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HYDROGRAPHY OF THE INNER SHELF OFFSHORE BAHÍA BLANCA ESTUARY, ARGENTINA

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ABSTRACT

In this paper a quantitative description of the hydrographic regime in the inner shelf offshore Bahía Blanca and Colorado River estuaries based on temperature, salinity, suspended matter and current velocity data is described. Both estuaries contribute in different ways to the physical characteristics of the environment. The Colorado River estuary is the major source of freshwater into the El Rincón area, whereas the Bahía Blanca estuary is a source of relatively warm and salty water. Accordingly, the influence of both estuaries in the distribution of the water properties is observed.

It is the first time the influence of the discharge of the Colorado River into the inner shelf was quantified. The processes involved at the Bahía Blanca Estuary are different from the typical estuary pattern. Exchange processes between estuaries and embayments with offshore waters are seldom analyzed in detail, especially in relation to the circulation of the inner shelves. With the information obtained by two currentmeters two regimes are identified, one associated with the estuarine waters and one with the coastal waters.

By means of statistical analysis (PCA), the importance of two measured parameters (salinity and suspended matter) has been determined in the study zone: a nearshore zone affected by estuarine discharge, and an offshore zone mixed by strong storm winds.

A comparison on the wind power needed to destroy stratification in the water measured in South Atlantic Bight with the results here obtained, demonstrate that in El Rincón area the wind power is much higher during "sudestadas", typical storm events in the region.

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INTRODUCTION

The study of coastal oceans and estuaries is important because through them, materials are exchanged between oceans and continents. From a geophysical fluid dynamics perspective, estuarine and

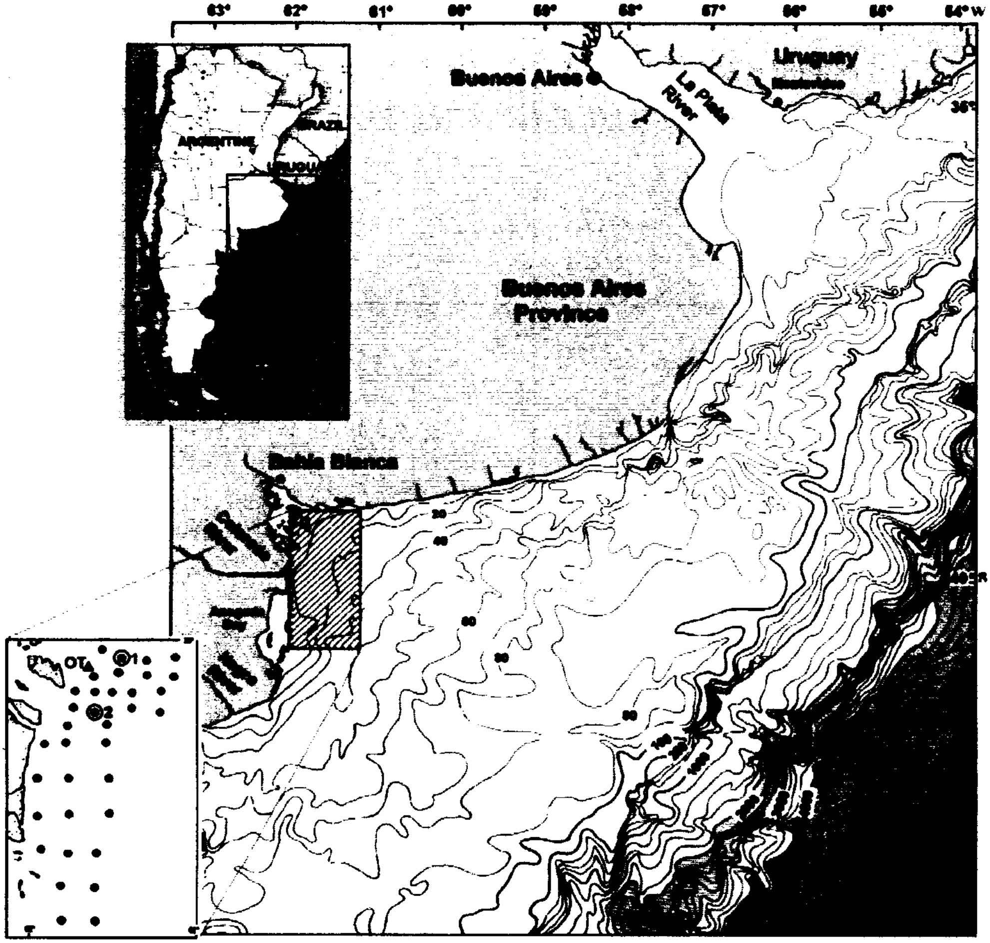

Figure 1. *Location of the study area. Station 1 and 2 are the currentmeter positions. OT corresponds to an Oceanographic Tower.*

coastal waters present a rich array of challenging phenomena due to the extreme ranges of density stratification and topographic variations encountered. The enormous variation in continental shelves waters are partly explained by the passage of atmospheric weather systems. River runoff, meandering boundary currents and synoptic/mesoscale eddies of the open ocean that impinge upon the continental margins entraining waters from the coastal oceans are also major variability sources (Piccolo, 1998). Within this regional framework, exchange processes between estuaries and embayments with offshore waters, although of vital importance, are seldom analyzed in detail, especially in relation to the circulation of the inner shelves.

