International Conference on Estuaries and Coasts
November 9-11, 2003, Hangzhou, China

SALINITY SIMULATIONS OF THE RIO DE LA PLATA

Monica FOSSATI
University of the Republic, Faculty of Engineering, J. Herrera y Reissig 565, Montevideo,
Uruguay. Tel.: (598) (2) 711 3386. Fax: (598) (2) 711 5277. E-mail: mfossati@fing.edu.uy

Ismael PIEDRA-CUEVA
University of the Republic, Faculty of Engineering, J. Herrera y Reissig 565, Montevideo,
Uruguay. Tel.: (598) (2) 711 3386. Fax: (598) (2) 711 5277. E-mail: ismaelp@fing.edu.uy

Abstract: A two-dimensional finite element hydrodynamic model, the RMA-10 code, is applied to study the dynamic of the salinity front in the Río de la Plata. The model extended from the continental shelf, up to the inner part of the Río de la Plata. The model simulates the time varying circulation and salinity distribution. The tidal range is the result of the co-oscillating tide, the momentum equations do not contain any forcing terms, and thus, the modeled currents are forced by open boundary conditions. The dynamic processes involving interaction between river discharges, tidal currents and wind effects are complex. A series of diary measured salinity data is used for model calibration and verification. Two different situations were considered to calibrate the model. The first one in March 2000, correspond to a low flow discharge condition (approximately 12,500 m^3/s), while the second one in February 1998 correspond to a high flow discharge (49,000 m^3/s). Four coastal stations located in Montevideo City were selected to carry out the comparison among measured and modeled salinity. The model with the calibration parameters shows that is able to simulated the salt field with a reasonably accuracy. Others two months were considered to verify the model and good agreement is obtained between modeled and recorded salinity data.

Key words: Numerical modelling, Estuaries, Salt field, Rio de la Plata

1. INTRODUCTION

The Río de la Plata is located on the east coast of South America, approximately between 34° and 36° South Latitude and 54° 50' and 58° 30' West Longitude, being a limit between the República Oriental del Uruguay and the República Argentina. Its axis runs on a NW-SE direction being approximately 280 km length. Its surface is about 35.000 km^2 and its width varies over 2 km at the inner part and about 220 km at its mouth (Fig. 1). The two major tributaries are the Paraná and Uruguay Rivers, with annual average discharges of 16,000 m^3/s and 6,000 m^3/s, respectively, with minor tributary discharges being several orders of magnitude smaller.

Two main regions can be identified based on the morphology and dynamics of the Rio de la Plata (CARP 1989, Framiñan and Brown 1996). Barra del Indio, a shallow area located in the line Punta Piedras and Montevideo, separates the inner from the outer region. The inner region has a fluvial regime with bi-dimensional flow. In the outer region, the river increases in width and this change in the geometry imply a new forcing balance that generates complex flow patterns.

From the hydrodynamical point of view the Río de la Plata behaves as an estuary since water currents are basically controlled by the oceanic tides penetrating through its mouth. Though the tides amplitude is small (about 0,60 m between low and high tide), the very large river width (minimum 40 km) allows for a tidal prism important enough to dominate the flow regime despite the huge discharge received from the tributaries. The base flow generated by this discharge is strong enough to avoid saline water penetration in the inner river, extending from its head to the upstream of the imaginary line Punta Piedras (Argentina) – Montevideo (Uruguay). The Plata's denomination as a river, instead of as an estuary, arises precisely from this freshwater character. The saline stratification can be detected in the outer region, though complete vertical mixing can occur for strong wind conditions (VAMOS 2001).

The Rio de la Plata dynamics and its environment are strongly affected by the variability of its tributary rivers and wind conditions. Salinity structure and distribution interact with accompanying processes, like sedimentation and ecosystem metabolism. Fisheries in the area, which are a significant economic resource, are affected due to the sensitivity of commercial species to changes in the position of the saline front in the river which controls the spawning and fish recruitment (VAMOS 2001).

