A STUDY OF THE SEASONAL FLUCTUATION OF THE SUSPENDED PARTICULATE MATTER IN THE RIO-ANTIRIO STRAIT, WITH THE USE OF OPTICAL METHODS.[1]

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ABSTRACT

The Rio-Antirio represents geomorphologically a sill with depth ~60 m, lying in between the Gulf of Patras (maximum depth of 120 m) and the Bay of Nafpaktos (some 100 m of water depth) that is connected to the western part of the Corinth Gulf. The waters in late spring (June) appear to be more clear as optical transmittance values vary between 70% and 95% (approximately 0,5-3 mg/l), while in late autumn (December) these values vary between 55% and 85% (approximately 1,5-5 mg/l). Furthermore, the distribution of particulate matter is influenced by the river influx (higher in autumn) and the overall hydrography of the area which includes the exchange of the Ionian Sea and Gulf of Corinth water masses (through the Rio-Antirio strait and mixed within the Nafpaktos Bay) and the associated current activity.

ΠΕΡΙΛΗΨΗ

Η περιοχή του στενού Ρίου-Αντιρρίου που αντιπροσωπεύει ουσιαστικά το ρηχό κατώφλι (περίπου 60 μ) μεταξύ του δυτικού Κορινθιακού Κόλπου (βάθη >300 m) και ειδικότερα του όρμου της Ναυπάκτου (βάθη ~100 m) και του σχετικά ρηχότερου Πατραϊκού Κόλπου (βάθη ~120 m). Το στενό χαρακτηρίζεται από ισχυρά ρεύματα που ξεπερνούν ακόμη και το 1 m/s, ενώ η ευρύτερη περιοχή δέχεται τις εισροές από ποτάμια (Στερεά Ελλάδα) και ποταμοχείμαρρους (Πελοπόννησος). Με βάση τις μετρήσεις θολερομέτρου, τα νερά είναι πιο διαυγή στο τέλος της άνοιξης (αιωρούμενο υλικό 0,5-3 mg/l) ενώ στο τέλος του φθινοπώρου έχουν υψηλότερες τιμές (1,5-5 mg/l). Τόσο η οριζόντια όσο και η κατακόρυφη κατανομή της θολερότητας επηρεάζεται από την παροχή των ποταμών σε αιωρούμενο υλικό (εδώ επικρατούν οι ποταμοχείμαρροι των Πελοποννησιακών ακτών έναντι των πολύ μεγαλύτερων αλλά σήμερα φραγμένων ποταμών του Εύηνου και Μόρνου της Στερεάς Ελλάδας), και της γενικότερης κυκλοφορίας νερών, η οποία σχετίζεται με την ανταλλαγή των θαλασσίων μαζών του Ιονίου Πελάγους και αυτών του Κορινθιακού κόλπου, με τα δεύτερα να έχουν υψηλότερες τιμές (2-3 mg/l) αιωρούμενου υλικού. Μάλιστα μέσω της κατανομής των ισοπληθών καμπυλών φαίνεται ότι τα μεν Ιόνια νερά καταλαμβάνουν το σύνολο του Πατραϊκού Κόλπου και εισέρχονται στον Κόλπο της Ναυπάκτου, μέσω του στενού Ρίου-Αντιρρίου , όπου και συναντώνται με τα νερά του Κορινθιακού κόλπου. Κάποια από αυτά στη συνέχεια φαίνεται να εξέρχονται προς τον Πατραϊκό από την πλευρά του Αντίρριου και να συμμετέχουν στην κυκλωνική κυκλοφορία που αναπτύσσεται σε αυτόν. Τέλος τις μεγαλύτερες συγκεντρώσεις αιωρούμενου υλικού της συναντάμε στο νοτιοανατολοικό τμήμα του Πατραϊκού, κοντά στον πυθμένα του κόλπου της Ναυπάκτου, λόγω της δράσης ισχυρών ρευμάτων, αλλά και κοντά στα στόμια των ποταμών της Αιγιαλείας (Πελοποννήσου).

