REGIONAL BOMB-PRODUCED RADIOCARBON INVENTORIES AND THE AIR-SEA GAS TRANSFER VELOCITY

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ABSTRACT

Two major problems in carbon cycle research are that the current data-based budget of artificially-produced radiocarbon is unbalanced and that the air-sea gas transfer piston velocity remains uncertain. In this study, the regional distribution of bomb-produced radiocarbon inventories in the ocean and their dependencies on the piston velocity is analysed within a seasonal, 3-d frictional-geostrophic balance ocean model. Model results and data-based reconstructions are compared to evaluate the consistency between the applied piston velocity field and data-deduced ocean inventories. Bomb-radiocarbon inventories in the GEOSECS and WOCE era are predominantly governed by the applied piston velocity. Here, the piston velocity field provided by the Ocean Carbon Cycle Intercomparison Project (OCMIP-II) were prescribed and scaled by a globally constant factor in a range of sensitivity simulations. Results suggest that the OCMIP-II piston velocity field must be scaled down by ~25% to match the data-based estimates of bomb radiocarbon inventories for the Pacific (GEOSECS and WOCE data), South Atlantic (SAVE) and Indian Ocean (GEOSECS), the pre-bomb surface-average $\Delta^{14}C$, and the earth system budget of artificially-produced ^{14}C. In contrast, the published data-based bomb inventories for the North Atlantic (GEOSECS, TTO) are much higher than simulated with the standard or scaled OCMIP piston velocity fields. A reduction of the published data-based North Atlantic inventory estimates by about a factor of two would yield consistency between the simulated and data-based regional inventories and reconcile estimates of the production of artificial radiocarbon and of changes in the global ^{14}C inventory.

MODEL AND DATA

A seasonal, 3-d frictional-geostrophic balance ocean model is applied [*Müller et al.*, 2005]. The piston velocity field for CO_2 gas exchange was taken from the OCMIP-II, which is now widely used. Piston velocity is assumed to be proportional to the wind speed squared and wind speeds were derived from satellite data. The 3-d model has been tuned to reproduce the ventilation time scales of the thermocline and the deep ocean by matching the radiocarbon signatures of different deep ocean water masses and the CFC-11 inventories in the Southern Ocean and the Indo-Pacific. The model was spun-up for several thousand years to reach a 'preindustrial' equilibrium and is then run over the industrial period with prescribed atmospheric CO_2 and $^{14}CO_2$ to simulate oceanic uptake of bomb-produced radiocarbon.

Published estimates of bomb-produced radiocarbon inventories from *Peacock* [2004], *Broecker et al.* [1995] and of $\Delta^{14}C$ from the GLODAP data base [*Key et al*., 2004] were used.

RESULTS

The modelled global inventory as well as the basin-wide inventories in the Pacific, Indian and South Atlantic are higher than the data-based estimates. In contrast, the simulated inventory for the North Atlantic is substantially lower than the data-based estimates. The higher than observed inventories suggest that the piston velocity from OCMIP-II is on average too high.

In a number of sensitivity simulations the piston velocity field was linearly scaled. A near-linear relationship between basin-wide inventories and the scaling factor was found. This is to be expected, as the air-sea disequilibrium in $\Delta^{14}C$ is on average very large and air-sea exchange is the rate limiting process for the uptake of bomb ^{14}C in the last century. Thus, the piston velocity is the governing factor for the magnitude of the bomb-^{14}C inventory.

The piston velocity must be scaled down by ~10% to 20% to match the bomb inventory estimates for the GEOSECS era and for the Pacific, Indian, and global ocean, and by around 30% to match the WOCE Pacific inventory. The situation is different for the North and South Atlantic. The piston velocity needs to be increased by 30% to 60% to match the data-based inventories in the North Atlantic from the GEOSECS and TTO data and decreased by 30% to 40% to match the South Atlantic inventories from the GEOSECS and SAVE cruises.

Ocean transport processes play a significant role for the pre-bomb surface ocean $\Delta^{14}C$ global mean as evidenced by the non-linear relationship between the piston velocity scaling factor and simulated values. Nevertheless, the piston velocity must be scaled down by around 25% to match the data-based pre-bomb surface ocean $\Delta^{14}C$ global mean. The global budget of bomb-produced radiocarbon implies an ocean uptake of 228± 50 10^{26} atoms between mid-1965 and mid-1989. The simulated change is 300 10^{26} atoms for the standard setup. The piston velocity in the model must be scaled down by at least 15% to bring simulated changes in agreement with the estimated range and by ~40% to match the best-guess value from the global budget.

DISCUSSION AND CONCLUSION

The ocean inventory of bomb-produced radiocarbon is governed by the piston velocity. The piston velocity field used in this study and in OCMIP-II must be scaled down by a quarter to match the data-based estimates of bomb radiocarbon inventories for the Pacific (GEOSECS and WOCE data), South Atlantic (SAVE) and Indian Ocean (GEOSECS), the pre-bomb surface-average $\Delta^{14}C$, and the earth system budget of artificially-produced ^{14}C [*Broecker et al*., GBC, 1995; *Peacock*, GBC, 2004; *Key et al.*, GBC, 2005]. The North Atlantic is anomalous in that simulated inventories are much lower than the data-based inventories.

The mismatch between the simulated and observed inventories in the North and South Atlantic could partially be due to a too weak transport of bomb-produced radiocarbon across the equator. However, about 80% of the total uptake of bomb radiocarbon occurred within the decade prior sampling. This leaves not much time for a substantial cross-equatorial transport. More likely, the piston velocity field in the North Atlantic or the data-based inventories for the North Atlantic may be in error.

We can not firmly distinguish between these two possibilities. However, the large differences in column inventories estimated with the potential alkalinity method of Key et al. and the silica method of Broecker et al. points to the difficulty to accurately assess bomb-produced radiocarbon inventories in the mid and high latitudes of the North Atlantic.

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