Optimal sea surface salinity impact on the oceanic circulation

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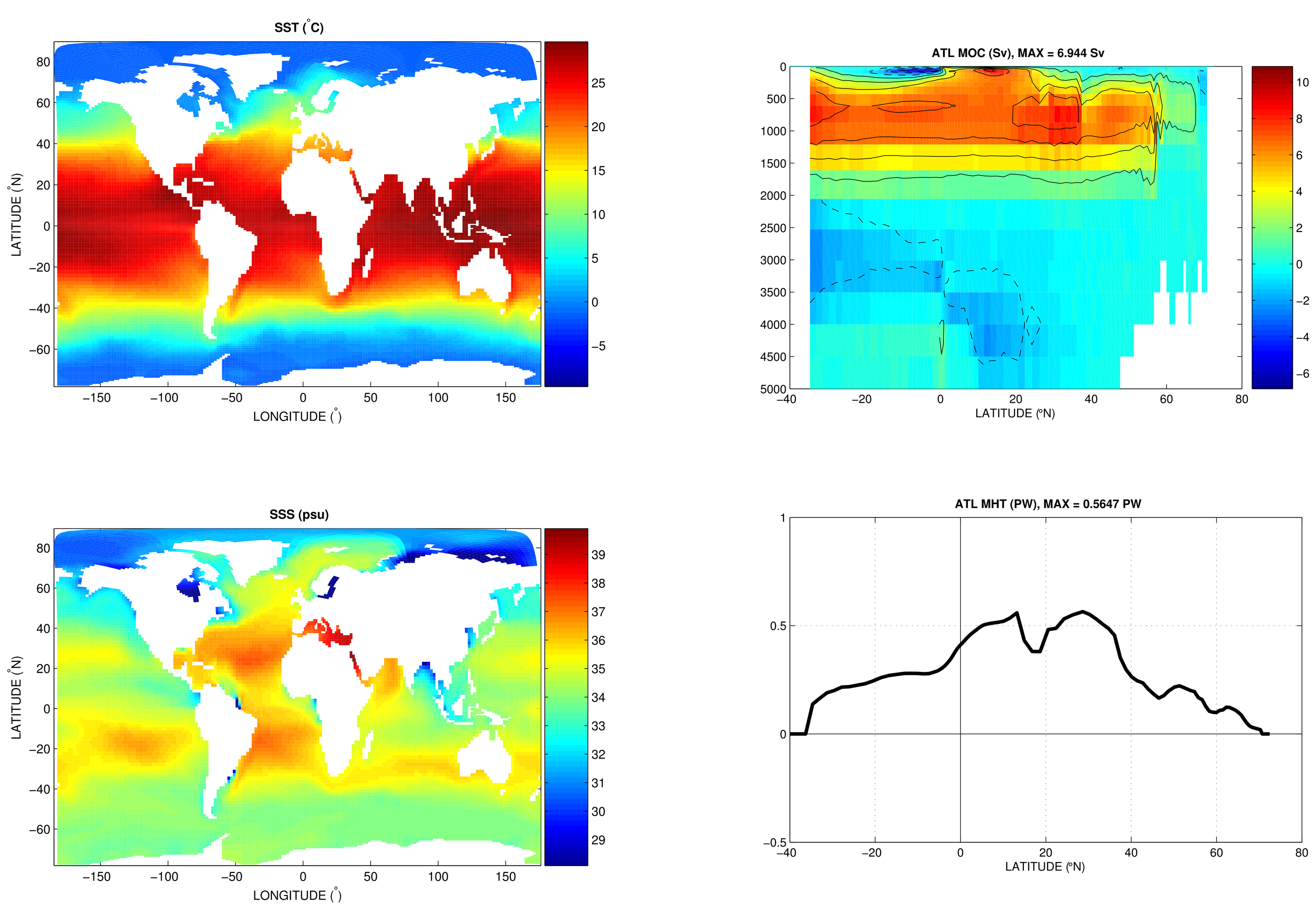
INTRODUCTION

One of the expected consequences of the global warming is the modification of the freshwater flux inducing changes in the ocean salinity. Actually, modifications of the north Atlantic salinity have been shown in the recent decades (Josey and Marsh, 2005; Curry et al., 2003; Curry and Mauritzen, 2005). In this context, explicit solutions of the optimal sensitivity to Sea Surface Salinity (SSS) perturbations are found for two measures of the oceanic circulation, the maximum of the Atlantic Meridional Overturning Circulation (MOC) and Meridional Heat Transport (MHT) intensity.

