OS25Q-20

Impact of subduction on the nitrate content of North Atlantic Subtropical Mode Water

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1. Objectives

The importance of water mass formation and subduction in the climate system has recently re-emerged from observational and modeling studies. The most distinct mode water in the North Atlantic is a highly homogeneous water mass that forms south of the Gulf Stream: the Subtropical Mode Water (STMW). The evolution of the biogeochemical characteristics within this mode water during and after subduction remains subject to conjecture.
Here we explore the role of subduction on the nitrate content of the North Atlantic STMW with a model.

2. Methods

a) Model configuration

- idealized double-gyre (2000*3000 Km) [1] (fig. 1)
- primitive equations (OPA 9.0) on the beta-plane
- free surface, no topography, no coast
- bilinear equation of state
- analytical forcings (heat, freshwater and wind-stress fields) with a seasonal cycle
- analytical initialization (mean Levitus temperature and salinity)
- spin up: 1000 years with Physics alone

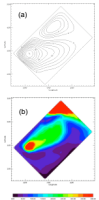


Fig. 1: (a) Annual mean barotropic streamfunction in Sv ($Sv = 10^6 m^3 s^{-1}$) and (b) averaged march mixed layer depth in meters

b) The biogeochemical model: LOBSTER

- nitrogen-based model [2] (fig. 2)
- analytical initialization (mmoleN/m3):

  NO3=f(density)
  PHY=ZOO=DET=NH4=0.1
  DOM=1

- semi-labile dissolved organic matter (DOM) (breakdown rate = 6 months^{-1})
- spin up: 100 years after equilibration of Physics

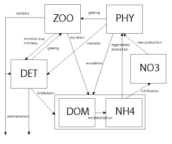


Fig. 2: General structure of LOBSTER
(NO3: nitrate, NH4: ammonium, PHY: phytoplankton, ZOO: zooplankton, DET: detritus, DOM: dissolved organic matter)

3. The North Atlantic seasonal cycle

a) Basin-scale chlorophyll

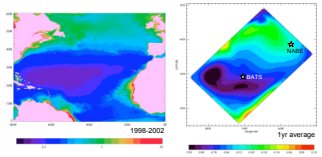


Fig. 3: (a) Annual averaged simulated and (b) observed SeaWIFS surface chlorophyll (mmol/m^3/day). White stars represent the location of the BATS and NABE sites in the idealized configuration.

➡ The model shows a strong meridional gradient of chlorophyll between subtropical and subpolar gyres (fig. 3)

➡ Good agreement between model and JGOFS data (fig. 4)

b) Validation at two selected JGOFS sites

We have chosen the location of BATS and NABE in our reduced representation of the North Atlantic gyres on the basis of their mixed layer seasonal cycle (fig. 4). The differences between model and data are shown in fig. 4.

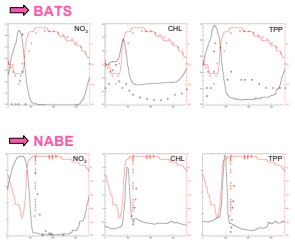


Fig. 4: Time series of NO_3 (mmol/m^3), chlorophyll (mg/m^3) and total primary production (mmol/m^3/day) at BATS and NABE (locations on fig. 3) as simulated by the model (line) and as deduced from BATS and NABE data (circles) [3, 5]. The simulated (red line) and observed (red crosses) mixed layer depth (m) is representing for each site.

4. Nitrate variability within the North Atlantic STMW

a) Identification of the STMW

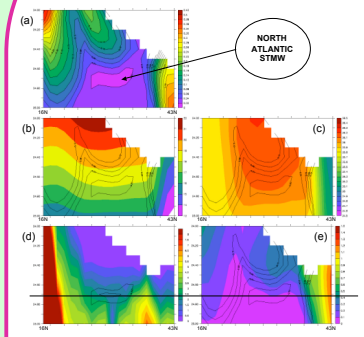


Fig. 5: Properties of the North Atlantic Subtropical Mode Water as a function of potential density along section A (located on fig. 7) in July. (a) Brunt-Vaisala frequency (BV), (b) temperature (°C), (c) salinity (psu), (d) NO_3 (mmol/m^3) and (e) DOM (mmol/m^3). The black contour lines represent BV. The STMW is characterized by low BV (<0.02).