ΛΕΞΕΙΣ ΚΛΕΙΔΙΑ:αιωρούμενο υλικό, θολερότητα, Ρίο-Αντίρριο, εποχιακή κατανομή.
KEYWORDS: Suspended particulate matter, transmittance, Rio-Antirio, seasonal distribution

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1:ΜΕΛΕΤΗ ΤΗΣ ΕΠΟΧΙΚΗΣ ΔΙΑΚΥΜΑΝΣΗΣ ΤΟΥ ΑΙΩΡΟΥΜΕΝΟΥ ΥΛΙΚΟΥ ΣΤΟ ΣΤΕΝΟ ΡΙΟΥ-ΑΝΤΙΡΡΙΟΥ ΜΕ ΤΗ ΧΡΗΣΗ ΟΠΤΙΚΩΝ ΜΕΘΟΔΩΝ.
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INTRODUCTION

In this paper, the seasonal (late autumn and late spring) fluctuation of the suspended particulate matter of the water body in the region of Rio – Antirio strait is described, with the relative data provided by measuring the actual light transmittance of the water column. Furthermore, the measured values of suspended particulate matter are examined in relation to river water/sediment discharges and the exchange of water masses over the Rio-Antirio sill.

The study area includes the Gulf of Patras that is separated to the east from the Bay of Nafpaktos by the Rio-Antirio strait which subsequently leads to the western part of the Gulf of Corinth via the passage between the capes Mornos and of Drepanon. The Rio-Antirio represents geomorphologically a sill with depth ~60 m, separating the deeper Gulf of Patras (maximum depth of 120 m) and the Bay of Nafpaktos (some 100 m of water depth), whilst the investigated western part of the Corinth Gulf has water depths exceeding the 300 m (Fig.1). Finally, the Gulf of Patras merges in the west with the open Ionian Sea between the Cape Papas and the Messologi lagoon.

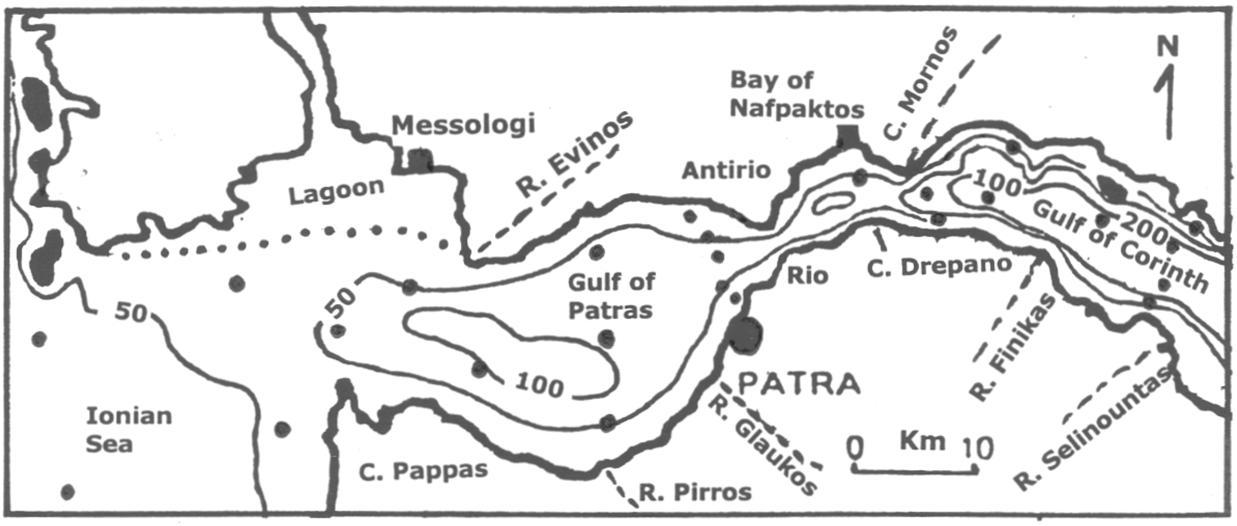

Figure 1. Map of the study area and data sampling locations.

