A HIGH-RESOLUTION HYDRODYNAMIC SIMULATION OF LESVOS SEMI ENCLOSED EMBAYMENT KALLONI GULF: PRELIMINARY RESULTS

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Abstract
Kalloni Gulf is an elongated, shallow embayment at the Aegean island of Lesvos of very high ecological, societal, economic and aesthetic value. In this work we investigate the physical oceanographic functioning of the Gulf, under high-frequency atmospheric and tidal forcing. To that aim, the ROMS model is exploited, forced by the ERA-Interim atmospheric data set and tidal constituents provided by the OSU Inverse Global Tidal Model. The model's performance is assessed via comparison to a data-validated model. The results reveal a seasonal dual behavior of the Gulf, as a dilution basin throughout the rainy season, and as a concentration basin during the dry period of the year. On annual basis, the Gulf acts as a dilution basin, as the net channel exchange is responsible for an equivalent of about 0.6 m sea-level drop annually. The Gulf's residence time is estimated to about 22 days. This estimate would increase to about 35 days in the absence of tides, which signifies the importance of tidal exchange, despite the low energetics of tides in the Mediterranean. Future work will include the adoption of different optical water types and different advection schemes, to improve the model's skill.
Keywords: *Kalloni Gulf*, *high resolution simulation*, *semi enclosed embayment*, *North Aegean*
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1. Introduction

Kalloni Gulf is located at the southwestern part of Lesvos island and is the biggest bay compared to gulf of Gera (Figure 1). The lagoon is a shallow, rich wetland that hosts aquatic and avian life. It is an economically important region due to intensive aquaculture and fishing activity. Several studies have been conducted all the previous years but they are mainly focus on the ecological state of the bay (Panayotidis *et al.* 1999; Evangelopoulos *et al.* 2007; Tsirtsis *et al.* 2008; Tamvakis *et al.* 2012). According to the available bibliography, only Spiropoulou *et al.* (2013) studied a part of the thermohaline functioning and dynamics of the bay using a water budget model but without taking into account tides.

In this work, we aim to understand the thermohaline functioning and dynamics of the Gulf, focusing on the impact of riverine and tidal forcing. To that aim, we have set up a high resolution 3D hydrodynamic simulation including high-frequency atmospheric and tidal forcing. Another innovation of the current study is the use of the results of a hydrological model (Sumaya *et al*. 2016; Chalazas *et al.* 2017) in an effort to assess the impact of realistic rivers and streams inflow to the Gulf's dynamics and mixing. At the current stage the results are referred to the period from 1st of January 2004 to 1st of January 2005, due to the availability of a reference calibrated simulation for that period.

2. Material and Methods

The hydrodynamic model hereby used is ROMS (Regional Ocean Modeling System) (Shchepetkin and McWilliams, 2003, 2005), a free – surface, terrain – following, primitive equations ocean model widely used by the scientific community for a diverse range of applications (Haidvogel *et al.* 2000; Wilkin *et al.* 2005). An orthogonal rectangular grid covering the Kalloni gulf with 120 meters resolution in both horizontal directions was developed (Figure 1b) with a vertical resolution of 15 sigma levels and a variable resolution from 0.03 m to approximately 65 m. High resolution bathymetric data was provided by a digitized naval map. Minimal smoothing was conducted on the bathymetry using a linear programming method (Sikiric *et al.* 2009).

From the available turbulence mixing schemes we adopted the *k-kl* parameterization, as implemented through GLS scheme (Umlauf and Burchard 2003; Warner *et al.* 2005). The model's default background values were used for the vertical viscosity and diffusivity. For the horizontal diffusion and viscosity a harmonic (Laplacian) operator was selected just for stability reasons. A quadratic drag law was used for the parameterization of the bottom stresses. The default 3rd order upstream – bias advection scheme was used for the momentum and the 4th order AKIMA (Shchepetkin and McWilliams 2003) was used for the horizontal and vertical advection of tracers. The initial and high-temporal resolution boundary conditions – 1hr time step – are provided from a regional model of the North Aegean sea (Figure 1a) (Mamoutos *et al.* 2018). Atmospheric forcing fields from ECMWF ERA – Interim dataset were used with a spatial resolution 0.125 × 0.125 degrees and three-hour time step. For the major rivers and streams that outflow inside the gulf we used data from a hydrological model (Sumaya *et al.* 2016; Chalazas *et al.* 2017). Finally the harmonics for 9 tidal constituents – Q1, O1, P1, K1, N2, M2, S2, K2, M4 – were obtained from Oregon State University Global Inverse Tidal Model (Egbert *et al.* 2002).

