COASTAL CURRENTS AND SEDIMENT TRANSPORT IN PARANAGUA ESTUARY COMPLEX NAVIGATION CHANNEL

CORRENTES COSTEIRAS E TRANSPORTE DE SEDIMENTOS NOS CANAIS DE NAVEGAÇÃO DO ESTUÁRIO DA BAÍA DE PARANAGUÁ

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ABSTRACT

The coastal currents variability and ability to carry sediment by bed load transport at the external area of the navigation channel of Paranaguá's estuary complex were analyzed from data obtained from two type L moorings located about 3.5 km from the coast, taken between 4/16/1997 and 6/17/1997. The local dynamics, as well as the bottom transport of sandy sediments are ruled mainly by tidal currents which work mostly perpendicular and outward from the coast. However, in a high energy situation associated to increased ocean wave energy, the parallel component to the coast gains prominence in the residual circulation, enhancing the sediment transport towards and along the coast.

Key words: coastal process; tidal currents; longshore currents; paranaguá; channel navigation.

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RESUMO

A variabilidade das correntes costeiras e a capacidade dessas correntes em transportar sedimentos por tração foram analisadas, na área externa do canal de acesso marítimo do Complexo Estuarino de Paranaguá, a partir de dados de dois fundeios do tipo L, localizados a aproximadamente 3,5 km da costa, e realizados entre os dias 16/04/97 e 17/06/97. A dinâmica local, bem como o transporte dos sedimentos arenosos do fundo, é governada principalmente pelas correntes de maré, as quais agem preferencialmente transversalmente à costa e no sentido costa afora. Contudo, em situações de elevada energia, associadas à maior agitação do mar, a componente longitudinal à costa ganha importância na circulação residual, intensificando o transporte de sedimentos em direção e ao longo da costa.

Palavras-chave: Processos Costeiros; Correntes de Maré; Correntes de Deriva; Paranaguá; Canal de Navegação.

INTRODUCTION

The coastal area, where rivers and estuaries meet the ocean and tides are usually called outlet. Outlets are complex and dynamic environments, usually shaped by gradients of ebb and flood tides, bars, tidal channels and tidal creeks. Constantly under the influence of countless forcing, their balance determines the outlet configuration. Among the main forcing are the waves and tidal currents and the discharge of fresh water, as well as winds. The surface waves normally play an erosive role, selecting and redistributing sediments and reshaping bars and beaches. Tidal currents exert force mostly over the transport by traction of the bottom sediments. (Trenhaile 1997).

In the outlet's tidal channels, the tidal currents are dominant and present a bi-directional pattern more often perpendicular to the coast line. The further the costal currents get from de outlet, the greater is their effect over tidal currents. These coastal currents tend to go along with the coast line and are generated mostly by the waves' incidence angle to the shore.

In the study of tidal channels and estuaries, the researcher must be aware of the parallel and perpendicular velocity components in relation to the direction of the estuary or channel's main axis. This is best achieved by the decomposition of the velocity vector (Miranda *et al.* 2002). In the particular case of the Paranaguá Estuarine Complex (PEC) outlet, there is a deep tidal channel bordered by shallow areas of sand banks. This channel has a SE-NW axis (orientation 130º N), which is perpendicular to the general orientation of the coast line in the area. This situation allows the analysis of the parallel tidal component as a tidal current, and its perpendicular component as a coastal current. From this understanding it is possible to estimate the role of these currents in the sediments transport.

At the Paraná's coast, it is known that the coastal circulation associated to the sediments transport is related to beach erosion and the filling of the navigation channel that leads to the Paranaguá Port (Angulo 1993; Soares *et al.* 1994). Although some studies have pointed these relations, there are no studies to assess the sources of energy, the related frequencies and extent of that entering into the system, providing the means of instability and alteration. Neither are there studies to demonstrate the probable space-temporal scales of these energies sources and their results.

OBJECTIVE

It is the aim of this study to characterize the coastal currents in the external area of the Paranaguá Estuary Complex (PEC) and evaluate these currents capability to transport sediment by traction.

