An isopycnic model study of the circulation of Sub-Antarctic Mode Water throughout the global ocean

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• Introduction

Winter convection north of the Sub-Antarctic Front (SAF) of the Antarctic Circumpolar Current (ACC) forms a deep, well-mixed layer known as the **S**ub-**A**ntarctic **M**ode **W**ater (SAMW). It has recently been recognized that **SAMW** is important in providing the source of nutrients to drive biological production over large proportions of the world's oceans, after subduction in the Southern Ocean and subsequent re-emergence into the mixed layer elsewhere. But many uncertainties exist regarding how this re-emergence occurs. The **HY**brid **C**oordinate **O**cean **M**odel is a primitive equation OGCM. The isopycnic nature of the model ocean interior makes it ideal to the purpose of this work, which is to investigate **SAMW** subduction, spreading pathways, and upwelling sites, as well as their sensitivity to perturbations in mixing parameters.

• Configuration of Numerical Model

The domain is spanned by a mesh consisting of 120 points in the E-W direction and 50 points in the N-S direction with a horizontal grid of resolution 3° in longitude and 3° in latitude. This covers a horizontal domain from 78°S to 69°N, and 0°W to 360°E with a uniform projection (Figure 1). The model comprises a total of 16 isopycal layers of constant potential density, varying from 30.90 to 37.23 with reference to 2000 db. Initialization was carried out with a state of rest using the Levitus climatology (Figure 2).

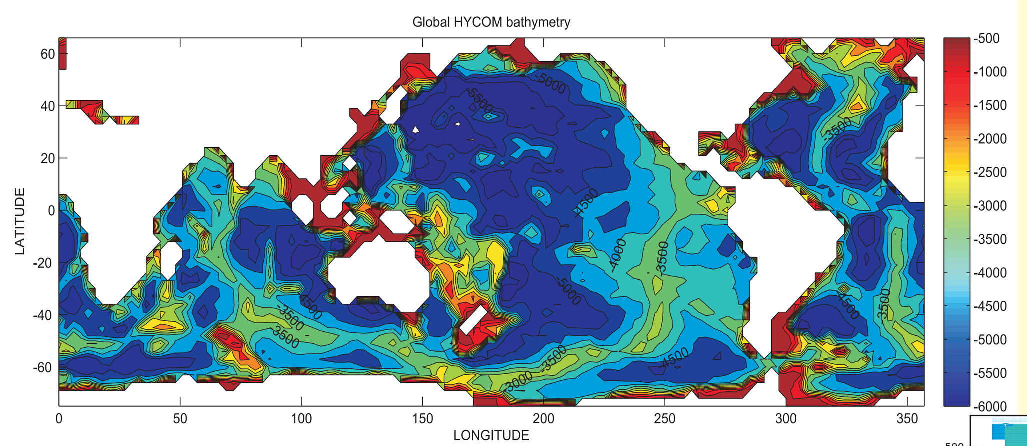


Fig 1. Bathymetry derived from 5 min ETOPOS dataset with minimum depth = 10 m.

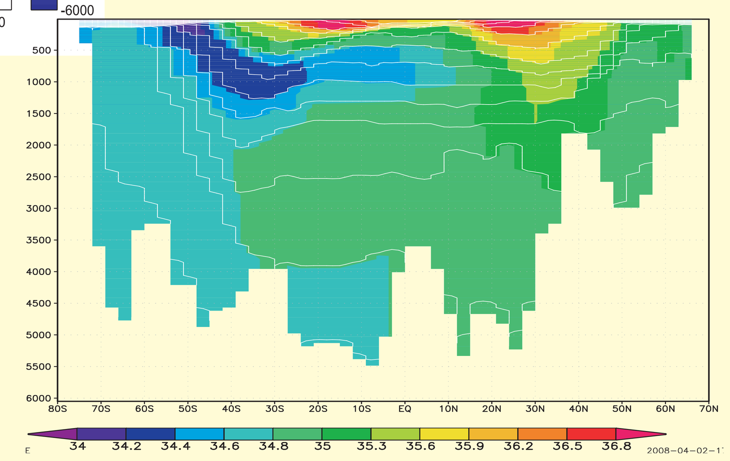


Fig 2. Meridional Section of HYCOM initial salinity

Table 1. summary of diapycnal mixing coefficients

Diapycnal Mixing	Diffusion Velocity
background viscosity	$1.0 \times 10^{-4}\ m^2s^{-1}$
background diffusivity	$0.1 \times 10^{-4}\ m^2s^{-1}$
max shear dependent vis/dif	$5.0 \times 10^{-3}\ m^2s^{-1}$
max gradient Richardson Number	0.7

A lateral boundary relaxation is applied over a region from 78°S to 72°S for 3 rows in the South, and from 57°S to 69°S for 5 rows in the North Atlantic (Figure 3) . Sea surface salinity restoration with a timescale of 5 months for 100 m mixed-layer thickness is used too. A Fickian law has been applied for the isopycnic exchange of momentum and diffusion of both layer thickness and Temperature/Salinity. The KPP mixing schema provides vertical mixing for the entire water column from surface to ocean interior (Table 1).