MODEL AND STEADY STATE

We use the oceanic primitive equation model OPA (Madec et al., 1997) in a global configuration with 2° resolution ORCA2 (Madec and Imbard, 1996). The model is integrated during 200 yr with annual mean forcing to obtain a steady state (leading to an autonomous problem after linearisation). Surface restoring is used for temperature and salinity, but has been switched off in the linearized equations.



Sea Surface Temperature (SST), Sea Surface Salinity (SSS), Atlantic Meridional Overturning Circulation (MOC) and Meridional Heat Transport (MHT) at the steady state after a 200 yr integration of the global PE model. The solid, dashed and dotted contour respectively represent the positive, zero and negative values with a 2 Sv interval

OPTIMAL SSS

We look for the optimal surface salinity perturbation influencing the oceanic circulation in a linearized approach. Two different measures of the circulation are chosen: the maximum of the Meridional Overturning Circulation and the maximum of the Meridional Heat Transport. The optimal SSS for the two different measures are obtained by propagation of the cost function, relative to each measure, through the adjoint of the linear tangent model OPATAM (Weaver et al., 2003). In addition we constrain the solution (1) to be SSS only, (2) to conserve salt and (3) to be normed (in such optimal linear problem a quadratic norm must be used). The optimal solution can be explicitly written in terms of the two constraints, the adjoint of the linear tangent model and the cost function:

$$\text{Maximisation problem:}\quad \mathrm{Max}\left(\langle F|u(\tau)\rangle, |u(0)\rangle\right),$$

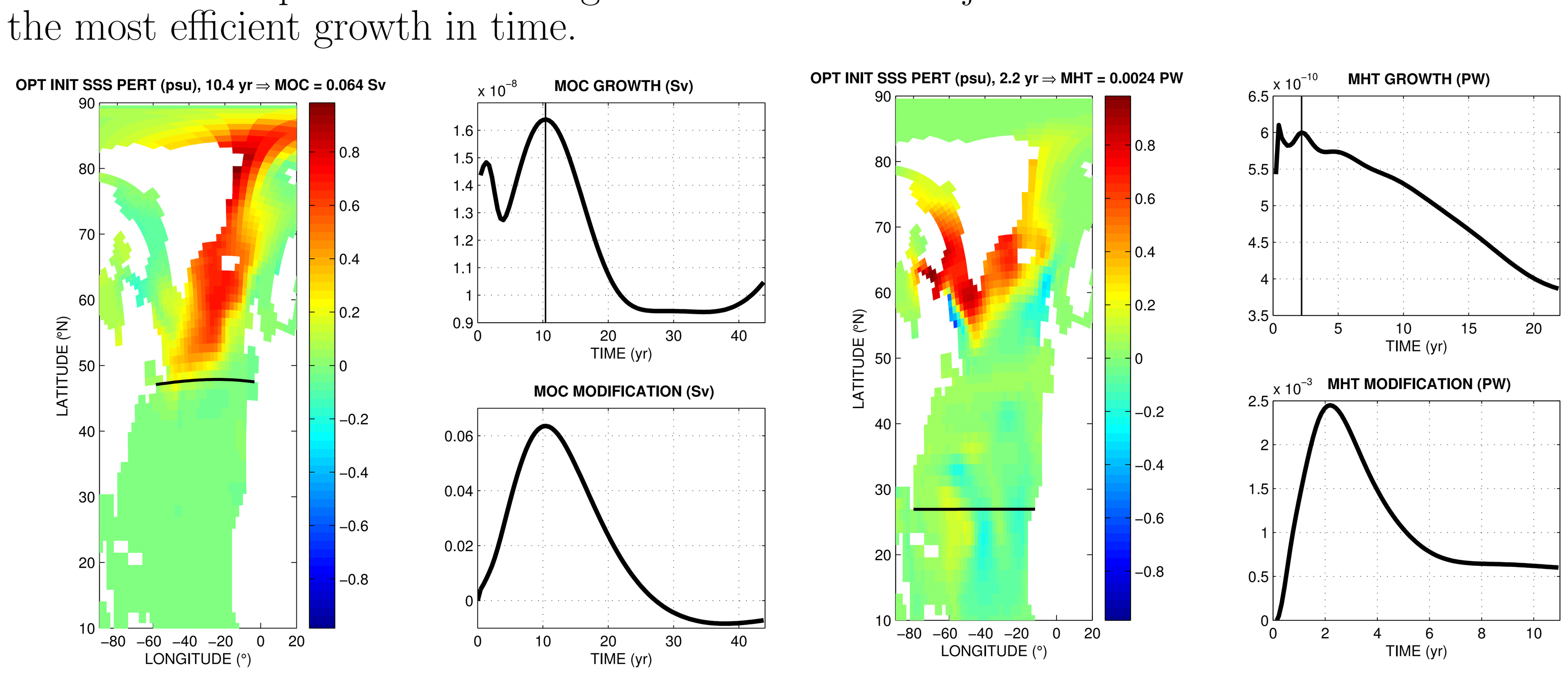
$$\text{Constraints: (1) } |u(0)\rangle = \mathbf{P}\,|u'\rangle, \text{ (2) } \langle C|u(0)\rangle = 0 \text{ and (3) } \langle u(0)|\mathbf{S}|u(0)\rangle = 1,$$