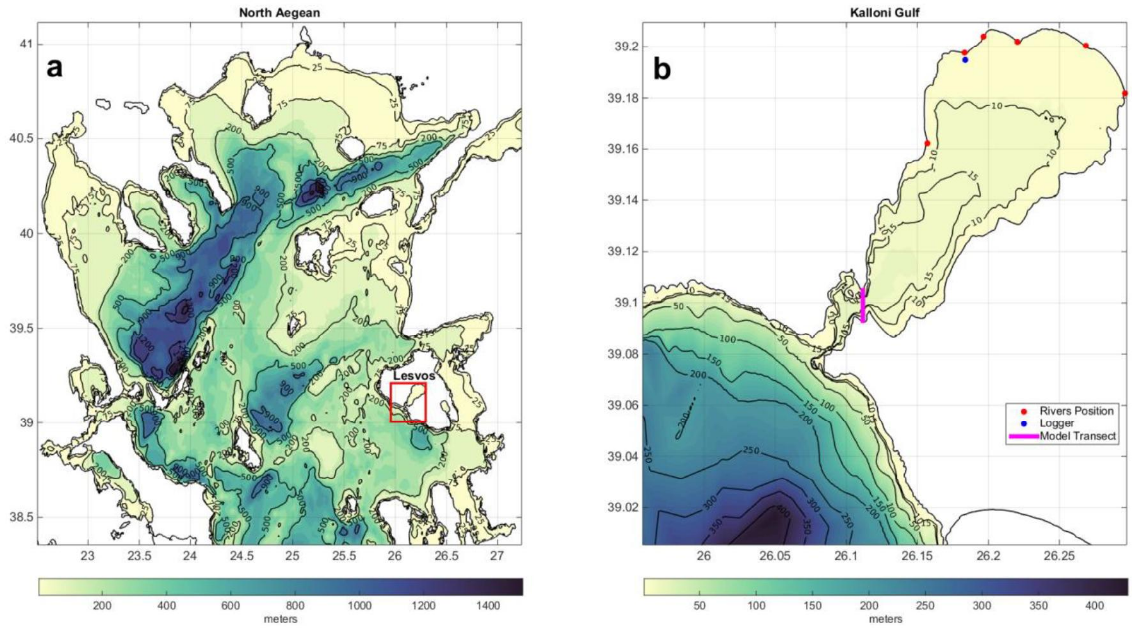

Figure 1.(a) Bathymetry of the North Aegean Sea in meters. (b) Kalloni's Gulf bathymetry in meters plus the position of major river mouths (red bullets). The position of the simulated time-series provided by the Kolovoyiannis *et al*. (this volume) is identified by the blue bullet (Logger). The magenta line shows the transect from which a first estimate of the net volume flux was calculated.

3. Results

A good test for model skill is to compare the results, in statistical terms using correlation coefficient, bias and Root Mean Square Error (RMSE) with results from another model that has been validated with observations and is presented on the current conference (Kolovoyiannis *et al.*). Figure 2 shows the evolution of salinity (a) and temperature (b) for both runs – tidal and non tidal run – at the station that is located at the northern part of the gulf (Figure 1b). For the salinity field we see that there is a good match for both cases, but the scores are better concerning the RMSE and bias for the non tidal run. On the other hand the scores of RMSE and bias show that the model underestimates the temperature for both runs.

