OCEANIC CONSTRAINTS ON THE SIZE OF THE TERRESTRIAL CO_2 FERTILIZATION SINK

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ABSTRACT

We have constructed an estimate of annual-mean surface fluxes of carbon dioxide for the period 1992-6 using observational constraints from the atmosphere and from the ocean interior. The method interprets *in situ* observations of carbon dioxide concentration in the ocean and atmosphere using transport estimates from global circulation models.

Uncertainty in the modeled circulation is explicitly considered in this inversion by using a suite of 16 atmospheric and 10 oceanic transport simulations. We estimate that the open ocean took up 2.1 $PgCyr^{-1}$ of anthropogenic carbon during this period, offset by the natural outgassing of about 0.5 $PgCyr^{-1}$ of carbon fixed on land and transported through rivers to the open ocean. Despite a comprehensive effort to quantify sources of error due to modeling biases, uncertain riverine carbon load, and biogeochemical assumptions, the uncertainty on this global air-sea flux estimate is driven down to ±0.2 $PgCyr^{-1}$ by the large number of oceanic observations used. While atmospheric data have little impact on the final air-sea flux estimates, the inclusion of ocean data drives a substantial change in terrestrial flux estimates. Our results indicate that the tropical and southern land regions together are a large source of carbon, with a 77% probability that their aggregate source size exceeds 1 $PgCyr^{-1}$. This value is of similar magnitude to estimates of fluxes in the tropics due to land-use change alone, making the existence of a large tropical CO_2 fertilization sink unlikely. This terrestrial flux result is strongly driven by ocean inversion estimates of a relatively small Southern Ocean sink (south of 44°S) and a relatively large sink in the southern temperate latitudes (44°S-18°S).

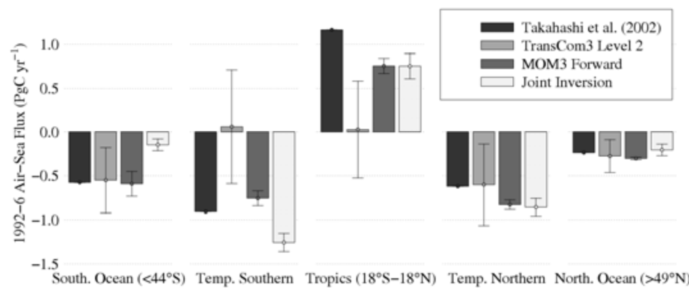

Fig. 1. Air-sea flux estimates from various sources for 1992-6, aggregated by broad latitude band. From left to right within each latitude band, the estimates are the ΔpCO_2-based climatology of Takahashi *et al.* [2002], the TransCom3 atmospheric inverse estimate of Gurney et al [2004], forward simulations of five configurations of the MOM3 ocean general circulation model, and the present results ("joint inversion"). Error bars represent one standard deviation for estimates that include uncertainties.

METHODS

We perform independent atmospheric and oceanic inversions using standard techniques of weighted linear least squares optimization. The atmospheric inversion differs from commonly used methods in that no priors or regularization techniques are used. The oceanic inversion follows the methodology of Gloor *et al.* [2003], and yields separate estimates of preindustrial and anthropogenic fluxes. These air-sea flux estimates are tightly constrained by the large number of ocean interior data used (more than 67,000 observations). The atmospheric and oceanic flux estimates are then statistically combined *ex post facto* by exploiting the fact that they both provide independent estimates of air-sea flux. In combining the results, the small oceanic uncertainty drives a readjustment of terrestrial fluxes. This is due to the interdependence of flux estimates for proximate regions in the atmospheric inversion, owing to the sparseness of observations and vigorous zonal mixing in the atmosphere. We exploit such flux correlations, and specifically those between land and ocean regions, to produce our joint estimate. Mathematically, information is communicated from the ocean to the land via the flux covariance matrix resulting from the atmospheric inversion.

RESULTS

In the southern hemisphere south of 18°S, air-sea flux estimates deriving from the oceanic inversion differ significantly from the ΔpCO_2-based climatology of Takahashi *et al.* [2002], and OCMIP2-style forward simulations of the ocean carbon cycle (Fig. 1). In particular, we find a smaller Southern Ocean sink and a larger temperate sink than predicted by other methods. These differences can be attributed to preindustrial fluxes, and are robust in the face of transport uncertainty, identified biases in the determination of anthropogenic carbon content, and assumptions about the stoichiometry of remineralized organic material [*Jacobson et al.*, submitted]. These oceanic inversion flux results are also consistent with those from inversions using a more diverse suite of models [*Mikaloff Fletcher et al.*, submitted].

The different meridional distribution of air-sea fluxes has a strong impact on the atmospheric inversion, since the southern hemisphere and tropical regions are particularly poorly constrained by available atmospheric observations. We find that while the land regions of the tropics and southern hemisphere cannot be reliably distinguished from one another, their aggregate can be reasonably constrained. This aggregate region becomes a statistically significant source of carbon (1.8 ± 1.1 $PgCyr^{-1}$) when the oceanic constraint is considered. Atmosphere-only inversions do not detect this source. This source, which represents the net land-atmosphere exchange, is of a size comparable to satellite- and field-based estimates of tropical land use change fluxes due principally to deforestation, which range from 1-2 Pg Cyr^{-1}. It is therefore unnecessary to invoke the existence of a large CO_2 fertilization sink in the tropics to close the carbon budget.

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