SEDIMENT FLUXES

Along the shoreline of the study area discharge the following river and torrents: (a) in the Gulf of Patras, the rivers Evinos (north coast), the large torrents of Pirros and Glaukos (south coast) and other smaller torrents, (b) in the Bay of Nafpaktos, the river Mornos (comprising its northern boundary to the Gulf of Corinth) and 2 small torrents at its south coast, (c) the eastern Gulf of Corinth, except the R. Mornos and along the Peloponnesian coastline receives the discharges of 2 small rivers (Finikas and Meganitis) and some torrents. On Table 1 the catchment areas of the main rivers and torrents are listed per geographical area.

The water discharge of the rivers is governed by the seasonal fluctuation of precipitation, which varies between the coastal area and the mountainous hinterland between 600 mm and more than 1100 mm per year. Measurements of the water discharge of the main rivers Evinos and Mornos have shown that they provide annually (and before being dammed) 873 $x10^6$ m^3 and 481 $x10^6$ m^3, respectively, presenting their maximum values in late autumn – early winter period (Nov to Jan) following the levels of precipitation (Therianos, 1974). Despite the fact of not available data fro the smaller rivers and torrents with respect to their catchments it can be seen that the study area is influenced primarily by the two big rivers without neglecting the importance of the smaller streams and especially nearby to their mouths.

Table 1. The physiographic characteristics of the rivers / ephemeral steams discharging along the coast of the study area.

Rivers/torrents	**Catchment area (km^2)**		
	Gulf of Patras	**Bay of Nafpaktos**	**W. Gulf of Corinth**
Evinos	635,000		
Mornos		430,000	
Pirros	491		
Glaukos	70		
Foinikas			97,4
Meganitis			60
Other streams	108	35,5	15

As field measurements of the suspended sediment load of the aforementioned rivers and streams are not available, only the estimated values by Poulos and Chronis (1997) of 10,000 ton/yr for Mornos and 220,000 for Evinos can be used as indicative. Moreover, it has been shown earlier (Poulos et al., 1996) that the suspended sediment fluxes, as in the other rivers of western Greece, follow generally the levels of water fluxes and presenting their maximum sediment fluxes also in autumn and early winter.

OCEANOGRAPHIC CHARACTERISTICS

The physical oceanographic conditions in the area and from west to east maybe described as follow: (a) the influx of more saline and warmer water from the open Ionian sea to the north of cape Pappas that develops a temperature difference (2.5-3 ^{0}C) (mainly in spring, summer autumn) between the northern and southern coasts of Patraikos Gulf. This hydrography is related also to a cyclonic movement of the water, which establishes a core of colder water in the middle of the Patraikos Gulf (this feature is more pronounced in autumn and it disappears when cold waters appear along the northern coast) (Lascaratos et al., 1989), (b) the Bay of Navpaktos is characterized by colder waters (in the order of 0.5-1 ^{o}C) from gulfs located at its both sides; this situation is profound from autumn to spring, whilst it is disturbed during summer due to the occurrence of wind-induced upwelling at its north coast (Lascaratos et al., op.cit.), (c) the western area of the Gulf of Corinth has similar characteristics to the Bay of Nafpaktos, representing with him a transition zone between the larger water bodies of the Gulfs of Patras and Corinth, (d) the Rio – Antirio strait which has a width less than 3 km is characterized by fast flowing currents with maximum speed in the order of 100 cm/s whilst relatively slower currents (<60 cm/s) are referred to Mornos – Drepano passage (Hellenic Hydrographic Service, Pilot, 1984). These currents and primarily those at the Rio-Antirio are associated with the exchange of water masses between the two large water basins (Gulfs of Patras and Corinth). Besides, more recent current measurements at the Rio-Antirio has shown that although the circulation in the area is wind-driven, as winds funneled at an WSW-ENE direction between the mountains of the north and south coast, the tidal flow component is also important; the latter has given tidal velocities, at the Rio, >80 cm/s. In addition, the strong surface tides combined with the bottom step-like topography (between the Gulf of Patras, the Rio sill, the Bay of Nafpaktos (100 m) and the western Gulf of Corinth (>300 m)) favor the generation of internal tidal waves (Drakopoulos & Lascaratos, 1998).