• Validation of the Control Run

The ability of the model to reproduce essential features of the Meridional Overturning Circulation and the Antarctic Circumpolar Current is one of the most important aspects in evaluating its performance and has been taken as the main criterion for HYCOM tuning. In order to obtain a control run which can simulate the ocean circulation as closely to reality as possible, we carefully selected the strength of the boundary relaxation and mixing coefficients (Figure 4). Two climatological surface forcing fields (NOC and NCEP) have been tested in HYCOM for intercomparison. A final MOC stream function and ACC flux transports for the control run can be seen in Figure 5 and Figure 6.

Fig 3. Lateral boundary relaxation strength for the Control Run (days)

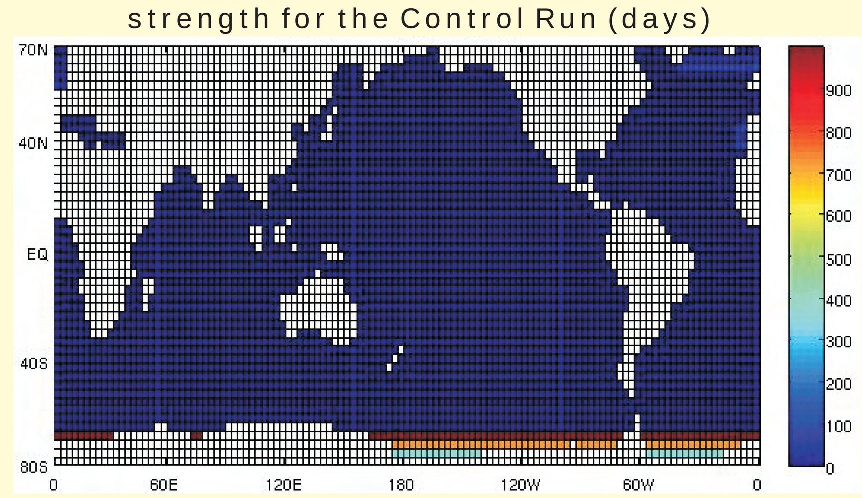


Fig. 4 Time series of Maximum MOC transport with different isopycnal eddy viscosities.

Experiment number	Laplacian viscosity	Bioharmonic viscosity
E-1	0.1	0
E-2	1	0
E-3	1	0.5

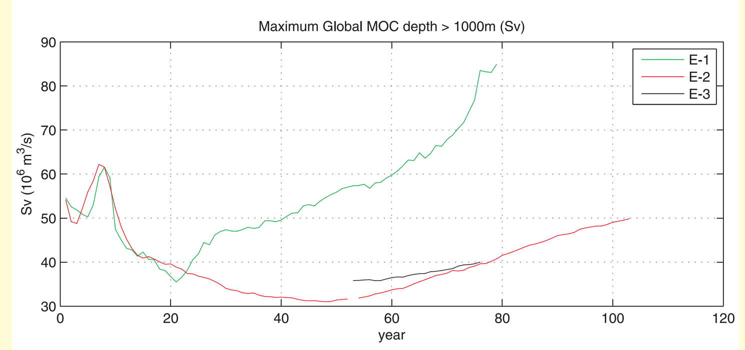


Fig 5. Time series of ACC and Maximum MOC transports during HYCOM spin-up for the Control Run

