VARIATIONS IN ATMOSPHERIC O_2 AND CO_2 IN THE SOUTHERN OCEAN REGION FROM CONTINUOUS SHIP-BASED MEASUREMENTS

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ABSTRACT

Variations in atmospheric oxygen (O_2) are a sensitive indicator of biogeochemical processes involved in the global carbon cycle. To improve our understanding of these processes, we developed a system for continuous high precision measurements of atmospheric O_2 and CO_2 that is suitable for shipboard use. This system was employed on two voyages in the Western Pacific sector of the Southern Ocean, in February 2003 and April 2004. Elevated O_2 concentrations were observed south of New Zealand and across the Chatham Rise suggesting that these regions of ocean are outgassing O_2 in late summer to autumn.

INTRODUCTION

In the last decade, high precision measurements of atmospheric O_2 have become increasingly important for tracing ocean-atmosphere and land-atmosphere exchanges of CO_2 [eg. *Keeling et al.*, 1996]. O_2 is a useful tracer because the processes of photosynthesis, respiration and fossil fuel burning involve stoichiometric changes in O_2 as well as CO_2. The development of new methods capable of measuring O_2 to ppm-level have enabled these changes to be observed and used to estimate the partitioning of atmospheric CO_2 uptake by the land and ocean [eg. *Keeling et al.*, 1996].

More recently, the ratio of the change in O_2 versus CO_2 for land photosynthesis and respiration (O_2:CO_2 = -1.1) has been used to subtract the land-based influence on atmospheric O_2 and CO_2 concentrations, resulting in an atmospheric tracer that is sensitive principally to ocean-atmosphere exchange [*Stephens et al.*, 1998]. This tracer is known as Atmospheric Potential Oxygen (APO):

$$APO = O_2 + 1.1[CO_2 - C_{ref}]$$

Measurements of APO are a valuable comparison for model estimates of ocean-atmosphere fluxes of O_2 and CO_2 when coupled to atmospheric transport models to produce spatial and temporal gradients of APO. However, large discrepancies currently exist between model-based and observation-based estimates of APO. Models underestimate APO in the southern hemisphere and predict a decreasing trend from the low to high southern latitudes, which is not observed in measurements from the flask-sampling network [*Stephens et al.*, 1998]. To resolve these discrepancies and to improve estimates of regional ocean-atmosphere O_2 and CO_2 fluxes more observational data are required. Ship-based measurements can cover large areas not sampled by the station network and continuous measurements enable short-term variations to be resolved. Our measurements are only the second set of continuous ship-based measurements anywhere in the world and are the first from the Pacific sector of the Southern Ocean. We measure O_2 mole fraction using a fuel cell technique (model: Oxzilla, Sable Systems).

RESULTS AND DISCUSSION

O_2 and CO_2 were measured from 18 to 26 February 2003 between Wellington, New Zealand (41°S, 175°E) and the Antarctic coast (66°S, 140°E). A southward increasing trend in APO was observed between 45°S and 47°S and APO remained elevated to 57°S, suggesting a significant oceanic O_2 source in the southern mid-latitudes. South of 57°S, APO decreased. The ship-based observations were compared with APO from two model simulations: 1) the GCTM atmospheric transport model [*Mahlman & Moxim*, 1978] coupled to O_2 flux estimates from *Gruber et al*. [2001] and *Najjar & Keeling* [2000], and to CO_2 flux estimates from *Gloor et al.* [2003] and *Takahashi* [1999], together this is denoted, GG-GCTM, and 2) the TM3 atmospheric transport model [*Heimann*, 1995] coupled to the ocean biogeochemistry model, PISCES [*Buitenhuis et al.*, 2005] together denoted, PISCES-TM3. The increasing APO gradient was predicted by GG-GCTM and PISCES-TM3, however, both models underestimated its magnitude (see Fig. 1a). The discrepancy in the GG-GCTM simulation most likely results from uncertainties in the spatio-temporal structure of the seasonal air-sea O_2 flux climatology. The PISCES-TM3 model also failed to reproduce the decrease in APO south of 57°S probably due to an under-estimation of isopycnal mixing in the high southern latitudes resulting in too little O_2 ingassing.

In the second voyage, 17 to 29 April 2004, O_2 and CO_2 were measured on a round trip from Wellington (41°S, 175°E) to an oceanographic mooring site (57°S, 175°E). High APO was observed south of 49°S and increased throughout the voyage. On the return leg, positive APO excursions were seen between 52°S and 47°S and corresponded with air originating from the southern coast of the South Island of New Zealand and the Chatham Rise. These regions appear to be outgassing O_2 at this time of the year due to the influence of biological production. The GG-GCTM model reproduced the observed southward increasing APO gradient but not the high APO between 52°S and 47°S, which was reproduced by the PISCES-TM3 model (see Fig. 1b).

CONCLUSIONS

The ship-based observations of APO exhibited significant variability on timescales of several hours to days most likely due to changes in air-sea O_2 fluxes resulting from oceanic mixing and biological production.

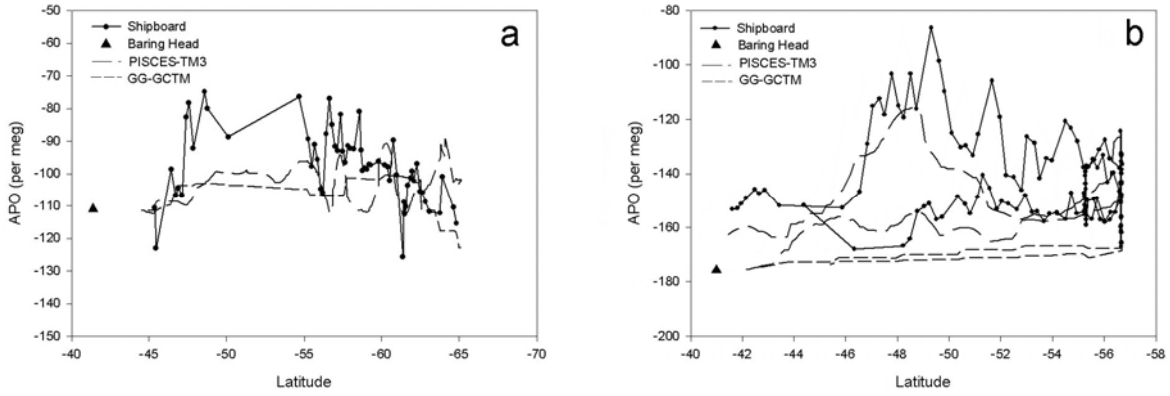

Fig. 1 Hourly averaged APO from shipboard measurements plotted with simulated APO from PISCES-TM3 and GG-GCTM. Simulated APO is adjusted on the vertical axis to match the mean concentration at the station Baring Head (41°S, 175°E) on the 15th of the month. February 2003 comparison (a), and April 2004 comparison (b).

Comparison of APO from the April 2004 observations with that simulated by PISCES-TM3 showed much better agreement suggesting that the improved resolution of biologically driven fluxes (as in the PISCES model) is necessary to improve estimates of the O_2 signal in the Southern Ocean.

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