MATERIAL AND METHODS

Currents data acquisition

The analyzed data were obtained through the APPA-CEM agreement (Paranaguá and Antonina Port Administration – Center for Marine Studies) and are the result of two moorings set between 4/16/1997 and 6/17/1997. These were type L moorings, using the pair of surface traffic buoys (3-4) in the Paranaguá Port access channel, located about a 3,5 km off from Galheta Island (Figure 1). Four electromagnetic S4 InterOcean Systems Inc. model current meter were used, a couple of which for each surface buoy, the first to reading bottom currents (11 m depth) and the second pair reading surface currents in 7 m depth (Figure 2). The data were recorded every 90 minutes and each record is the result of the average reading obtained from a 3 minute long reading at 2 Hz sampling rate. The current meter placed at the bottom of the surface buoy on the south rim of the channel did not present data due to a malfunction.

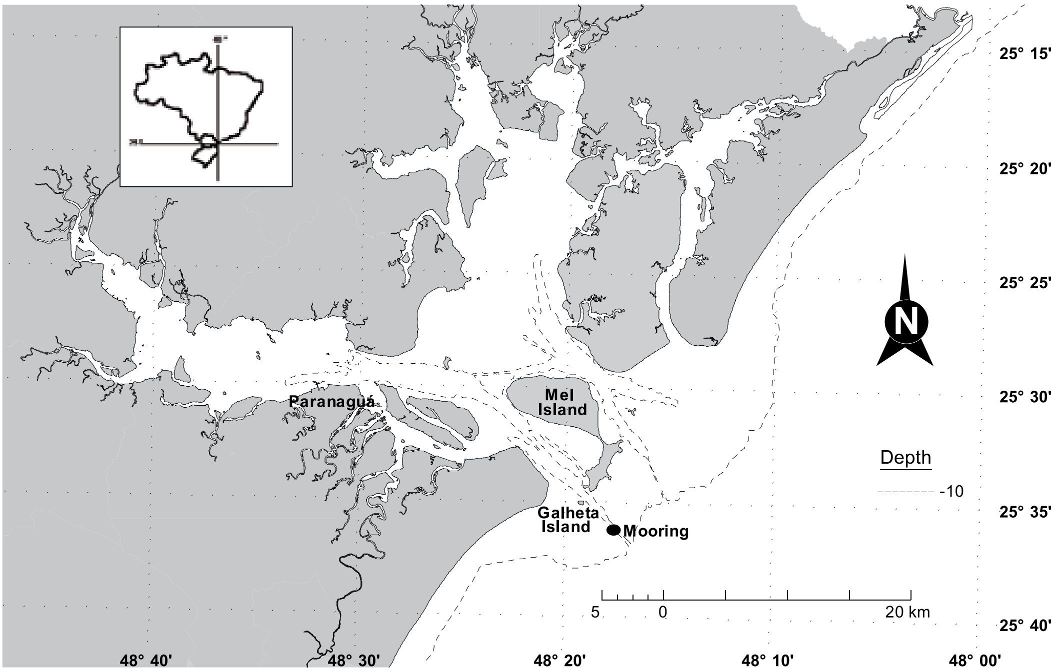

Figure 1 - Paranaguá Estuary Complex

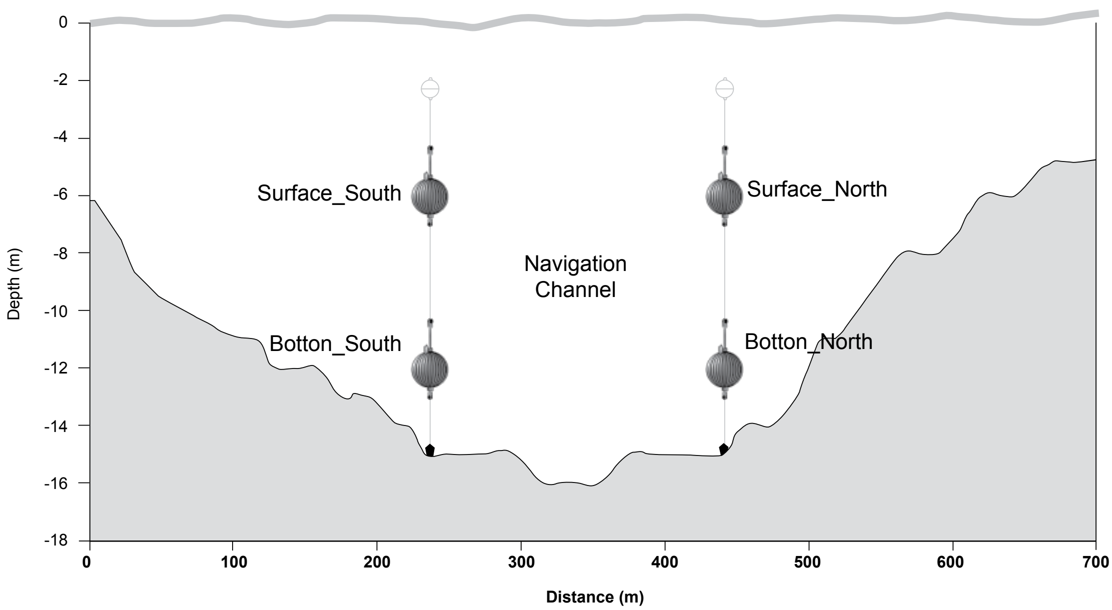

Figure 2 - Mooring position

Assessment of the sediment transport by traction

To assess the sediment transport by traction, the threshold of sediment displacement (µ*) was estimated, this assessment takes into consideration some characteristics and conditions of the fluid and those of the sediment, to indicate the requested velocity to trigger the displacement of the non-cohesive bottom sediments. The sediment displacement threshold was calculated through the graphic method suggested by Yalin (1972). This laboratory method takes into account the density of the sediment, the density of the fluid, the kinematic viscosity of the fluid, the acceleration of the gravity, the average sediment diameter and the shear velocity.

The shear velocity is the speed next to the sediment particles, calculated with the Karman – Prandtl (Yang, 1986) logarithmic equation,

$$\mu(z) = (\mu^*/k)\ln(Z/Z_o) \qquad (1)$$

