MULTIPLE EQUILIBRIA AND OVERTURNING VARIABILITY OF THE AEGEAN-ADRIATIC CIRCULATION

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Abstract
The Eastern Mediterranean Transient—a transition of the Eastern Mediterranean Sea deep water source from the Adriatic Sea to the Aegean Sea—was observed in the mid-90'. Here we show that the overturning circulation of the Eastern Mediterranean (Adriatic-Aegean-Ionian basins) has multiple equilibria states under present-day-like conditions, and that the water exchange between the Aegean and the Adriatic Seas can drastically affect these states. More specifically, we found two stable states and hysteresis behavior of deep water formation in the Adriatic basin when changing the atmospheric (restoring) temperature over the Aegean.

Keywords: Deep waters, Mediterranean Sea, Levantine Basin, Models

The Eastern Mediterranean Transient (EMT) is an intriguing change in Mediterranean circulation that has been observed in the mid-90' . Understanding the causes and nature of abrupt changes such as the EMT is important for various reasons. For example, Deep Water Formation (DWF) processes affect the exchange of physical and biochemical properties (e.g., oxygen and nutrients) between the surface and the deep layers. There is an ongoing discussion whether the EMT was a single phenomenon that was caused by the unique conditions during 1987-1992, or whether it is a recurrent phenomenon associated with the natural variability of the EM circulation. Stommel [1] raised the possibility of multiple equilibria states of the overturning circulation in the Mediterranean Sea, similar to the ones he predicted (using a simple two-box model) to exist in the Atlantic Ocean. Recently, [2] showed, using a three-box model representing the Adriatic, Aegean, and Ionian basins, that the overturning circulation of the EM may indeed have a few steady states and a transition between them may be associated with the EMT. Here we performed a set of numerical experiments using the Massachusetts Institute of Technology general circulation model to show the multiple equilibria states under present-day-like conditions. Specifically, we modified the Aegean temperature boundary condition, i.e., the restoring temperature over the Aegean, but kept fixed the rest of the forcing and boundary conditions.

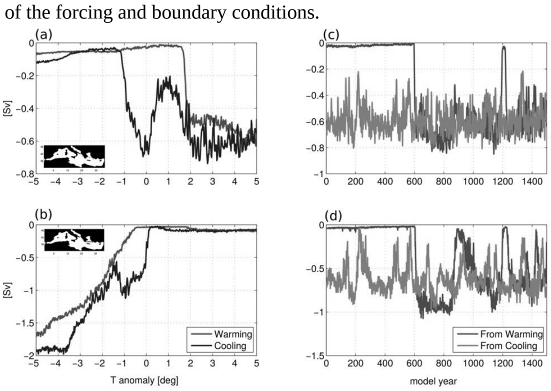

Fig. 1. Adriatic (a,c) and Aegean (b,d) annual mean outflow of water denser than 1029.1 kg m^{-3} as a function of the temperature anomaly of the Aegean (a,b) and as a function of the model year (c,d) in the entire set of experiments.

The Adriatic and Aegean DWF during the adiabatic warming\cooling of the Aegean is presented in Fig. 1a,b. The most prominent result is that the Adriatic outflow exhibits hysteresis despite the fact that the boundary conditions were modified only over the Aegean. Such hysteresis curve suggests that there are two Adriatic steady states, with either active or passive DWF, under the same Aegean forcing. The largest difference in the outflow is found around zero forcing anomaly, i.e., under present-day-like conditions. To examine the stability of the two Adriatic DWF states shown in Fig. 1a,b, we initiate the model transient states from the warming and cooling steps under zero forcing anomaly, and ran them for additional 1500 years (Fig. 1c,d). Both simulations kept their initial Adriatic outflow for 600 years until passive DWF state abruptly changed and merged with the active. In year 1200 of the 'From Warming' (previously passive) simulation there is another abrupt, but transient, change of a drastic weakening of the Adriatic outflow for almost a decade. To understand the interaction between the Aegean and Adriatic Seas, we retrieved density profiles in the south Adriatic and south Aegean over years 1170-1270 of the 'From Warming' simulation, during which the abrupt transient occurred in the Adriatic.

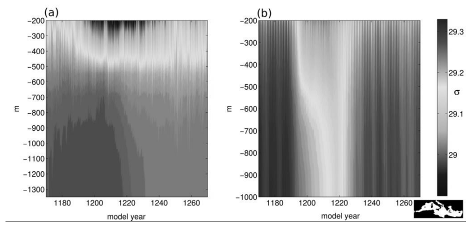

Fig. 2. Density profile time series in the Aegean (a) and in the Adriatic (b) over the years 1170-1270 of the 'From Warming' (shown in Fig. 1) simulation. Profiles locations are marked by the squares in the reference map embedded.

It is evident from Fig. 2 that a freshening of intermediate south Aegean water occurred prior to and during the Adriatic transition. It appears that dense (saline) water associated with the Levantine Intermediate Water (200-700 meter) is found only deeper than 400 meter starting from year 1190, indicating that when the Aegean stops providing saline intermediate water to the Adriatic, the Adriatic DWF becomes passive. The Ionian upper circulation was reported to play an important role in this saline water advection into the Adriatic [3], and indeed we detect a mainly unidirectional influence of the Aegean outflow on the Adriatic outflow. The Aegean-Adriatic interaction can be summarized as follows: warm and saline water of the Aegean can either flow in the sub-surface to the Adriatic, switching "on" its DWF by increasing its salinity, or the Aegean water can feed the deeper layer of the Ionian and Levantine basins, turning "off" the Adriatic DFW. Furthermore, the fast transition between the two steady states resembles some aspect of the EMT abrupt nature.

References
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