A box model of the Miocene Mediterranean Sea with emphasis on the effects of closure of the eastern gateway

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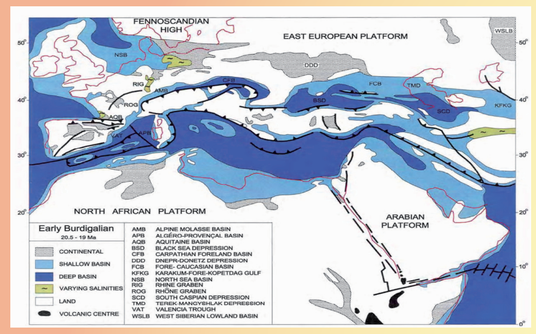
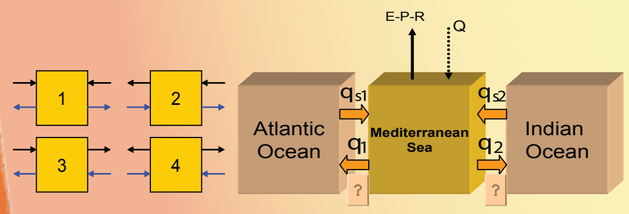
Introduction



Closure of the connection between the Mediterranean Sea and the Indo-Pacific Ocean in the Middle Miocene is thought to have had important effects on the water properties and circulation of the Mediterranean. For the first time we use a box model to study the possible circulation of the Mediterranean before and after closure.

Methods

The simplest model has three boxes representing the Atlantic Ocean, the Mediterranean Sea, and the Indo-Pacific Ocean. The boxes exchange water, heat and salt. The deep flow is a density-driven flow due to salinity and temperature differences. In general there are four configurations for the deep exchange flow between the three boxes.



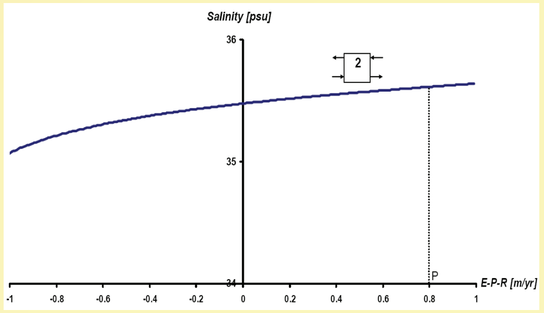
Variables and Parameters

Besides salinity S and temperature T there are control parameters which play an important role in the behavior of the system.

Model control parameters

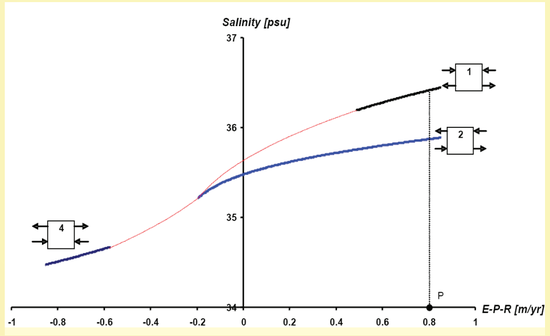
Control parameter	symbol	Value
hydraulic constant	$f_{(1 \text{ or } 2)}$	$\geq 0; m^3 s^{-1}$
f_2 / f_1	a	≥ 0; -
q_{s2} / q_{s1}	b	≥ 0; -
Atlantic salinity and temperature	$S_1;T_1$	≥ 0
Indian salinity and temperature	$S_2;T_2$	≥ 0
$10^4(\beta(S_2-S_1)-\alpha(T_1-T_2))0.125$	dZ	$\{-\infty,\infty\}$;-
evaporation – precipitation	E–P	$\{-\infty,\infty\}; m^3 s^{-1}$
River discharge	R	$\geq 0; m^3 s^{-1}$
net Surface heat flux	Q	$\{-\infty,\infty\}$;W

Results

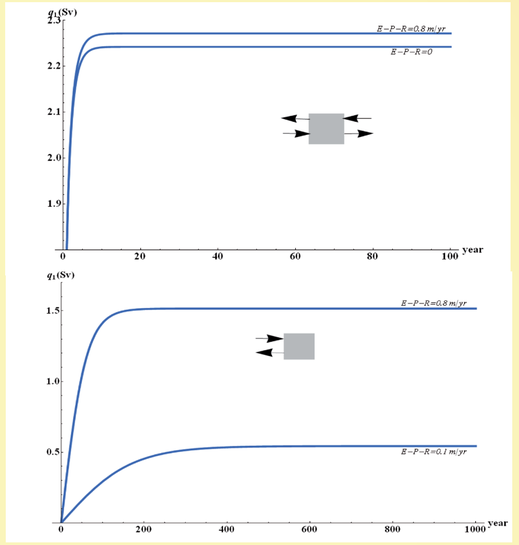


When we choose a large hydraulic constant to simulate larger gateways between the basins, configuration (2) is the only possibility when the Atlantic Ocean is denser than the Indian Ocean. It follows that for large gateways the net evaporation flux does not play an important role in controlling the water properties.

