INVESTIGATION OF THE MEDITERRANEAN-BLACK SEA COUPLING USING MULTI-SCALE MODELS OF THE TURKISH STRAIT SYSTEM

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Abstract

A multi-scale, high-resolution ocean-ecosystem numerical model suite is implemented for the Turkish Strait System (TSS) to study the dynamics of the coupling between the Black Sea and the Mediterranean, specifically to assess the role of TSS on the behaviour of the coupled ecosystems, to understand the relative importance of remote and local forcing mechanisms on the exchange flows and mixing in the TSS, and to quantify the two-way transport of materials through the TSS. Since the problem of coupling between the adjacent basins of the Black and Mediterranean basins is truly a complex one, an assembly approach is used. Various levels of models are used, producing simulations corresponding to different levels of approximation in order to enable feedbacks on the effects of resolution, model parameterizations, and setup between these levels.

Keywords: Models, Bosphorus, Dardanelles, Marmara Sea, Black Sea

The TSS is much like a fjord system, characterized by two-layer exchange flow with a strong pycnocline maintained by density and sea level gradients between the Black Sea and the Aegean Sea, and controlled by hydraulic constraints in the straits and exit regions. The depth of the interface undergoes high temporal and spatial variability inside the straits and their exit regions, but has a relatively stable depth at about 25m in the Marmara Sea proper, occasionally exceeding this depth under conditions of extreme surface mixing. The Marmara Sea is a small, enclosed body of water with complex topography, comprised of three deep basins of depth greater than 1000m each, separated by deep sills of 600-700m in depth, adjoining a wide continental shelf of 100m depth occupying the southern half of the basin, which then connect to the straits through canyons extending out from them. Horizontal re-circulating flows under constraints of a highly irregular coast in the confined geometry of the Marmara Sea induce horizontal shears and inhomogeneity. The surface exit flows from straits into the Marmara and Aegean basins are in the form of buoyant turbulent jets. The relatively fresh surface water ($S = 18$) entering from the Black Sea is modified to reach higher salinities ($S = 22\text{-}30$) within the upper layer of the Marmara Sea, separated from the underlying salty Mediterranean water ($S = 38.5$). The wider Marmara Sea acts as a buffer zone, or a ‘stilling basin’ between the two larger basins. The shallowness of the upper layer makes its response to winds and other driving forces extremely rapid.

Due to the lack of sufficient computational resources to handle the required fine-scale spatial resolution, present ocean numerical models implemented for the coupled Mediterranean – Black Sea system can neither correctly simulate the stratified exchange flow between these basins through the Turkish Straits nor the compounded effects of such exchange on the energetics, stratification, and sea level in these adjacent seas. Extremes in cross-shelf interaction, such as dense water cascading, surface jets, hydraulically controlled, super-critical, non-linear, non-hydrostatic, layered and occasionally blocked flows occur in the region of the straits, in response to remote forcing from the adjacent seas and the complex topography with very fine details.

In parallel with advances in computer technology, ocean general circulation numerical models (OGCM) have become widely used tools to estimate the consequences of physical, chemical, and biological processes in the ocean and to evaluate the ocean response to atmospheric forcing under realistic and extreme scenarios.

Modeling the Turkish Straits System (TSS) and its role in coupling the adjacent seas is a grand challenge. Features described above make it a formidable problem to forecast currrents and circulation in the Turkish Straits System. Traditional ocean models with simplified physics and topographical representation are often unable to comprehensively capture the features and multiple space-time scales that are involved. A true and full coupling considering the entire system of adjacent Mediterranean and Black Sea basins is in fact far beyond reach for most of the present day ocean models. Therefore, a multi-scale, three-level, hierachical numerical model suite is designed and executed in an attempt to realistically represent the challenging physical and biogeochemical dynamics of the TSS.

For the first level, a barotropic unstructured grid model (MOG2D) is set up covering the Mediterranean and the Black Sea together to predict water levels and net transport through the straits. On the second level, a laterally integrated (x-z) time dependent model solving two-dimensional vorticity equation is adapted for the Bosphorus and is initialized with a lock-exchange situation, specifying property contrasts between adjacent seas. The third level consists of three-dimensional models of the Bosphorus and Dardanelles Straits driven by net through-flow, boundary conditions specified in the adjacent Aegean and Black Seas and a three-dimensional model of Marmara Sea alone, excluding the straits and attempting to simulate Marmara Sea circulation based on strait exit boundary conditions. The third level models are all based on the Regional Ocean Modeling System (ROMS) [1]. The Fennel ecosystem components [2] are implemented as well in the three-dimensional ROMS models of the Bosphorus, Dardanelles Straits and the Marmara Sea.

Control runs with the Bosphorus model show that major features of the observed currents are successfully reproduced by the model (Figure 1). Following the set-up and testing phase, the control runs established from hindcasts produced by the dynamical and coupled ecosystem models of the TSS are validated with available data and fine-tuned before advancing to forecast, and potentially operational modes of simulation.

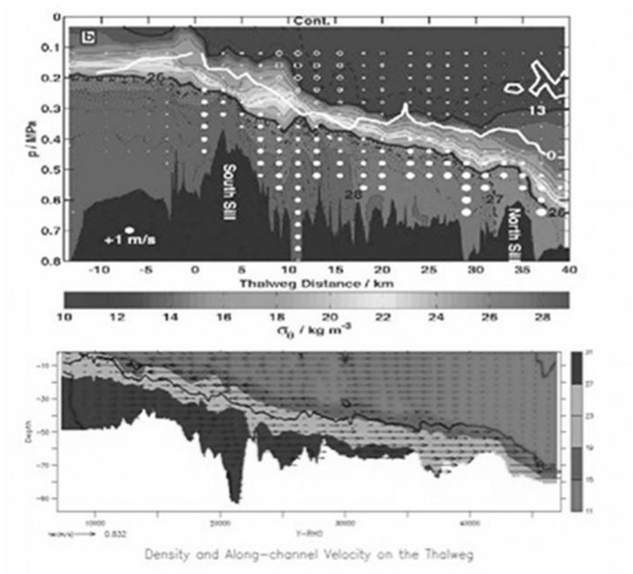

Fig. 1. Observed (top) and simulated (bottom) velocity and density distribution along the thalweg of the Bosphorus Strait.

References

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