CARBON CYCLE DECADAL VARIABILITY IN MODE WATERS OF THE SOUTH WEST INDIAN OCEAN: ANTHROPOGENIC VS. NATURAL CHANGES

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ABSTRACT

Mode Waters provides a privileged pathway for the transport of heat, salt and anthropogenic CO_2 into the ocean interior. The carbon cycle decadal variability in response to environmental changes is investigated using historical and recent data collected during the INDIGO (1985-1987) and OISO (1998-2003) oceanographic campaigns conducted in the South West Indian Ocean, an important zone for Mode Waters formation. The observed change in dissolved inorganic carbon over the 15-year period was 8 µmol/kg in Subantarctic Mode Water (500-800m), which is less than the anthropogenic carbon increase alone (13 µmol/kg). This difference may be explained by natural or climate-induced changes in ocean processes. Predictions from a global ocean-carbon model (OPA-PISCES) are used as a means to help interpret changes in the controlling processes: ocean dynamics, biological activity and air-sea interactions.

INTRODUCTION

The ocean carbon cycle is closely linked to climate. Ocean's uptake of anthropogenic CO_2 regulates the increase of this greenhouse gas in the atmosphere and thus global warming. In turn, the rate of ocean's uptake of CO_2 is affected by climate-induced changes in biogeochemical and physical ocean processes. Global models have shown that the Southern Ocean is of particular interest here both because it is where most anthropogenic CO_2 enters the ocean and because it will be most sensitive to future climate change [*Friedlingstein et al.,* 2003]. However, the Southern Ocean is also the region where the highest disagreements exist among different ocean carbon models [*Orr et al.,* 2001]. Observation-based estimates of the ocean's uptake of anthropogenic CO_2 and its variability are needed to reduce uncertainties attached to current ocean carbon models and to validate predictions made by climate-carbon coupled models.

Subantarctic Mode Water (SAMW) is formed during the deep winter mixing that occurs north of the Subantarctic Front (45-50°S) and sinks at intermediate depth (500-800m) towards low latitudes, thus providing a privileged path for the penetration of anthropogenic CO_2 into the ocean interior. Current observation-based methods for estimating the ocean's uptake of anthropogenic carbon (C^{ant}) agree on a large accumulation of C^{ant} in SAMW, both in terms of cumulated uptake (20-40 µmol/kg, e.g. Lo Monaco et al., 2005) and in terms of recent increase (20-25 µmol/kg over the last three decades according to *McNeil et al.,* [2001]). However, these methods do not account for natural (climate-induced) changes in biogeochemical and physical processes. Instead, one must consider changes in dissolved inorganic carbon (DIC) which result from both the increase in C^{ant} and changes in the carbon cycle.

METHOD

We have investigated changes in DIC and C^{ant} by comparing data collected 15 years apart during INDIGO (1985-1987) and OISO (1998-2000) cruises conducted in the Indian sector of the Southern Ocean.

Assuming the steady state, the increase in C^{ant} can be determined using the TrOCA method developed by Touratier and Goyet (2004), as follows:

$C^{ant} = (TrOCA – TrOCA^0) / 1.2$

TrOCA is a tracer combining oxygen, carbon and alkalinity (TrOCA = O_2 +1.2DIC - 0.6TA) and $TrOCA^0$ is the preindustrial TrOCA value expressed as a function of potential temperature.

If we assume that ocean dynamics have remained the same over the past few decades, the change in DIC generated *in situ* through biological activity (C^{bio}) can be deduced from changes in oxygen (ΔO_2) and alkalinity (ΔTA) [*Brewer*, 1978 and *Chen and Millero*, 1979]:

$C^{bio} = 0.8\ \Delta O_2 + 0.5\ \Delta TA$

RESULTS

In the central south-indian region (75-80°E), a deep mixing is observed during winter in the Subantarctic Zone (down to 500m). In this region the potential temperature-salinity diagrams show no difference in SAMW over 15 years, while changes are observed in the mixed layer (warming) and in Antarctic Intermediate Water (freshening). In SAMW we can therefore reasonably attribute changes in oxygen and alkalinity to modifications of biological processes.

Just below the mixed layer we observed an increase of 8 µmol/kg in DIC concentrations over the 15-years period (Fig. 1). This increase is associated with an increase in C^{ant} of 13 µmol/kg (about 0.9 µmol/kg/yr) and a decrease in C^{bio} (-5 µmol/kg).

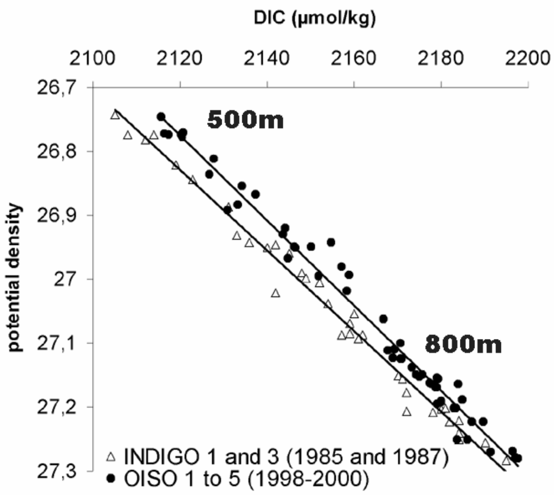

Fig. 1. Increase in DIC observed over 15 years in the Subantarctic Zone of the Indian Ocean (34-44°S, 75-80°E) plotted as a function of density.

Changes in DIC and C^{ant} simulated by the ocean carbon model over the same period in the same region are very similar (+7 and +12 µmol/kg, respectively). In addition, the model shows that gradual increase in both DIC and C^{ant} also occurred in the South East Indian Ocean and South Pacific Ocean, suggesting that modifications of SAMW's properties are driven by long-term changes at a global scale rather than episodic or regional events.

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