Mediterranean Marine Science

Vol 18, No 1 (2017)

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doi: 10.12681/mms.1877

Research Article

Mediterranean Marine Science
Indexed in WoS (Web of Science, ISI Thomson) and SCOPUS
The journal is available on line at http://www.medit-mar-sc.net
DOI: http://dx.doi.org/10.12681/mms.1877

Water Exchange through Canal İstanbul and Bosphorus Strait

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Handling Editor: Takvor Soukissian

Received: 11 August 2016; Accepted: 8 December 2016; Published on line: 13 February 2017

Abstract

The Turkish Straits System (TSS) regulates the transports of water, material and energy between the Black Sea and the Mediterranean Sea. Amidst existing environmental threats to the region surrounding İstanbul, the environmental footprint of the proposed Canal İstanbul project needs to be evaluated through methods of natural science. We take the elementary step to answer the particular problem of coupled strait dynamics by adding the Canal to an existing hydrodynamic model and estimate changes in their common response. Compared to the virtually unmodified exchange flow in the Bosphorus, the flow in the Canal has a weak lower layer current component, contrasted with intense currents at the exit controls at its junction with the Marmara Sea. The upper and lower layer transports through this simplest hypothetical TSS configuration are slightly increased for a given net barotropic flow across the system. The modified regime is expected to have climatological consequences.

Keywords: Canal İstanbul, Bosphorus, strait dynamics, exchange flows, hydrodynamic modeling.

Introduction

Located at the junction of Asia Minor and Europe, the Turkish Straits System (TSS) is a natural wonder (Fig. 1a): a complex system consisting of Dardanelles and Bosphorus Straits and Marmara Sea, interconnecting the Black Sea with the Mediterranean Sea, thereby regulating the exchanges of water and materials between these Seas. High population and industrial pressures of the megapolis of İstanbul, earthquakes, climatic variability and changes under high local gradients make the TSS an environmentally sensitive region (*e.g.* Beşiktepe *et al.*, 1994; Gündüz & Özsoy, 2005; Lionello *et al.*, 2006; Georgievski & Stanev, 2006; Yanko-Hombach *et al.*, 2006).

Based on his experimental discovery of the Bosphorus exchange flow, Marsigli (1681) put forward the first theory of strait dynamics, thereby laying the foundations of modern ocean science (Defant, 1961). Detailed measurements more than three centuries later have revealed unique features of the Bosphorus exchange and its influence on the adjacent seas (Ünlüata *et al.,* 1990; Özsoy *et al.*, 1998, 2001; Gregg *et al.*, 1999, Gregg & Özsoy, 2002; Jarosz *et al.*, 2011a,b; Schroeder *et al.*, 2012; Jordà *et al.*, 2016).

For the past thirty years, a limited number of modelling studies of the Bosphorus flow have been carried out, with either simplified physics or geometry (Johns & Oğuz, 1989; Oğuz *et al.*, 1990; Oğuz, 2005; Ilıcak *et al.*, 2009; Maderich & Konstantinov, 2002; Maderich *et al.*, 2015) or utilizing fully three-dimensional solutions (Öztürk *et al.*, 2012; Sözer, 2013; Sözer & Özsoy, 2016), with recent fine resolution modeling extended to examine the coupled behavior of the entire TSS including the straits (Sannino *et al.*, 2015, 2016; Gürses, 2017; Gürses *et al.*, 2016).

In 2011, the "Canal İstanbul" project was first announced, proposing to build a secondary waterway in parallel to the existing natural channel of the Bosphorus Strait, with the declared aim to reduce the congested marine traffic in the Bosphorus, but also as part of a plan to develop "New İstanbul". The pros and cons of the proposed construction have been subjects of active discussion, with a series of implications on marine transport, maritime security, international trade and international law regulating the rights of passage through the TSS.

While some of the declared socio-economical motives behind the Canal have been scrutinized often from the points of view of economic and political interests, possible environmental effects have received little attention to date. The essential background information focusing on the environmental issues relevant to the intended Canal have been issued in few reports released by non-profit civic organizations (TEMA, 2014; WWF, 2015), proclaiming an urgent need for baseline studies.

Despite active debates following the announcement of the project in 2011, much needed baseline studies of environmental data collection, analyses of the environmental effects, or the development of engineering design alternatives to alleviate such effects have not been addressed to date. The details of the channel design, such as the location, shape and associated development objectives and engineering applications are not yet clear and have not been publicly announced.

Although questions on environmental effects are answerable only by methods of natural sciences, they are amongst the least rationally discussed and objectively evaluated at present. In addition to effects on land ecosystems, the project would most likely influence the delicate marine ecosystems of the region. Key questions to be asked are: (1) Would the existing hydrodynamic regime of the Bosphorus be changed due to the construction of the Canal? (2) In which way does the newly created regime of the Canal differ from the existing exchange flows of the Straits? (3) Would the water and material fluxes between the Black Sea and Mediterranean Seas be permanently changed? (4) What are the expected short-term or climate-scale regional impacts on sensitive ecosystems of the region?