Which uses the current speed (µ(z)), the current depth measurement (Z), the Von Karmam constant (k=0,4) and a non-dimensional bottom roughness factor (Zo), which is a function of the wave length of the bottom ripples/ sand waves and their heights. Due to the lack of data to establish the bottom roughness factor, a pre-determined factor for a rippled bottom was used (ripples) (Trenhaile 1997), considering that the configuration of the bottom at the mooring is of fine sand ripples (Angulo 1999).

It is accepted in this work that, like most of the empiric developed equations, the Equation (1) is neither ideal nor applicable for every case, suffering applicability restrictions in the "real world". Nevertheless, the use of the Karman – Prandtl equation in countless environments and distinct situations has been of great use, being a good method to obtain, in a first approximation, the order of magnitude of the acting forces and their potential to displace sediments. It is with this understanding that the following results will be presented.

RESULTS AND DISCUSSION

Current measurement in the PEC navigation channel

The period for the current measurement can be determined by two very distinct situations: first, warmer months, with water temperatures between 24ºC and 25ºC in April until mid May. Second, a colder season that features the entrance of frontal systems from the South lowering the water temperature down to 21ºC and colder, after the second half of May (Figure 3).

The analysis of the current vectors throughout two lunar months (Figure 4), shows that the direction of the ebb and flood current go along with the PEC navigation channel orientation, SE-NW (orientation 130o N). However, there is an ebb current detour to East, with respect to the channel orientation, of about 10o.

The ebb currents are stronger than flood currents, as much on the surface as on the bottom, and present lesser direction variation and a more consistent pattern. The current variation, relative to a complete tidal cycle between high and low tides, generally occurs with a northward orientation (Figure 5)

