Proceedings of 8 ICSHMO, Foz do Iguaçu, Brazil, April 24-28, 2006, INPE, p. 1311-1314.

MODELING THE HYDRODYNAMICS OF THE SOUTHERN BRAZILIAN SHELF

Wilian Correa Marques, Igor Oliveira Monteiro, Osmar Olinto Möller Jr, Elisa Helena Fernandes*

Fundação Universidade Federal do Rio Grande (FURG), Departamento de Física
CP 474, CEP 96201-900, Rio Grande, RS, Brazil.

1. INTRODUCTION

Continental shelves are among the most productive and diverse environments of our planet. However, they are also one of the most human-impacted environments, serving as the ultimate collector for sediments and disposals of the human population concentrated in coastal areas (Soares, 2003). Freshwater and materials are carried to coastal and shelf areas by the river discharge and the resulting dynamic structures are the river plumes. The understanding of coastal and shelf circulation is certainly an important factor determining the equilibrium of these systems.

Modeling studies in the Southern Brazilian Shelf (SBS) are rare and either lack in space-time resolution or do not include the adequate forcing needed for a realistic simulation of the coastal circulation (Pimenta, 2001; Ghisolfi, 2001). Studies on the dynamics of the Patos Lagoon river plume are even more limitated. Zavialov et al (2003) monitored the behavior of this river plume under intense river runoff conditions using salinity and temperature observations. Soares (2003) carried out hydrodynamic simulations for the SBS, but his results were limited to considering the large scale coastal currents. Thus, the objective of this study is to investigate the response of the Patos Lagoon river plume to the main physical forcing, namely the tides and the winds, providing a specific insight on the hydrodynamics of the SBS.

2. STUDY AREA

The Patos Lagoon (Figure 1) is located in the *southernmost part of Brazil, between 30º - 32ºS and 50º - 52º W, being connected to the South Atlantic Ocean via a narrow channel less than 1 km wide. The lagoon drains a hydrographic basin of approximately 200.000 km² and their principal rivers contribute with an annual mean discharge of about 2000 m³s^{-1}. This region is influenced by synoptic atmospheric systems which contribute to the northeast – southwest dominant wind circulation and enhance coastal upwelling – downwelling, respectively. The tides are mixed with diurnal dominance and their effects are restricted to the coastal and estuarine zone.

The SBS is limited by the Santa Marta Cape (28°30'S) and the Arroio Chui (33º48'S). The adjacent continental shelf has a mean cross-shelf gradient of about 1.41 m km^{-1} (Figueiredo, 1980). It is narrow in the northern and southern part becoming wider up on the central portion, and the shelf break is located on the 180 m isobath (Castro and Miranda, 1998). The inner shelf is dominated by the coastal currents originated along the Patagônia coast (Piola e Rivas, 1997) and by the Plata River discharge along the Uruguayan coast (Framinan and Brown, 1996; Pimenta, 2001; Ghisolfi, 2001; Soares; 2003). The outer shelf is influenced by the Brazil and Malvinas western boundary currents (Castro and Miranda, 1998).

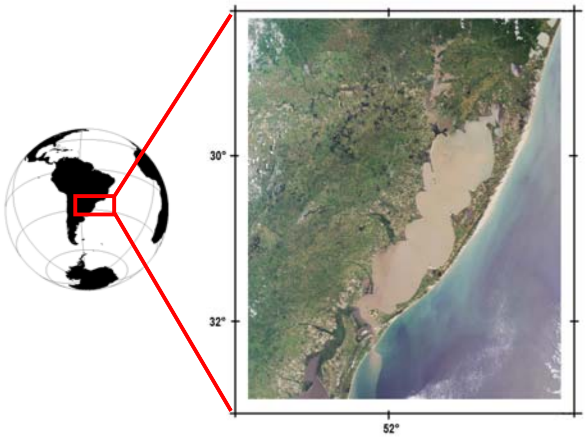


Figure 1 - Satellite image of the study area.

2. METHODOLOGY

The TELEMAC model was used to carry out two-dimensional hydrodynamic simulations for the study area in order to investigate the response of the Patos Lagoon river plume to the main physical forcing. TELEMAC is a finite element flow model developed by the *Laboratoire National d´Hydraulique (EDF, France)* to simulate the flow in estuaries and coastal zones (Hervout and Van Haren, 1994; 1996). The study area was defined between 28ºS and 34ºS and the oceanic boundary was located at the 100m isobath. The resulting finite element mesh contains around 23500 elements and is presented in Figure 2.