The patterns and rates of bottom sediment transport on the continental shelf are virtually unknown, although the subject field of inquiry is becoming increasingly active. Some examples of these studies consider the influence of the estuarine flows or plumes in coastal seas (Stanley and Swift, 1976; Garvine, 1975; Simpson and James, 1986; Holloway, 1996).

As estuaries and rivers discharge on the inner shelf, the general circulation based on gravitational, wind and tide induced mass transport is disturbed by the input of normally less dense water that is forced by the ebb-oriented residual currents. In contrast, inner shelf waters are forced into estuaries producing a recirculating process in which not only river-born water enters the shelf but also its own shelf water is returned partially diluted after a certain residence time. In regions such as the Argentine shelf, quantification of this type of exchange is very difficult because of lack of information. On the other hand, it is important to consider the influence of storms since strong winds may mix the whole water column (Atkinson and Blanton, 1986).

The Argentine Continental Shelf (ACS) is one of the largest and flattest in the world. Parker *et al.* (1997) gave a general review of what is presently known about its geomorphology and sedimentology. These authors point out the lack of basic information in most areas of the ACS, although the inner shelf offshore Buenos Aires Province may be considered an exception.

In general, they consider a set of four major terraces along the shelf as the main feature of the ACS. The terraces are found at 25-30 m, 85-95 m, 110-120 m and 130-150 m, but have notable differences in plan view development. There is not enough information about their origin, but they may be associated to the sea-level stand stills related to the Pleistocene glaciations.

The uppermost terrace is observed along the Buenos Aires Province coastal area from the Negro River and continues northward across the La Plata River into Uruguay and the southern coast of Brazil (Parker *et al.*, 1997). On top of this terrace a series of well developed shoreface-connected linear shoals have been described by Parker and Perillo (1977), Parker *et al.* (1978; 1982) and Gómez and Perillo (1992). Although these ridges may have a strong influence on the circulation of the inner shelf, there is not enough data to quantify it. Swift *et al.* (1977) in comparing linear shoals from the Americas and Europe believe that a possible formation mechanism for these bedforms may be related to major storm activities that develop strong hellicoidal flows combined with a shore retreat process.

Geomorphologically, the region offshore the Southeast Buenos Aires province (between 38° and 42° S) is one of the smoothest of the ACS with bottom gradients close to 1:10000 (Lonardi and Ewing, 1971). Isobaths follow a NE-SW orientation. Based on geomorphological criteria, the shelf was divided in three regions. The coastal region or inner shelf limited by the 20 m isobath; the middle shelf between the 20 and 80 m isobath and the outer shelf that extends as far as the shelf breaks. Tidal currents, river inflow and winds dominate the inner shelf dynamics while the middle shelf, which is controlled by winds, interacts with both the inner and the outer shelf. Obviously, the Malvinas and Brazil currents govern the outer shelf. Recently, Guerrero and Piola (1997) and Piola and Rivas (1997) have described the general hydrography and circulation of the ACS.

A detailed analysis of a sector of the ACS between 38° and 42° S which took more than 23 years (1957 - 1980) of data gathered within the area was made by Martos and Piccolo (1988). The analysis included the study area known as El Rincón, between Bahía Blanca Estuary and Anegada Bay (Fig. 1). They further concluded that coastal waters, landward of the 40 m isobath, are generally homogeneous and they did not find any horizontal or vertical gradients of temperature and salinity in the shelf waters.

There was little information about the physical parameters or current structure offshore the second largest estuary of the Argentine coast, the Bahía Blanca Estuary. Previous surveys had normally been performed up to the 10 m isobath. Therefore, the goal of this paper is to present a quantitative description of the hydrographic regime offshore Bahía Blanca Estuary based on temperature, salinity, suspended matter and current velocity data. The main hypothesis is that significant variations in time and space are present in the inner shelf, not only because of the presence of the Bahía Blanca Estuary but also the influence of the Colorado River discharge in the study zone.