With experience gained from modeling the Bosphorus, and based on preliminary and rather vague information available on the path and dimensions of the Canal, we have designed a preliminary experiment to investigate the combined response of the system, with the proposed channel functioning simultaneously with the Bosphorus. On the other hand, it is very important to mention that the model totally neglects time-dependent hydrodynamic effects at this stage, as well as the coupling with the adjacent shelf regions. In reality, these certainly important aspects of the system behavior deserve further investigation in the future, towards a better understanding of the long-term environmental consequences of the project. For this preliminary evaluation, we assumed the simplest straight channel configuration, immediately to start addressing the above questions, in particular items (1-3). The model setup is described in Section 2, and results and conclusions are provided respectively in sections 3 and 4.

Model setup

The modeling approach used in this study is based on the free-surface, topography following, primitive equations modeling platform of the ROMS (Hedström, 1997; Haidvogel *et al.*, 2000; Shchepetkin & McWilliams, 2005). We setup two slightly different configurations of the same model originally used in studying the Bosphorus Strait hydrodynamics, in order to be able to comparatively evaluate the effect of an artificially introduced second channel (the "Canal") proposed to run in parallel with the original Bosphorus Strait channel.

The first case (referred to as "ONLYBOS") represents the existing configuration, based on the original study on the Bosphorus exchange flow dynamics (Sözer, 2013; Sözer & Özsoy, 2017). In the second configuration (referred to as "DUALBOS"), a further channel representing "Canal İstanbul" at its simplest possible form, a straight channel, is added in "parallel" to the original strait. The study is basically a modeling comparison between the current situation and the imaginary future case, especially focusing on the impacts on the fluxes and the structure of currents.

A variable resolution rectilinear grid (*163*716*) of *dx=50-200m* (cross-channel) and *dy=50-325m* (along-channel) is used, while a vertical resolution of *dz=0.7-2.85m* is obtained with *35* evenly spaced s-levels. The domain is extended into the neighboring seas in the form of artificial rectangular boxes with open boundary conditions specified at the ends. High resolution bathymetry data obtained from Gökaşan (2005), those sampled on board the NATO research vessel NRV "Alliance" (1995-1996) and digitized from maps of the Turkish Navy Office of Navigation, Hydrography and Oceanography (ONHO) have been combined with data from the General Bathymetric Chart of the Oceans GEBCO 08 (http://www.gebco.net) and coastline data from METU-IMS (Middle East Technical University, Institute of Marine Sciences) to construct the model bathymetry, which later has been minimally smoothed, setting minimum depth of *25m* for shallower regions gently joined with the steep interior topography. This setup forms the basis of the "ONLYBOS" case. For the "DUALBOS" simulations a second passage is placed between the Black Sea and the Marmara Sea at a distance of *~9 km* from the the Strait, to exclude direct interactions of the inflow and outflow patterns of the individual Straits. This second channel has a constant depth of *25m* and a constant width of *150m* allowing three grid points across the channel with grid resolution of *50m*, as shown in Figure 1.

Four simulations are performed (Table 1), representing various cases of uniform and stratified reservoir conditions under moderate ($300km^3/yr \approx 9460\ m^3/s$) to low ($175km^3/yr \approx 5420\ m^3/s$) values of barotropic flux, respectively corresponding to those estimated by Ünlüata *et al.* (1990) and typically observed during the September 1994 measurements of Gregg & Özsoy (2002).

Simulations with uniform reservoir conditions are started from a lock-exchange (LE) initial condition, releasing two uniform water bodies meeting at a mid-section of the strait, with contrasting salinity and temperature values of $S=38.0$, $T=13°C$ in the south and $S=17.6$, $T=24.1°C$ in the north, constant values devoid of any vertical structure, but roughly approximating water types at the Marmara and Black Sea ends of the Strait observed in late summer. In the stratified simulations, temperature and salinity profiles are specified at the reservoirs, with characteristics typical of the fall season consistent with the September 1994 observations of Gregg &Özsoy (2002). Accordingly, constant values, $S=23$ above *11m* and $S=38$ below *25m* depth, with linear change in between, were specified to represent the two-layer stratification on the Marmara side. On the Black Sea side, warm water in the first *20m*, with a linear decrease till the Cold Intermediate Water (CIL) layer starting at *45m* and extended to the bottom, along with a constant salinity of $S=17.6$ are assumed.

The lock-exchange (LE) simulation largely governed by enhanced vertical mixing is stepped by a very small baroclinic time-step (*dti*) of *1.75s*, aiming to reduce instabilities due to the sharp initialization adjusted to *4.0s* after the first day, using a *20* times smaller external time-step (*dte*) during the whole simulation period of *5.5days*, long enough to achieve steady-state. The Generic Length-Scale (GLS) turbulence scheme (Warner *et al.*, 2005) is activated after this restart, with the $k-\varepsilon$ formulation assuming a background vertical diffusivity and mixing for all scalar variables. Lateral diffusivity and viscosity are parameterized by the Smagorinsky (1963) formulation, specified on constant geopotential surfaces. Open boundaries are maintained with the Orlanski (1976) radiation conditions for the *2d* and *3d* flow variables except for the depth averaged velocity (south-north component) prescribed at the southern boundary to drive a net volume-flux through the strait. The alternative method of specifying sea level at the two ends of the strait has also been tested under simplified conditions. Although the results were nearly same with the equivalent specification of the barotropic velocity, this method was not used because it was found to produce disturbances at the boundaries. The MPDATA advection scheme for tracers (Smolarkiewicz, 2006) is utilized to handle sharp gradients of salinity and temperature. No-slip boundary conditions are assumed at the side-walls and a quadratic bottom friction coefficient of *0.005* is implemented, while all surface-fluxes are set to zero. The use of the non-linear equation of state was essential because of the wide range of properties of the water masses being mixed. The rotation of the earth is neglected, since the internal Rossby Radius of Deformation is significantly larger than the strait width.

