BOX MODELING STUDIES OF THE MEDITERRANEAN THERMOHALINE CIRCULATION

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Abstract

A 6 x 4 and a 2 x 2 simple box models are used to study the stability of the thermohaline cells of the Mediterranean basin under mixed boundary conditions and stochastic fluctuations of the freshwater flux superimposed. Results indicate that under present - day conditions the two cells connected with the deep waters production within the basin are sensible to freshwater flux fluctuations and can undergo weakening while the main thermohaline cell of the basin remains stable. By modifying the external conditions applied and making them comparable to those prevailing during the last sapropel formation event in the basin (8 kyrs B.P.) we find that the main cell can switch between two different states.

Key-words: circulation, models

Introduction

Mediterranean present - day circulation involves the production of at least two deep and intermediate water types by surface heat and water fluxes forcing [1]. To these water types there are distinct thermohaline cells associated with, possibly sensitive to external (*i.e.* atmospheric) conditions changes and to the internal dynamics of the basin as well.

The main thermohaline cell of the Mediterranean basin is linked to the eastward path of surface waters of Atlantic origin (AW), their transformation into intermediate waters (LIW) taking place in the Eastern Levantine basin and their subsequent westward return route all the way to the Gibraltar Strait.

Two additional cells are related to the deep water formation processes occurring inside the basin in geographically separate areas namely the Lions Gyre and the Adriatic region.

It is well known by now that the thermohaline circulation in the ocean is set by the interplay between thermal and saline fluxes. High temperatures in the equatorial regions versus low surface temperatures in the polar regions favour sinking at the poles and upwelling at the equator. This thermal cell is opposed by the distribution of precipitation and runoff which induces low salinities at high latitudes and thus favours a reverse meridional circulation. In the Mediterranean however, judging on the present - day distribution of temperature and salinity along the longitudinal direction, the main cell seems to be driven by the salinity east-west gradient while the temperature increase to the east can potentially oppose it. Thus there is an open question related to the existence of other possible states (weak or reversed east - west thermohaline circulation due to thermal effects) within the basin. Another important issue is related to the stability of the two "secondary" cells involving the deep waters formation processes in the Western (WMED) and Eastern (EMED) basin respectively.

The box modeling approach

A first approach to the issues stated in the previous section is accomplished through a box modeling study of the Mediterranean dynamical system.

In the 6 x 4 box model developed, the main body of the Mediterranean basin is divided into three subsystems namely the Western Mediterranean the Ionian and the Levantine basins while three additional subsystems stand for the deep and intermediate waters formation areas (Lions Gyre - Adriatic and Rhodes Gyre regions respectively). Each of the six subsystems consists of four distinct boxes in vertical, allowing for the representation of surface, intermediate and deep waters of the basin. Volume of all different boxes is considered to be fixed.

Within the model individual boxes are connected by horizontal/vertical advection and mixing. In particular horizontal advection of properties is parameterized as being proportional to the hydrostatic pressure gradient while convective overturn is treated as a vertical diffusion process.

Within each box water properties are well mixed and the density is calculated using a linear state equation. Forcing is in the form of a Rayleigh boundary condition for temperature and a flux boundary condition for salinity. Restoring the sea surface temperature to prescribed values is a good approximation for the actual coupling of SST and surface heat flux. On the other hand the use of restoring boundary condition on the salinity has no physical justification. Temperature at the surface boxes is relaxed to prescribed climatological values with a time constant equal to 5 days. Temperature and E-P flux values used to drive the model to a steady state are shown in fig. 1. Although the model by construction is not representing the full dynamics of the system, a quite fair representation of the basin's T-S characteristics is attained at the steady state.

A possible way to study the existence of different states of the Mediterranean dynamical system is by adding a stochastic (white noise in time) component to the E-P flux used to drive the model to the steady state. This procedure has been already used by Mikolajewicz and Maier-Reimer [2] in their global ocean model and by Cessi [3] in a simple Stommel type box model [4].

