DECADAL CHANGES IN INORGANIC CARBON IN THE ATLANTIC OCEAN

R. Wanninkhof[1], S. Doney[2], C. Langdon[3], J. L. Bullister[4], G. C. Johnson[5], M. Warner[6], and N. Gruber[7]

[1]*Atlantic Oceanographic and Meteorological Laboratory of NOAA, Miami FL, 33149 USA; rik.wanninkhof@noaa.gov*
[2]*Woods Hole Oceanographic Institution, Woods Hole MA, 02543 USA; sdoney@whoi.edu*
[3]*Rosenstiel School of Marine and Atmospheric Sciences of the University of Miami, Miami FL 331249, USA; clangdon@rsmas.miami.edu*
[4]*Pacific Marine Environmental Laboratory of NOAA, Seattle WA, 98115 USA; John.L.Bullister@noaa.gov*
[5]*Pacific Marine Environmental Laboratory of NOAA, Seattle WA 98115, USA; Gregory.C.Johnson@noaa.gov*
[6] *Box 355351 School of Oceanography University of Washington , Seattle, WA 98195 USA; mwarner@ocean.washington.edu*
[7]*5853 Slichter Hall University of California, Los Angeles, Los Angeles, CA 90095-4996, USA, CA USA; ngruber@igpp.ucla.edu*

ABSTRACT
Changes in dissolved inorganic carbon (DIC) and apparent oxygen utilization (AOU) in the water column are quantified for meridional hydrographic sections through the Atlantic from 63 ˚N to 60 ˚S between 1988/1993 and 2003/2005. Changes are most pronounced in the upper 1000 m water column. DIC changes range from -5 to 40 µmol/kg and AOU changes by a similar amount. The remainder is caused by changes in positions of fronts, gyres, remineralization and ventilation as manifested by changes in watermass properties. In particular AOU increases of similar magnitude as increases in DIC point towards a significant contribution of oxidation of organic matter to the DIC increase. The large changes in biogeochemical properties of the upper water column of the Atlantic have been one of the big surprises in the decadal reoccupation of the transects.

DISCUSSION
The global ocean sequesters about 1.5 to 2 Pg C, or about 25 to 30 %, of the carbon dioxide emitted by fossil fuel burning annually. As part of the CLIVAR/CO_2 Repeat Hydrography Program the invasion of this anthropogenic carbon is monitored by decadal reoccupation of hydrographic cruises. Quantification of the anthropogenic DIC increase is challenging because the annual cycle in DIC due to biological processes can be two orders of magnitude greater than the annual uptake of anthropogenic CO_2 in the upper water column. The separation of the small anthropogenic signal from the large and varying background is performed in two different ways. The biological contributions to DIC increases are separated from the anthropogenic increase using changes in inorganic nutrients and oxygen assuming a constant stoichiometry between carbon, oxygen and nutrients (the Redfield ratio) such that the remaining DIC change can be attributed to anthropogenic CO_2. A multi-linear regression (MLR) empirical approach based on regressing DIC during one time period with salinity, temperature and nutrients and determining the differences between the regression and observations for a later time period is used as well to determine decadal changes in DIC in the water column.

The results from meridional cruises in the Atlantic basin from 63 ˚N to 60 ˚S completed in 2003 and 2005, respectively are compared to data from cruises along these sections during the late 1980's and early 1990's with the measurement of hydrographic, biogeochemical parameters and transient tracers over the full water column. The traceable accuracy of DIC measurements to better than 2 µmol/kg for the cruises makes it possible to quantify small differences over time. DIC remains largely unchanged below 1000 m but large increases up to 40 µmol/kg are observed in the upper water column Fig 1. Assuming that the ocean remains in equilibrium with the atmospheric CO_2 rise, increases of 16 to 8 µmol/kg per decade would be expected for colder high latitude water and warmer low latitude waters, respectively. Large changes over time are also found in the spatial distributions of oxygen and nutrients, suggesting that some of the observed changes in water column DIC are due to changes in the oceanic biology, circulation and/or ventilation patterns. The larger than expected increases in DIC are primarily caused by increased oxidation of organic material as manifested by increased AOU (Fig. 2) in the upper water column. Changes in the chlorofluorocarbon distributions imply that a decrease of ventilation is the dominant cause rather than changes in remineralization rates.

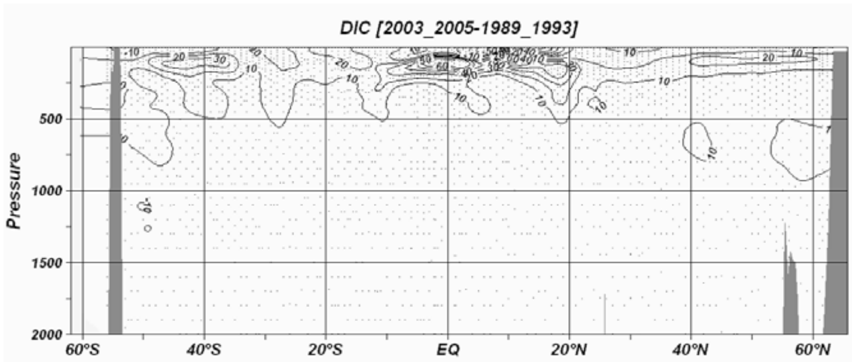

Fig. 1. Measured differences in DIC in the upper water column of the Atlantic Ocean based on observations in 1989/93 and 2003/05.

The increase in DIC corresponding to the decadal increase in AOU does not follow a constant stoichiometric ratio. Since our methods to determine the amount of anthropogenic carbon in the ocean rely heavily on the assumption of a constant stoichiometry between carbon and oxygen, the change in oxygen impacts our ability to quantify the decadal change of anthropogenic carbon. Using canonical Redfield ratios to subtract the oxidative carbon that accumulated over the decade yields relatively small anthropogenic carbon increases or in some locations apparent decreases over time suggesting an overcorrection. The MLR technique yields invasion patterns that follow expectations but the empirical nature of this approach exempts an objective analysis of its validity in an ocean basin that is undergoing natural changes.

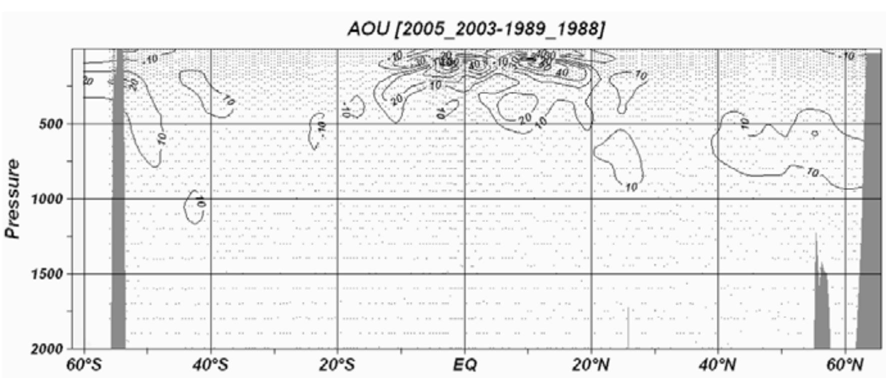

Fig. 2. Changes in AOU in the upper water column of the Atlantic Ocean based on observations in 1989/93 and 2003/05.