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ABSTRACT BOOK

INVESTIGATING THE HYDRODYNAMICS AND WATER QUALITY IN THE POTIDEA CHANNEL (NW AEGEAN SEA)

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The design and analysis of field measurements concerning the hydrodynamics and water quality in Potidea channel that connects Thermaikos and Toroneos Gulfs, (northwestern Aegean Sea) was the research objective of the present work. Two stations were selected, in that aim, located at the two extremities of the channel. The current velocities along the channel were recorded by means of mechanical current meters, enabling the calculation of the water mass exchanges between the two adjacent gulfs. At the same time temperature and salinity measurements were conducted, using autonomous CTD data-logger, and necessary meteorological data were obtained from a station in close proximity. Seawater samples were collected from two depths; near the sea surface and near the bottom. Dissolved oxygen and nutrient concentrations were measured in order to investigate the effect of the physical factors on the temporal and spatial variation of water quality parameters in the channel. These measurements were also used as indicators of the state of the marine environment and identification of possible pollutant forcing events. During the time of the field works, on a seasonal basis, the currents were unidirectional along the channel and the velocities ranged over a few cm/s to approximately 0.5m/s, with alternate direction, exhibiting good correlation with the wind forcing (concerning the wind speed and direction). The water column was homogeneous, with no significant stratification for the majority of the field measurements. Flow rates were found to reach the order of a few tens of cubic meters per second. Finally, it was estimated that the time needed for a tracer substance to go through the channel, entering from the one gulf and reach the other opening to the adjacent gulf, was less than an hour (with strong currents) up to the order of a day (with weak currents).

WEDNESDAY, JULY 7th 2010	
ROOM B	
11:30-12:45	**Session B4: Protection and Restoration of the Coastal Environment** **Chairs: G. Korfiatis, M. Lekka**
11:30-11:45	**ENVIRONMENTAL RISK ASSESSMENT MODEL FOR POTENTIALLY CONTAMINATED SITES** *C. Vatseris, T. Tsatsarelis, A. Karteris, S. Papadopoulos, D. Dermatas*
11:45-12:00	**INVESTIGATING THE HYDRODYNAMICS AND WATER QUALITY IN THE POTIDEA CHANNEL (NW AEGEAN SEA)** *Y. Savvidis, A. Moriki, K. Kombiadou, X. Dimitriadis, E. Tsianaka, S. Kerpitsopoulou, A. Hatzinikolaou*
12:00-12:15	**WATER NEEDS IN COASTAL LOCATIONS FOR SUSTAINABLE AGRICULTURAL AND TOURISTIC DEVELOPMENT** *I. Livaniou, E. Paleologos, N. Paranychianakis*
12:15-12:30	**ESTIMATION OF MARINE EUTROPHICATION LEVELS BASED ON SATELLITE DATA** *D. Kitsiou, T. Nitis*
12:30-12:45	**A STUDY OF ENERGY PERFORMANCE OF THE GREEK HOTEL SECTOR** *S.N. Boemi, A. Papadopoulos, T. Fotiadis, G. Mihalakakou*
12:45-15:00	**Lunch break**

INVESTIGATING THE HYDRODYNAMICS AND WATER QUALITY IN THE POTIDEA CHANNEL (NW AEGEAN SEA)

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ABSTRACT

The hydrodynamics and water quality in the Potidea channel that connects Thermaikos and Toroneos Gulfs was the research objective of this paper. In that aim, 2 stations were selected in which flow velocities were recorded using current meters. At the same time, temperature, salinity, dissolved oxygen and nutrient measurements were conducted. The research revealed that W, NW and SW winds generally transport waters from Thermaikos to Toroneos, while E, SE and NE winds vice versa. The column was found almost homogenous, except for one period, and the water quality was found at good to satisfactory levels. The effects of the North Aegean Sea, tides and pressure gradients have also been substantiated by the research.

1. INTRODUCTION

The Potidea Channel is a narrow, artificial, navigational canal of the North Aegean Sea that connects two gulfs, Thermaikos, to the west, with Toroneos, to the east (Figure 1). The channel stretches along the west-east axis with a total length of 1150m and width that varies from 40-55m. The existence of this strait appears to significantly impact the hydraulic behavior of the adjacent coastal areas, particularly regarding mass-exchanges and interactions of physicochemical parameters between the two gulfs. The flow conditions in the channel are affected by the local wind-wave regime, the tidal influences, the possibility of existing density or atmospheric pressure gradients between the two extremities of the strait, as well as by the general circulation of the North Aegean Sea.