The use of steady-state net volume-fluxes excluding time-dependent effects clearly is a great simplification of the physical system. In reality the flux through the Bosphorus Strait, even in its simplest form, is time-dependent. The unsteady response displayed by Bosphorus currents and induced variations in the state variables results from a dynamic response to the following basic drivers: the net volume budget of the adjacent basins, the sea-level and the density difference between the two ends of the strait with hourly to seasonal time-scales, which in turn depend on the remote forcing in the adjacent basins by atmospheric volume, momentum and buoyancy fluxes at the ocean surface and volume and buoyancy inputs from rivers. Here, only a steady-state solution is seeked for a specified constant net volume-flux, for which the corresponding free-surface response is obtained.

In the stratified simulations, a mixed radiation and nudging open boundary condition was applied with a nudging coefficient of *0.1day* for outflow and *0.01day* for inflow conditions (Marchesiello *et al.*, 2001), along with laterally uniform, stratified salinity and temperature as detailed above. For the inflow and outflow conditions, the phase speed of information radiated at the open boundary is computed in accordance with Orlanski (1976). Stratified simulations are restarted from the steady solutions of the uniform reservoir cases and have cumulative duration of *23.1days,* for a steady-state solution to develop in terms of energy and volume conservation excluding residual oscillations of any significance. Briefly, the steady-state solution for a stratified simulation is achieved in a three-stage numerical experiment starting from a lock-exchange initial condition continued by successive restarts. The "spin" phase with enhanced vertical mixing is started from lock-exchange initial condition followed by the "steady" phase with GLS vertical mixing imposed on the uniform reservoir solution at day *5.5* and finally the "nudge" phase with forced tracer fields at the two open boundaries in accordance with Sözer and Özsoy (2017).

Results

Bosphorus before the addition of the Canal

The adjustment of the model following LE initialization in the ONLYBOS solution is quite rapid in terms of kinetic energy and volume-fluxes in the case of constant basin properties. Solutions in the case of stratified reservoir conditions started from day *5.5* with nudged boundary conditions need greater settling time due to the generation of large amplitude initial oscillations generated during initial adjustment. In this case, steady-state is achieved after about ten days when residual oscillations of kinetic energy and mid-strait volume-flux are decreased to less than *1%* of the mean values. These general characteristics are the same as those experienced earlier by Sözer (2013) and Sözer & Özsoy (2017), only repeated here for reference.

In the solution with uniform reservoir conditions and moderate volume flux of $300km^3/yr$, referred to as "uni1", the along-channel salinity and temperature sections following the thalweg are displayed in Figures 2a,b. A sea-level difference of *~40cm* with realistic features similar to those observed in the Bosphorus is produced despite the uniform reservoir conditions assumed. In the corresponding simulation "str1" with stratified boundary conditions, the model successfully preserves the CIL and the two-layer stratification in the Marmara Sea, as shown in Figures 2c,d. Comparison of the two solutions with uniform and the stratified boundary conditions shows significantly altered temperature due to the penetration of the CIL into the Strait, while the salinity is relatively less influenced.

As shown in Figure 3, the solution for salinity in the stratified case "str2" for a net flux of $175km^3/yr$ demonstrates qualitative and quantitative agreement with the September 1994 observations of Gregg & Özsoy (2002),

