INTERANNUAL VARIABILITY OF THE CARBON DIOXIDE SYSTEM AND AIR-SEA CO_2 FLUXES IN THE HIGH LATITUDE OF THE NORTH ATLANTIC OCEAN : 1993-2004 (SURATLANT PROGRAM)

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ABSTRACT
Since 1993, regular seasonal water sampling has been conducted along a ship-track between Island and Newfoundland in the open ocean of the North Atlantic subpolar gyre in the frame of the long-term SURATLANT program. In this study, we analyse the interannual variation of the carbon dioxide system, including seawater fugacity (fCO_2) and air-sea CO_2 fluxes for the period 1993-2004. During 1993-1997, the data present a clear seasonality in this region marked by a strong CO_2 sink in summer and near-equilibrium in winter. For recent years, 2001-2004, we observed a dramatic change of the source/sink seasonality. An extreme case was observed in 2003 when oceanic fCO_2 was above equilibrium during all seasons. This strong anomaly was driven by ocean warming.

INTRODUCTION
The North Atlantic Ocean is believed to act as the most intense ocean sink in the Northern Hemisphere about -0.3 to -0.4 PgC/yr on average [*Takahashi et al*., 2002]. In this region it is expected that air-sea CO_2 flux is varying, possibly modulated by large-scale climatic event such as North Atlantic Oscillation (NAO), through thermodynamics, ocean circulation, wind speed and/or biological processes. The evaluation of both interannual variations, decadal trends and rapid (or slow) changes of air-sea CO_2 flux requires repeated in-situ observations at different years and at different seasons as it has been well documented that the ocean carbon cycle experienced strong seasonality in high latitudes of the North Atlantic Ocean. Such repeated observations where conducted between Island and the Newfoundland since 1993 (SURATLANT project). In this study we analysed sea surface seasonal variations of temperature, salinity, dissolved inorganic carbon (DIC), total alkalinity (TA) and use these data to calculate ocean CO_2 fugacity, fCO_2, and associated air-sea CO_2 fluxes.

DATA COLLECTION
The analysis on decadal variability is focus on the open ocean region, 53°N-62°N/45°W-20°W, to limit the effect of the coastal zones near Island and Newfoundland where interannual variations may not be attributed to large-scale forcing only. During each cruise, about 30 bottles were sampled for DIC and TA measured back at laboratory in USA and France. During 1993-1997 the DIC was measured using a coulometric method, whereas for the period 2001-2004, DIC and TA were measured using a potentiometric method. For calibration, we used Certified Reference Material (CRM) provided by Pr. A. Dickson (SIO/ San Diego). The precision for DIC and TA is estimated to be around 2 µmol/kg [*DOE*, 1994]. During 1993-1997, TA was not measured; however a strong relationship between TA and salinity was estimated with all data obtained at different seasons in 2001-2002:

$$TA = 45.808.\ SSS + 713.51$$

This relation is then used to simulate surface TA distribution for the period 1993-1997. We then use DIC and TA to calculate the sea surface ocean fugacity (fCO_2) [*Lewis and Wallace*, 1998].

RESULTS

The DIC and TA concentrations appear relatively stable over ten years indicating a complex balance between primary production, vertical mixing and anthropogenic CO_2 increase. On the other hand, we found that seasurface fCO_2 has regularly increased from 1993 to 2004, with a dramatic change starting in 2002 (Fig. 1). Because no strong variations was observed for DIC, this rapid variation was clearly controlled by the warming of sea surface waters, up to 2°C over 10 years and results in a large changes for the air-sea CO_2 fluxes. Based on ocean fCO_2 , atmospheric fCO_2 and satellite derived wind speeds, we calculate the net air–sea CO_2 fluxes using the gas transfer coefficient proposed by Wanninkhof (1992). The seasonal fluxes vary from -10 to -5 $mmol.m^{-2}.d^{-1}$ between 1993-1996 (ocean sink) up to +10 $mmol.m^{-2}.d^{-1}$ during January 2003 (ocean source). In summer 2003, the source was still very high, around 5 $mmol\ m^{-2}\ d^{-1}$.

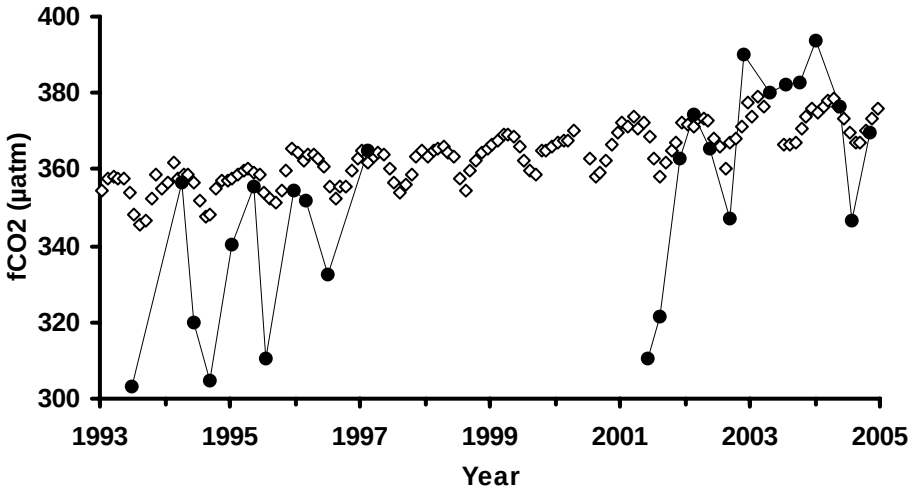

Fig. 1 : The open diamonds represents the monthly atmospheric CO_2 (Mace Head). The black line represents the seawater fCO_2 average in the region 53°N-62°N/45°W-20°W (about 20 samples during each cruise).

CONCLUSION

From 1993 to 2004, we observed substantial variability of the North Atlantic carbon sink. As an extreme case, we observed that region was a CO_2 source during all seasons in 2003. This unexpected situation, explained by sea surface warming, could play a significant role to explain the anomaly of CO_2 atmospheric growth rate.

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