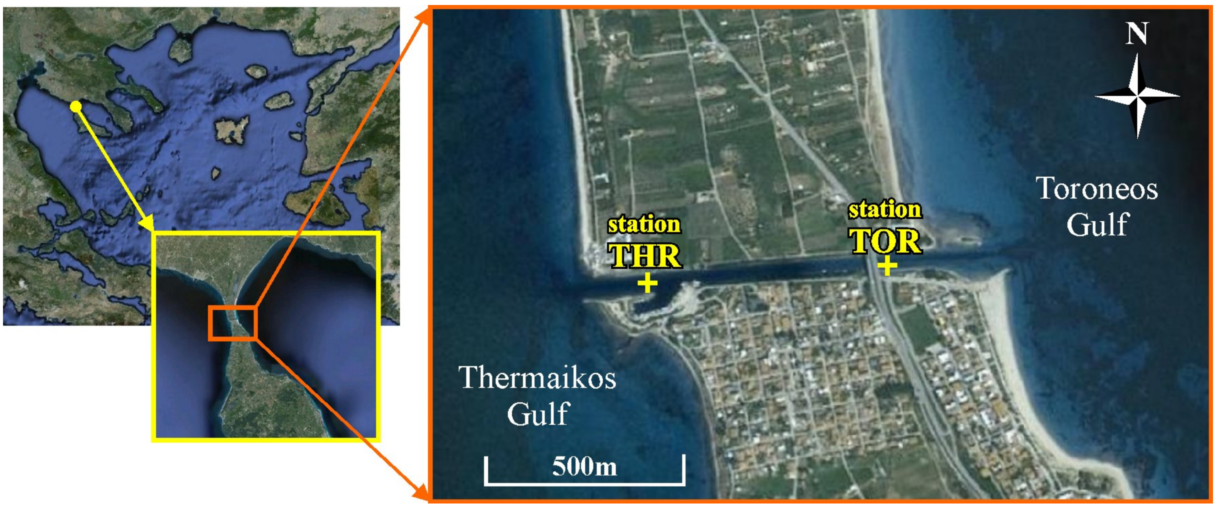

Figure 1: Location of the channel in the North-West Aegean Sea and positioning of the two monitoring stations, THR and TOR (satellite images source: Google Earth).

In an attempt to identify and assess the hydraulic behavior of the channel and to estimate its' effects to the adjacent coastal areas, a monitoring program has been undertaken in the area, including periodic current and physicochemical parameter measurements.

2. THE IN-SITU MEASUREMENTS

2.1 The monitoring stations and parameters

Two stations were selected for monitoring, located at the two extremities of the channel (Fig. 1), THR and TOR, at the communication of the channel with the Thermaikos and Toroneos gulfs, respectively. The current measurements were conducted by means of three Valeport lightweight mechanical current meters (model 106), two of which were deployed near the surface of the two stations, at 0.5m from the sea surface, and the third was placed near the bed of THR station, at a depth of a about 3.5m, in order to record information for the velocity profile in the channel. The aforementioned configuration of current meters' (hereafter CM) moorings in the channel is depicted in figure 2. At the same time temperature and salinity measurements were conducted at the two stations, using autonomous CTD data-logger (SBE 19) in profiling mode, along with measurements of dissolved oxygen and nutrient concentrations, defined after water sampling and laboratory analysis, using methodology analyzed in [1]. These parameters were monitored in order to investigate the effect of the physicochemical factors on the temporal and spatial variations of water quality parameters in the channel and, also, to be used as indicators of the state of the marine environment and identification of possible pollutant forcing events.