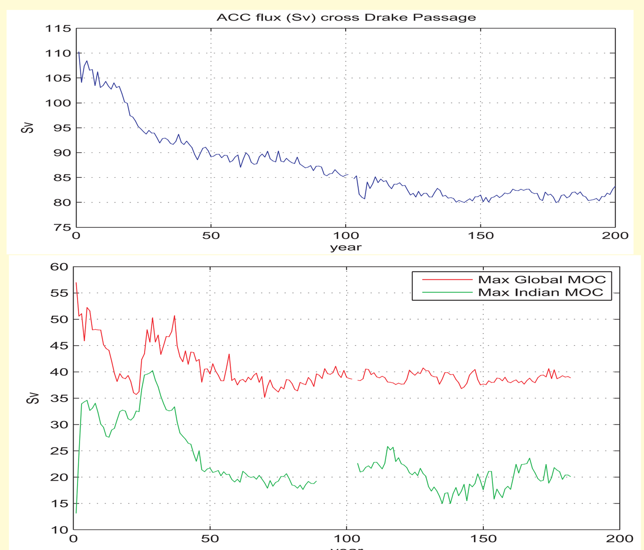
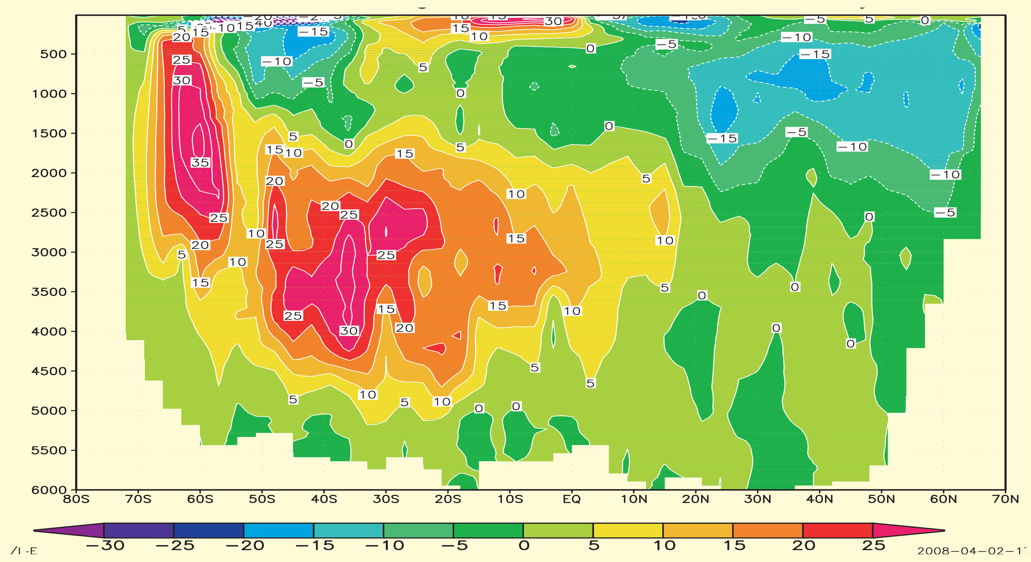


Fig 6. Global MOC Streamfunction after 120-year's spin-up in the Control Run



• Tracer Experiments

The HYCOM simulated formation region of SAMW covers mainly the Southern Indian and Pacific Oceans between latitude 30°S to 60°S, and includes mainly 4 isopycnal layers (from ó2= 34.24 to 35.80) (Figure 7). We find a good similarity when comparing with OFES (Ocean general circulation model For the Earth Simulator) results and Argo float data. A conservative tracer is then injected into the mixed layer in the formation regions of SAMW after model spin-up and continuously released for over 100 years. An expected northward spreading of tracer away from the southern source with two well identified plume can be seen in Figure 8, showing the main subduction location of SAMW and advection direction once out the source region. Tracer crosses the equator associated with western boundary current systems and follows the spreading pathway of the subtropical gyre in the North Atlantic Ocean. The Upwelling in Figure 9 is caused by enhanced diapycnal mixing originated from the shear dependent term and generated by strong surface velocity shear in these regions.

Fig 7. HYCOM generated southern winter mixed-layer depth after model reaches quasi-equilibrium state, varying from 150 db to 500 db.