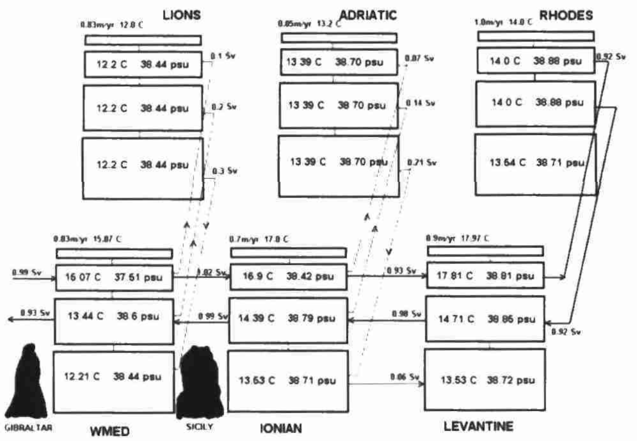

Figure 1: Steady state reached by the 6 x 4 box model under mixed boundary conditions. Arrows indicate direction of transport between the boxes.

Stochastic forcing is randomly picked from a Gaussian distribution with a standard deviation equal to 0.5m/yr and zero mean. In fig. 2 we show the basin mean temperature time series for a 50000 years integration of the model in the case where the stochastic component is applied with a period of one year. The system after a certain period reaches a state which involves a weakened deep waters formation cell in the WMED. This reflects in the increased (~14°C) basin mean temperature attained. The system exhibits also additional peaks of variability due to the weakening of the EMED deep waters formation cell which comes into play. The duration of these peaks approximately equals to 500 years and their excitation is connected to the frequency of the stochastic forcing application. In this experiment the main thermohaline cell of the basin is never perturbed even if the standard deviation of the stochastic component is highly increased. The same holds also in the case where the frequency of the stochastic forcing application is changed.

To study the behavior of the main cell alone, we develop a simple 2 x 2 box model with a longitudinal length scale L = 4000 km and a typical width of 350 km. Upper boxes (with a depth of 150 m) stand for the fresh waters of Atlantic origin (AW) while lower boxes represent the saltier intermediate waters of the basin (LIW) with a depth of 350 m. Advection is parameterized as being proportional to the density difference between the boxes. Apart from mixing associated with advection and overturning, there is no other type of mixing between boxes in the model. With the above configuration and a volume transport at Gibraltar of ~1 Sv the advective time scale of the cell is approximately equal to 22.5 years. The forcing is still in the form of a Rayleigh boundary condition for temperature and a flux boundary condition for salinity. The conservation equations for temperature and salinity for each of the four boxes are:

$$V_1\dot{T}_1 = \gamma V_1(T_1^* - T_1) + \begin{cases} U_m T_m & U_m > 0 \\ U_m T_1 & U_m < 0 \end{cases} - \begin{cases} U_1 T_1 & U_1 > 0 \\ U_1 T_2 & U_1 < 0 \end{cases} + \begin{cases} W_1 T_4 & W_1 > 0 \\ W_1 T_1 & W_1 < 0 \end{cases} + \kappa(T_4 - T_1)$$

$$V_2\dot{T}_2 = \gamma V_2(T_2^* - T_2) + \begin{cases} U_1 T_1 & U_1 > 0 \\ U_1 T_2 & U_1 < 0 \end{cases} + \begin{cases} W_2 T_3 & W_2 > 0 \\ W_2 T_2 & W_2 < 0 \end{cases} + \kappa(T_3 - T_2)$$

$$V_3\dot{T}_3 = \begin{cases} U_2 T_4 & U_2 > 0 \\ U_2 T_3 & U_2 < 0 \end{cases} - \begin{cases} W_2 T_3 & W_2 > 0 \\ W_2 T_2 & W_2 < 0 \end{cases} + \kappa(T_2 - T_3)$$

$$V_4\dot{T}_4 = \begin{cases} U_o T_o & U_o > 0 \\ U_o T_4 & U_o < 0 \end{cases} - \begin{cases} U_2 T_4 & U_2 > 0 \\ U_2 T_3 & U_2 < 0 \end{cases} - \begin{cases} W_1 T_4 & W_1 > 0 \\ W_1 T_1 & W_1 < 0 \end{cases} + \kappa(T_1 - T_4)$$

$$V_1\dot{S}_1 = \begin{cases} U_m S_m & U_m > 0 \\ U_m S_1 & U_m < 0 \end{cases} - \begin{cases} U_1 S_1 & U_1 > 0 \\ U_1 S_2 & U_1 < 0 \end{cases} + \begin{cases} W_1 S_4 & W_1 > 0 \\ W_1 S_1 & W_1 < 0 \end{cases} + \kappa(S_4 - S_1)$$