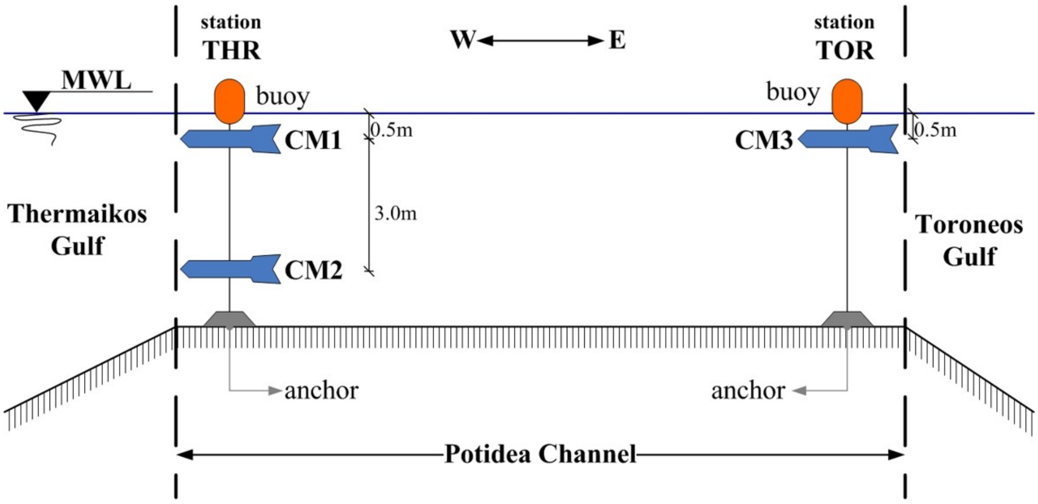

Figure 2: Schematic representation of the CM configuration at the two monitoring stations (THR and TOR) along the channel (east-west cross-section).

2.2 The surveys

Four bimonthly oceanographic surveys have been conducted (23/10/2009, 17/12/2009, 04/03/2010 and 29/04/2010), in each of which, current recordings for at least 6 hours were conducted, in order to cover the half-period of the semidiurnal tide. In these surveys the CM mooring at the THR station was deployed first, followed by CTD deployment and water sampling at the location. The same procedure was repeated for the TOR station and, after completion, the water samples were taken to the laboratory for analysis. It must be noted that in the second (17/12/2009) and fourth (29/04/2010) survey, due to malfunctioning of CM2, no data have been recorded and, unfortunately, no information was obtained regarding the current speed and direction for the near-bottom layer of the channel. The results of the conducted measurements are presented and discussed in the following parts of the paper.

3. RESULTS - DISCUSSION

3.1 Current and physicochemical parameters measurements

The recorded current speed during the four surveys is depicted in figure 3 (timeseries diagrams). It can be noted that, in most cases, the magnitude of the current velocity evolves approximately conjunctly in the surface layer for both stations. However, during the second measurement (fig. 3b), the recordings of TOR were steadily lower that the currents at THR. Regarding the near-bed currents (CM2), they were found to be approximately of the same magnitude as the ones of the surface layer (CM1).

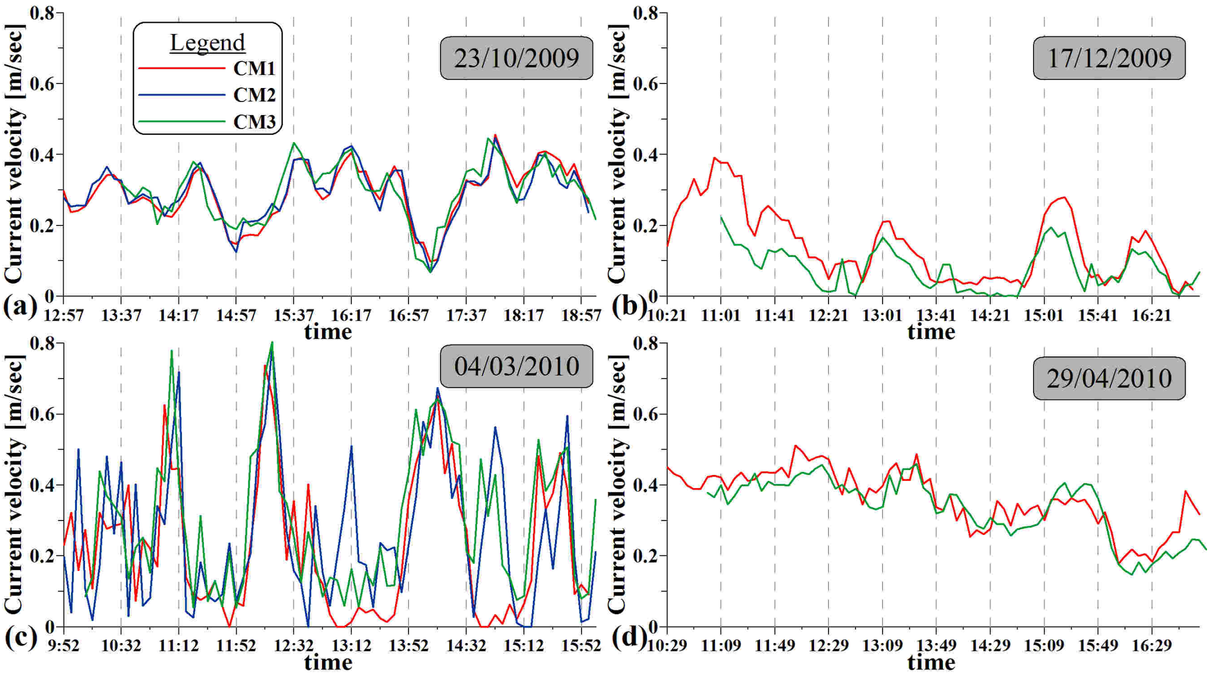

Figure 3: Temporal evolution of measured current velocities during the four measurements.