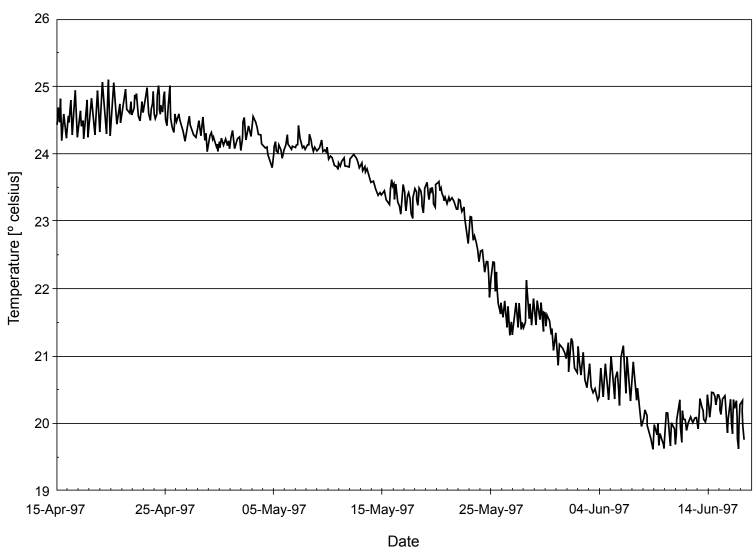

Figure 3 - Water temperature variation in the Paranagua estuary complex (Pec) navigation channel

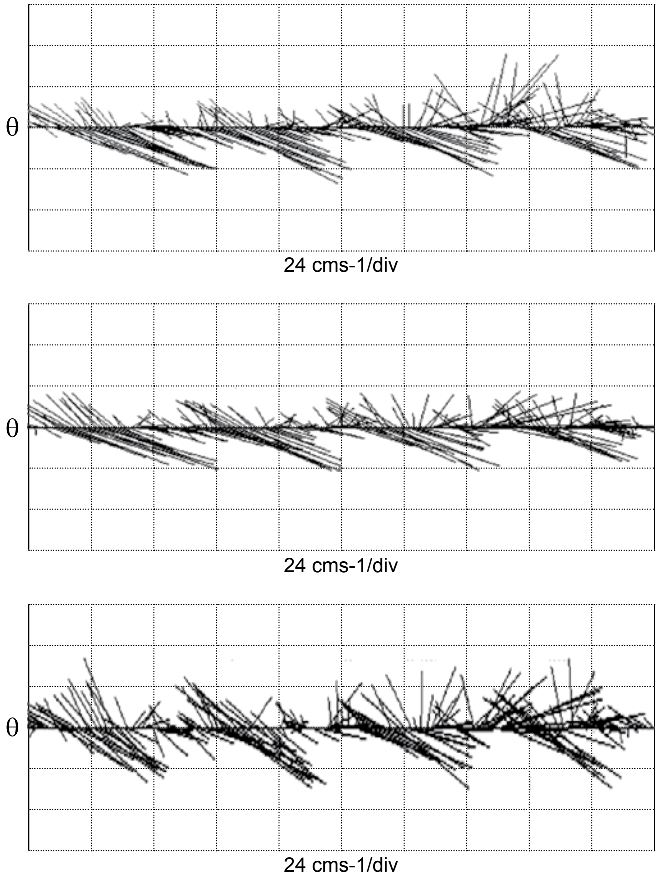

Figure 4 - Current vector variation in the Paranagua estuary complex (Pec) navigation channel between 04/16/1997 And 06/17/1997

