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Gateway control on circulation and water properties of a semi-enclosed sea: The Mediterranean/Paratethys case

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Straits and marine gateways are vital for enclosed or semi-enclosed basins. The exchange flow through the straits influences the circulation of the landlocked basin and determines its sensitivity to variations in local climate. Changes in the geometry of the gateways and straits, resulting from tectonic activity and/or sea level variations, can change the circulation, temperature and salinity of the basin, which in turn can alter the regional climate.
The present-day Mediterranean Sea and Black Sea are the successors of the southern (the Mediterranean) and northern (the Paratethys) domain of the old Tethys Ocean, respectively, which were caught up in the convergence zone between Africa and Europe. During the Early Miocene (around 20 Ma) the Mediterranean Sea and the Paratethys had gateway connections to both the Indian and the Atlantic Ocean. The gateways to the Indian Ocean were closed in the Middle Miocene (13-15 Ma). This closure had important effects on the water properties and circulation of the Mediterranean Sea and the Paratethys. The Paratethys presents an outstanding case for studying the evolution of enclosed basins and the impact of gateway closure because of the availability of a large variety of studies and the accessibility of this part of Europe for geological study. As yet, a model or physics-based study regarding the closure of the gateway between the Mediterranean/Paratethys and the Indian Ocean and its effects is not available. Investigating the past evolution of these basins and their circulation as controlled by their straits, will contribute greatly to our understanding of the role of straits in basin circulation.
We apply a hierarchy of ocean models, starting from simple box models and proceeding with circulation models with idealized and realistic geometries. We aim to determine the variation of (1) temperature, salinity, and residence time, (2) flows in the gateways, and (3) circulation of the basin, in response to changes in the gateways and in particular their closure. It is of much interest to understand whether the changes observed in proxy data were caused by variations of the gateways or reflect changes in regional climate.
Our main conclusions are: (1) semi-enclosed seas with a limited connection to the open ocean are more sensitive to climate change (and vice versa), (2) in the presence of two gateways multiple equilibrium states are possible (i.e., different surface and deep flow for the same value of freshwater flux), (3) in a basin with multiple straits, the dynamics of flow in one of the straits have a non-linear relation to flow in the other straits, (4) interdecadal oscillations appear in a semi-enclosed basin for some values of gateways geometry, (5) the response of the Mediterranean/Paratethys water properties and flow to gradual closure is non-linear, (6) closure of the gateways to the Indian Ocean most likely resulted in cooling and a rise of residence time of the Mediterranean Sea/Paratethys, (7) the enigmatic Mid-Burdigalian cooling in the geological record of the Paratethys resulted from closure of the gateways between Paratethys/Mediterranean and the Indian Ocean.