STMW PROPERTIES

➡ 18 °C, 36.1 psu, low stratification (BV<0.02), 24.6 – 24.8 (fig. 5)
➡ Low-DOM concentration
➡ Evidence of a low-NO_3 content compared with the surrounding waters (high latitudinal gradient): 1.5 mmole/m3 as in Palter et al. [4]
➡ Subduction occurs from March to April (fig. 6)

NITRATE SEASONAL VARIABILITY

➡ When it is formed, STMW have a low-NO_3 content (fig. 6): 1.5 mmole/m^3 as in Palter et al. [4]
➡ Hence the nutricline is deeper at the location of the mode water (fig. 7)
➡ Along the seasonal cycle, remineralization is responsible for the increase of the NO_3 content of the STMW (fig. 8,9)
➡ This causes the nutricline to shallow (fig. 7)

b) Nitrate seasonal variability within the STMW

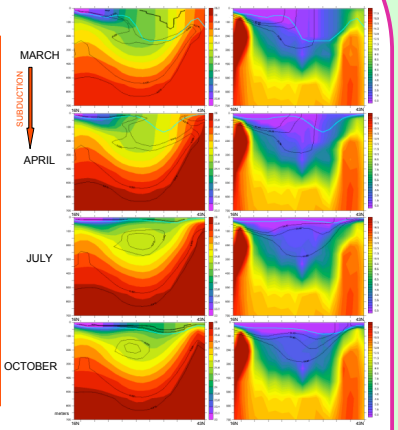


Fig. 6: Seasonal evolution of the Subtropical Mode Water and of its nutrient content as a function of depth along section A (located on fig. 7). (a) Potential density and (b) NO_3 (mmol/m^3). The black contour lines represent BV in a) and isopycns in b). The STMW is characterised by low BV (<0.02). The mixed layer depth is represented in light blue.

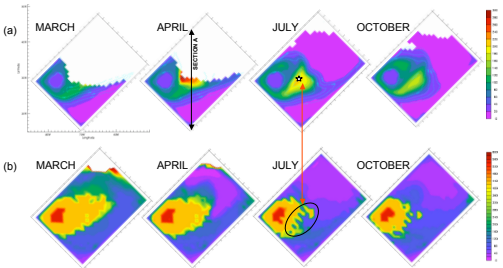


Fig. 7: Monthly-averaged STMW thickness (a) and nutricline depth (b) in meters. The STMW thickness is calculated between the 24.6 and 24.8 isopycns. The nutricline is defined as the depth of the maximum vertical nitrate gradient. The light blue contour lines represent BV frequency. The STMW is characterized by low BV (<0.02). The latitudinal section A and the white star are located for the 2D and 1D diagnostics respectively.

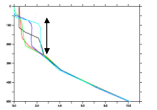


Fig. 8: NO_3 concentration (mmol/m3) as a function of depth within the STMW formation zone (point located on fig. 7). Simulated concentrations are shown for February (black), April (red), May (green), July (blue) and October (light blue)

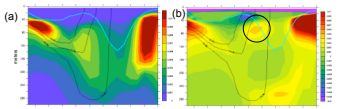


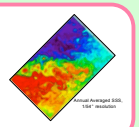
Fig. 9: (a) Remineralization and (b) detritus sedimentation trends (mmol/m3/day) as a function of depth along the section A (location on fig.) in April. The black contour lines represent isopycnes. The [24.6,24.8] isopycns represent the STMW. The mixed layer depth is represented in light blue.

5. Conclusions

(1) model provides successfully an idealized representation of the seasonal cycle of the North Atlantic
(2) North Atlantic STMW: low-NO_3 content when formed then enriched in nutrients during its circulation through the subtropical gyre

…and next steps

- sensibility analysis to export and remineralization & to winter productivity
- sensiblity analysis to the resolution of the mesoscale dynamics



References
[1] **Hazeleger, W. et al.**, 1998, Mode water variability in a model of the subtropical gyre; Response to anomalous forcing. *J. Phys. Oceanogr.*, 28, 266-288.
[2] **Levy, M. et al.**, 2001, Impacts of sub-mesoscale physics on phytoplankton production and subduction. *J. Mar. Res.*, 59, 535-565.
[3] **Kleypas and Doney**, 2001, Nutrient, Chlorophyll, Primary production and Related Biogeochemical Properties in the Ocean Mixed Layer, A compilation of data Collected at nine JGOFS sites
[4] **Palter J. et al.**, 2005, The effect of advection on the nutrient reservoir in the North Atlantic subtropical gyre, *Nature*, 437, 687-692.
[5] Data also reported from http://www.uib.no/jgofs/jgofs.html and http://www.bbsr.edu/