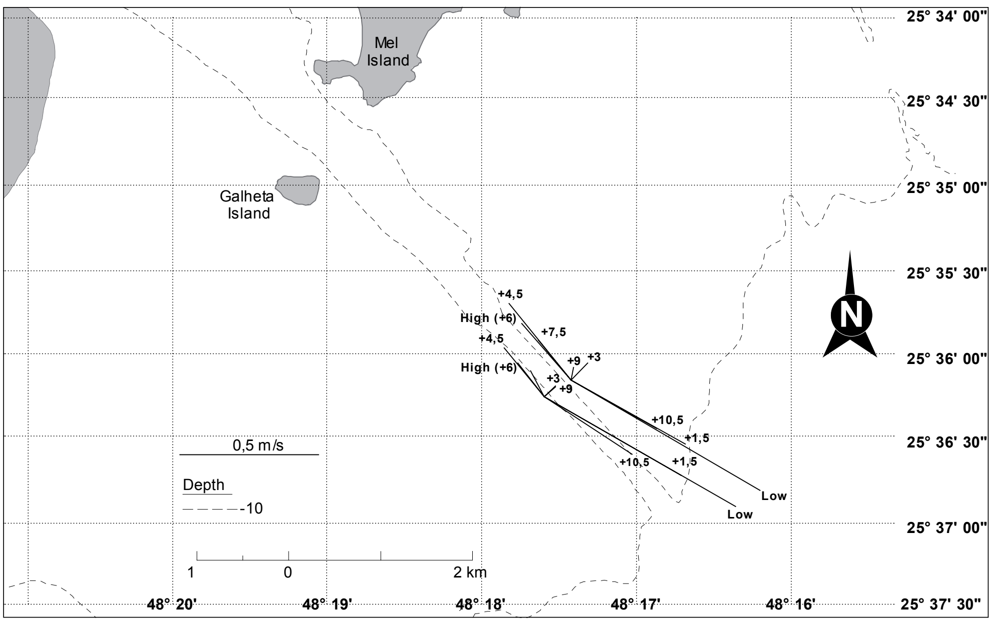

Figure 5 - Tidal current variation in the course of a spring tide cicle

The theorical displacement of a suspended particle undergoes during the mooring period, in conformity to the so called progressive vector, occurs in the SE direction for the data obtained by the equipment moored on the South side of the navigation channel, meanwhile for the data obtained on the channel's North side, the displacement is eastward (Figure 6).

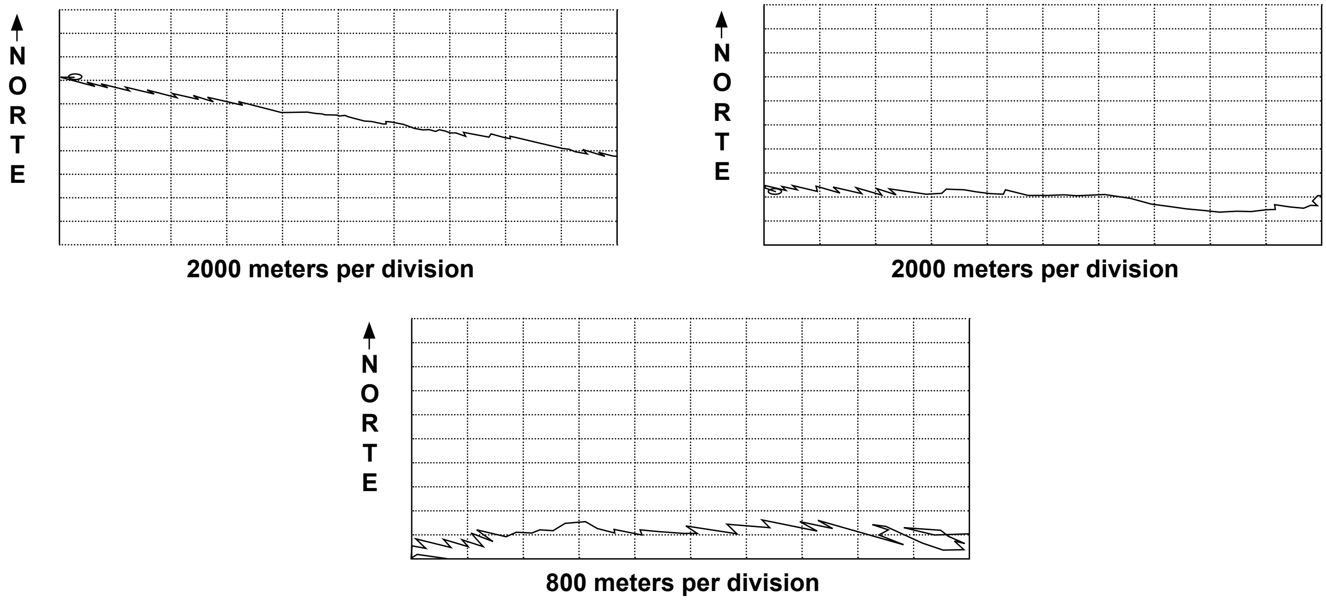

Figure 6 - Progressive vector in the Paranagua estuary complex navigation channel between 0416/1997 and 06/17/1997

It is known that for such displacement to be considered really ideal, the current field should be kept homogeneous all over the study area during the observation period, which is not the real case. Nevertheless, this method is effective and widely used to assess the particles potential trajectory, mainly for comparative purposes such as in this case. Therefore, the difference between both channel's margins can be related to the SE-NW orientation of the CEP navigation channel and in relation to its role as a hydraulic breakwater, working as a type of barrier to the coastal parallel fluxes. These factors will contribute to the fact that the South side currents are slightly weaker than those on the north side. Therefore, progressive vector are displaced in the SE direction at the South side (Figure 6a).