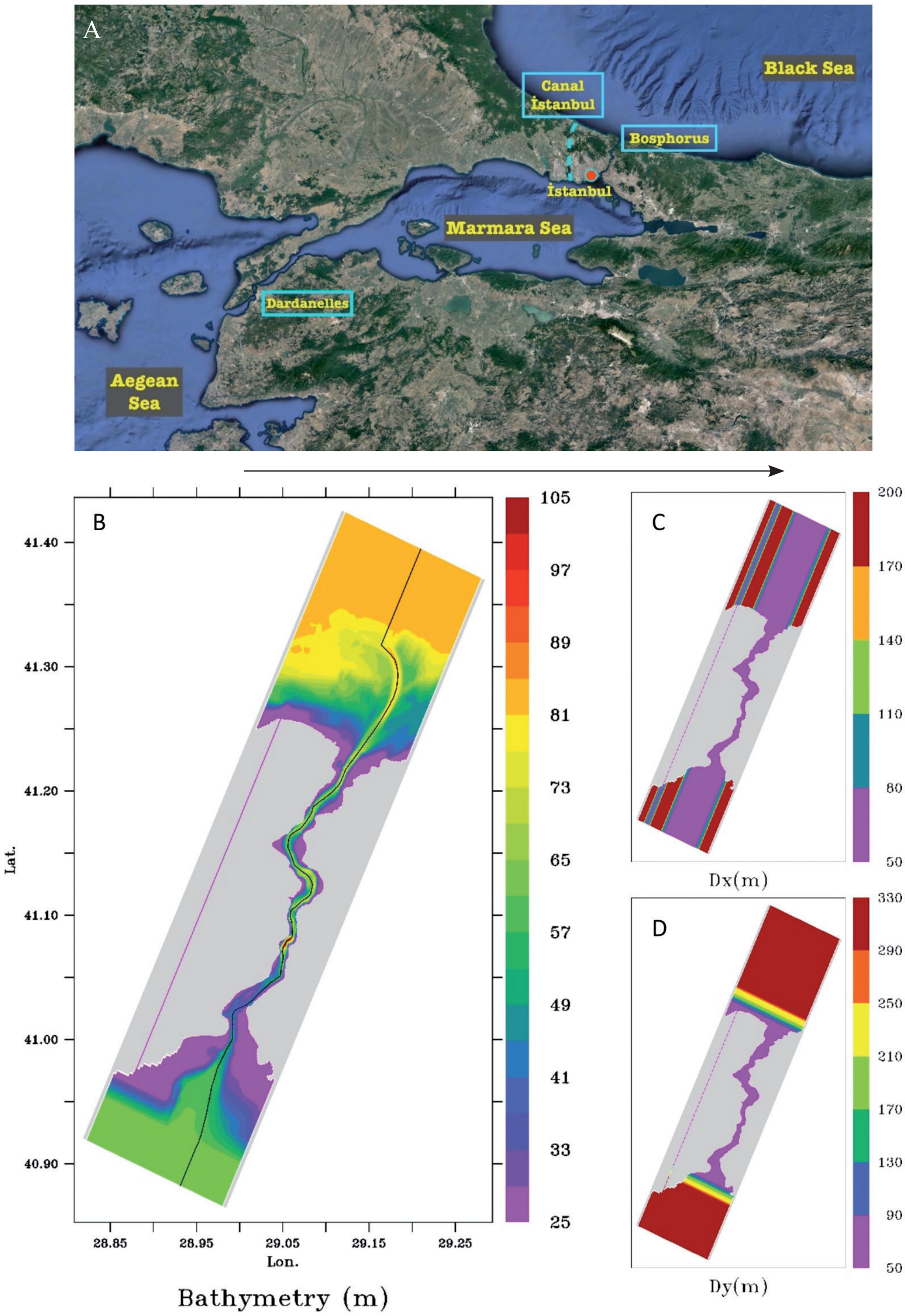

Fig. 1: **A** Google Earth view showing the Bosphorus, Dardanelles Straits and the possible location of Canal İstanbul as part of Turkish Straits System (TSS) and the neigbouring seas, **B** Layout and the bathymetry of the Bosphorus model domain discretized on a rectilinear grid and the thalweg used in the demonstration of the along-channel variations. **C** Cross-channel and **D** along-channel grid size distributions.

although the interfacial layer appears a little thicker than the observed one. A non-linear variation of sea-level is produced in all model solutions with almost all the adjustment occurring in the southern part of strait in response to variable geometry south of the contraction region. With stratification imposed in the neighboring seas, the density difference is significantly decreased compared with the uniform reservoir case ("uni2"), therefore favoring smaller sea-level difference ($\Delta\eta$) between the two ends of the strait for the given net volume flux. From uniform to stratified reservoir conditions, $\Delta\eta$ is reduced to *~22cm* in the stratified case "str2", to almost half the value of the uniform case, closer to the sea-level difference estimated by Gregg & Özsoy (2002).

Bosphorus with a Canal in parallel

For two different volume-flux rates implied under two different reservoir conditions, the salinity, temperature and the along-channel velocity responses in the Bosphorus Strait are very close to each other between the "DUALBOS" and