The exchange of water masses through the Rio-Antirio strait, from field measurements (26/6 to 30/7 in 1986) has shown that there is an eastward water movement at Rio, moving Ionian waters towards the Gulf of Corinth throughout the water column, with the exception of the surficial layer (0-~15 m) a few days period when strong easterly winds blew. In contrast, at the north side (Antirio) when the eastward flow was constant below the surface mixed layer, the latter presented an opposite (westward) flow to that observed in Rio. Therefore, it is believed that the major influx of the Ionian Sea water (via the Gulf of Patras) moves above the Rio-Antirio sill at water depths below the surface mixed layer, when waters form the Gulf of Corinth are expected to enter the Gulf of Patras (passing and mixed in Nafpaktos Bay) at the north side (Antirio) and at the surface following.

METHODOLOGY

Data implemented in this work come from two cruises held by R/V Philia during June and December of 1999. This survey included 30 stations within the area under investigation.

The transmissometer used was a C-Star manufactured by WetLabs. It measures the light transmittance at 660 nm wave-length at a path length of 25 cm. The losses of light in this configuration can be attributed to two primary causes: scattering and absorption. Suspended particles, phytoplankton, bacteria and dissolved organic mater all contribute to the losses sensed by the instrument.

In order to quantify the effect of the phytoplankton presence in the measured transmittance a fluorometer was used in tandem. Thus, if absence of correlation is observed between transmittance and fluorescence (phytoplankton concentration) this is an indication that the beam attenuation results mainly from the particulate matter concentration (Dickey 1991).

Although there are no data available concerning the actual concentrations, expressed in mg/l, from the study area, to a first approximation the following relationships between transmittance (%) and of suspended matter (mg/l) is presented in Table 2.

Table 2. The relation between transmittance (%) and concentration of suspended particulate matter (mg/l), after Chronis et al. (2000).

Transmittance (%)	**Αιωρούμενο υλικό (mg/l)**
60	3,6-4,3
70	2,6-3,1
80	1,7-1,8
90	0,6-0,8

These relationships have been deduced from an earlier investigation concerning the northern continental margin of Crete, where the same nephelometric probe was used and its measurements (transmittance %) have been interrelated with measured concentrations of the suspended matter.

RESULTS AND DISCUSSION

Analysis showed that there is no significant correlation between beam attenuation at 660 nm and chlorophyll concentration. This is also evident in the scatter plot of Figure 2 between transmittance and chlorophyll concentration. Therefore, we are confident that the optical attenuation observed is related to suspended particulate matter.

The transmittance in surface waters present similar values varying between 60 and 90% but having their maxima (more clear waters) and minima (more turbid waters) in different geographical areas (Fig. 3); thus, in June the higher values are present in Nafpaktos Bay and in the western part of the Gulf of Corinth when in December they are present at the southeast part of the Gulf of Patras. Besides, the most turbid surface waters in June 1998 (east to 22^0 longitude) are present along the coast of Peloponnessos, possibly related to riverine sediment influx. Especially, in the area of Rio-Antirio strait in June is observed a frontal structure to the east of the strait and within the Nafpaktos Bay where the transmittance varies from 80% (approx. 1,7 mg/l) to 60% (~4 mg/l). In contrast, in December the passage presents a uniform picture