Another means of graphic representation for currents is hodographs that show the hypothetic trajectories (in time and space) of an element of water mass which starts its course at the position of the CM. Examining the direction and velocity of the currents jointly, as depicted in the hodographs of figure 4, it can be noted that during the first and last measurement (fig. 4a and d) the transport of the water masses was constant, with a direction from Toroneos to Thermaikos (E to W). Especially in the first period, where CM2 data exist, it can be seen that the currents were nearly stable with depth, illustrating a water column that resembles the laminar flow of an open channel. The flow seems to be totally controlled by the wind forcing of the period, data depicted as vector graphs in figure 4. These data were obtained by the Sani meteorological station, situated 6n.m. south from the channel. During the second survey (Fig. 4b) the water masses were transported from Thermaikos to Toroneos with a significant reduction of current amplitudes due to the corresponding drop in wind strength. The third surveying period presents very interesting shifts in current directions, with the general transport for the upper layer in THR station to occur from E to W and the near-bottom layer in alternating directions. This behavior is analyzed further down (§3.2), along with the recordings of the last survey, in which, the currents presented a stable E to W direction and significant minimal current velocities (~0.2m/s), revealing the existence of a residual current. Considering the western direction of winds in the period (fig. 4d), the indication of other forcing factors that interact with the wind and, in fact, damp the wind-driven circulation is made clear.