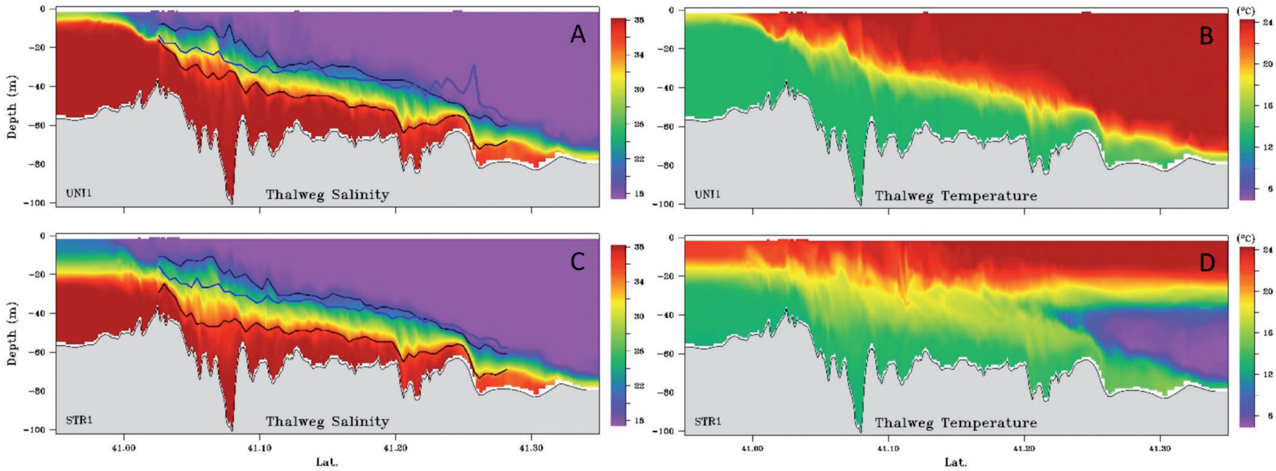

Fig. 2: Steady-state fields on lengthwise transects following the thalweg of the Bosphorus displaying **A** salinity and **B** temperature in run "uni1", and the same for **C** salinity and **D** temperature in run "str1" for the ONLYBOS case, before including the effect of Canal İstanbul in the model system. The Bosphorus Strait solutions in the DUALBOS case not shown here are almost the same, with only very small changes. The variation of the along-channel zero-velocity isotach and the limits of the upper, interfacial and lower layers based on appropriately salinity limits are visualized in the salinity plots of **A, C**.

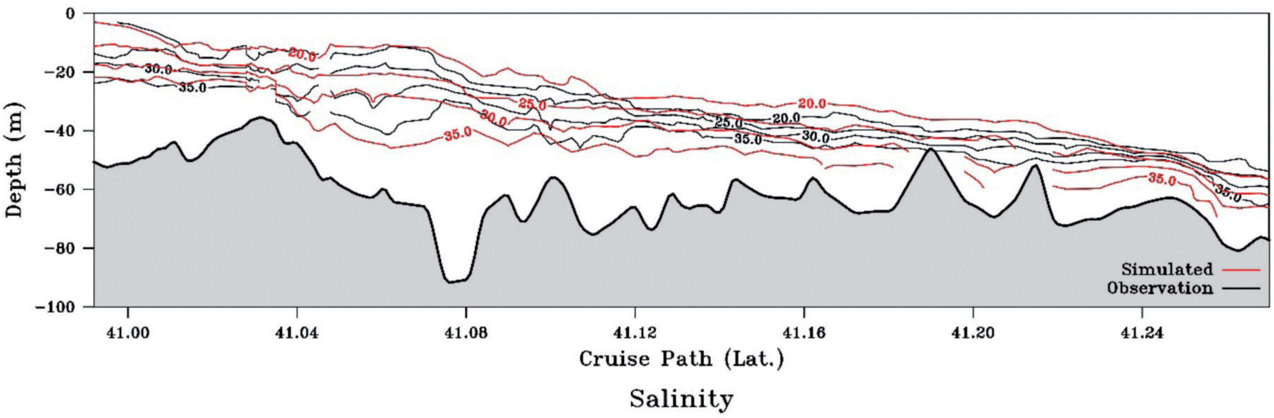

Fig. 3: Comparison of model predicted and measured salinity along the Bosphorus. The model case corresponds to ONLYBOS case "str2", with relatively low flux, while the observations for similar conditions have been obtained during the September 1994 measurements reported by Gregg and Özsoy (2002).

"ONLYBOS" solutions. The steady-state salinity along the Bosphorus thalweg and mid-channel sea surface height profiles through both channels are compared for the "uni1" case in Figures 4a,b. In Figures 4a,b, the ONLYBOS solution is shown by fill colours while the DUALBOS solution is shown by contours, demonstrating the fact that the two different solutions for the Bosphorus are almost identical. The strong similarity between the ONLYBOS and DUALBOS solutions in the Bosphorus displayed for this case is also valid for all cases given in Table 1.

When it comes to the flow features in the newly added channel, we encounter novel features as shown in Figures 4c-e. The lower-layer flow through the new channel is blocked (Fig. 4c), the penetration distance of the Marmara waters into this new channel being dependent on the strength of the net barotropic flux. A hydraulic adjustment at the south-exit of the channel is clearly evident (Fig. 4c), where also most of the free-surface drop through the second channel is observed to occur within a very short distance of the exit region (Fig. 4e).

The variations in the upper and lower layer fluxes through the Bosphorus Strait and the second channel for both of the ONLYBOS and the DUALBOS solutions are computed by cross-channel integrated values of currents averaged over a *2km* length increment at the mid-strait/channel location. Considering that there are some residual oscillations especially for the stratified solutions, the volume-flux values are averaged over the last few time-levels of the model output (corresponding to *~0.5day* and *~3days* respectively in the uniform and stratified cases). Due to the influence of radiation open boundary conditions, steady-state net-fluxes are not exactly equal between the ONLYBOS and the DUALBOS solutions within differences of less than ±*1%*. Results for the ON-