The study area (Fig. 1) involves the external part of the Bahía Blanca Estuary in the north, and the mouth of the Colorado River in the west. The Bahía Blanca estuary is a mesotidal one formed by a system of northwest to southeast channels separated by

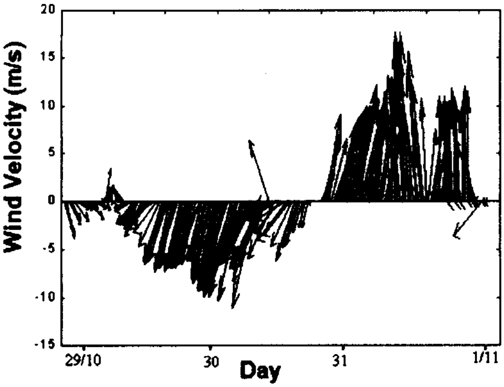

Figure 2.
Wind velocity and direction recorded at the Oceanographic Tower from October 29 to November 1. The direction is in the meteorological convention.

islands and wide tidal flats and salt marshes. There are two small rivers that provide most of the freshwater inflow. Other creeks reach the estuary only during periods of local precipitation. The annual mean runoff is around 3 m^3s^{-1}, but peaks of up to 100 m^3s^{-1} have been described (Piccolo and Perillo, 1990). In this work the authors also show the difference between the inner and outer part of the estuary. At the outer estuary a salinity value of 32 was detected; while the temperature was 16°C.

The Colorado River also discharges into the study area. It has a length of 922 km from the Andes to the Atlantic coast, runs across different provinces and outflows in the SW of the Buenos Aires province. At the lower valley of the river there are several artificial drainage channels made to irrigate the zone. The mean annual runoff is 138 m^3s^{-1} and it is now controlled by an upriver dam.

METHODS

A survey on the R/V El Austral was carried out from November 1 to 4, 1993 (spring in the Southern Hemisphere) on El Rincón inner shelf up to the 23 m isobath. The inner continental shelf next to the mouth of the Bahía Blanca Estuary was sampled at 35 stations from the coast to nearly 50 km offshore (Fig. 1). Profiles of water temperature, turbidity and salinity were taken along the water column at each station. Just before the measurement period, a strong southerly storm passed over the study area. The cross shelf structure of water properties was supported together with wind and current data, to understand the dynamical response of the shelf waters to meteorological and oceanographic forcing.

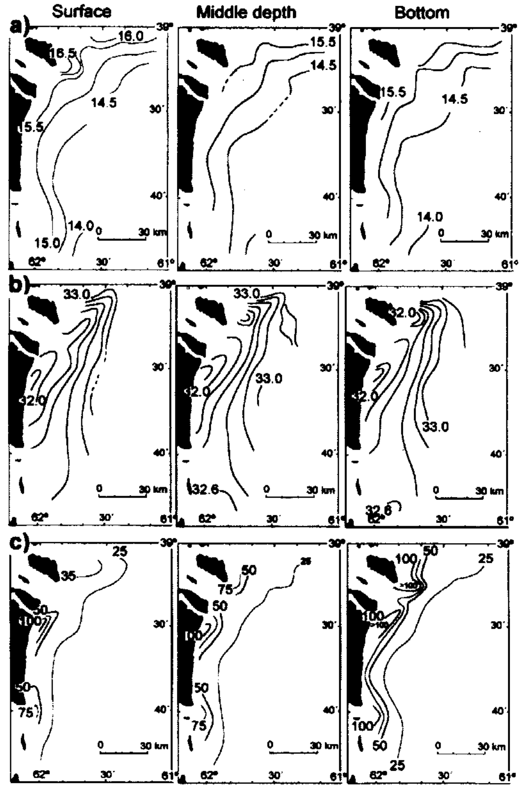

Figure 3.
Distribution of a) Water temperature (°C), b) Salinity, c) Suspended matter (mg l^{-1}) at surface, middle and bottom depth.

The salinity and temperature of the water were determined with an InterOcean miniCTD. The measurements were made continuously from the surface to the bottom and back and the results averaged for each depth. Suspended matter concentration was determined with a Kahlsico Turbidity meter. This sensor detects the attenuation of an emitted light owing to the suspended matter. Water samples were gathered at specific points in time and depth simultaneously for calibration purposes. By means of a calibration curve the concentration of suspended matter in mg/l was obtained.