Sediment transport by tidal and longshore currents

To assess the relative importance of perpendicular coastal currents, the velocity vectors were decomposed in the NW-SE direction (Figures 7a and 7c), and for the longshore current the velocity vectors were decomposed in the SW-NE direction (Figures 7b and 7d). Figure 7 also represents the sediment displacement threshold (μ^*=20,4 cm/s), demonstrating the intensity of current which is needed for the occurrence of bottom sediment transport by traction.

It is more often that the current velocities exceed the threshold for bottom sediment displacement during the spring tide than during a neap tide, even though there are displacements of sediments by traction along many neap tides. During ebb tide episodes (SE component), shown by positive values, the displacement threshold was easily exceeded. During the event of neap tide floods, however, the displacement threshold is not reached; nevertheless, the displacement threshold can be surpassed during the ebb tide.

The analyses of the SW-NE components related to coastal parallel currents (Figures 7b and 7d), shows that these currents are mainly Northeast oriented, due to the higher NE components values (positive values). This comes to confirm the longshore current tendency to Northeast (NE), as previously shown by Lana *et al.* (2002) and Angulo (1999).

The effects of the sea state on sediment transport

It is noticeable that the longshore currents capability to trigger bottom sediment movements occurs in few cases. However, comparing situations when the threshold of agitation was reached with the occurrence of high wave energy episodes accordingly to warnings issued by the weather forecast bulletins from DHN (Hidrography and Navigation Council) (Figures 7b and 7d), a clear relation between the increase of wave energy is observed, usually related to the arrival of frontal systems and sediment transport along the coast. For the purposes of this study, waves of a minimum of 4m high in the Bravo/Charlie areas (Santa Marta Cape to Cabo Frio) were considered episodes of high wave energy.

By the end of May, the appearance of strong currents parallel to the coast is verified, associated with the great energy of waves entering in the coastal zone (Figures 7b and 7c). During these phenomena, an intensification of the flood currents is noticeable on the South side of the channel; the same is not seen on the North side. This may indicate that the increase in wave energy also results in an increase of sediment transport towards the coast and into the PEC navigation channel, since the dominant flux, due to the tidal pumping, is confined at the navigation channel and tends to act as an hydraulic breakwater, trapping the sediments coming from SW.

At the points where the currents were measured, the analyses allows to assume that the bottom sediment transport, perpendicular to the coast line, occurs as much as in direction into the PEC as much as outward to the open ocean, the latter being more intense. The transport of bottom sediments perpendicular to the coast line is independent of the tides and it is associated with the increase of the wave energy.