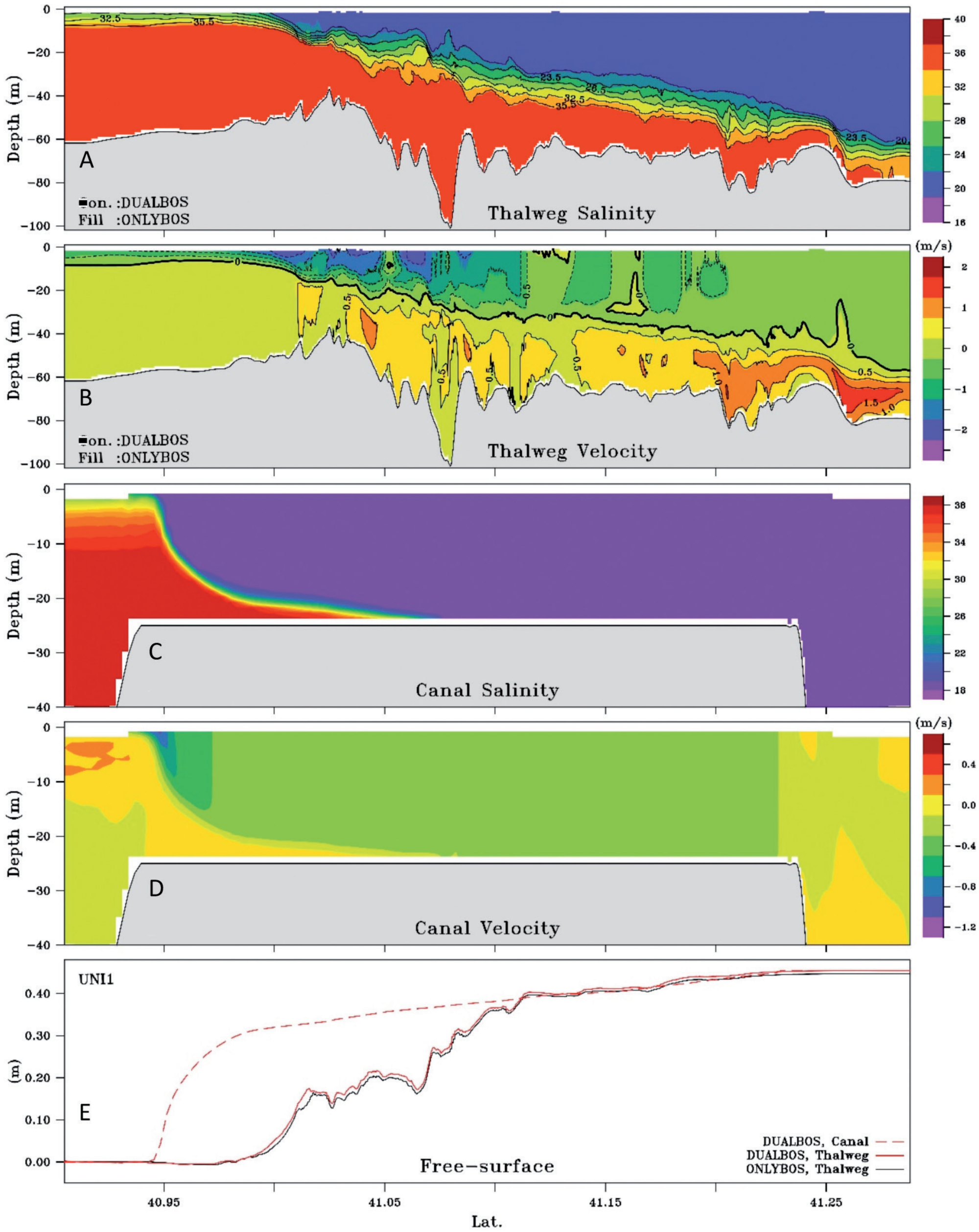

Fig. 4: Model results for **A** salinity and **B** northward velocity component in the Bosphorus corresponding to the ONLYBOS (fill colours) and DUALBOS (contours) configurations for the "uni1" run, showing very similar fields in the Bosphorus whether or not Canal İstanbul configuration has been added. In the DUALBOS configuration with the parallel channels **C** salinity and **D** northward velocity component in the imaginary Canal estimated for the first time reveal a rather assymmetric structure with increased currents near the southern entrance. The sea-level comparison **E** between the ONLYBOS (black line) and DUALBOS (red) cases in the Bosphorus and the DUALBOS case in the new Canal (dotted line) are revealing very little change in Bosphorus sea-level, but a completely different response in the Canal with rapid changes near the southern entrance.

LYBOS solutions are linearly interpolated/extrapolated only slightly to obtain exact net flux values enabling exact comparison with the DUALBOS cases.

The comparison of ONLYBOS and DUALBOS solutions in terms of layer fluxes are given in Table 2 and the relative change of layer fluxes and the exchange flux in the DUALBOS setup with respect to the ONLYBOS solutions are presented in Table 3. Perhaps one of the most significant effects of the second channel on the environment would be the additional southward flux through the second channel estimated to be about *4%* of the flux through Bosphorus from four exemplary simulations of the dual channel setup, shown in Table 1. The effect of the Canal would not be limited by the extra flux generated through itself; as we see from the table, concurrently a decrease of about *1.5-2.5%* occurs in the upper-layer flux of the Bosphorus, part of which is compensated by the flux through the imaginary Canal. Similarly, an increase of *2-3.5%* is expected to occur in the lower-layer flux of the Bosphorus as a result of the changes introduced by the artificial Canal.