$$\text{Perturbation propagation}\quad |u(\tau)\rangle = \mathbf{M}(\tau)\,|u(0)\rangle,$$

$$\Rightarrow |u'\rangle = (2\gamma_1)^{-1}\left(\mathbf{N}^{-1}\mathbf{P}^{\dagger}\mathbf{M}^{\dagger}(\tau)\,|F\rangle - \gamma_2\mathbf{N}^{-1}\mathbf{P}^{\dagger}\,|C\rangle\right),\quad \text{Explicit solution}$$

$$\text{with } \mathbf{N} = \mathbf{P}^{\dagger}\mathbf{S}\mathbf{P}, \gamma_1 = \mathrm{fct}\left(\mathbf{M}(\tau), |F\rangle, |C\rangle, \mathbf{N}, \mathbf{P}, \gamma_2\right) \text{ and } \gamma_2 = \mathrm{fct}\left(\mathbf{M}(\tau), |F\rangle, |C\rangle, \mathbf{N}, \mathbf{P}\right).$$

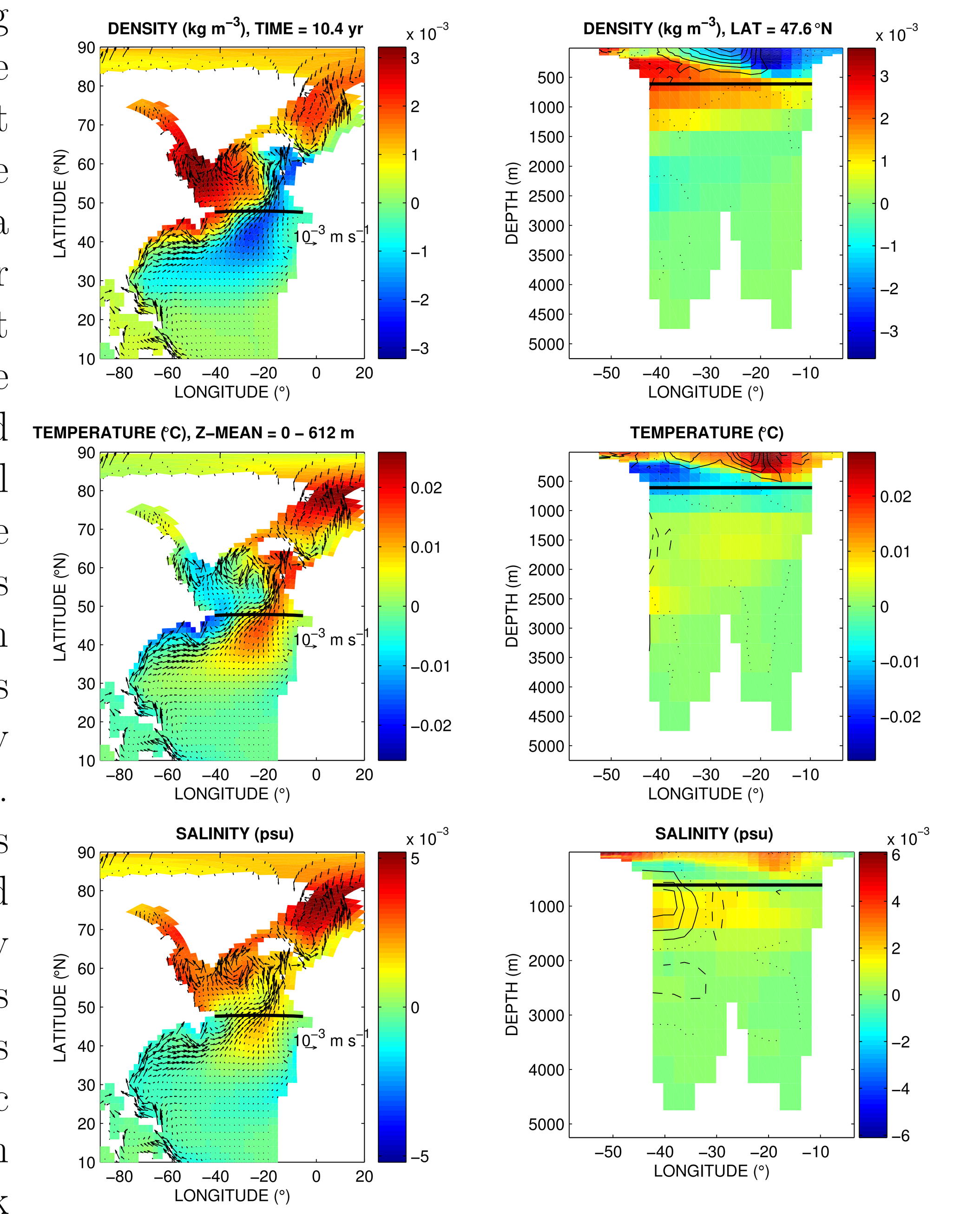
The solution depends on the integration time of the adjoint model: we choose to examine the most efficient growth in time.