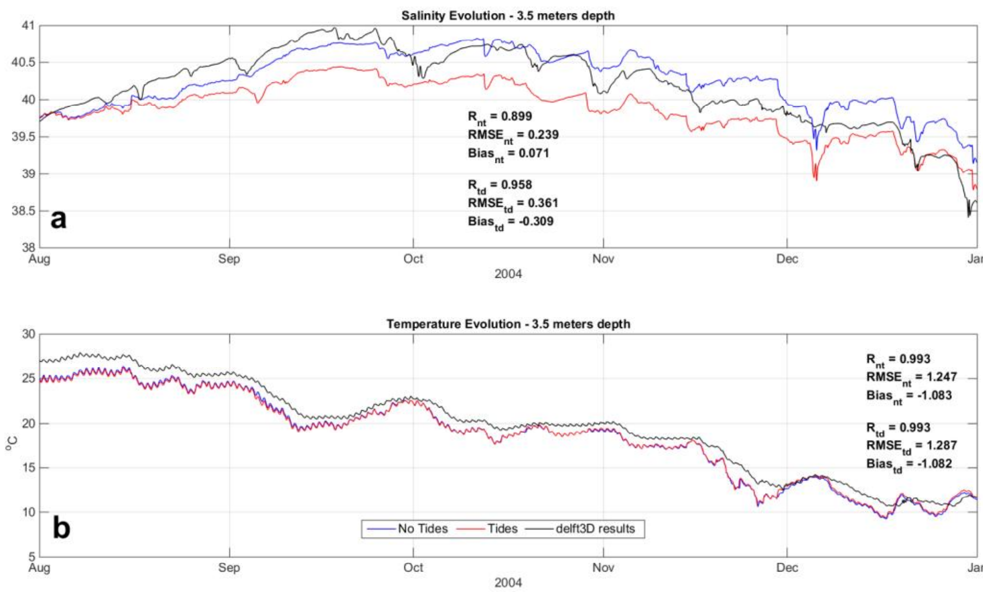

Figure 2. Statistical comparison of model results with delft3D model results. The upper panel (a) shows the evolution of salinity at approximately 3.5 meters depth with the scores for both runs and the lower panel (b) the same for temperature.

The vertical means of the currents in the gulf (as calculated from the vertical integration of the 3D velocity fields) are presented in the next figure for tidal (Figure 3a) and non tidal (Figure 3b) runs. From the results we can see that there are no significant differences in the general circulation except from within the channel connecting the bay with the Aegean Sea (Figure 3c). This difference between the runs gives us a first and crude estimation of the residual current that dominates the channel and intensifies the volume flux when the tides are present.

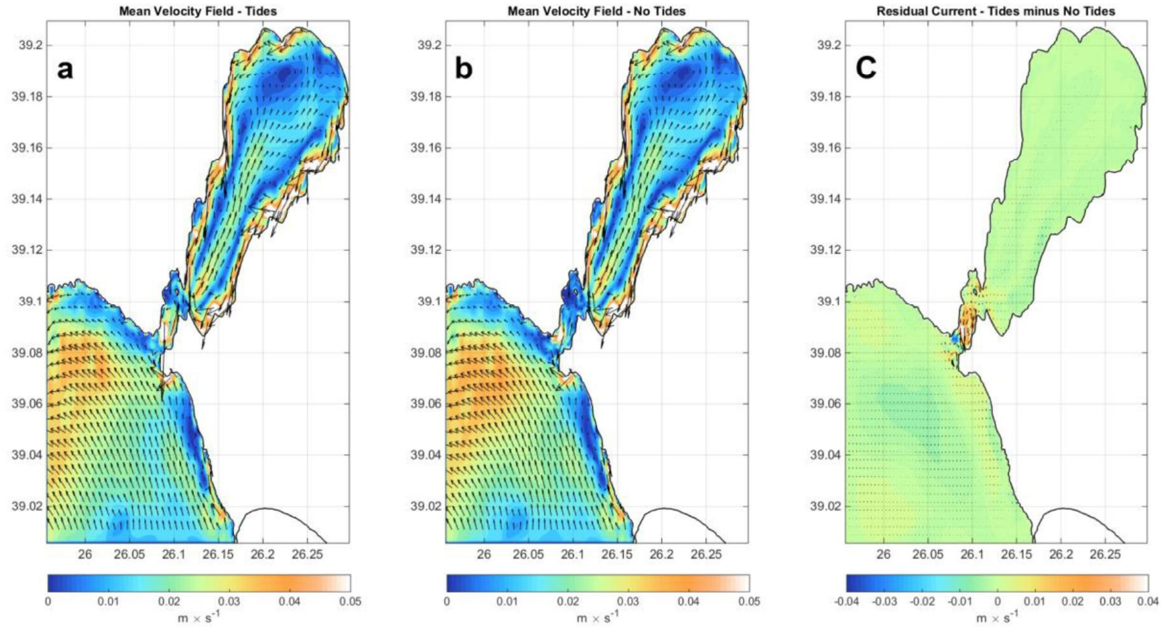

Figure 3. Mean velocity fields, as calculated from the vertical integration of 3D momentum variables, for tidal (a) and non tidal run (b). Panel (c) shows the mean residual current as estimated from difference between the two cases.

The last figure (Figure 4) on the upper panel (a) shows the simulated net volume flux through the transect at the channel (identified in Figure 1b) for both runs. The mean net volume flux ($\overline{Q}$) for the tidal case is -2.02 m^3/s and for the non tidal case equals to -1.55 m^3/s (where negative flux denotes a net volume export from the Gulf). The fact that the net volume flux as an absolute value is larger when the tides are present agrees with the dominant role of the residual current that seems from our analysis to exist inside the channel. One other interesting thing is the difference on the magnitude between the two series and is associated with the spring – neap cycle of the tides inside the bay.