Table 1. Summary of the experiments for the ONLYBOS and DUALBOS configurations, "uni" simulations start from a lock-exchange initial condition having uniform reservoir conditions defined by initial salinity and temperature profiles given in the table and "str" cases have stratified boundary conditions corresponding to respective steady-state lock-exchange solutions.

RUN	Initial Salinity		Initial Temperature (°C)		Net Flux (Q_{net})
	Marmara	Black Sea	Marmara	Black Sea	(km^3/yr [m^3/s])
uni1	38.0	17.6	13.0	24.1	-300 [9460]
uni2	38.0	17.6	13.0	24.1	-175 [5420]
str1	stratified (started from uni1 steady-state)				-300 [9460]
str2	stratified (started from uni2 steady-state)				-175 [5420]

Table 2. Upper and lower layer fluxes for the DUALBOS and ONLYBOS solutions computed at mid-strait/channel together with the corresponding exchange flux ($EF = |Q_{upp}| + |Q_{low}|$). (negative sign implies flux in the southward direction).

RUN	Q_{net} ($10^3 m^3/s$)	DUALBOS ($10^3 m^3/s$)							ONLYBOS ($10^3 m^3/s$)		
		Bosphorus		Canal İstanbul		Total		EFD	Bosphorus		EF
		B_{upp}	B_{low}	C_{upp}	C_{low}	T_{upp}	T_{low}	$=\|T_{upp}\|+\|T_{low}\|$	Q_{upp}	Q_{low}	$=\|Q_{upp}\|+\|Q_{low}\|$
uni1	-9.45	-20.47	11.83	-0.81	0.00	21.28	11.83	33.11	-20.98	11.53	32.51
uni2	-5.57	-18.25	13.40	-0.74	0.01	-18.99	13.41	32.40	-18.71	13.13	31.84
str1	-9.51	-18.19	9.37	-0.69	0.00	-18.88	9.37	28.25	-18.57	9.06	27.63
str2	-5.54	-15.69	10.74	-0.59	0.01	-16.28	10.75	27.03	-15.94	10.39	26.33

Table 3. Percent ratio of upper layer flux through the second channel to the Bosphorus upper layer flow in the DUALBOS setup and changes of layer fluxes and EF in the DUALBOS setup with respect to the original solutions.

RUN	Flux ratio (%)		Change in upper layer flux (%)			Change in lower layer flux (%)			Change in EF (%)
			Bosphorus	Canal İstanbul	Total	Bosphorus	Canal İstanbul	Total	
	C_{upp}/B_{upp}	C_{low}/B_{low}	$(B_{upp}-Q_{upp})/Q_{upp}$	C_{upp}/Q_{upp}	$(T_{upp}-Q_{upp})/Q_{upp}$	$(B_{low}-Q_{low})/Q_{low}$	C_{low}/Q_{low}	$(T_{low}-Q_{low})/Q_{low}$	(EFD-EF)/EF
uni1	3.96	0.00	-2.43	3.86	1.43	2.60	0.00	2.60	1.85
uni2	4.05	0.07	-2.46	3.96	1.50	2.06	0.08	2.13	1.76
str1	3.79	0.00	-2.05	3.72	1.67	3.42	0.00	3.42	2.24
str2	3.76	0.09	-1.57	3.70	2.13	3.37	0.10	3.46	2.66

Accounting for the increased flow through the artificial Canal, a net increase of about *1.5- 2%* occurs in the total volume flux from Black Sea towards the Marmara Sea. A net increase of *2- 3%* in the total exchange flux between the seas is also expected.

Two other solutions of the DUALBOS configuration under stratified boundary conditions and reversed barotropic net fluxes directed from the Sea of Marmara towards the Black Sea (*1400*m^3/s and *4500*m^3/s), not presented here, indicate lower layer fluxes of the second channel to be still very weak, *20*m^3/s and *50*m^3/s respectively, and hardly reaching the Black Sea shelf.

We finally note that the geometrical dimensions, water course and shape of the imaginary second channel that we have envisioned here have been selected entirely artificially, in the absence of accurate design information or any study for a realizable project for that matter. The estimates of the changes in fluxes as well as those on the flow fields could sensitively change with projected changes in dimensions, course and design elements. For instance, few proposals appearing in press have suggested changes in channel width amounting to 2-3 times of the present values, and slight increases in depth, required from the point of view of navigation authorities, although these have been left uncertain. If such changes occur, or even in the event of small changes in the simple channel that we envision, the estimates could be sensitively modified. We also have already noted the importance of time dependent effects not presently addressed, which are bound to significantly change the coupled behavior of the two-channel configuration.