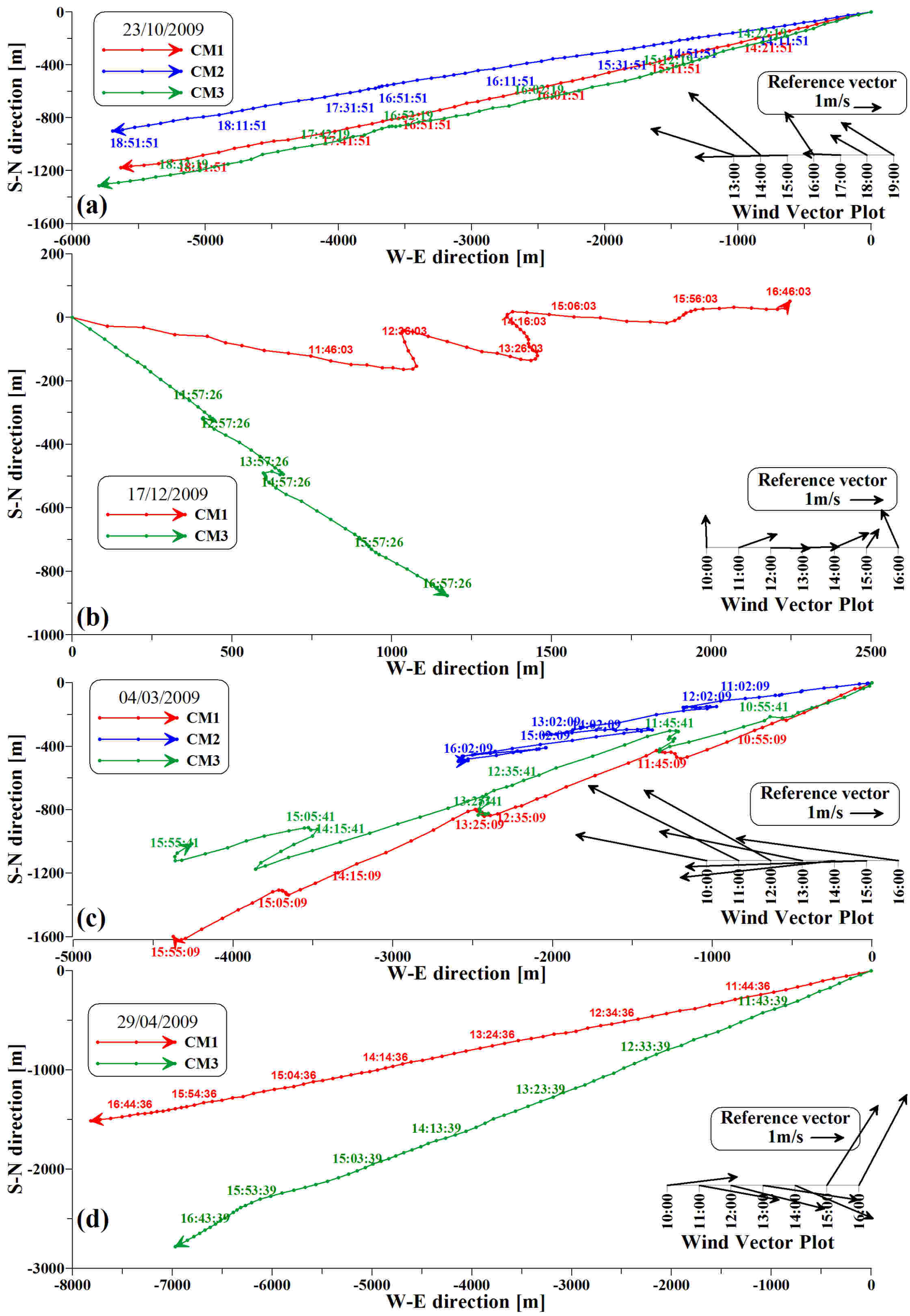

Figure 4: Hodographs of current measurements (W to E and S to W directions are considered as positive and the axes [m] scaled proportionally) and wind vector graphs for the 4 surveys.

The physical parameters' (T, S, σ_θ) profiles during the surveying periods are depicted in figure 5, in which it can be noted that the values remain uniformly distributed over the length of the channel and that the column appears almost fully homogenized for the total of the periods. There is, however, the exception of 03/04/10, during which the lower layer presents significantly higher salinities than the surficial one and, moreover, with values significantly greater than the ones recorded in the other surveys. This indicates the presence of a different water mass in the lower layer of the channel during the period. The full homogenization of temperatures is due to the low depths of the strait and the faster diffusion of heat compared to salinity and does not contradict the presence of distinct water types in the location.

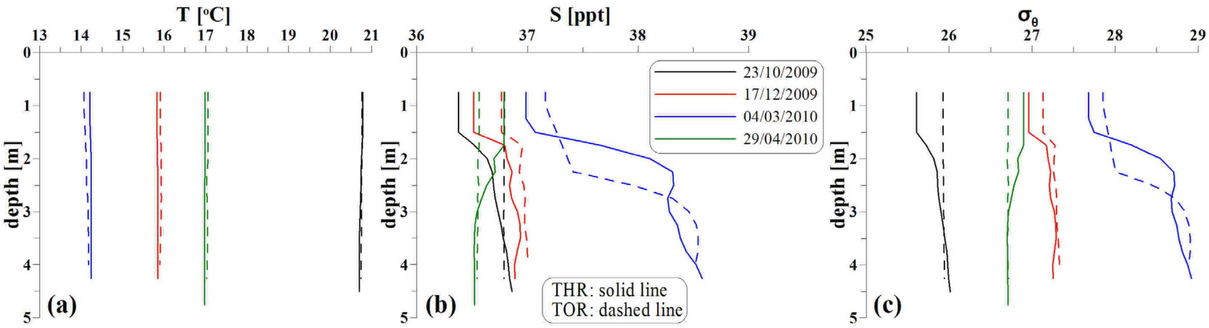

Figure 5: Vertical profiles of temperature (a), salinity (b) and seawater density (c) for the four measurement periods (THR station profiles: solid lines, TOR station profiles: dashed lines).

The values of the physicochemical parameters defined after water sampling are listed in table 1 and include dissolved oxygen (DO), phosphates, silicates, nitrates, nitrites and ammonium concentrations. The waters are well oxygenated, apart from the near-bed layer during 29/04/10. Phosphate values in TOR station were higher than THR during the October and December sampling periods. The mean phosphate value was 0.51 μg-at P/l. Nitrate values ranged from 0.01 to 12.95 μg-at N/l, with a mean concentration of 2.44 μg-at N/l, while ammonium concentrations ranged from 1.5 to 13.09 μg-at N/l (mean value 5.45 μg-at N/l). Phosphate, nitrate and ammonium values classify the water masses in the area as mesotrophic, typical of inshore gulf waters [1] and the water quality as good to satisfactory according to the Water Framework Directive (2000/60/EC). Nitrite concentrations were very low, representative of pelagic seawater conditions. The two stations presented similar levels of dissolved oxygen and nutrients in all the periods. Some differences in silicate values, associated with different phytoplanktonic species, need to be further investigated.