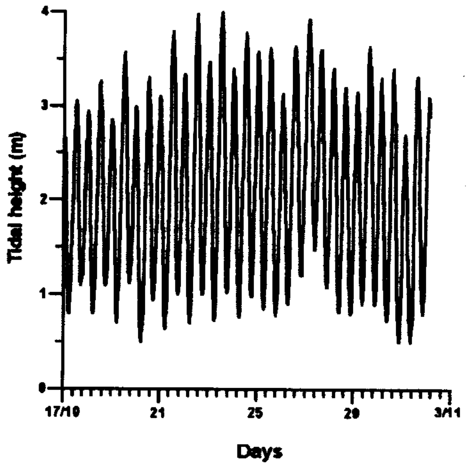

Figure 4.
Tidal records at the Oceanographic Tower from October 17 to November 3

Two InterOcean 135 currentmeters were moored at 6 m above the sea floor at two stations offshore the estuarine mouth, named 1 and 2 (Fig. 1). The sampling interval of the currentmeters was 5 minutes. Fourteen days of measurements were obtained from currentmeter 1, and only 7 days from currentmeter 2 due to a mechanical failure. Comparisons were made between the velocities and directions of both meters. Tidal data was obtained from an Oceanographic Tower (OT), located at the mouth of the estuary (Fig.1), and supplied by the Dirección Nacional de Construcciones Portuarias y Vías Navegables, Argentina. Hourly data was used to calculate the astronomical tides by the method of Godin (1972) and Foreman (1979). Meteorological information, especially wind velocity and direction was also obtained from the Oceanographic Tower and from the Bahía Blanca Airport. The wind sampling interval was half an hour.

RESULTS

Physical characteristics of estuaries and inner shelf environments depend on river inflow, tides, waves, wind and other atmospheric forcing. To understand these forces, it is necessary to examine the independent contribution of each factor and then the combined contribution of interacting factors expressed as specific mechanisms.

The weather over the study area is characterized by the continuous passage of low-pressure systems coming from the west and southwest. A major influence on this general atmospheric circulation is the presence of a semipermanent high over the southwestern Atlantic Ocean centered at 30°S, approximately. This feature dominates most of the wind distribution over the region. The prevailing winds in Bahía Blanca are from the N and NW direction throughout the year (Servicio Meteorológico Nacional, 1985). During the winter and spring, the region is characterized for recurrent events called "sudestadas", which means strong winds blowing from the Southeast and South for many days, generating significant storm surges along the coast.

Before the oceanographic cruise a "sudestada" had passed over the study region (Fig 2). The storm generated mean wind velocities of 11.5 ms^{-1} with peaks of 32 ms^{-1}. Air temperature varied from 5°C to 20°C during the measuring period. Fig. 2 shows the recorded wind in the Oceanographic Tower three days before the cruise was undertaken. The wind distribution reveals the presence of strong winds first from the N and later from the S sectors reaching wind velocities greater than 10 and 15 ms^{-1} respectively. Due to mechanical problems, wind measurements could not be obtained during the cruise but the coastal Airport meteorological data (50 km from the study site) reported weak E and NE winds.

Water temperature distribution at the surface, middle depth and bottom is presented in Fig. 3a. At the surface, temperature varied from 16.5°C in the mouth of the Bahía Blanca Estuary to 14°C offshore. At the mouth of the estuary, warm superficial water flows out, while cooler water entered into the estuary near the bottom.

Runoff is a coastal source of freshwater and the manner in which it spreads over the shelf determines the physical characteristics of the region. River discharge is highly variable and is one of the most important contributions of mass and buoyancy flux for the inner shelf with diminishing impact offshore depending on the degree of spreading. Lower salinity values were found in superficial waters near the continent, north of the mouth of the Colorado River. The river flume is associated with salinities of 31.8.

Fig. 3b shows a plume increasing the salinity from the mouth of the Colorado River toward the Bahía Blanca Estuary in a northeast direction. Low salinity is also found at the mouth of the Bahía Blanca Estuary at middle and bottom depths. These observed value (32) were also found in a previous study (Piccolo and Perillo, 1990) at the outer zone of the estuary in the same season.

Suspended matter distribution is presented in Fig. 3c. Offshore waters were characterized by suspended matter concentration (SMC) of 21.6 mg l^{-1}. This value was considered as a reference concentration because it was found all over the water column at the outer part of the inner shelf (there is no data either historical or parallel to this survey related to the SMC on the ACS that can allow us any comparison). Near the coast the concentration was greater, exceeding, in some places, 100 mg l^{-1}.

The distribution of SMC in the surficial water shows one important plume with values higher than 50 mg l^{-1} near the coast. A plume concentration exceeding 100 mg l^{-1} flowing in a NNE direction at the north of the Colorado River agrees with the salinity plume. Another less important plume is located southward, at Anegada Bay, with concentrations around 80 mg l^{-1}. A third plume was detected at the middle and bottom depths at the mouth of the Bahía Blanca Estuary. It reaches concentrations of 80 mg l^{-1} for the middle depth and exceeds 100 mg l^{-1} at the bottom.