The model was forced with a constant river discharge of 3000 m³s^{-1} at the top of the Patos Lagoon and by the main tidal components for the area (M1, N2, O1, S2 e K1) obtained from the FES95.2 model (Finite Element Solution V95.2). Figure 3 shows the amplitude and phase of the alongshore variation of the tide components. The wind data prescribed (Fig. 4) as the surface boundary condition is a spacially homogeneous

* *Corresponding author address:* Wilian C. Marques. Fundação Universidade Federal do Rio Grande; Departamento de Física. Rio Grande do Sul
e-mail: wilian_marques@yahoo.com.br

theoretical time series which represents the passage of a frontal system over the area.

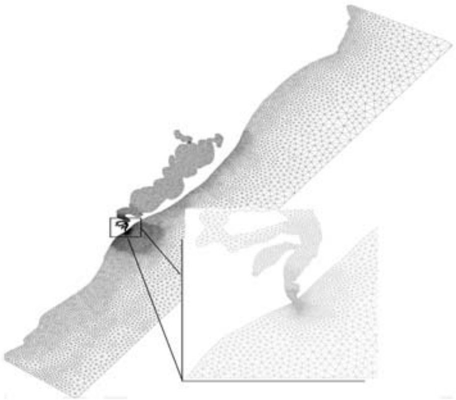


Figure 2 - Finite element mesh (23500 elements).

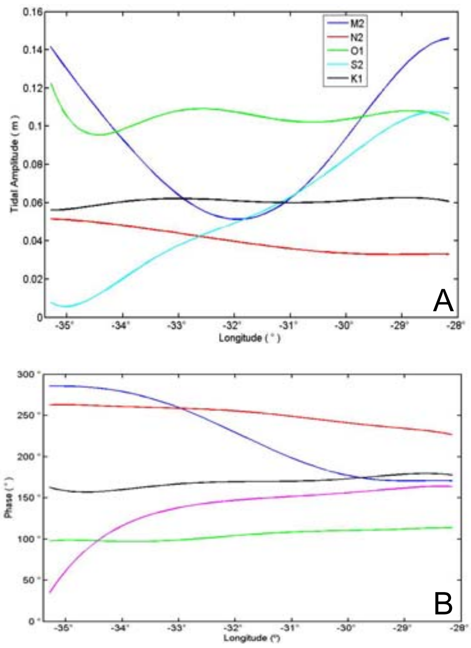


Figure 3 - Tide components. Amplitude (A) and phase (B).

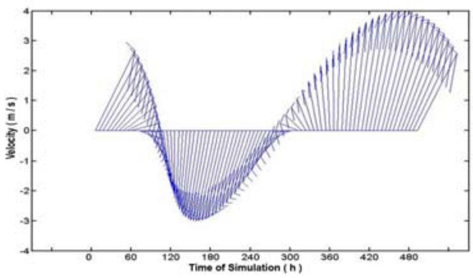


Figure 4 - Theoretical curve of wind time series. Positive (negative) values represent southwest (notheast).

3. RESULTS

Figure 5A presents calculated results after 56 hours of simulation, indicating that southwest winds enhance the Ekman drift towards the coastal zone. The resulting increase in water level generates a pressure gradient that contributes to flooding flow in the estuarine zone and promotes the formation of an estuarine front throughout the navigational channel.

After 180 hours of simulation (Fig. 5B), the wind shifts to the northeast, decreasing the water levels along the coast and enhancing the offshore Ekman drift. These conditions contribute to the establishment of an ebb flow in system and subsequent buoyant plume formation. 36 hours after (Fig. 5C), the northeast winds reach the maximum intensity. At this moment, the plume extends about 40 km to southwest of the estuarine mouth.