TABLE 1: Physicochemical parameters defined after water sampling and laboratory analysis. (N:P ratio highlighting: blue – P surplus, orange – N surplus, green – normal value of 16:1)

Para-meter	**Layer**	**23/10/2009 THR**	**23/10/2009 TOR**	**17/12/2009 THR**	**17/12/2009 TOR**	**04/03/2010 THR**	**04/03/2010 TOR**	**29/04/2010 THR**	**29/04/2010 TOR**
DO [mg/l]	surface	5.64	5.15	6.44	6.76	7.73	---	6.60	7.89
	bed	5.96	4.19	6.44	6.60	6.76	---	3.86	4.19
P-PO_4 [μg-at /l]	surface	0.01	0.34	0.10	0.20	3.34	0.39	0.25	0.25
	bed	0.01	0.30	0.10	0.25	0.89	0.54	0.20	1.03
S-SiO_4 [μg-at /l]	surface	14.37	1.85	7.18	23.18	8.92	23.76	18.19	20.16
	bed	40.91	2.09	---	38.36	8.34	12.75	10.31	7.65
N-NO_2 [μg-at /l]	surface	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
	bed	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
N-NO_3 [μg-at /l]	surface	9.14	3.49	0.22	0.64	0.95	0.28	0.01	0.01
	bed	10.41	12.95	0.16	0.22	0.19	0.25	0.04	0.04
N-NH_3 [μg-at /l]	surface	3.41	1.50	7.09	7.23	13.09	4.23	2.73	3.27
	bed	4.09	10.91	7.64	7.91	3.55	3.82	3.41	3.41
TN [μg-at /l]	surface	12.56	5.00	7.32	7.87	14.04	4.51	2.75	3.29
	bed	14.51	23.87	7.80	8.13	3.74	4.08	3.46	3.46
N:P	surface	1007.80	14.52	74.43	40.02	4.20	11.47	11.16	13.39
	bed	1164.42	80.88	79.30	33.07	4.23	7.54	17.57	3.35

3.2 The hydrodynamics in the channel and the driving forcing events

A general, and expected, finding of the monitoring process is that prevalence of winds of the west sector (NW, W, SW) initiate mass-transport from Thermaikos to Toroneos and that the opposite takes place for winds of the east sector (NE, E, SE). These observations are in agreement with previous findings, based on field and modeling work [2]. However the persistence of strong south-easterlies in the North Aegean can generate very interesting transport phenomena in the channel. This situation has been captured by the third survey (4/3/2010), during which constant, strong (6-7bf) NE winds blew off the Sporades islands [3]. As indicated previously, the hydraulic behavior of the channel was quite different during this period, with the lower layer presenting alternating current directions. This can be observed more clearly in the temporal evolution of the horizontal (W-E direction) current component of figure 6a. The eastern current direction has been set positive and the west negative, depicted in green and red colors, respectively, in the contour plot. The same plot presents vertical profiles of the horizontal current component at indicative instances (Fig. 6a1-a5), marked with arrows in the temporal evolution. The profiles reveal the existence of a two layered structure of the water column in the channel, with independently moving layers. It can be seen that the upper layer of the column retains stable current direction from E to W, even though the speed is, in some cases, very low. This circulation is probably wind-driven and is in accordance with the generalized pattern, stated previously. The near-bed layer, on the other hand, presents higher current velocities of alternating directions. Therefore, this layer moves faster than the overlying one, transporting masses from Toroneos to Thermaikos (red areas in Fig. 6) and vice-versa (green areas in Fig. 6). These shifts seem periodical, interchanging every 30 to 50 minutes. The factor controlling this hydrodynamic behavior is probably the circulation of the North Aegean under the prevalence of strong SE winds in its central part, combined with the coastal morphology. These winds generate strong NW currents which, reaching the coasts of the Chalkidiki peninsula, due to its alignment along the SE-NW direction, are forced to separate in two coastal branches, one entering the Thermaikos and the other entering Toroneos. Under these forcing conditions, as simulated by the HYCOM hydrodynamic model applied in the North Aegean Sea [4], anticyclones form in the two gulfs, one near the northern coastal boundary of Toroneos and the other in the coastal area of the Thermaikos shelf, south from Cape Epanomi. These anticyclones appear to interact with the aforementioned NW coastal currents, creating the observed shifts in the transport of the near-bed waters inside the Potidea channel. Moreover, the presence of highly saline waters in the lower depths of the channel (Fig. 5b) confirms the designation of the North Aegean as the factor controlling the hydrodynamics of the near-bed waters. The high density of the lower layer, along with the elevated shear stress at the surface, probably inhibited mixing of the layers.