Tides and Tidal Currents

In coastal areas, especially those with a relatively small astronomical tide, meteorological forces can play a significant, and sometimes dominant role, in creating water level variations over time scales ranging from a few hours to several days. This is especially true in estuaries or semi-enclosed coastal bays, where the constricting effects of narrow channels and shallow water serve both to damp progressive tidal waves of astronomical origin and to amplify meteorological effects (Smith, 1974). However, the study area is considered as mesotidal with a mean tidal range of 2.2 m. The wind forcing is significant in the dynamics of the estuary and induces major changes in water level conditions (Perillo and Piccolo, 1999).

The observed tide before and during the cruise is shown in Fig. 4. The most important astronomical constituents calculated from the data are the semidiurnal M_2, S_2, and the diurnal ones O_1 and K_1. Naturally, the shallow water constituents are also significant, the most important of which, the MSF, is produced by the interaction of the M_2 and S_2. This harmonic constituent is greater in amplitude than the O_1 and K_1. The semi-diurnal, diurnal or mixed nature of the tide is defined by the ratio of the principal diurnal and semidiurnal constituents: $F=(O_1+K_1)/(M_2+S_2)$. The magnitude of this ratio at the outer zone of the Bahía Blanca estuary is 0.18, indicating that it is predominantly a semi-diurnal, mixed tide.

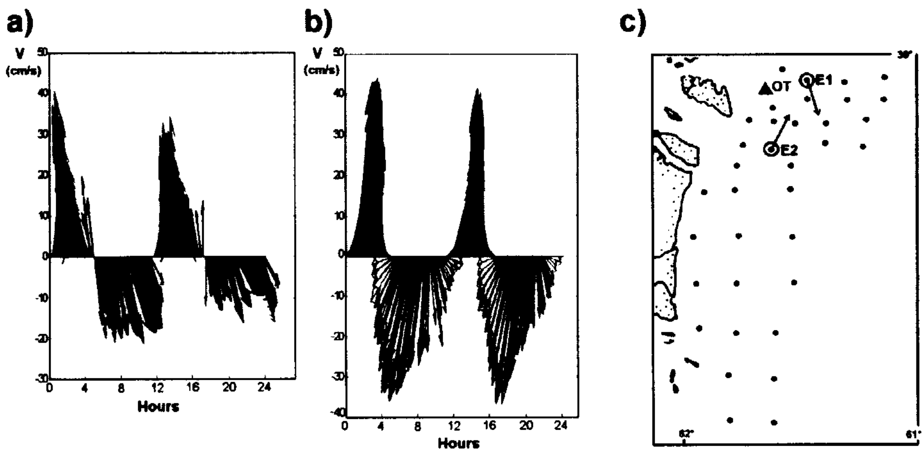

Figure 5. *a) Current vectors for station 1 in Oct 21st, 1993. b) Idem for station 2. c) Residual currents for station 1 and station 2.*

The currentmeter at station 1 located at the mouth of the estuary measured maximum velocities of 57 cm s^{-1} while 30% of the time the velocity was over 30 cm s^{-1}. Station 2 located southward station 1 measured the same maximum velocity, and 43% of the time the velocity was greater than 30cm s^{-1}.

In both stations the form of the tidal ellipse is very irregular. Examples of current vectors for one day (21/10/93) at both stations are shown in Fig. 5a and 5b. The currents tend to be stronger during the flood with less vector dispersion than in ebb conditions. The circulation in station 1 (Fig. 5a) is under the influence of the flow of the Bahía Blanca estuary, producing the vector dispersion principally during ebb conditions because of the presence of an ebbing delta north of that station. The ellipse of the station 2 is relatively more regular in its form.

Current vectors were decomposed into N-S (v) and E-W (u) components. In station 1 the v component was stronger than the u one, reaching in some cases twice its velocity. That was not the case for station 2, where the u and v velocity components did not show large differences. The arrows representing the residual currents shown in Fig. 5c display the mean circulation of the area. The energy spectrum calculated reveal similar characteristics for both stations records (Fig. 6). The spectrum of the u component shows that the predominant peaks occur at semidiurnal, quarter diurnal and diurnal frequencies. Smaller peaks also appear at the M6 tidal harmonic. The energy spectrum of the v component also presents the peaks in the mentioned frequencies but a significant peak appears at a period of 2.9 days. Meteorological effects produce this, because it is the typical frequency of the passage of the synoptic systems over the region.

Statistical Analysis

A Principal Component Analysis (PCA) (also known as Empirical Orthogonal Functions EOF) was applied to determine the weight of each variable in the water characteristic. PCA is a tool for the analysis of the spatial or temporal variability of physical fields. It has successfully resolved the variance structure in multivariate geophysical data (Resio and Hayden, 1975), and provides a method for determining patterns in large data fields (Hayden, 1981a). The objective of the analysis is to isolate characteristic, recurrent and independent modes of covariance among variables into a new set of independent variables. Typically, each component is identified with some property of the data field (Cuadrado and Perillo, 1997). Finally, the analysis provides an estimate of the total percent of variance in the data set, which can be explained on the basis of each component (Hayden, 1981b; Hayden and Smith, 1982).

