ROBUST ESTIMATES OF PREINDUSTRIAL AND ANTHROPOGENIC AIR-SEA CARBON DIOXIDE FLUX

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ABSTRACT

Accurate estimates of the spatial distribution of pre-industrial and anthropogenic air-sea carbon fluxes are crucial to understanding the processes driving ocean carbon uptake. We present regional anthropogenic and pre-industrial air-sea fluxes estimated separately from their reconstructed concentrations and Ocean General Circulation Models (OGCM). The ocean interior carbon transports required to explain these fluxes are calculated and their implications for the global carbon cycle are discussed.

METHODS

We apply an ocean inversion approach to estimate air-sea fluxes into 23 ocean regions from ocean interior observations and an OGCM [e.g. *Gloor et al.,* 2001, *Gloor et al.,* 2003]. Tracer-based methods are used to estimate the component of the observed dissolved inorganic carbon due to anthropogenic carbon uptake, ΔC_{ant}, [*Gruber et al.,* 1996] and pre-industrial air-sea carbon flux, ΔC_{gasex}, [*Gruber and Sarmiento*, 2001]. Then, each of these data-based estimates are treated as a linear combination of regional surface fluxes multiplied by basis functions, which are generated using OGCM simulations and describe how a unit flux at the surface influences observations in the ocean interior. In order to quantify the uncertainty associated with ocean transport, we have used a suite of nine OGCMs, which are described in Mikaloff Fletcher et al. [2005].

PREINDUSTRIAL CARBON

The ΔC_{gasex} inversion finds a robust pattern of out-gassing in the Southern Ocean between 44 S and 58 S, vigorous uptake at mid-latitudes, and out gassing in the tropics (Fig. 1a). This pattern in the inverse estimates is robust with respect to model transport, and is driven by spatial gradients in the data-based ΔC_{gasex} estimates.

These fluxes imply that preindustrial carbon is transported equator-ward from southern high-latitudes and pole-ward from southern mid-latitudes, with convergence and out gassing between 44 S and 58 S (Fig. 1b). In the northern hemisphere, the inverse fluxes imply that pre-industrial carbon taken up at high- and mid- latitudes is transported equator-wards. Much of this pre-industrial carbon is returned to the atmosphere in the tropics, leading to a modest southward cross-equatorial transport. This does not support the hypothesis of strong pre-industrial transport of carbon from the northern hemisphere to the southern hemisphere, which has been proposed to explain the northern hemisphere carbon sink [*Keeling et al.,* 1989].

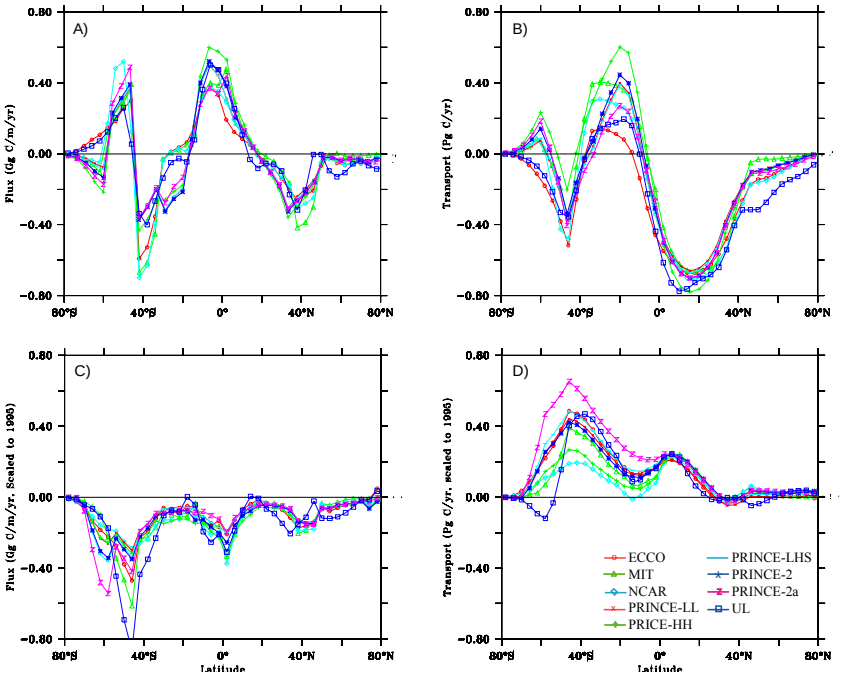

Fig. 1 The zonally, vertically integrated a) air-sea flux of preindustrial carbon, b) ocean transport of pre-industrial carbon, c) d) oceanic transport of anthropogenic carbon. Positive (negative) fluxes indicate flux out of (into) the oceans, and positive (negative) transports indicate northward (southward) transport. air-sea flux of anthropogenic carbon, and d) oceanic transport of anthropogenic carbon.

ANTHROPOGENIC CARBON

We estimate a global anthropogenic carbon uptake of 2.2 +/- 0.25 Pg C yr^{-1}, scaled to a nominal year of 1995. The greatest anthropogenic carbon uptake occurs at mid- to high- latitudes, with a large anthropogenic carbon sink in the Southern Ocean (Fig.1c).

The vigorous anthropogenic carbon uptake in the Southern Ocean drives substantial equator ward transport in most of the Southern Hemisphere (Fig. 1d). About half of the anthropogenic carbon taken up in the high-latitude Southern Ocean is entrained in the Antarctic Circum-polar Current and stored in the Southern Ocean, while the rest is transported equator wards along the surface. Anthropogenic carbon taken up in the tropics is transported pole-ward along the surface and then entrained in the sub-tropical gyres, leading to convergence and storage at mid-latitudes.

ROBUSTNESS OF THE INVERSE ESTIMATES

The large scale features of the fluxes and transports estimated by the ocean inversion are robust with respect to the choice of OGCM (Fig. 1). Both the pre-industrial and anthropogenic flux estimates are most uncertain in the Southern Ocean, where the inverse estimates are strongly dependent on the rates of deep water ventilation in the OGCM.

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