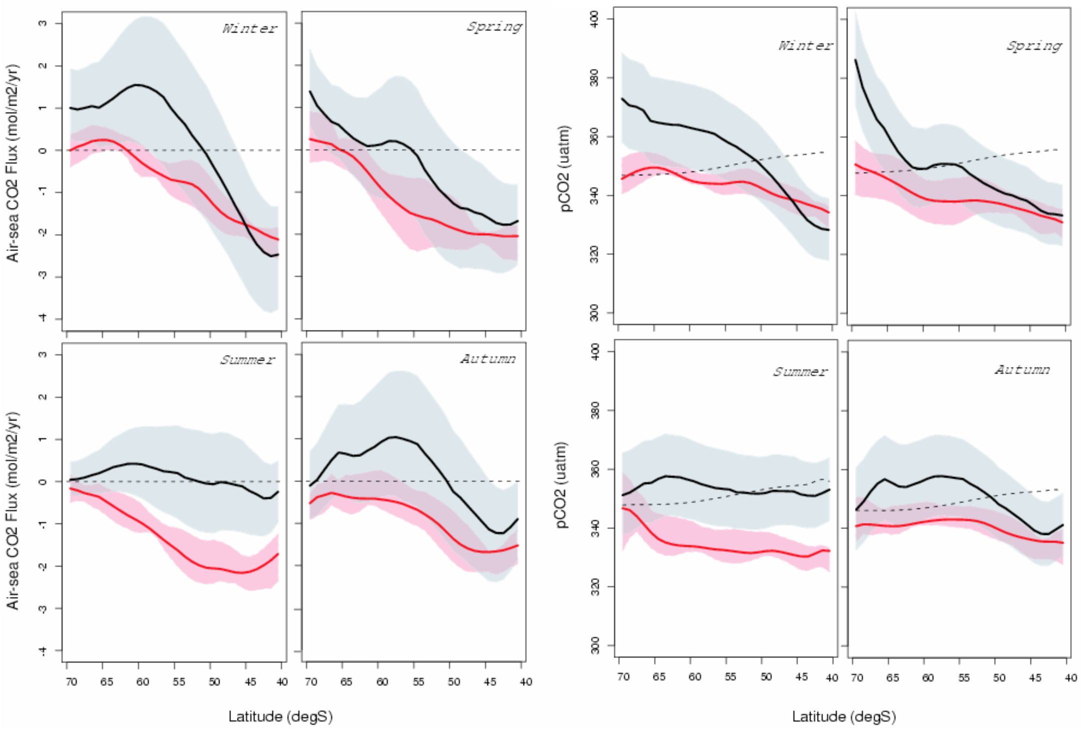

Fig. 1: Zonally average pCO_2 (μatm) and air-sea flux distributions for each season in the Southern Ocean. The red line and associated shading shows the T02 estimates. The solid black line and grey shading shows our estimates and associated uncertainty. The dashed line represents the atmospheric pCO_2 concentrations in 1995.

Table 1: Recent estimates of the air-sea CO_2 flux in the Southern Ocean

Reference	Method and Latitude Band	Estimate (Pg C /yr)
(*Gloor et al.*, 2003)	Oceanic Inversion (>58°S)	-0.1
(*Gurney et al.*, 2002)	TRANSCOM-2 Atmospheric Inversions (>45°S)	-0.4±0.3
(*Takahashi et al.*, 2002)	Oceanic pCO_2 climatology (>50°S) – NCEP 0.995 sigma winds	-0.5 to -0.7
Takahashi (2004)	Oceanic pCO_2 climatology (>50°S) – NCEP 10m winds	-0.35 to -0.45
(*Louanchi and Hoppema*, 2000)	Semi-prognostic Model with some observational constraints (1984-1994)	-0.5
(*Metzl et al.*, 2004)	Summer/winter pCO_2 measurments (>50°S)	-0.1
This Study	Oceanic DIC/ALK climatology (>40°S)	-0.2±0.3

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