The lower panel of Figure 4 (b) gives us a first idea about the thermohaline functioning of the gulf during a year from the variability of sea level within the gulf as estimated solely from the accumulated temporal integral of net volume flux. For both cases – non tidal and tidal – we can see that from January to March the gulf operates as a dilution basin (as the Channel keeps exporting more water than importing, thus the channel-exchange-induced sea-level keeps falling), from March until October as a concentration basin and from that point until the end of the year as dilution basin again. It is worth mentioning that the sea level rises more in the presence of tides when the bay acts as a concentration basin. The mean value of sea level variability is -0.26 meters and -0.14 meters for tidal and non tidal run respectively. On longer-than-seasonal time scales, the net exchange through the channel removes an equivalent of 0.6 m of water annually from the Gulf, thus on greater time-scales the Gulf behaves as an overall dilution basin.

Having estimated not just the net volume flux, but also the inflow and outflow volume fluxes through the channel, we are able to estimate residence times of the waters within the Gulf. To compute the residence time, we used

$$T = \frac{V}{Q_{out} + E},$$

where V the volume of the Gulf, Q_{out} the mean volume outflow (in m^3s^{-1}) and E the evaporation rate through the Gulf surface (also in m^3s^{-1}). Our result is approximately 34.6 days and 22.8 days for non tidal and tidal cases respectively. As expected the residence time when the tidal forcing is present is smaller compared to the non tidal run.

As a conclusion our preliminary results suggest that the model reproduces the dynamics and the thermohaline functioning of the bay in an adequate way and there is a good representation of the salinity field compared to validated model results. The Kalloni Bay exhibits a dual behavior, dictated mainly from the fresh-water budget: during the wet season (October – March) the Gulf behaves as a dilution basin, while during the dry season (April-September) the functioning reverses. The residence times of the waters are small, of the order of 20 days, and the tides have a significant role in enhancing the exchange with the open sea. Regarding the model performance, it appears that the model in its current form underestimates mixing inside the Kalloni Gulf. One of our first aims for our future runs is to try to tune the horizontal diffusion coefficient using different values because from our analysis it seems that this parameter is crucial also to the vertical mixing process. Another one is to explore the performance of a different advection scheme for salinity and temperature and identify any significant differences. Finally, our next aim is to experiment with different optical water types according to Jerlov parameterization.

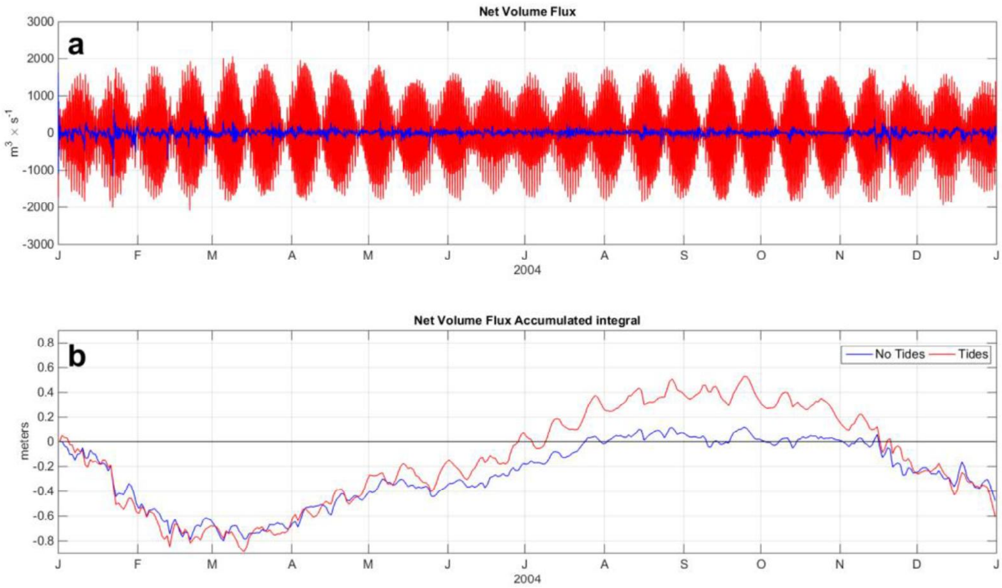

Figure 4. Upper panel (a) shows the simulated net volume flux for no tidal and tidal run for Kalloni gulf through transect. The lower panel (b) gives the accumulated temporal integral of the simulated net flux and reveals the thermohaline functioning of the bay during a year, in particular 2004.

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