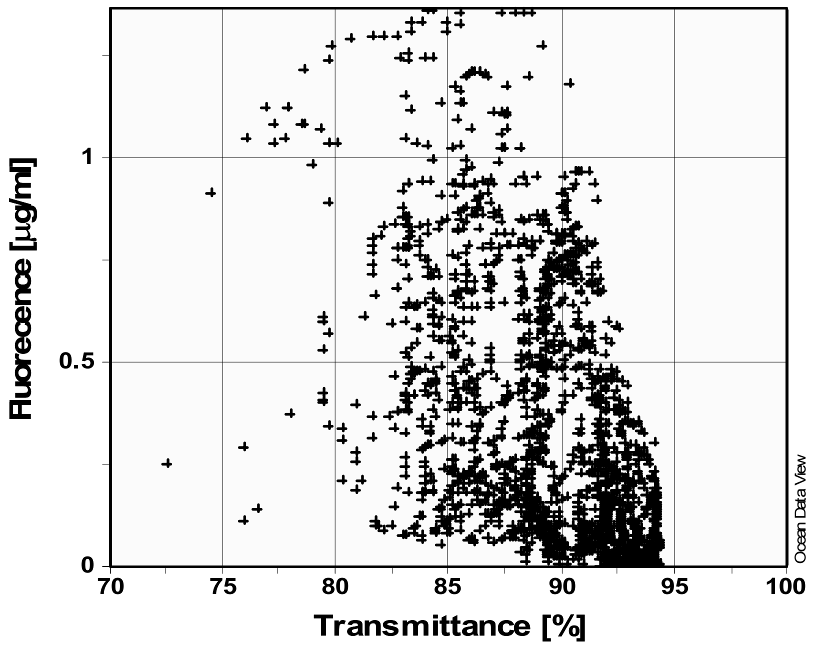

Figure 2. Scaterplot of transmittance versus chlorophyll concentration values

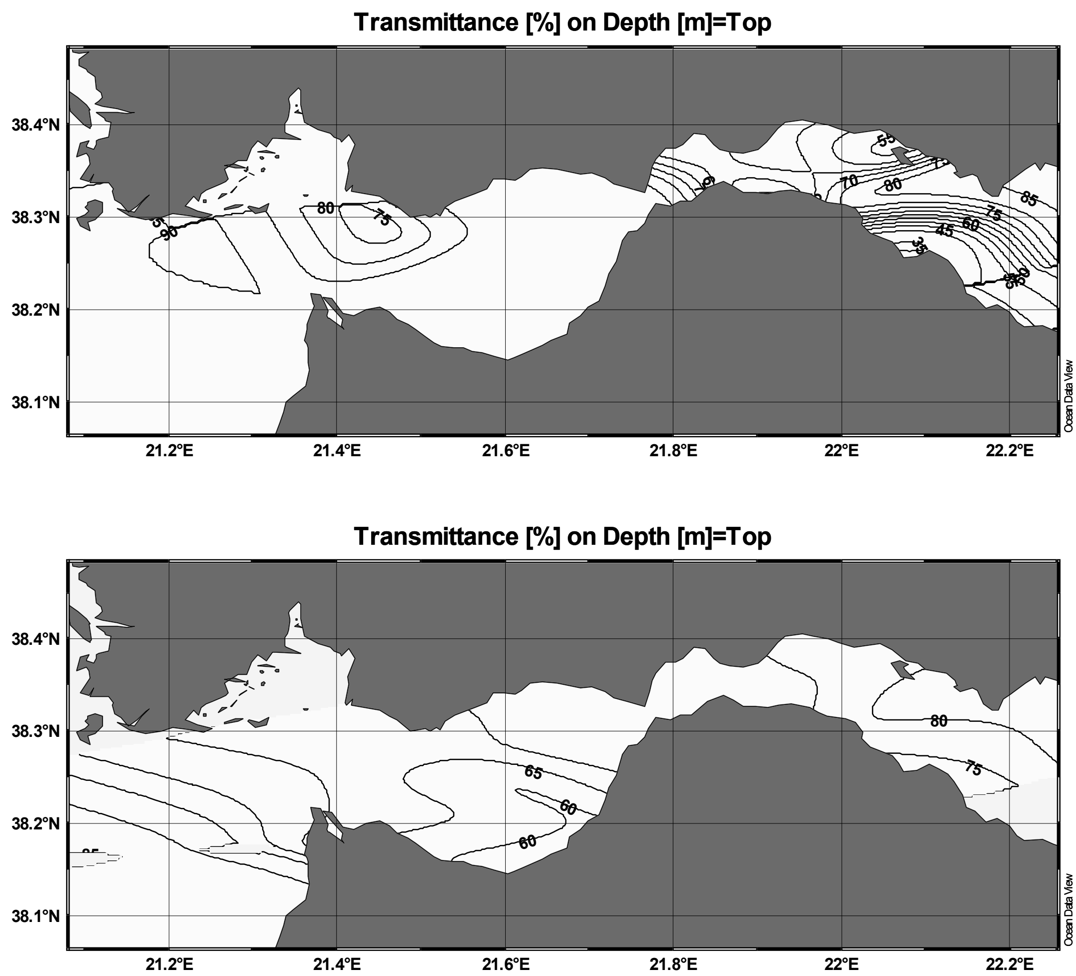

Figure 3. Surface distribution of transmittance (%) in: (a) late spring (June) and (b) late autumn (December).