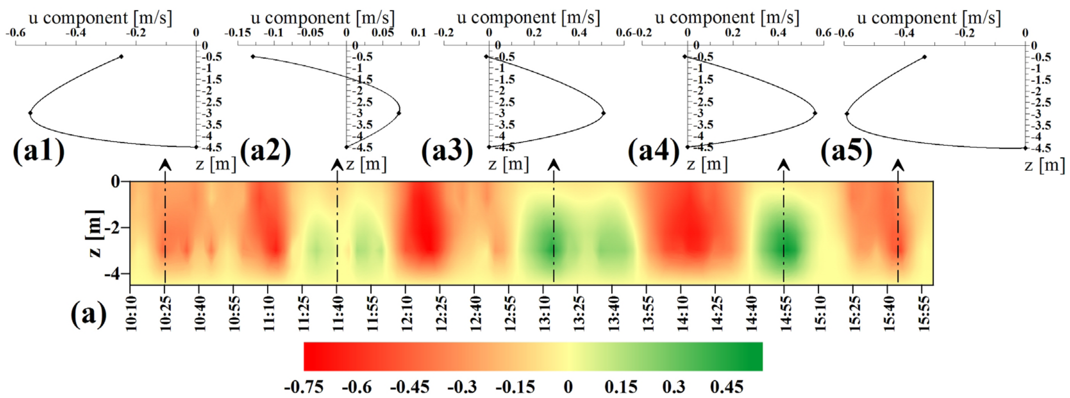

Figure 6: Horizontal (W-E) current component temporal evolution (lower) in the THR station during 04/03/2010 and vertical profiles (upper) at selected instances (location indicated with arrows). The eastern current has been set as positive.

Regarding the last survey (29/04/2010), as briefly discussed previously, the current recordings showed mass-transport from Toroneos to Thermaikos that was initiated by forces other than wind. The current velocities were filtered using Fast Furrier Transformation (FFT), removing high frequency data using a cutoff frequency of $2\cdot10^{-4}s^{-1}$. Thereby, data due to forcing factors of periods lower than 1.4hrs have been removed and the filtered data variation, depicted in figure 7, appears cosinusoidal. The morphology of the curve indicates the presence of a tidal signal in the recordings of amplitude of 0.155m/s. It must be noted that the selection of lower cutoff frequencies did not alter the filtered data curve and that no significant or detectable tidal signal was traced in the other surveys. Considering that the tidal wave is indeed a long wave, it has been calculated by the equations of linear wave propagation in shallow waters that the tidal range in the channel was of the order of 21cm. Removing the tidal velocity from the current measurements, the remaining current velocity (blue line in Fig.7) consists of one fluctuating and one stable component, of the order of 0-0.2m/s and 0.17m/s, respectively. The fluctuation is probably due to wind forcing, whereas the stable component is most probably generated by the existence of a pressure gradient between the two extremities of the channel. However, the direction of the wind is opposite from the one in which the general transport takes place. It is, thereby, concluded that the force that controls the circulation, during this period, is the result of the balance between the tidal and pressure forces, transporting masses from Thermaikos to Toroneos and the wind that forces waters in the opposite direction. Thus, the residual current due to pressure gradient is attenuated by the opposing wind-driven current and is, in absolute quantity (without the effect of wind), much greater than the value of 0.17m/s that has been estimated by the filtered current recordings. These two final surveys revealed the significance of forcing factors (general circulation, tide and pressure gradients) that can alter, or even overcome, the effects of wind to the hydrodynamics of the Potidea channel, phenomena that are very interesting and should be further investigated.

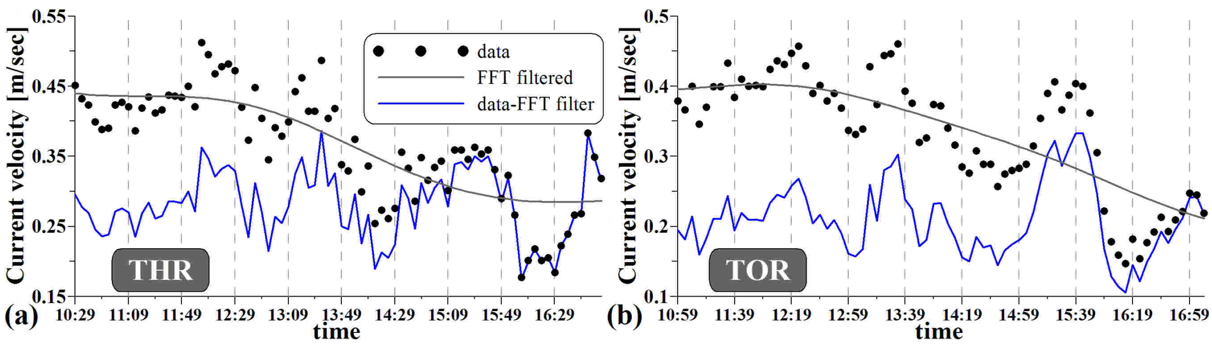

Figure 7: Application of Fast Fourier Transformation (FFT) filter to the current measurements of 29/04/2010