Left (right), optimal SSS structure modifying the MOC (MHT). The sensitivity has a maximum at respectively 10.4 and 2.2 yr for the MOC and the MHT, the corresponding stucture (left and center right) have respectively an intensification in the Irminger and Artic seas and in the Labrador sea. The integration of the linear tangent model with the optimal structure for initial conditions confirms the finite time growth at 10.4 or 2.2 yr.

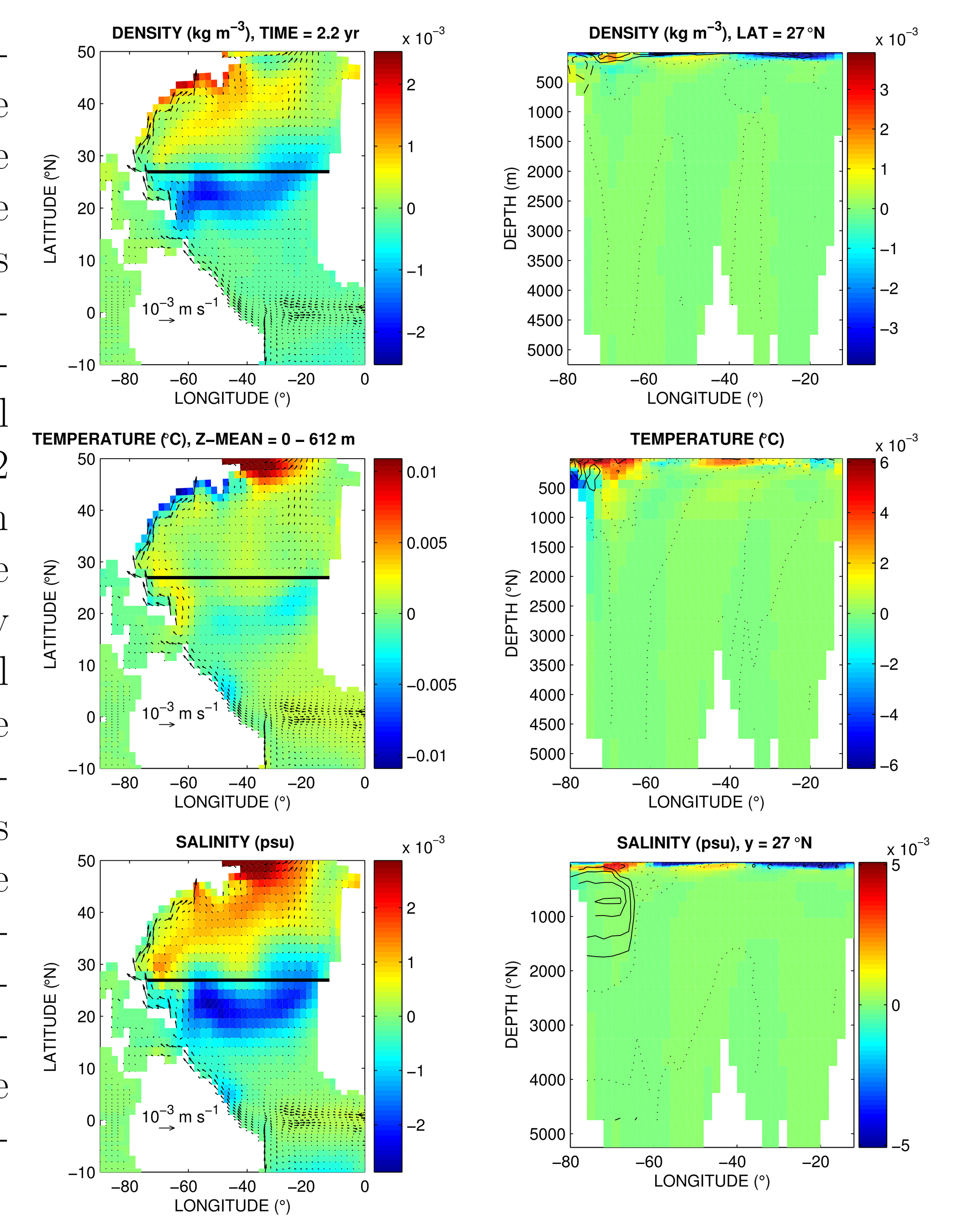
FINITE TIME GROWTH MECHANISMS

The salinity anomaly in the Irminger sea creates a strong meridional density gradient in the first 1000 meters. This gradient is increased during 10.4 yr by the salty water stored in the Artic sea which supplies in salt the Irminger sea through the Denmark strait and Iceland-Scotland ridges. The meridional density gradient, created in the north Atlantic, induces zonal westward velocities at the latitude of the MOC maximum. This advection creates an upwelling in the east of the bassin which induces a negative temperature anomaly in the eastern 1000 first meters. This temperature gradient creates a northward surface and southward bottom circulation, as expected by the thermal wind relation. This finite time growth mechanism is closed to the planetary geostrophic interdecadal oscillation mechanism of Colin de Verdière and Huck (1999); Te Raa and Dijkstra (2002).



Linear model integration of the optimal SSS perturbation influencing the MOC after 10.4 yr. Density, Temperature, salinity in the upper ocean 600 m on the left and along 48°N section (mean MOC maximum) on the right. The quiver represent the horizontal velocity anomalies. The solid, dashed and dotted contours respectively represent the positive, zero and negative values The zonal, meridional and vertical velocities (the latter is average over 20° of latitude) are respectively plotted on the density, temperature and salinity with contour interval of 5×10^{-5}, 5×10^{-5} and 1×10^{-9} m s^{-1}.