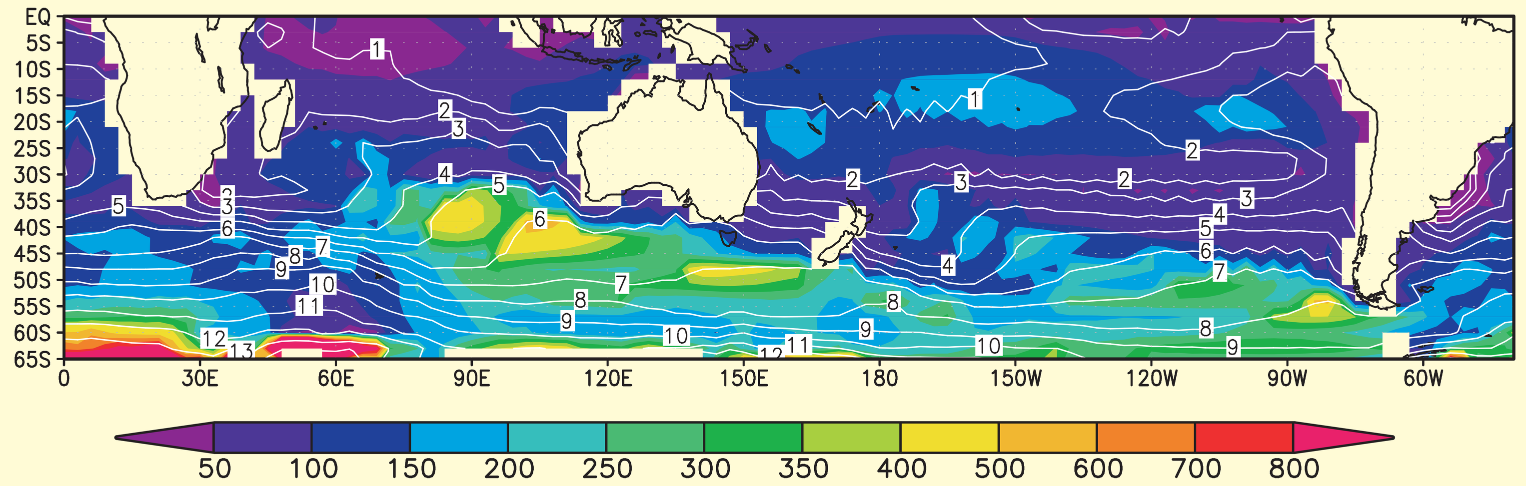


Fig 8. Tracer concentration along density surface ó2= 34.85 and the mixed layer with the end of winter outcrop. 40 years after tracer injection.

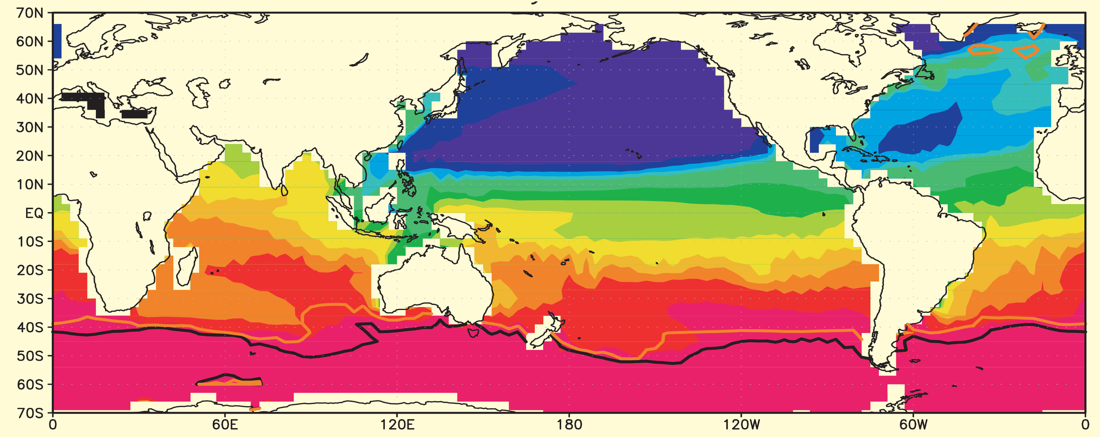


Fig 9. Tracer concentrations along density surface ó2= 34.24 after 4 years releasing. A barrier has been set up from 33°S to 24 °S