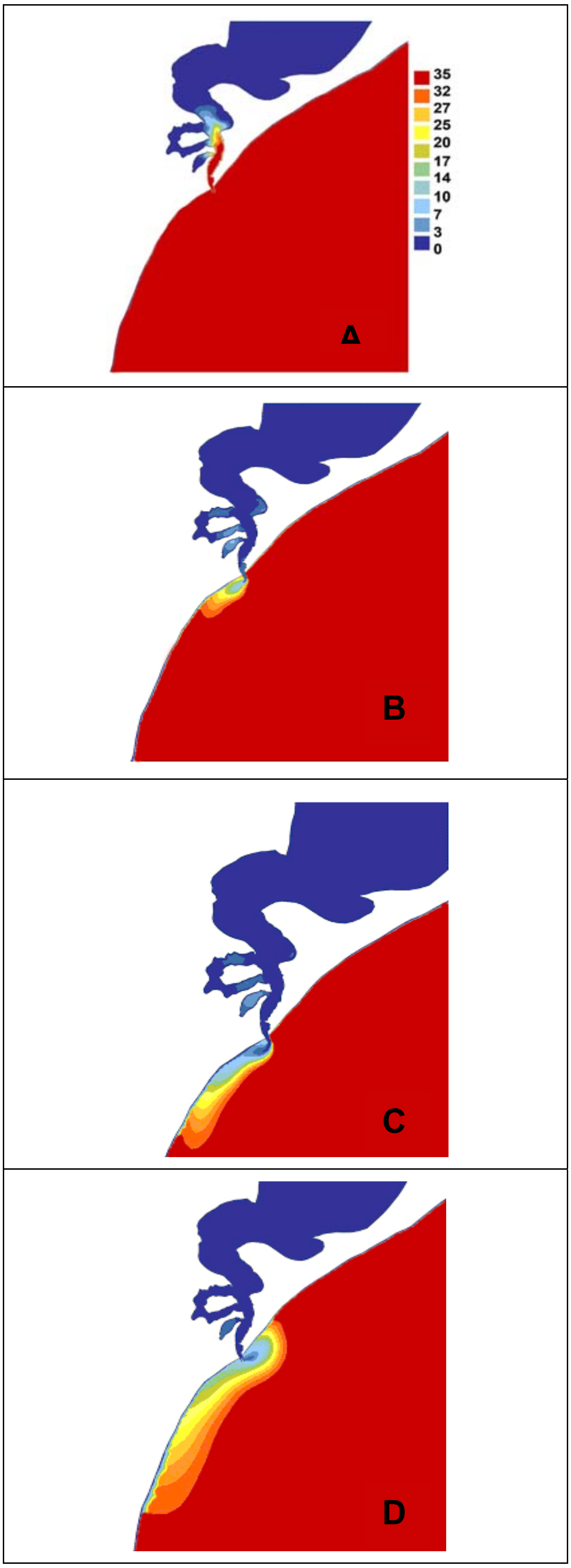
Figure 5D presents the maximum southward displacement of the river plume, which reaches around 64 km off the mouth. Soon after that, the wind shifts to the southweast and begins to push the brackish water in the same direction. After 455 hours of simulation (Fig. 5E), the southwest winds reach the maximum intensity. At same time, the plume starts to move towards the north, reaching a maximum displacement of about 146 km off the Patos Lagoon mouth.

4. DISCUSSION

River plumes over continental shelves can assume many different forms according to the main forcing mechanisms. Chao (1988a) suggested a method for classifying plume forms based on the relation between the Froude number and a dimensionless parameter which indicates the amount of dissipation acting on density currents. According to his method and to the preliminary 2D modeling results, the Patos Lagoon river plume can be classified as of the subcritical or diffusive-subcritical type. However, as the dynamics of a river plume over coastal areas is essentially a 3D problem, further 3D modeling experiments are required to verify this hypothesis.

Csanady (1978) comments that the freshwater discharge over coastal areas can create a response like an arrested pressure field. Brink (1991), Wong and Münchow (1993) and Kourafalou et al. (1996a), observed that this pressure filed can propagate on the same direction of the Kelvin wave phase velocity. Garvine (1987) and O'Donnell (1990) have shown that the surface buoyant plume of the Connecticut River tends to spread from its source, being deflected to the right (direction of Kelvin wave propagation) on the northern hemisphere by the Coriolis force and/or the alongshelf current. Zhang et al. (1987) observed that the spreading of the Changjiang estuary plume and the Savannah River plume are seasonally controlled by the Kuroshio Current and wind driven currents on the South Atlantic Bight, respectively.

In the southern hemisphere, the waters discharged by the rivers and lagoons onto the continental shelf can leave the coast on the left side, being deflected by the Coriolis force or along shore coastal and tidal currents.



