INVENTORY AND UPTAKE OF ANTHROPOGENIC CARBON IN LABRADOR SEA WATER ESTIMATED USING TRANSIT TIME DISTRIBUTIONS

F. Terenzi[1], *T.M. Hall*[1, 2], *and D.A. LeBel*[3]

[1] *Department of Applied Physics and Applied Mathematics, Columbia University, S.W.Mudd, New York, NY 10027; ft2104@columbia.edu*

[2] *NASA Goddard Institute for Space Studies, 2880 Broadway, New York, NY 1002; thall@giss.nasa.gov*

[3] *Lamont-Doherty Earth Observatory, Columbia University, P.O. Box 1000, Palisades, NY 10964-1000;lebel@ldeo.columbia.edu*

ABSTRACT

We apply to Classical Labrador Sea Water (CLSW) the "transit-time distribution" (TTD) method to estimate the inventory and uptake anthropogenic carbon (ΔC). A parametric model of TTDs representing bulk-advective and mixing processes is constrained with WOCE *CFC* data. The constrained TTDs are then used to propagate ΔC into the interior of the CLSW. Compared to many past studies the key advantage of this methodology is that mixing is not assumed to be a negligible component of transport.

INTRODUCTION

The North Atlantic is considered to be the largest ocean sink for the anthropogenic carbon dioxide CO_2 (ΔC), overall taking up on average about 0.7 ± 0.1 Pg C $year^{-1}$ [*Gruber et al.*, 2002]. Despite recent improvements in the understanding of this uptake, substantial uncertainties still remain. Addressing this issue is important for fully understanding the perturbed global carbon cycle. In this work we apply to Classical Labrador Sea Water (CLSW) a technique developed by *Hall et al*. [2004] and by *Hall and Primeau* [2004] for the case of the Indian Ocean.

METHOD

We assume the anthropogenic *DIC* ($\Delta DIC(t)=DIC(t)-DIC(1780)$, the year 1780 chosen as the beginning of the industrial era) to penetrate the upper ocean as a passive tracer along isopycnals, and the ocean circulation to be in steady state. For a spatially uniform concentration over the outcrop region *S*, $\Delta DIC_s(t)$, the concentration averaged over the isopycnal volume *V*- assuming no diabatic mixing is present - is thus given by:

$$\Delta DIC_v(t) = \int_0^\infty \Delta DIC_s(t - t')G_v(t')dt' \qquad (1)$$

in which $G_v(t)$ represents the domain averaged distribution of transit times since water in *V* was last in contact with surface *S*. A two parameter model of TTD is obtained using observations of another passive tracer, *CFC11*, that obey to the same kind of equation as (1), with the substitution: $\Delta DIC \rightarrow CFC11$. The two parameters are the Peclet number *Pe*, and the mean transit time τ, which can *a priori* span over a wide range of values so to accommodate any portion of diffusive mixing and bulk advection (large *Pe* values correspond to weak mixing). Because we assume steady state circulation, $G_v(t)$ is the same for the two passive tracers, so once the TTD is constrained (i.e. via the V-averaged *CFC11* concentration *datum*), it can be applied to $\Delta DIC(t)$ at any given time. As a single datum cannot simultaneously constrain a two parameters function, a family of TTD is instead obtained, all consistent with the $CFC11_V$ *datum*. Dissolved *CFC* observations from the WOCE campaign have been objectively mapped onto isopycnal surfaces in the North Atlantic [*LeBel et al.*, manuscript in preparation, 2005]. In particular we apply the technique described in detail by *Hall et al* [2004] to the case of CLSW. The analysis is performed on 3 different isopycnals with σ ranging from 27.897 to 27.895 to include Top, Core and Bottom of CLSW. In order to apply Eq. (1) to *CFC11*, we use the atmospheric history [*Walker et al.*, 2000] scaled to match the observed 1997 outcrop values, so that the degree of saturation is somehow included in $CFC11_S(t)$. We then estimate the anthropogenic uptake of dissolved inorganic carbon by assuming surface waters in the North Atlantic followed the atmospheric perturbation and have thus taken up anthropogenic carbon dioxide in equilibrium with Δ*C* in the atmosphere (i.e. the so called "constant disequilibrium" assumption). Thus $\Delta DIC_s(t)$ is computed using the non linear equilibrium inorganic ocean carbon chemistry, for which this quantity can be computed from the knowledge of atmospheric Δ*C* for known salinity and temperature values [*Lewis and Wallace*, 1998]. $\Delta DIC_V(t)$ is then computed using (1). The constraint the *CFC* observation imposes on ΔDIC_V is found from the intersection of ΔDIC_V and $CFC11_V$ contours,