The resulting eigenvector from the applications of PCA redefines a set of correlated variables as a set of uncorrelated variables. Linear combinations of the original variables are chosen so that each component explains a maximum of the variance left unexplained by the preceding components, subject to the limitation that all components be orthogonal to each other. The first eigenfunction explains most of the mean square value of the data. Thus several variables can be efficiently represented by a few empirical functions that describe most of the mean square value of the original data.

PCA was applied to all collected data: temperature, salinity and suspended matter to detect the relationship between them. Thus a data matrix of 9 columns and 35 rows was obtained. The columns correspond to the variables SMC, salinity and

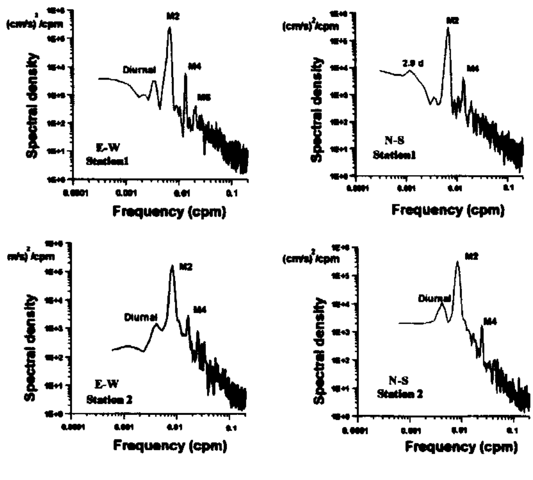

Figure 6.
The energy spectrum for the u and v components of station 1 and 2.

temperature measured at the top, middle and bottom depths while the rows refer to the stations. For the analysis, the correlation matrix was used because the variables have different units, which made it necessary to standardize the data.

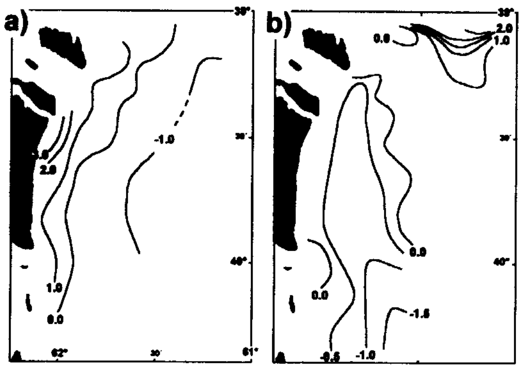

Figure 7. *a) The first principal component plotted on the study zone. b) Idem to the second principal component.*

The correlation matrix between the variables and the principal components is shown in Table 1 and indicates that the first two eigenvalues explained 85% of the original information. For the first eigenvector the coefficients for salinity are negative against the other variables that are positive. This fact may show that there is a contrast between salinity versus both the SMC and temperature. The first principal component was plotted in Fig. 7a, showing that the zero isoline differentiates two zones. One, with positive values near the coast; and the other with negative values offshore.

The second eigenvector show the difference between both salinity and temperature coefficients against the SMC (Table 1). As the salinity was thoroughly explained by the first eigenvector the second one may explain the SMC parameter, considering that temperature is rather uniform in all the area. The second principal component was plotted. It exposes a tongue-shape constructed by negative values (Fig. 7b), while the negative correlation values correspond to SMC (Table 1).

DISCUSSION

The distribution of the variables in the study area shows important variations in two different zones: the Colorado River outflow, and the Bahía Blanca Estuary. The two zones featured different characteristics in the measured parameters. To observe such a variation, a transect was made between these end points with a SW-NE direction (Fig. 8).

The Colorado River discharges into the inner shelf influencing the whole water column significantly. The Coriolis effect induces a northward propagation of the plume. Obviously, the outflow (station 20) is fresher and warmer than the surrounding shelf waters (Fig. 8). SMC is also greater than 100 mg l^{-1} all over the water column which tends to propagate to the NE. A similar situation is observed on the plume of the Bahía Blanca Estuary which is also diverted to the north by Coriolis force. A theory that was originally proposed by Perillo and Cuadrado (1990) to explain the concentration of suspended matter along the coast of Monte Hermoso Beach and by Perillo and Piccolo (1991) to account for the high temperatures registered there in summer.