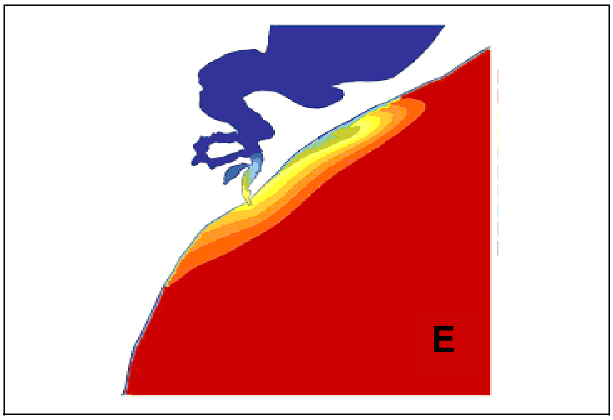


Figure 5. salinity plots after 56 hours of simulation (A), 180 hours (B), 216 hours (C), 408 hours (D) and 455 hours (E)

The scenario simulated here indicates that the fate of the Patos Lagoon plume was strongly controlled by the wind action, being transported on its preferential direction. Our results are in accordance with observations on the South Atlantic Bight by Zhang et al (1987) and Kourafalou et al. (1996a; 1996b), where the wind action carries the brackish water on the prevailing direction.

Pritchard (2000) observed that the prevailing wind direction is responsible for the majority of the alongshore transport, which affects the direction of the plume propagation and its spatial structure. Other modeling studies showed that plumes are very sensitive to local wind changes due the perturbations caused in the Ekman layer on the surface (Royer and Emery 1985; Chao 1988b; Kourafalou et al. 1996a; 1996b; Pimenta 2001; Ghisolfi 2001; Soares 2003). On the SBS, the Plata River water intrusion, scattering and its interaction with the Patos Lagoon discharge is a function of prevailing winds (Pimenta, 2001, Soares, 2003). But, the better representation of wind effects is a function of vertical density stratification that controls the surface and bottom boundary layers (Ghisolfi, 2001). In this way, the 3D modeling experiments are necessary.

The dynamics of the Patos Lagoon river plume was described based on a theoretical time series of tides and wind speed and direction, and considering mean river discharge conditions which are representative of late autumn and late spring periods (Marques 2005). Our preliminary results indicate a subcritical comportment for the Patos Lagoon river plume under these conditions. But, in accordance with Chao (1988a), the seaward bulge width has the same order of the coastal jet indicating a dominance of the dissipative effects under rotational ones.

Although the tides may play an important role in spreading river plumes offshore (Chao, 1990), and the plumes in the presence of strong alongshore tidal currents can undergo significant changes over the ebb and flood cycle (Lewis 1984; Hickey 2000), the tidal contribution to plume formation, movement and mixing is not the dominant factor (Pritchard 2000). Soares (2003) observed through numerical experiments for the area that the transport of the Plata River waters along the SBS is higher in the presence of tides due to the northward residual current, which is produced by interaction of the tides with topography.

Our results show the interaction between tides and wind effects over the plume spreading. We can not discuss each effect separately, but, based on previous results obtained by Soares (2003) for the coastal current on the SBS, we can infer that the tidal influence can contribute to increase the northward displacement of the Patos Lagoon plume due the tidal currents forced on the Kelvin wave phase propagation.

The results obtained agree with previous studies, indicating the wind action as the most important forcing over the SBS circulation. The use of a 2D hydrodynamic model, however, can overestimate the southward displacement of the Patos Lagoon plume. Thus, the implementation of a 3D hydrodynamic model is essential. Furthermore, the inclusion of the coastal current influence over our study domain can also produce a better scenario for the dynamics of the area.

5. PRELIMINARY CONCLUSIONS

Modeling results for the scenario under investigation indicates the wind influence as the principal mechanism of transport over the SBS. The northeast (upwelling favorable) winds contribute to southward and offshore displacement of the Patos Lagoon waters, inversely, the southwest (downwelling favorable) winds contribute to northward and onshore displacement. It is possible to infer from these results that the tidal influence contributes to the increase of the northward displacement of the brackish waters due the tidal currents created by the interaction between tides and topography. The intensity of southwest winds also contributes to a larger displacement on the northward direction.

6. ACKNOWLEDGEMENTS

The authors are grateful to CNPq for sponsoring this research under contracts 590006/200-3 (WCM and EHF), 540467/2001-4 (EHF), and 302173/2004-8 (OOM Jr).

7. REFERENCES

BRINK, K. H. 1991: Coastal-trapped waves and wind-driven currents over the continental shelf. Annu. Rev. Fluid Mech. 23,389-412.

CASTRO, B. M., and MIRANDA, L. B. 1998: Physical oceanography of the western Atlantic continental shelf between 4ºN and 34ºS. In: Brink, K., Robinson, A. (Eds.), The Sea – The Global Coastal Oceans, Vol 10. Wiley, New York, pp. 209-251 (chapter 8).

CHAO, S.-Y. 1988a: River-Forced Estuarine Plumes*. Journal of Physical Oceanography. 18,72-88.