with values in between 70% and 75%, whilst farther to the west, in the Gulf of Patras the more turbid waters are present to the south; this is possibly related to the combined effect of the cyclonic circulation within the Gulf and the increased sediment influx from the torrents (e.g. Pirros, Glaukos) discharge at its southern coast. In June (late spring) the Gulf of Patras is rather clear (trans. ~85%) and homogenous having slightly smaller value (77-80%) in the area in front of R. Evinos, indicating the occurrence of rainfall that is best expressed from the no-dammed ephemeral rivers and torrents of the Peloponessos.

The transmittance values near the sea bed present an inverse picture to that of the surficial waters with the highest values, as expected, to belong to the late spring period (80-90%) and the lowest (60-75%) in late autumn, as they have been developed during the beginning of the rain period when the rivers and streams have their maximum sediment fluxes. Furthermore, the cyclonic type of circulation and the increased occurrence of reduced values of transmittance at the SE part of The Gulf of Patras seem to be present during both seasons near the bed. Similarly, the frontal structure within the Nafpaktos Bay is present as well, but more pronounced in December.

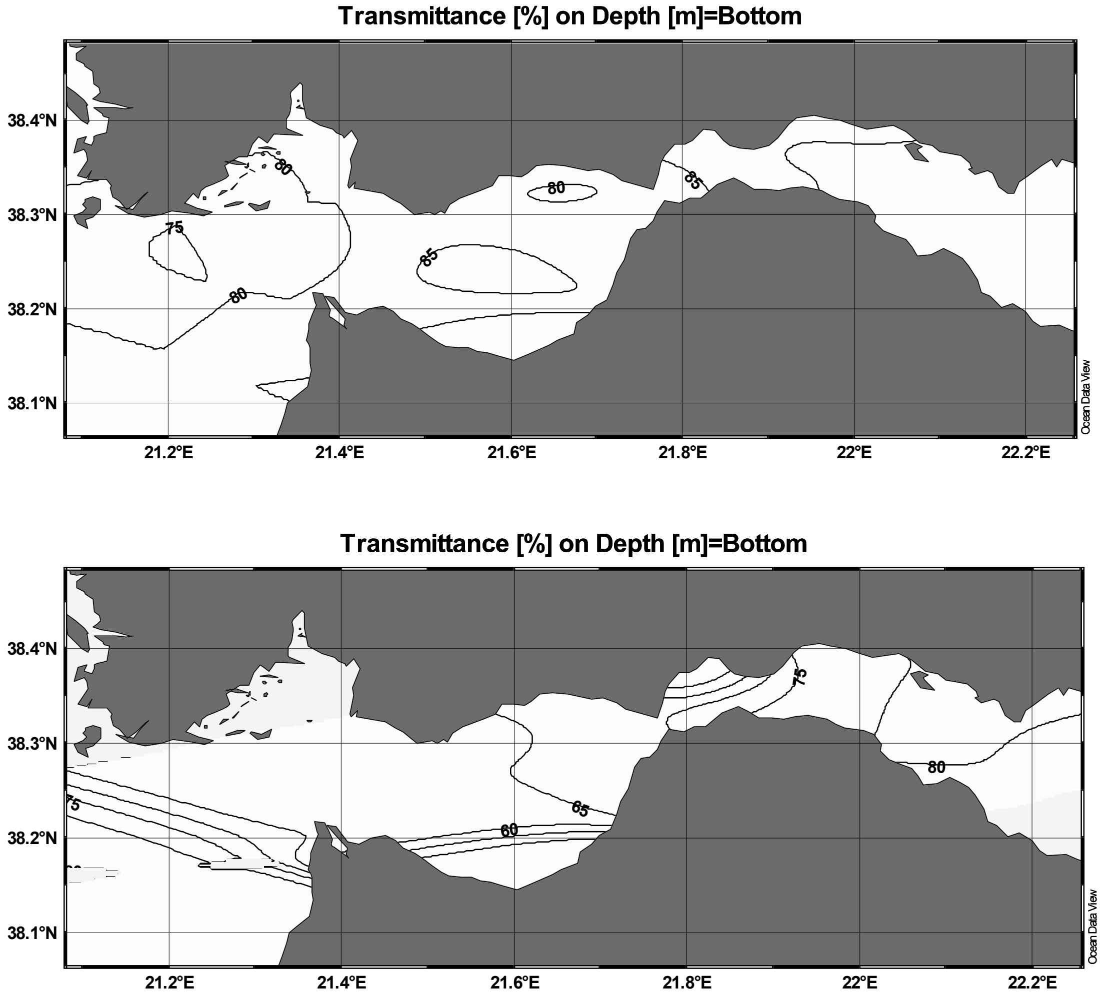

Figure 4. Nearbed distribution of transmittance (%) in: (a) late spring (June) and (b) late autumn (December).

Along the cross section, presented in Figure 5, it is shown that in late spring the transmittance increases with depth having similar values near the sea bed (>90%), whilst at surface there is a development of a thin layer with smaller values (70-80%) that is located within and to west of the Nafpaktos Bay. The increased concentration of suspended matter (1,7-3 mg/l) in this area maybe attributed to R. Mornos which is assisted by the smaller torrents that discharge along the Peloponnesian coast. From the configuration of the isopleths we can also deduce the presence of two water masses. The western mass, occupying the Gulf of Patras and the Nafpaktos Bay is extended eastward to the Gulf of Corinth, where a wedge-type of circulation seems to have been formed (with the waters from the Gulf of Corinth to overlay the incoming waters from the Gulf of Patras (basically representing Ionian Waters).