At the mouth of the Bahía Blanca Estuary, conditions vary from surface to bottom (stations 8 and 9, Fig. 8). The warm surface water outflow at station 8 has higher salinity than at the bottom. Evaporation over the extensive tidal flats and inner estuarine salt flats induce hypersaline conditions in the Bahía Blanca Estuary. Therefore, during the ebb conditions, high salinity water reaches the mouth along the surface layer. Water is then expelled from the estuary through a series of channels across an ebb delta. Thus, the geomorphology and the strong ebb current force the saltier estuarine waters to the upper part of the water column. High SMC (>100 mg l^{-1}) is detected only near the bottom, decreasing toward the surface (40 mg l^{-1}). The processes involved in this area could be related to sediment resuspension, considering that the maximum velocities were 57 cm s-1.

The temperature and salinity data taken at the mouth of the Bahía Blanca Estuary were similar to those gathered, some years ago in the same season by Piccolo and Perillo (1990). In the present study the same salinity was observed at the mouth of the estuary (32), with a temperature of 16.5°C.

Table 1.
Correlation between the variables and the two factors

Variable	Factor 1	Factor 2
Surficial Susp. Sed.	0.837	-0.013
Middle Sus. Sed	0.885	0.051
Bottom Susp. Sed.	0.876	-0.013
Surficial Salinity	-0.745	0.625
Middle Salinity	-0.762	0.597
Bottom Salinity	-0.749	0.542
Surficial Temperature	0.745	0.546
Middle Temperature	0.686	0.665
Bottom Temperature	0.707	0.623
% total variance	60.89	24.18
% cumulative	60.89	85.07

PCA is a strong tool to provide a description of the major modes of variability in the data set. The first principal component shows two zones (Fig. 7a). One, with positive values near the coast; and the other with negative values offshore. The salinity variable has a negative coefficient in the PCA, so the offshore water is identified by low salinity. Therefore, the first principal component showed a differentiation in the inner shelf between nearshore and offshore waters.

The second principal component explains the SMC distribution, as can be seen in Table 1, Fig. 7b shows that the distribution of the second principal component is similar to the distribution of the SMC shown in Fig. 3, which it has a tongued shape with a SW-NE direction. The circulation pattern obtained by a currentmeter moored at the northern sector of the study area (station 2 Fig. 1) indicates a SW-NE direction. Though there are not enough current measurements in the area, results from numerical models (Lusquiños and Schrott, 1983) also indicate that the circulation is from South to North. Therefore the second principal component may probably be related to the water circulation in this portion of the continental shelf.

Coastal regions are very different from the outer continental shelf, so that the coastal boundary layer is a unique dynamic regime found near the shore of continental shelves and this environment differs markedly from offshore regions (Pettigrew and Murray, 1986). The coastal boundary layer and inner shelf can be strongly influenced by freshwater input and local heating and cooling. These processes generate horizontal density gradients that in turn drive thermohaline circulation and alter the nearshore response to other forcing.

The magnitude of the nearshore water masses involved is liable to be greater along coastlines with major riverine inputs. It was found that the Colorado River freshwater discharge into the inner shelf develops a boundary layer. A homogeneous plume of high suspended matter concentration and low salinity was detected with a SSW-NNE direction, along the isobaths. This result confirmed Pettigrew and Murray (1986) findings in which the motion near the shoreline was characteristically along isobaths.

The estuary-mouth dynamics depend, to a large extent, on its interactions with the inner shelf (Wiseman, 1986). In other studies of the area, a residual transport toward the mouth of the estuary was detected (Perillo and Cuadrado, 1990) and an erosive process for the whole estuary was observed during the last years (Perillo, 1989, Perillo and Piccolo, 1999).

The two currentmeters moored at the study zone measured two different flows. The currentmeter at station 1 showed the mean direction of the Bahía Blanca estuarine plume, where all the estuary flow discharges in that area. The residual outflow has a NNW-SSE orientation, measuring the estuary impact. The station 2 detected the Colorado River outflow as a SSW-NNE residual current direction.

Stratification of shelf waters reflects the balance between buoyancy forces that result from heating and cooling, evaporation and precipitation, and runoff, and mixing forces such as wind stress at the surface and current stress at the bottom. Undoubtedly buoyancy flux due to river discharge is the most important contribution to buoyancy flux for the inner shelf, with diminishing impact offshore depending on the degree of spreading. It creates stratification in the inner and middle shelf near rivers. Several processes such as evaporation, cooling, surface and bottom stresses, apply power at the surface and bottom boundaries that act, along with a negative buoyancy flux, to weaken, if not destroy, stratification. Atkinson and Blanton (1986) determined that the advection of buoyancy, which is usually neglected, is another process that creates and destroys stratification and often dominates all other processes.