and this gives a range of possibilities for ΔDIC_V from a minimum (strong mixing) to a maximum (weak mixing) value.

RESULTS

This analysis is carried out on each of the isopycnals under consideration, and for any given time t ∈ [1780, 2001] - the lower and upper values correspond to the limits in the given ΔC time series - so that for each density surface we obtained the mass of ΔDIC taken up by that slab of water:

$$M^{\sigma}_{\Delta DIC}(t) = V_{\sigma} \times \Delta DIC_{V_{\sigma}}(t) \qquad (2)$$

where V_{σ} is the volume of the considered isopycnal. Summing over the isopycnals we obtain the time series of anthropogenic carbon mass for the CLSW in the North Atlantic Ocean, $M_{\Delta DIC}(t)$, and the correspondent net air-sea flux of anthropogenic carbon:

$$F_{\Delta DIC}(t) = \frac{dM_{\Delta DIC}(t)}{dt} \qquad (3)$$

The results for $M_{\Delta DIC}(t)$ and $F_{\Delta DIC}(t)$ - assuming constant disequilibrium - are shown in Fig.1. *Hall et al* [2004] demonstrated that this approximation leads to a positive bias in the estimates of both inventory and the uptake, and we are at the moment in the process of generalizing the technique of *Hall and Primeau* [2004] in order to apply it in the particular case of the CLSW and thus relaxing this approximation.

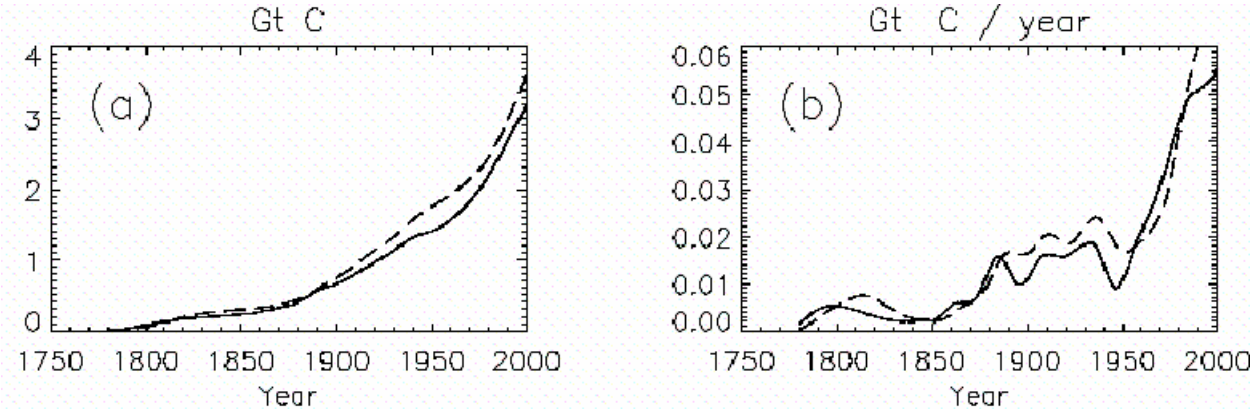

Fig. 1. (a) Constant disequilibrium total $\Delta DIC(t)$ mass and (b) net air-sea flux for the CLSW in the North Atlantic. The solid lines represent the low (strong mixing) limit and dashed lines the high Pe limit (weak mixing).

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