BIOGEOCHEMICAL CHANGES IN SUBTROPICAL AND SUBPOLAR MODE WATERS – A MINER'S CANARY FOR CLIMATE CHANGE?

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ABSTRACT

Long-term observations of carbon, nutrients and oxygen in upper thermocline waters, such as subtropical and subpolar mode waters, have revealed substantial interannual to decadal variations. While part of this variability can be ascribed to internal ocean and ecosystem dynamics as well as large-scale climate phenomena (like ENSO, NAO or the PDO), we presently do not know to which extent this variability is influenced by anthropogenic climate change. As a first step to answer this detection question, the impact of natural variability on biogeochemical properties in thermocline waters must be understood and quantified. This permits us then to accurately describe the natural "noise" against which an anthropogenic change needs to be detected. Subtropical and subpolar mode waters may be ideally suited to look at this task since they tend to respond sensitively to climate variations, integrate short-time scale variations over time, and hence exhibit maximum signal to noise ratio. We investigate the role of mode water formation and spreading on interannual to decadal accumulation and release of nutrients and carbon by analyzing results from model runs with the Upper Ocean Model [*Danabasoglu and McWilliams* 2000] coupled to the ecosystem model of *Moore et al.* [2002]. We compare results from a run forced with NCEP reanalysis data for the period from 1948 to present with a climatological control run. To better isolate the mechanisms forcing these biogeochemical changes, we compare our results also to a set of experiments in which we manipulate the wind stress forcing and sea surface temperature fields of the model locally.

INTRODUCTION

Upper thermocline waters in the subtropics and subpolar regions hold a high potential for the detection of climate change signals, as they tend to integrate variability over time. Changes in mode and intermediate waters have been documented throughout the world's ocean [e.g. *Bates et al.*, 2002; *Johnson et al.*, 2005; *Emerson et al.*, 2004; *Wanninkhof et al.* 2005]. To determine a climate change signal in physical and biogeochemical properties in mode waters we need first to establish a "reference" state of the system. We do this by performing a suite of model runs with climatological forcing as well as runs forced with NCEP (National Centers for Environmental Prediction) reanalysis data. We also vary atmospheric CO_2 concentrations from pre-industrial conditions (278ppm) to observed values to separate the invasion of anthropogenic CO_2 from the variations in natural CO_2.

MODEL DESCRIPTION

Model runs are performed with the Upper Ocean Model (UOM) [*Danabasoglu and McWilliams* 2000]. The model has a horizontal resolution of approximately 3 degrees (102x116 grid boxes) and 15 vertical (sigma) layers that extend down to between 500 and 1200m. The model's lower boundary is specified by observational and full-depth model data (see below). The physical model is coupled to the ecosystem model of *Moore et al.* [2002], which includes five potentially limiting nutrients (NO_3, NH_4, PO_4, Si and Fe), three phytoplankton classes, one zooplankton class, and multiple classes of dissolved organic matter.

Initial and Boundary Conditions:

We use World Ocean Atlas data for nutrients and O_2, GLODAP (GLobal Ocean Data Analysis Project) data for dissolved inorganic carbon (DIC) and alkalinity, and results from a CCSM (Community Climate System Model) global model run, which uses the same ecosystem model but different physics, for all other fields. The lower boundary uses climatological model data for beneath the deepest layer.

Forcing:

As upper boundary condition, the model uses either NCEP reanalysis data (1948-2002) or a climatology derived from these data for its physical forcing. Iron and dust fluxes have been provided by the Woods Hole Oceanographic Institution (WHOI), atmospheric CO_2 values by the Northern Ocean Carbon Exchange Study (NOCES) project.

Model runs:

The model has been spun up for 30 years with pre-industrial atmospheric CO_2 values and pre-industrial DIC initial conditions as provided for the NOCES project. It was then restarted using the NCEP reanalysis data forcing for 1948. For this transition the model's DIC field has been multiplied with a factor derived from the observation that the anthropogenic DIC perturbation scales with the atmospheric CO_2 perturbation:

$$DIC(t) = DIC(t_0) + pCO_2^{atm,ant}(t)/pCO_2^{atm,ant}(1994) * C_{ant}(1994),$$

with $DIC(t_0)$ the pre-industrial DIC field, $pCO_2^{atm,ant}(t)$ the anthropogenic perturbation of atmospheric pCO_2 field and $C_{ant}(1994)$ the anthropogenic DIC perturbation based on GLODAP data for 1994. This relationship is demonstrated in Fig.1 (left panel), which shows the relationship of the anthropogenic DIC perturbation for 1953 with that for 1994 for all depths taken from an OCMIP (Ocean Carbon-Cycle Model Intercomparison Project) model run with the Princeton abiotic model. The data points show a highly linear relationship between the DIC perturbations for both years. The model restart year 1948 is repeated 3 times to moderate the initial shock of the transition from the pre-industrial spin-up.

