BOMB RADIOCARBON CONSTRAINTS ON AIR-SEA GAS EXCHANGE: A NEW PARAMETERISATION OF THE PISTON VELOCITY – WIND SPEED RELATIONSHIP

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ABSTRACT

We used recent ocean bomb radiocarbon inventory estimates for the time of GEOSECS (mid-1970s) and WOCE (mid-1990s) from *Peacock* [2004] and *Key et al*. [2004], corrected for missing ocean areas [*Naegler* 2005], to develop a new parameterisation of the piston velocity – wind speed relationship of CO_2 air-sea gas exchange. For monthly mean climatological winds on a 1°x1° grid, this results in a gas exchange parameter $a_{q,660}$ of 0.32±0.04 (in cm hr^{-1} m^{-2} s^2) and a net oceanic CO_2 uptake of 1.53±0.18 PgC/yr for the mid-1990s, when using the *Takahashi et al*. [2002] pCO_2 data.

INTRODUCTION

The inventory of bomb radiocarbon in the global oceans provides constraints for the air-sea gas exchange of CO_2, as the exchange flux of CO_2 is controlled by the same piston velocity as that of bomb $^{14}CO_2$. *Broecker et al.* [1985] have used their ocean bomb radiocarbon inventory estimate for the time of GEOSECS to estimate a global mean piston velocity of 21.9 cm hr^{-1}. *Wanninkhof* [1992] used this value to parameterise a quadratic relationship between the piston velocity and the wind speed, which has been the standard parameterisation since then. However, *Peacock* [2004] and *Key et al.* [2004] published observation-based ocean bomb radiocarbon inventory estimates for the time of GEOSECS and WOCE which are significantly lower than the *Broecker et al*. [1985] estimate. In *Naegler et al.* [this issue, see also *Naegler*, 2005], we can show with the help of a simple (radio-) carbon cycle model that the ocean bomb radiocarbon inventory estimates from Peacock [2004] for the GEOSECS and WOCE ocean surveys and from *Key et al.* [2004] for WOCE are consistent with available tropospheric and stratospheric radiocarbon observations and our general understanding of the global carbon cycle, whereas the inventory estimate from *Broecker et al.* [1985] is too high. These new findings urge for a re-evaluation of bomb radiocarbon inventory constraints on air-sea gas exchange.

METHOD

The air-sea flux of CO_2, F_{CO2}, is usually calculated from the piston velocity k, the solubility L and the CO_2 partial pressure difference ΔpCO_2 between atmosphere and surface ocean: $F_{CO2} = k \cdot L \cdot \Delta pCO_2$. The flux of (bomb) radiocarbon into the ocean, $F_{14CO2,b}$, depends on the same piston velocity k and the same solubility L, but is driven by the effective (fractionation-corrected) bomb $^{14}CO_2$ partial pressure difference $\Delta^{14}pCO_2^{b,eff}$ between atmosphere and ocean: $F_{14CO2,b} = k \cdot L \cdot \Delta p^{14}CO_2^{b,eff}$. The piston velocity k is usually parameterised as a function of wind speed u and the Schmidt Number Sc. Here we follow the approach of Wanninkhof [1992] who assumed a quadratic relationship between the piston velocity and wind speed. The piston velocity k is therefore parameterised as follows: $k = a_{q,660} \cdot u^2 \cdot (Sc/660)^{-0.5}$. As the bomb radiocarbon inventory in the ocean is equal to the (temporally and spatially) integrated flux of bomb radiocarbon into the ocean, the crucial parameter $a_{q,660}$ can be calculated from the observed bomb radiocarbon inventory I_b^{14} in the ocean:

$$a_{q,660} = \frac{I_B^{14}(t_1)}{\int_{t_o}^{t_1}\int_S u^2 \cdot \left(\frac{Sc}{660}\right)^{-0.5} \cdot L \cdot \Delta p^{14}CO_2^{b,eff}\, dS\, dt}$$

To calculate $a_{q,660}$, we use the new ocean bomb radiocarbon inventory estimates from *Peacock* [2004] and *Key et al.* [2004]. The original inventory estimates were corrected for missing ocean areas [*Naegler* 2005]. Furthermore, we use five different global wind speed estimates from satellites and reanalyses and $\Delta^{14}pCO_2^{b,eff}$ values from *Naegler* [2005] in our analysis.

RESULTS

Our analysis shows that (1) global wind speed estimates differ significantly in many regions over the ocean, which introduces a significant source of uncertainty into any gas exchange parameterisation; (2) the parameterisation of air-sea gas exchange depends on the temporal and spatial resolution of the wind fields; (3) it is possible to approximate $a_{q,660}$ by the following equation (where the square brackets denote the global average):

$$a_{q,660} = c_{q,660} \cdot \frac{I_b^{14}}{\langle u^2 \rangle} \qquad \text{with } c_{q,660} = \int_{t0}^{t1}\int_S L \cdot \left(\frac{Sc}{660}\right) \cdot \Delta p^{14}CO_2^{b,eff} \, dS \, dt$$

This formulation has two main advantages: It can easily be adapted to any future estimate of the ocean bomb radiocarbon inventory as well as to improved global wind speed estimates. Furthermore, the uncertainty of $a_{q,660}$ can be addressed by taking into account uncertainties in the wind fields and in the observed bomb radiocarbon inventory. Uncertainties in $c_{q,660}$ are difficult to assess; in this analysis, they are neglected. However, $c_{q,660}$ (and therefore $a_{q,660}$) still depends on the temporal and spatial resolution of the analysis. For a monthly mean climatology of wind fields on a 1° x 1° grid, we obtained a value for $a_{q,660}$ of 0.32±0.04 cm hr^{-1} m^{-2} s^2, significantly lower than the estimate from *Wanninkhof* [1992] for long term winds (0.39 cm hr^{-1} m^{-2} s^2). Applied to the Takahashi et al. [2002] pCO_2 distribution, our gas exchange formulation yields a net CO_2 uptake by the ocean of 1.53±0.18 PgC/yr for the reference year 1995. The given error comprises uncertainties in the wind fields and in the ocean inventories, but not uncertainties in ΔpCO_2 nor $\Delta p^{14}CO_2^{b,eff}$. Our estimate is lower than the (corrected) value from *Takakashi* [2002] of 1.64±0.33PgC/yr. If a natural oceanic CO_2 source of 0.6PgC/yr due to the river loop is taken into account [*Sarmiento and Sundquist*, 1992], we yield an oceanic uptake of anthropogenic carbon of about 2.1PgC/yr, which is lower (but still consistent within uncertainties) than estimates based on the change of the atmospheric O_2/N_2 ratio (2.4±0.7 PgC/yr for the 1990s, *Plattner et al.* [2002] resp. 2.3±0.7 PgC/yr for 1990-1996, *Bopp et al*. [2002]).

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