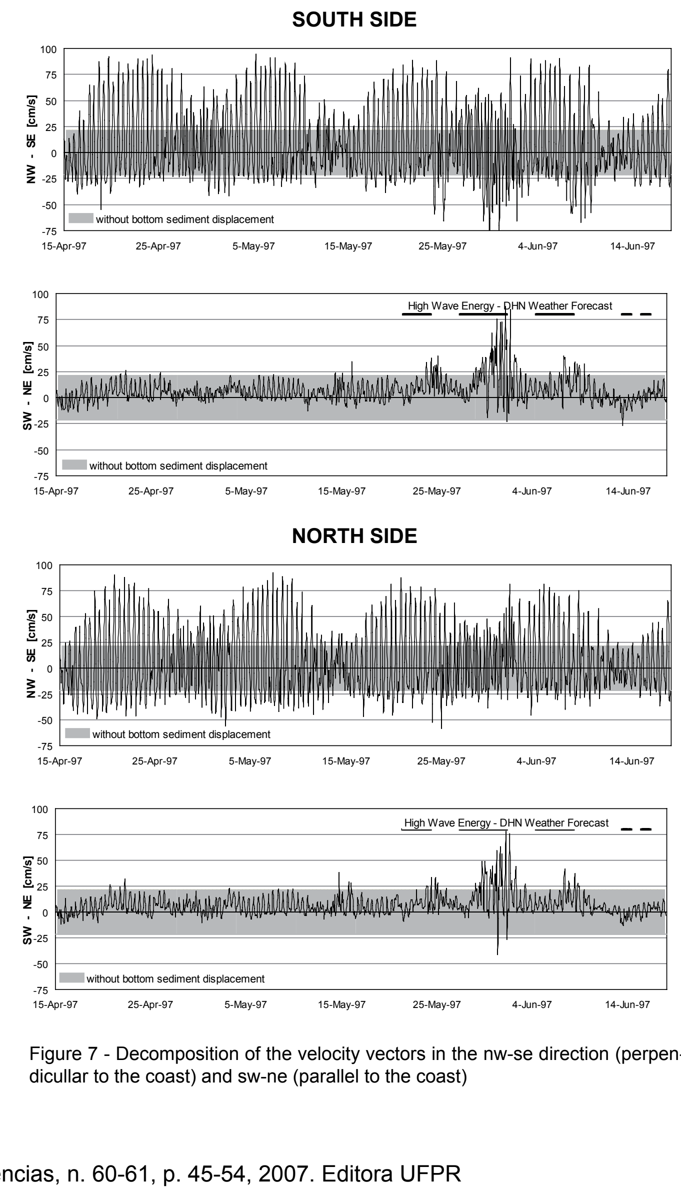

Figure 7 - Decomposition of the velocity vectors in the nw-se direction (perpendicullar to the coast) and sw-ne (parallel to the coast)

Residual Currents

When considering the factors that may affect the sediment transport processes, a great distinction between the calm sea state situation and those of high energy waves is that both must be independently analyzed. Leaving that aside, the residual currents were estimated for both conditions (Table 1). For the mean conditions during calm periods, the current velocity is under 10 cm/s for the North as well as for the South side of the channel being the resulting direction almost parallel to the coast line (Figure 8). For the high wave energy conditions, the residual currents were obtained during the longest period on which this condition prevailed, during 6 days at the end of May. The velocity of the residual currents in high wave energy episodes is faster than 20 cm/s on the surface, however the biggest relative increase with respect to calm conditions had happen with the bottom currents. This observation is a meaningful evidence of the local dynamic, considering that bottom currents are more important for the transport of sediments re-suspended by waves. Also, the residual currents direction suffered strong variation when compared to the calm condition, becoming oblique oriented to the coast line (Figure 8).

Table 1 - Residual currents figures for normal sea agitation and for high seas

Calm/Mean Wave Energy Condition (04/16//97 – 06/17/97)				
	Residual Components		Residual Vector	
	NE-SW (cm/s)	NE-SW (cm/s)	Direction (degrees)	Velocity (cm/s)
Surface_South	6,78	6,33	43,04	9,28
Surface_North	6,71	5,02	36,82	8,38
Bottom_North	4,38	1,85	22,84	4,76
High Wave Energy Condition (05/29/97 – 06/03/97)				
	Residual Components		Residual Vector	
	NE-SW (cm/s)	NW-SE (cm/s)	Direction (degrees)	Velocity (cm/s)
Surface_South	20,60	-2,22	353,84	20,72
Surface_North	19,89	8,60	23,38	21,67
Bottom_North	17,30	5,63	18,03	18,20