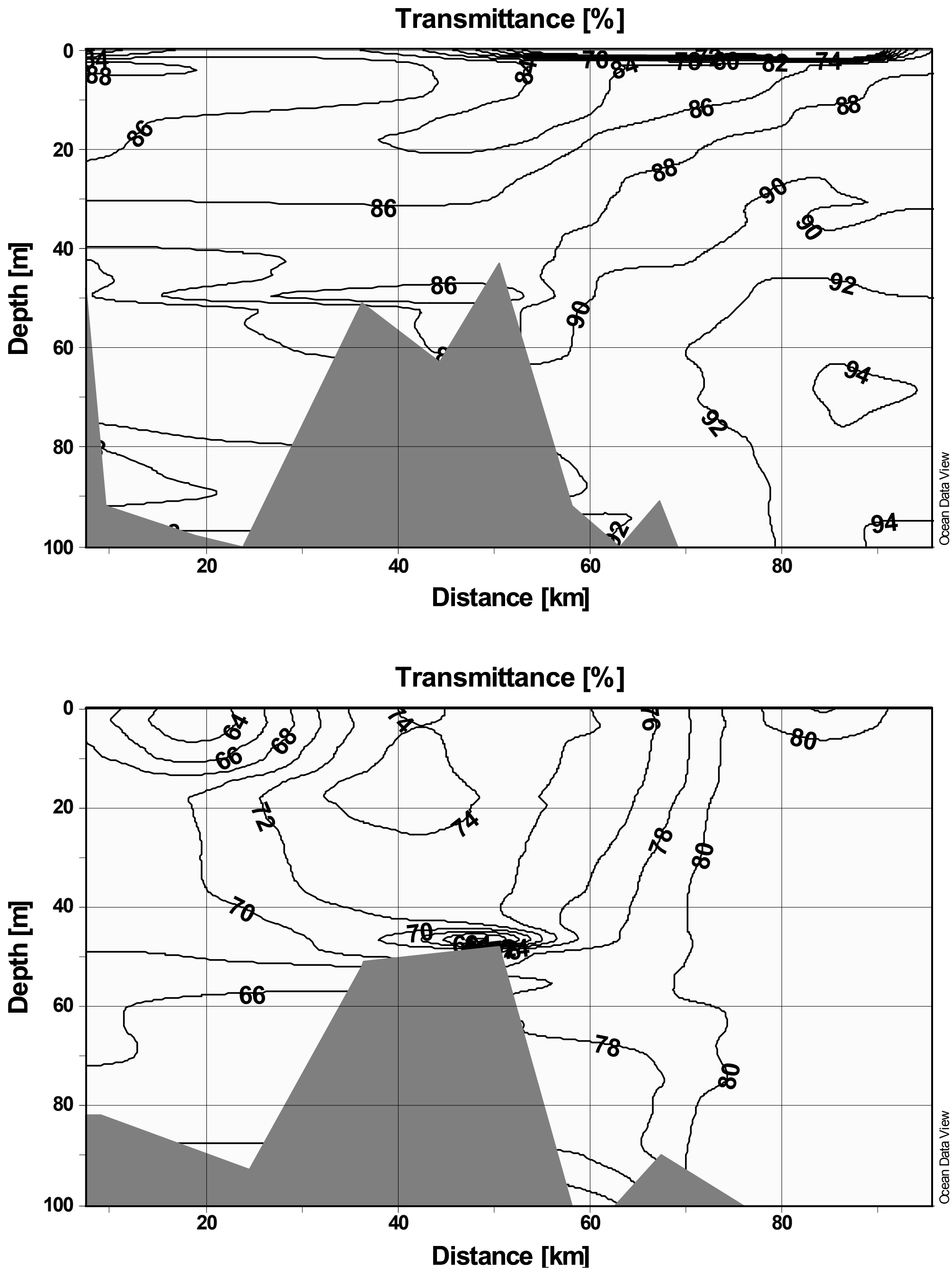

Figure 5. The vertical distribution of the transmittance qlong the Rio-Antirio passage (including Gulf of Patras, Nafpaktos Bay and western Gulf of Corinth).

During the following autumn, a frontal-type of circulation had been developed with the front being present to the west of Nafpaktos Bay, as indicated by the almost vertical alignment of the transmittance-isopleths. In general, the values are smaller (higher concentration of suspended matter) that is attributed to riverine sediment fluxes that reach their maximum following the maximum values of water discharge during autumn (Therianos, 1974). Another interesting characteristic is the uniformity of the Gulf of Corinth waters, in contrast to the layered-type hydrography within the Gulf of Patras, where the higher values (<70%) are present near both the surface and the seabed. The surface increased values of suspended matter is possibly related to the presence of R. Evinos and the water exchange with the Messologi lagoon, whilst the near bed increase values maybe related to the near bed current activity that either re-suspends the fine-grained material and/or inhibits the final deposition of the suspensates. The action of the near bed activity is rather obvious at the western limit of the Bay of Nafpaktos (offshore to C. Drepano) where it has been developed a near bed nepheloid layer <5m in thickness and having concentrations >3,5 mg/l (<70% transmittance).

CONCLUSIONS

The distribution of particulate matter in the water bodies at either side of the Rio-Antirio strait, as deduced by the transmittance values, shows that is influenced by the river influx (higher in autumn), the overall hydrography of the area that induces the exchange of the Ionian Sea and Gulf of Corinth water masses and the associated current activity. In general, the Corinth waters are more turbid than the Ionian ones (by 2-3 mg/l) with the exchange to take place mainly within the Nafpaktos Bay, where a front is developed. The Rio-Antirio strait is occupied basically by waters coming from the Gulf of Patras and only at the Antirio side there is evidence of an outflow of more turbid waters towards the Gulf of Patras that are subsequently incorporated in the cyclonic circulation of the Gulf. Besides, in both seasons the most turbid waters are observed at the southeastern part of the Gulf of Patras, possibly being the result of the cyclonic circulation and the local influx of terrigenous material.

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