For the estimation of the water mass exchanges between the gulfs, the area of a cross section of the channel needs to be determined, surface that can satisfactorily be considered as a trapezoid with an area of $175m^2$. Therefore, the average flow discharges, calculated from the product of the average u velocity component and the area of the aforementioned cross section of the channel, range between 16 and $58m^3/s$. The maximum value ($58m^3/s$) was deduced by the final survey, considering parabolic velocity profile. During this survey, the tidal prism was approximately $42,000m^3$, resulting to an average exchange rate of the order of $17m^3/s$ due to tidal forces. Regarding the flow rates of the two-layered structure of the channel (4/3/2010), the mean surficial layer discharges were around $16m^3/s$, whereas the near-bed layer average flux from Thermaikos to Toroneos was of the order of $26m^3/s$ and the flux from Toroneos to Thermaikos was higher, about $42m^3/s$. Finally, considering the flow velocity measurements, the time needed for a tracer to cross the strait was found to vary from 0.75 to 5.6 hours.

4. CONCLUSIONS

In this study, the hydrodynamics and water quality of an artificial channel that connects two adjacent gulfs (Thermaikos and Toroneos) at NW Aegean Sea were investigated. The research, based on field measurements, revealed that the current speed (0-0.75 m/s) and direction were mainly depended on the prevailing wind conditions as well as tides and local pressure gradients. It can be generally stated that under the influence of winds with important west component the water masses tend to move from Thermaikos to Toroneos gulf, while the opposite occurs with wind forcing of important east component. Since N-NW as well as SE and NE winds are the most frequent over the extended area of NW Aegean Sea [5], for winter and summer respectively, it is expected that in winter masses are mainly transported from Thermaikos to Toroneos while the opposite is true during summer. This pattern, however, as evidenced by the measurements, can be altered by the presence of significant pressure gradients between the two gulfs to the extent of full overcoming of the wind-driven current and reversal of the flow. Another significant factor, which may extensively affect the local hydrodynamics, is the North Aegean circulation. It has been substantiated that under strong SE winds in the central Aegean, a two layered structure is formed in the channel with significant near-bed currents that present alternating directions. The near-bed layer, therefore, transports masses from Toroneos to Thermaikos and vice-versa, having the haline signature of the North Aegean. Homogeneity of the water column was found to prevail, while only under the influence of North Aegean waters a stratified column was detected. In that view, the water masses in the channel move usually in a one-layer mass transport mode (one direction) and, conditionally (strong SE winds), in a two-layered mode with alternating directions. The physiochemical parameters' values, measured as water quality indices, varied among good to satisfactory levels, according to the Water Framework Directive (2000/60/EC). The tidal range in the channel was found of the order of 0.20 m. Finally, the flow rates varied between 16 and 58m^3/s, corresponding to water-mass residence times in the strait of 0.75 to 5.6 hours.

ACKNOWLEDGEMENT
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REFERENCES

1. Moriki A., Galinou-Mitsoudi S., Petridis D., Kosti D., Savvidis Y., Dimitriadis X., Koutitas C. and Alvanou L. (2008) "Environmental Impacts of Intensive Mussel Culture in the Coastal Waters of the Gulf of Thessaloniki (N. Greece)" **Fresenius Environmental Bulletin**, Vol. 17(11b), pp. 1945-1955.
2. Savvidis Y.G., Koutitas C.G., and Krestenitis Y.N. (2005) "Modelling the water mass exchange through navigational channels connecting adjacent coastal basins – application to the Channel of Potidea (North Aegean Sea)" **Annales Geophysicae**, Vol. 23, pp. 231–238.
3. Poseidon System, **HCMR**, http://www.poseidon.hcmr.gr/
4. Androulidakis Y., Krestenitis Y. and Kourafalou V. (2009) "Application of Hybrid Hydrodynamic Model in the Northern Aegean" **Proc. Conf. 9th Panhellenic Symposium on Oceanography and Fisheries**, (in Greek), Patra, Greece, 2009, Vol. 1, pp. 456-461.
5. Poulos S.E., Chronis G.Th., Collins M. and Lykousis V. (2000) "Thermaikos Gulf Coastal System, NW Aegean Sea: an overview of water sediment fluxes in relation to air-land-ocean interactions and human activities" **Journal of Marine Systems**, Vol.25, pp. 47–76.