The effect of wind on stability is two-fold: direct local forcing causes vertical mixing, while wind-induced advection may cause low-salinity coastal water to move into other regions, effectively causing a buoyancy flux in the offshore region or vice versa (Atkinson and Blanton, 1986). Wind-induced advection can have a substantial effect on stratification, since significant amounts of fresh water can be advected offshore (Blanton and Atkinson, 1983).

The vertical mixing due to local wind forcing is not intense because of the relative by weak mean winds, although occasional storms may cause strong mixing. Work done in mixing the water column due to wind can be obtained by multiplying wind stress by friction

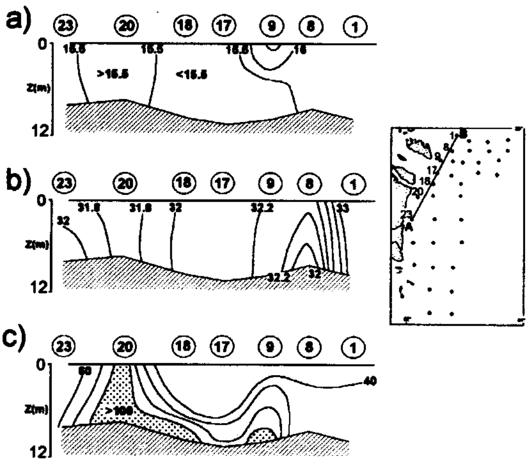

Figure 8.
Distribution of a) Temperature, b) Salinity, c) suspended sediment along the profile AB.

velocity (U*). Considering

$$r_w U*^2 = r_a C_d U_a^2 \qquad (1)$$

where r_a and r_w are the density for air and water, respectively, U_a is wind speed, U* is friction velocity, and C_d is a drag coefficient. Since $r_a / r_w = 10^{-3}$, the friction velocity is

$$U* = (10^{-3} Cd)^{½} U_a \qquad (2)$$

Thus the work done by the wind, W_w, is

$$W_w = k_w U*^3 = k_w [(k_a/k_w) C_d]^{3/2} U_a^3 \qquad (3)$$

The work done by the wind is in milliwats per square meter (mW m^{-2}). The drag coefficient, C_d, is typically $2x10^{-3}$ (Blanton and Atkinson, 1983). Considering the "sudestada" event measured before the cruise, the mean magnitude of the winds was $U_a = 11.5$ ms^{-1} over one day long. This resulted in $W_w = 4.45$ mW m^{-2}. Meanwhile, during the cruise, the wind was weaker with a mean velocity of 7.5 ms^{-1}, which impart a $W_w = 1.19$ mW m^{-2}.

The values obtained in the argentine continental inner shelf are similar to those obtained by Atkinson and Blanton (1986) at the South Atlantic Bight. They had concluded that the mean wind induce a $W_w = 1.0$ mW m^{-2}, while typical storm winds would yield a higher value, $W_w = 3.1$ mW m^{-2}. They stated that the power required to destroy advectively created stratification may reach 3 mW m^{-2} and concluded that winds are important sources of mixing energy only during storm events. They also argued that mean winds are too weak to affect stratification.

In the present study the measured parameters showed that the offshore waters were fully mixed due to the mixing force of the storm wind which occurred before the cruise. So, the work done by the wind, nearly 4.5 mW m^{-2}, was sufficient to totally mix the inner shelf waters.

It is important to note that even the whole water column is vertically mixed, the Colorado River homogeneous plume of high suspended matter concentration and low salinity, and resuspended matter in the Bahía Blanca Estuary is found.

CONCLUSIONS

In this paper the hydrography of the inner continental shelf offshore the Bahía Blanca Estuary is described. Significant spatial variability was found in the area. The most important finding is the influence of the Colorado River on the inner shelf. This river outflow penetrates the inner shelf waters with high suspended matter concentration and low salinities all over the depth. The plume has a maximum velocity of 57 cm s^{-1} and a SSW-NNE direction. Tides and winds are the driving forces in the study area.

At the Bahía Blanca Estuary the processes involved are different from the typical pattern in estuaries. Here, there is a surface flow, which is warmer and denser seaward instead of a diluted land runoff. The salinity distribution shows how small the influence of the freshwater input into the inner shelf is. The suspended matter is important near the bottom, suggesting that resuspension would be the most important process.

The PCA shows that among all the measured parameters, only two were important enough to determine the physical characteristics of the study zone: salinity and suspended matter. The result of the statistical analysis determined that the temperature was always associated with another parameter and it showed no differences, spatially or in depth, so this factor is unimportant. By means of the first eigenvector of the PCA two different zones were found. The offshore zone was mixed all over the water column, probably by the storm winds that reached velocities of 11.5 m s^{-1}. The nearshore zone delimited by the PCA involved different processes due to the runoff of the Colorado River and the Bahía Blanca Estuary interacting with the inner shelf, respectively.

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