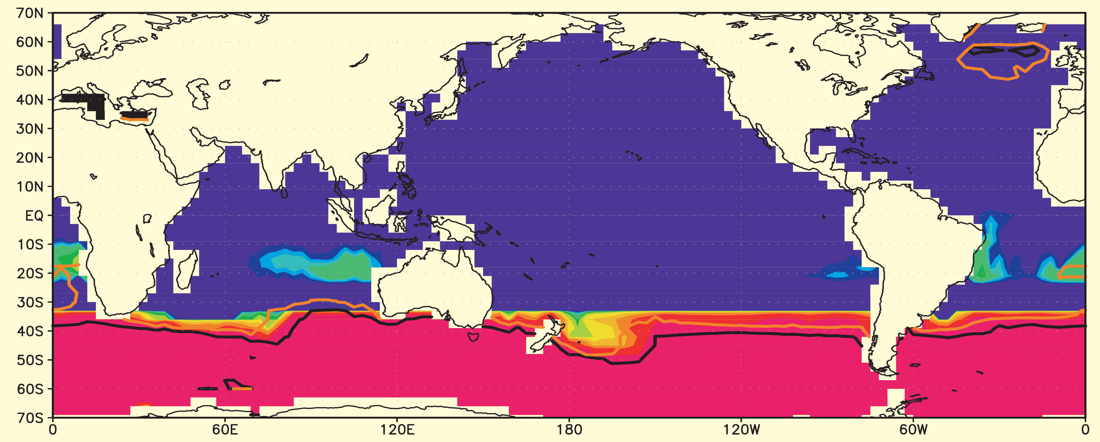
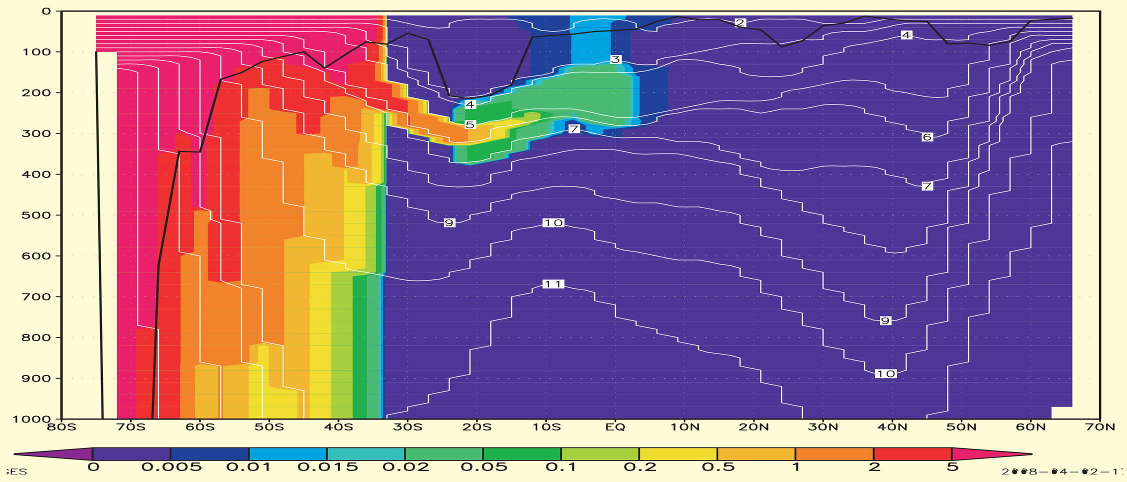


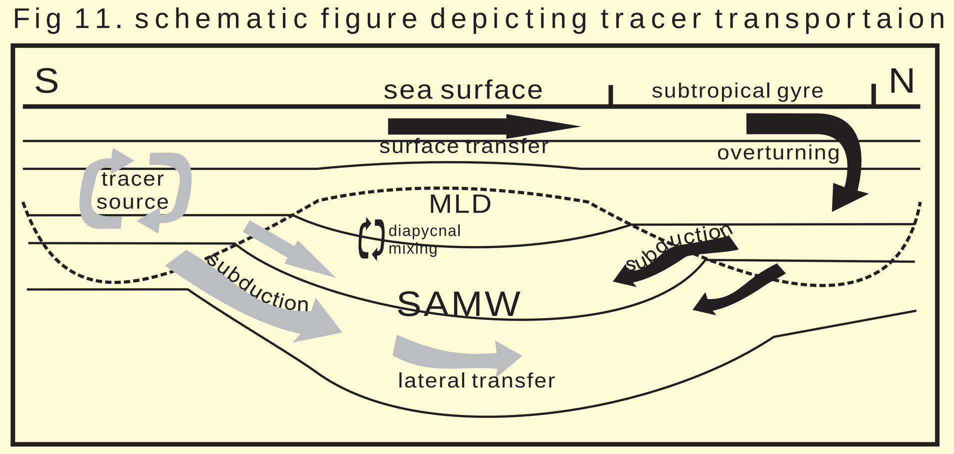
Fig 10. Tracer concentration along 30°W with isopycnal layer interfaces (white contours) and the base of the winter mixed layer (black contour). 20 years after tracer injection.



• Discussion

Because conservative tracer is always transported faster in the surface light water than along the intermediate SAMW layers, the tracer subduction in the North Atlantic winter outcropped region makes it hard to locate the upwelling location of the SAMW/nutrient there and has been stopped by a barrier. Future investigations will first consider tracer spreading with only one type of lateral transport mechanism at a time, and then repeated within a range of plausible ocean mixing regimes. The importance of different mechanisms of SAMW/nutrient re-emergence north of the Southern Ocean (diapycnal mixing, nutrient spiral, induction) will be assessed in each of the above ocean mixing regimes too.

Fig 11. schematic figure depicting tracer transportaion



Reference:

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Sarmlento J. L., Gruber N., Brzezinski M. A. and Dunne J. P., 2004, High-latitude controls of thermocline nutrients and low latitude biological productivity. Nature, 427, 56-60

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