CHAO, S.-Y., 1988: Wind-driven motion of Estuarine plumes. Journal of Physical Oceanography. 18,1144-1166.

CHAO, S.-Y., 1990: Tidal modulation by estuarine plumes. Journal of Physical Oceanography. 20,1115-1123.

CSANADY, G. T. 1978: The Arrested Topographic Wave[1]. Journal of Physical Oceanography. 8,47-62.

GARVINE, R. W. 1987: Estuary plumes and fronts in shelf waters: A layer model. Journal of Physical Oceanography. 17.1877-1896.

FIGUEIREDO, A. G. 1980: Response of the water column to strong wind forcing, Southern Brazilian Inner Shelf: Implications for sand ridge formation. Marine Geology 35.367-376.

FRAMINAN, M., and BROWN, O. 1996: Study of the Rio de La Plata turbidity front, part I: spatial and temporal distribution. Continental Shelf Research 16(10).1259-1282.

GHISOLFI, R. 2001: Oceanic fronts off the Southern Brazilian coast. PhD thesis, University of New South Wales – School of Mathematics, New South Wales, Australia.

HERVOUET, J. M., and VAN HAREN, E., 1994: TELEMAC-2D Principle Note. Eletricité de France. Thecnical Report HE-43/94/051/B.

HERVOUET, J. M., and VAN HAREN, E., 1996: Recents Advances in numerical methods for fluid flows. In: ANDERSON, M. G.,; WALLING, D. E. and BATES, P. D., Floodplain Processes. Local: Editora, pp. 183-214.

HICKEY, B. M., 2000: Trasnport due to freshwater discharge into the coastal ocean In: University of Maryland Centre for Environmental Science Technical Report TS-237-00.

KOURAFALOU, V. H., OEY, L. Y., WANG, J. D., and LEE, T. N., 1996a: The fate of river discharge on the continental shelf 1. Modeling the river plume and the inner shelf coastal current. Journal of Geophysical Research. 101(C2),3415-3434.

KOURAFALOU, V. H., LEE, T. N., OEY, L. Y., and WANG, J. D. 1996b: The fate of river discharge on the continental shelf 2. Transport of coastal low-salinity waters under realistic wind and tidal forcing. Journal of Geophysical Research. 101(C2),3435-3455.

LEWIS, R. E., 1984: Circulation and mixing in Estuary outflows. Continental Shelf Research. 3,201-214.

MARQUES, W. C. 2005: Padrões de variabilidade temporal nas forçantes da circulação e seus efeitos na dinâmica da Lagoa dos Patos, Brasil. Master's thesis, University of Rio Grande, Rio Grande do Sul, Brasil.

O'DONNELL, J. 1990: The formation and fate of a river plume: A numerical model. Journal of Physical Oceanography. 20,551-569.

PIMENTA, F. 2001: Estudo numérico da influência da descarga fluvial e dos ventos sobre a dinâmica da pluma do rio da Prata. Master's thesis, University of São Paulo – School of Oceanography, São Paulo, Brasil.

PIOLA, A., and RIVAS, A. 1997: Corrientes en La Plataforma Continental. In Boschi, E., editor, El Mar Argentino e sus Recursos Pesqueros, volume I, pp. 119-132. INDEP.

PRITCHARD, M. 2000: Dynamics of a small tidal Estuarine plume. Phd Thesis. University of Plymouth. Institute of Marine Studies, Faculty of Science, Plymotuh, United Kingdom.

ROYER, L., and EMERY, W. J. 1985: Computer simulations of the Fraser river plume. Journal of Marine Research. 43,289-306.

SOARES, I. D. 2003: The Southern Brazilian Shelf Buoyancy-driven currents. PhD thesis, University of Miami, Florida, United States of America.

VAZ, A. C., 2005: Modelagem do transporte e retenção larval da Anchoíta Engraulis anchoita na plataforma continental do Atlântico Sudoeste. Master's thesis. University of São Paulo – School of Oceanography, São Paulo, Brasil.

WONG, K. C, and MÜNCHOW, A. 1995: Buoyancyforced interaction between estuary and inner shelf: observation. Continental Shelf Research. 15,59-88.

ZAVIALOV, P. O., KOSTINOY, A. G., AND MÖLLER JR, O. O. 2003: Mapping river discharge effects on Southern Brazilian shelf. Geophysical Research Letters. 30(21), 2126

ZHANG, Q. H., JANOWITZ, G. S., and PIETRAFESA, L. J. 1987: the interaction of estuarine and shelf waters: A model and applications. Journal of Physical Oceanography. 17,455-469.