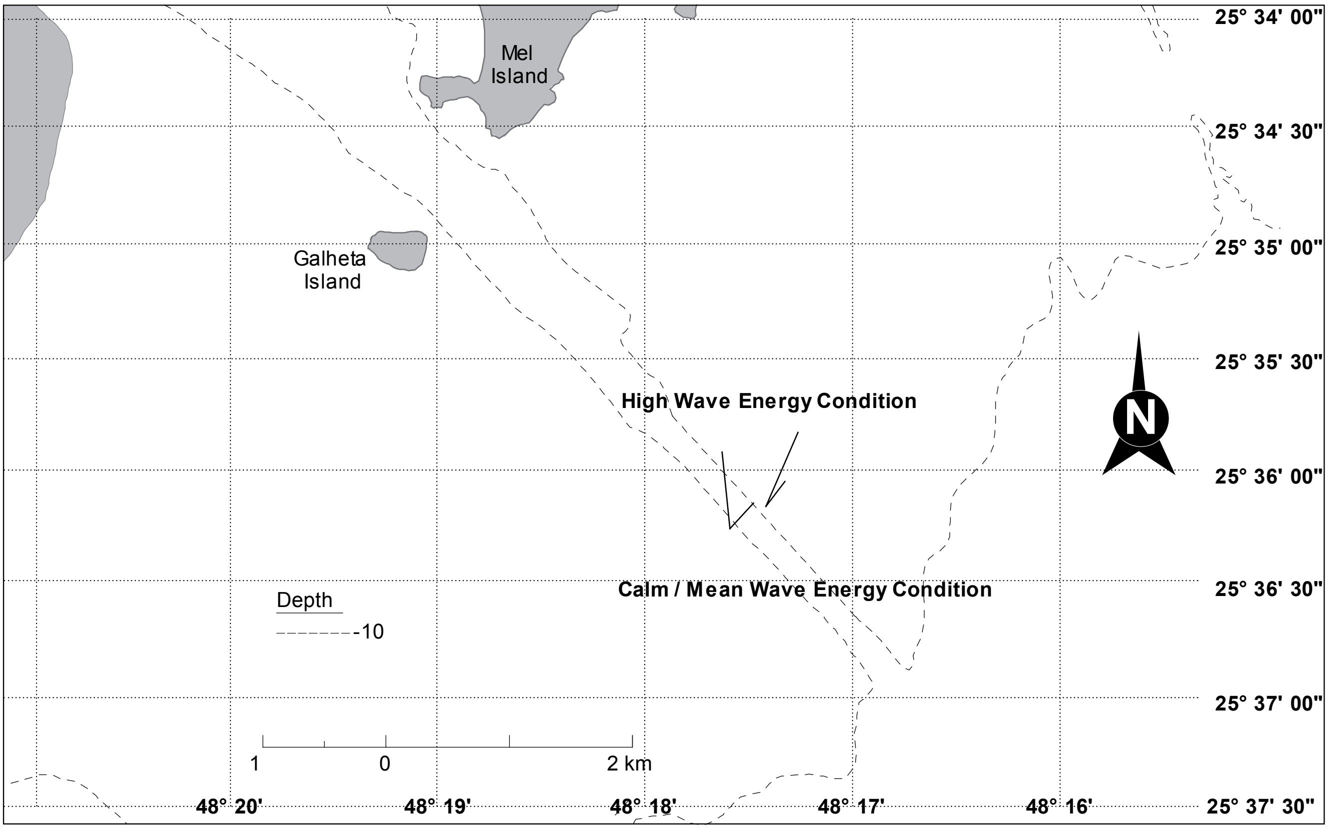

Figure 8 - Resultant vectors showing the residual currents for calm waters and for high wave energy conditions

CONCLUSION

The current direction in the couple of surface traffic buoys 3 and 4 go along with the orientation of the PEC navigation channel, SE-NW, with a slight detour to East during ebb currents. These currents are stronger than flood currents, in both the surface and the bottom and show lesser variation in their directions.

The presence of a deeper channel in the outlet area, acts as a hydraulic breakwater, impacting local circulation and currents along the coast. This barrier also acts over the sediment transport, promoting sediment deposition into the channel.

The spring tide ebb and flood currents have enough energy to trigger displacement of bottom fine sand sediment by traction.

During the neap tides, the phenomena will be less common, being more frequent during ebb tides. Therefore, the balance of the sediment transport by tide is seaward. However, in a high wave energy situation, the displacement is landward and into the PEC navigation channel.

The alongshore currents are mainly Northward. The capability of these currents to trigger bottom sediment displacement is related to high wave energy events that usually occur along with the arrival of frontal systems from the South. Therefore the transport of bottom sediments by traction is independent of the tide and mainly northward.

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