ANTHROPOGENIC CO$_2$ IN THE OCEANS ESTIMATED USING TRANSIT-TIME DISTRIBUTIONS

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INTRODUCTION

Quantifying the uptake of anthropogenic carbon by the oceans is a crucial component of understanding the global carbon cycle. Accordingly there has been considerable research in the area, and recently global estimates of the inventory and decadal uptake of anthropogenic carbon have been made using carbon measurements [*Sabine et al.,* 2004] and CFC measurements [*McNeil et al.*, 2003]. However, these methods introduce several assumptions that may introduce systematic biases. In particular, both methods assume that mixing plays a negligible role in the transport. Here we estimate the ocean uptake, inventory, and distribution of anthropogenic carbon (C$_{ant}$) in the oceans using the transit-time distribution (TTD) method (see Hall et al. 2004, Waugh et al. 2004), which avoids the assumption of weak mixing.

METHOD

The implementation of the TTD method used is the same as in *Waugh et al.* [2004]. We assume that the flow is steady and that the TTDs are Inverse Gaussian distributions with specified width to mean ratio. A CFC-12 measurement then enables the TTD distribution to be uniquely determined, and convolution of this TTD with the surface history of anthropogenic dissolved inorganic carbon yields the interior C$_{ant}$. At this stage we neglect, as in C* and most other studies, the evolution of the air-sea CO$_2$ disequilibrium in our estimates. The TTD calculations are performed using the same hydrographic and CFC data used by [*McNeil et al.*, 2003] and *Sabine et al.* [2004], and direct comparisons are made between the TTD and these earlier estimates.

RESULTS

The comparisons show that overall there is good agreement between the C* and TTD estimates, see Fig. 1. As these methods are very different and make many different assumptions, it gives us confidence in the estimates of C$_{ant}$.

There are, however, some differences in details. In particular, significant differences are found in the North Atlantic, North Indian, and Southern Oceans. In most of these cases the differences are consistent with biases in the treatment of transport in the C* method, i.e. an overestimate of C$_{ant}$ compared to TTD estimates in "fully contaminated" isopycnals due to the assumption of weak mixing, and an underestimate in deep "uncontaminated" isopycnals due to assumption of no penetration of C$_{ant}$. For example, between 1000 and 1500 m in the North Atlantic and 400 and 800 m in the North Indian Oceans the C* estimate matches the CFC-age estimate but is greater than the TTD estimate. This difference is consistent with the no mixing assumption made when calculating disequilibrium term in the C* calculations. Furthermore, in both cases there is a discontinuity in the C* estimate of C$_{ant}$ when plotted versus σ. This discontinuity occurs at a key level ($\sigma = 27.5$ and 27.25, respectively) in the calculation of the disequilibrium term in the C* calculation, and the discontinuity in C$_{ant}$ appears to be an artifact of the determination of the disequilibrium term. Differences are also found below 3000m in the North Atlantic, where the C* estimates are much lower than the TTD estimates. This bias is consistent with the assumption of no penetration of C$_{ant}$ made in the C* calculations. The C* estimates are also lower than the TTD estimates in the deep Southern Ocean, although this bias varies with longitude (not shown).
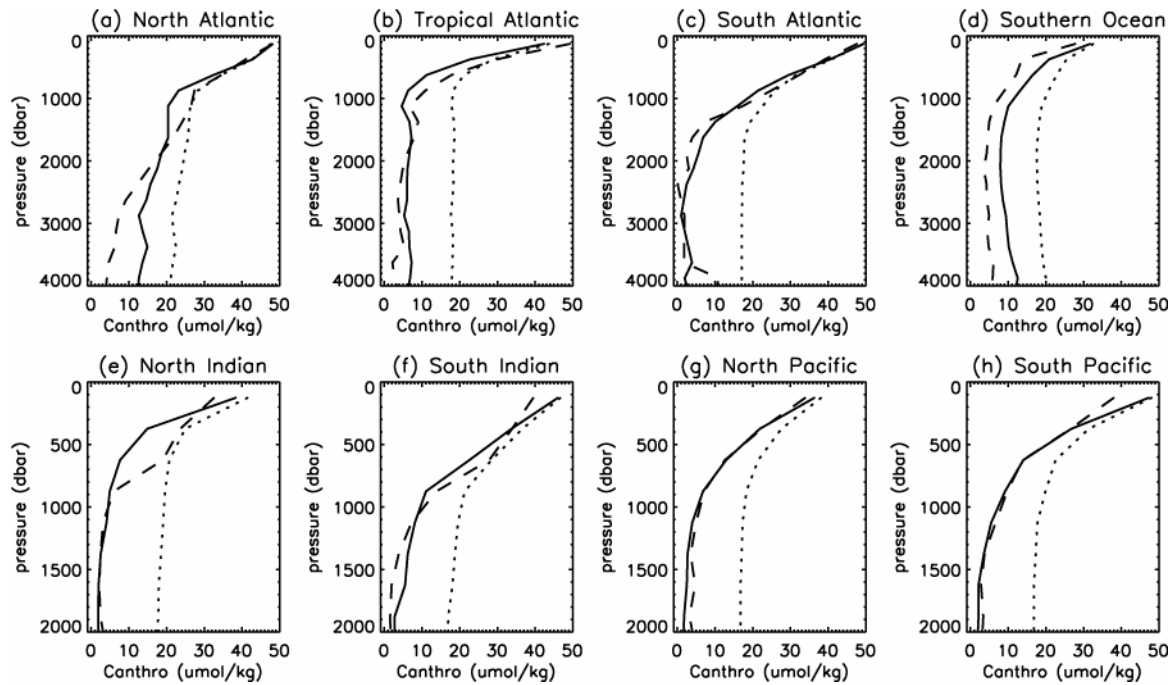
Fig. 1. Comparison of regional averages of C_{ant} from TTD (solid curves), CFC age (dotted) and C* (dashed) methods.

The above results suggests that if, as the transient tracers indicate [e.g,, *Waugh et al.*, 2004], mixing plays an important role in transport over decadal scales , the TTD estimates of C_{ant} may be more realistic. However, further examination and assessment of impact of the assumptions in our implementation of the TTD method is required.

REFERENCES

Hall, T.M., D.W. Waugh, T.W.N. Haine, P.E. Robbins, and S. Khaliwala 2004, Reduced estimates of anthropogenic carbon in the Indian Ocean due to mixing and time-varying air-sea CO_2 disequilibrium, *Global Biogeochem. Cycles, 18*, 10.1029/2003GB002120.

McNeil B.I., R.J. Matear, R.M. Key, J.L. Bullister, and J.L. Sarmiento (200-3), Anthropogenic CO_2 uptake by the ocean based on the global chlorofluorocarbon data set, *Science*, *299,* 235-239.

Sabine, C.L., et al. (2004), The oceanic sink for anthropogenic CO_2, *Science, 305*, 367-371.

Waugh, D.W., T.W.N. Haine, and T.M. Hall (2004), Transport times and anthropogenic carbon in the subpolar North Atlantic Ocean, *Deep-Sea Res., 51*, 1475-1491.