FIRST RESULTS

The results presented here are annual means for the model year 1977. The right panel of Fig. 1 shows the difference between DIC sections for the upper 500 m along 20°W in the Atlantic Ocean for observed minus pre-industrial pCO_2 values. The increase of DIC in the upper water column shows maxima in the subtropics of both hemispheres of almost 40 mmol C m^{-3}. Further analyses will concentrate on the impact of the variability of physical forcing on production and spreading of mode waters, especially the accumulation and release of nutrients on interannual to decadal time scales.

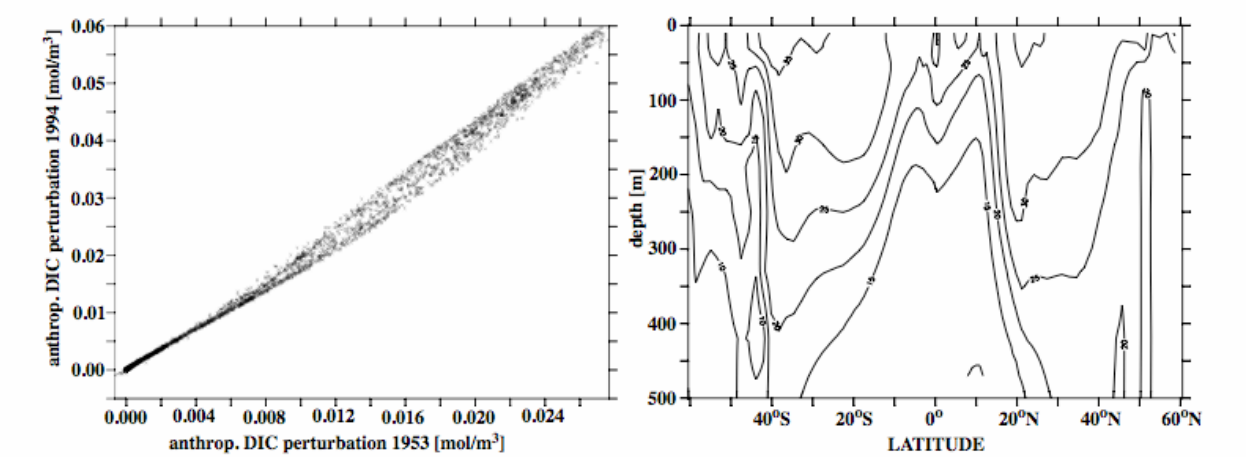

Fig. 1: left panel: Scatterplot of anthropogenic DIC perturbations for the years 1953 vs. 1994 in mol C/m^3 in a model run with an abiotic version of the Princeton OCMIP model runs. Right panel: Differences of annual mean DIC concentrations for 1977 for a section along 20°W in the Atlantic Ocean in mmol C/m^3 between model run with observed pCO_2 and pre-industrial pCO_2 (model is UOM, coupled to Moore et al. [2002] ecosystem model).

REFERENCES

Bates, N. R., A. C. Pequignet, R. J. Johnson, and N. Gruber (2002), A short-term sink for atmospheric CO_2 in Subtropical Mode Water of the North Atlantic Ocean, *Nature, 420*, 489-493.

Danabasoglu, G., and J. C. McWilliams (2000), An upper-ocean model for short-term climate variability, *J. Climate, 13*(19), 3380-3411.

Emerson, S., Y. W. Watanabe, T. Ono, and S. Mecking (2004), Temporal Trends in Apparent Oxygen Utilization in the Upper Pycnocline of the North Pacific: 1980-2000, Journal of Oceanography, 60 (1), 139-147.

Johnson, G. C., J. L. Bullister, and N. Gruber (2005), Labrador Sea Water Property Variations in the Northeastern Atlantic Ocean, *Geophys. Res. Letters, 32*, L07602, doi:10.1029/2005GL022404.

Moore, J. K., S. C. Doney, J. A. Kleypas, D. M. Glover, and I. Y. Fung (2002), An intermediate complexity marine ecosystem model for the global domain, *Deep-Sea Res. II, 49*(1-3), 403-462.

Wanninkhof, R., S. Doney, C. Langdon, J. L. Bullister, G. C. Johnson, M. Warner, and N. Gruber (2005), Decadal Changes in inorganic carbon in the Atlantic Ocean, Extended Abstract of the 7th International CO_2 conference, Broomfield, CO.