The maximization of the heat transport is at first order due to the advection of the mean temperature gradient by the perturbation. The finite time growth mechanism is fairly the same as for the MOC maximization except that the meridional gradient is now due to a zonal salinity gradient rotated during 2.2 yr by both the effects of the mean subpolar gyre advection and of the meridional variation in the Rossby wave velocities. This meridional gradient of density, controlled by the salinity, induces an eastward surface current. This velocity creates a weak upwelling on the east of the bassin. This upwelling cools the water around 500 meters and thus induces a northward surface circulation. This circulation advects the mean meridional temperature gradient and thus reinforces the MHT.



As previous plot for the optimal SSS perturbation influencing the MHT after 2.2 yr. The section is at 27°N, (mean MHT maximum). Contour interval of the horizontal and vertical velocity is respectively 5×10^{-5} and 5×10^{-9} m s^{-1}.

RESULTS

Two finite time growth respectively modifying the Meridional Overturning Circulation and Meridional Heat Transport have been found and their mechanisms have been described. The first one corresponds to an anomaly in the Artic and Irminger seas and leads to an 0.8 Sv modification for an equivalent salinity perturbation of a great salinity anomalies (0.5 psu on 250m). The second one evolves both by the subplolar gyre mean advection and the baroclinic mode propagation. Because we have studied the optimal perturbation for both, we know that this finite time growth is the upper bound for modification of the MOC and MHT.

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