Conclusions

Although the estimates presented in the last section may seem to be small in comparison to the natural levels of the fluxes, they indicate important changes nevertheless. The increase in the upper-layer flux is threatening for the Marmara Sea ecosystem, with further downs tream effects possibly transmitted to the Aegean Sea, especially in the North Aegean Sea whose stratification and dense water formation properties are sensitive to the Black Sea Water (BSW) transported via buoyant surface currents of the Dardanelles Strait (Zervakis *et al.*, 2000). Similarly, the increased lower-layer flow entering the Black Sea has potential to influence the sensitive Black Sea stratification and mixing processes (Özsoy *et al.* 1993, Delfanti *et al.*, 2014; Falina *et al.*, 2007, 2017). Both types of influences may have significant consequences on climate time-scales. In particular, the region is under threat of "tropicalization" in the Aegean Sea and "Mediterranization" in the case of the Black Sea, subject to climate change effects regulated by the exchange between the two basins, and the modification of their ecosytems. Notably, Canal Istanbul may have an ameliorating impact on the tropicalization of the North Aegean.

As mentioned earlier; the design details such as the location, shape, dimension and possible engineering applications that could be included in the design were not clear at the time of this study. Therefore, our modeling experiment focuses only on the most basic effects of the two-layer exchange between the Black Sea and the Marmara Sea by assuming an artificial Canal, designed as simple as possible at this stage. In addition to this geometrical simplicity, the model simulations presented in this study exclude the time-dependent effects. Solutions are sought for only the steady-state defined by a net barotropic volume flux between the two basins. Considering that the exchange between the Mediterranean and the Black Sea relies on a two-way coupled system one can also claim that the simple representation of neighboring basins with reservoirs of limited volume and with open boundaries is also a deficiency that could largely differ from reality.

With all these limitations, it is clear we only lightly touch upon the various ways the proposed 'development' project can influence nature. On the other hand, utilizing an ocean model is one of the rational ways to estimate anticipated effects of exchange modification between the Black Sea and the Marmara Sea. Using either uniform or stratified boundary conditions, and for a small range of net fluxes tested, we see that significant upper-layer transport is expected from Black Sea towards the Marmara Sea as a result of the artificial Canal.

Without knowing the design details and the engineering details, it would be immature to explain exactly how a second inflow effects the circulation, hydrography and the ecosystem of the inland Sea of Marmara, as well as the neighboring Seas. Yet, it is instructive to estimate the direction and level of the expected changes based on simple models as we have done here.

Increases in the layer fluxes estimated to be few percent of the existing net fluxes is not something to be taken lightly, especially when one thinks about the long-term influences. In fact, these changes are also not very small even in the short-term because of the endangered ecosystems of the adjacent seas, especially of the Black Sea in particular. The environmental status of the Marmara Sea is rather poor in terms of increasing events of Harmful Algal Blooms (HABs) and mucus in recent years. It is noteworthy that a *3%* increase in the average upper-layer flux of the Bosphorus will amount to about $600 m^3/s$, that is, about three times the average discharge of a medium sized river, such as the Sakarya River, discharging into the Black Sea. On the other hand, it is not relieving to think that a relatively small proportion of Black Sea waters are to be additionally transferred to the Marmara Sea on a continuous basis, when one realizes the water quality aspects of the transport. The Black Sea is already threatened by eutrophication processes due to the input of excessive amounts of nutrients by large rivers such as Danube in the northwest, transported with currents around the periphery. These waters are then injected to the Marmara Sea by the energetic jet flow issued from the Bosphorus where entrainment and recycling further contributes to excessive biological production leading to the sorry state of the Marmara Sea, which now seems to face additional threats induced by the influence of Canal İstanbul on the horizon, possibly introduced by the additive injection of polluted waters from the Black Sea, which could have serious consequences for the Marmara Sea. On the other hand, the model solutions point to a slight decrease of the upper-layer flux through the Bosphorus compared with the current situation. This decrease is important, considering the decisive role of the Bosphorus Jet on the complex circulation of the Marmara Sea clarified by coupled modeling of the TSS circulation including the effects of Straits (Sannino *et al.*, 2017; Gürses *et al.*, 2016).

An equally important effect is the predicted increase in the lower-layer flux of the Bosphorus, which is all too important in terms of the interior mixing processes of the Black Sea (Özsoy *et al.*, 1993; Delfanti *et al.*, 2014; Falina *et al.*, 2007, 2017). One of the adverse influences in the long-term would be the potential to change the stratification in the Black Sea, with increased injection of the nutrient rich lower-layer waters of the Marmara Sea contributing to the long-term decline of the Black Sea basin. Furthermore, the discharge of wastes of the megapolis of İstanbul is based on a waste disposal system design option making use of the lower layer currents to transport wastes to the Black Sea (Özsoy *et al.*, 1995), and changes in the lower current are also significant in those respects. The increase in the lower-layer flux through the Bosphorus is persistent for all the DUALBOS solutions, although this increase is higher under the stratified boundary conditions with values nearly *3.5%* of the lower-layer flux of the ONLYBOS cases.

In summary, it would probably be too pessimistic to foresee a direct and immediate effect on the circulation and the hydrography of the Marmara Sea or the Black Sea. However, increased exchange activity especially under the time-dependent forcings are quite likely to create larger volumes of water to be exchanged, the deteriorating water quality aspects threatening the sensitive shelf areas and ecosystems of the adjacent seas.

Acknowledgements

This study benefited from various independent observational studies carried out over the last 30 years at the IMS- METU including the SESAME European integrated project and TÜBİTAK research project 111Y308.

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