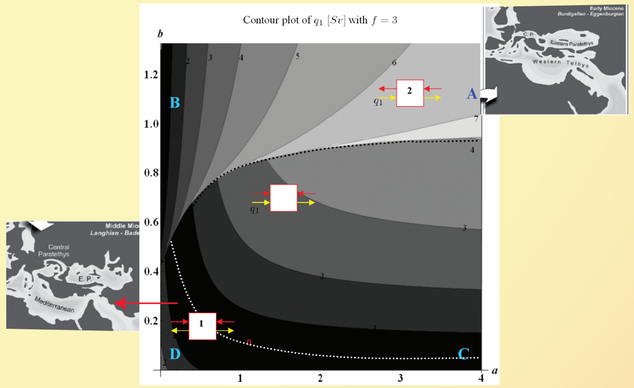
Decreasing connection to the east



As we decrease the hydraulic constant to simulate a decreased connection to the east, different configurations are possible and bistability occurs. Each configuration happens for specific range of net evaporation. Point P refers to the present-day value of the net evaporation.



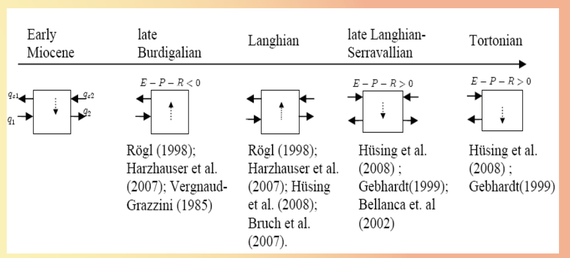
Deep flow to the Atlantic versus time: Top panel shows configuration(2) before closure; Bottom panel is for configuration (1) after closure.In both panels, the values of deep flow are shown for different values of the net evaporation. The basin is more sensitive to the external forcing after closure. The three-box model reaches the steady state faster.



Contour plot of the deep flow between the Atlantic Ocean and the Mediterranean versus a and b that illustrates the effect of a decrease of the connection to the Indian Ocean.

Discussion

- We tentatively propose a "best fit scenario" for the history of closure linking the available data and our model results. Based on this scenario we suggest a qualitative evolution for temperature and residence time which is consistent with the existing data.



Rögl (1998); Harzhauser et al. (2007); Vergnaud-Grazzini (1985)

Rögl (1998); Harzhauser et al. (2007); Hüsing et al. (2008); Bruch et al. (2007).

Hüsing et al. (2008) ; Gebhardt(1999); Bellanca et. al (2002)

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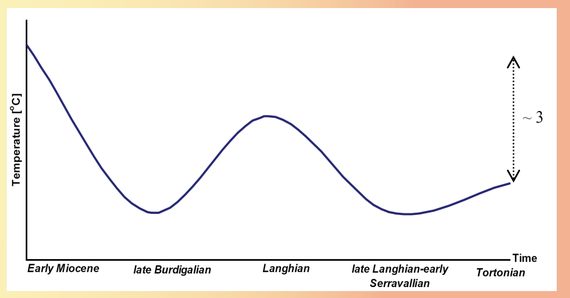

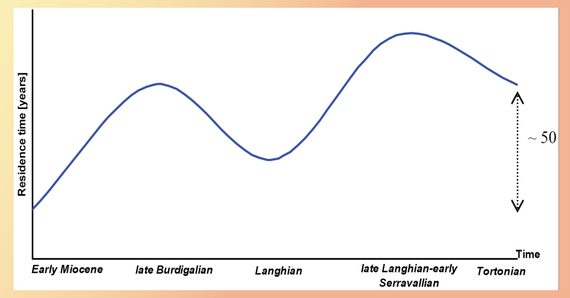

Conclusions

- Prior to closure deep flow was most likely west to east in both connections provided the density of the Indian Ocean was less than that of the Atlantic Ocean. It is of interest to point out that this configuration is the most similar to the ones suggested by earlier publications.
- It was found that circulation of the Mediterranean changes to present-day circulation after closure for the case of a positive net evaporation.
- We showed that response of the Mediterranean Sea to closure is non-linear.
- The Mediterranean Sea is more sensitive to heat and fresh water flux after restriction of the basin. The former can be observed in isotope data as larger amplitudes and shorter periods of fluctuations.
- Closure probably resulted in a cooling and salinity increase of the Mediterranean for positive net evaporation. However, we expect only cooling if net evaporation is considered negative.
- Each configuration of the exchange flows occurs in a specific range of parameter values. Multiple equilibrium states are a consequence of the presence of two gateways to open oceans.