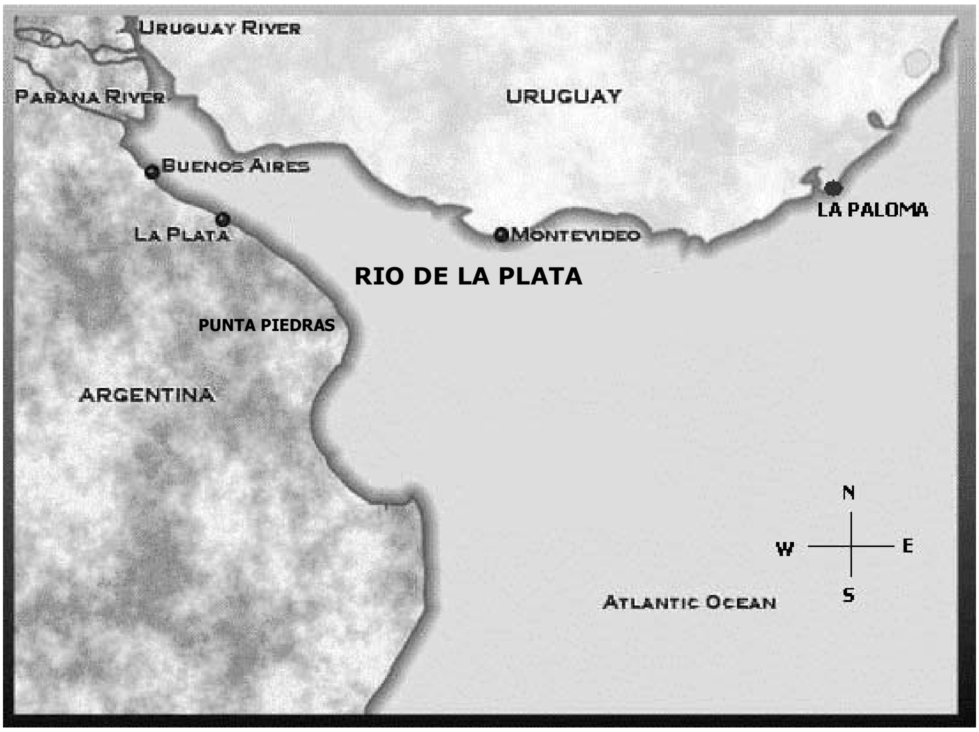

Fig. 1 Map of the Rio de la Plata system

2. HISTORICAL DATA

A study on salinity structures in the Rio de la Plata based on periodic salinity monitoring by the Municipality of Montevideo since 1997 was performed. The frequency of sampling was usually daily during summer time, and weekly during winter. This 5 year salinity monitoring record for 1997-2001 was used as the basis for this modeling study. Four coastal stations located in Montevideo were selected to perform a statistical study of salinity: Sarandí breakwater and the following beaches: Ramirez, Pocitos and Verde (Ramirez, Pocitos and Verde beaches). This study shows minimum and maximum values varying from 1.0 ppt to 32.0 ppt, strong alongshore salinity gradients and high temporal salinity variability. These results agree with the fact that Montevideo City is located in the salinity front of the Rio de la Plata.

During summer time, monthly average salinity values vary from 5 ppt to 25 ppt. For the calibration propose, two representative situations were selected: February of 1998 and March of 2000, corresponding to low and high values of salinity in Montevideo respectively. In both cases, the quantity of data measured month by month was a condition to make a model that represents the reality in a better way.

A comparison between monthly average river discharge and salinity data in the coast of Montevideo shows that salinity values are partially correlated with river discharge: high values of flow discharge correspond to low salinity values and low flow discharge to high salinity values. This results indicate that the position of the salinity front displace toward upstream or downstream depending of the flow discharge. However, a strong influence of the position of the salinity front on wind conditions was found, that could explain some anomalies on the salinity distribution, in which high salinity values were recorded at high flow discharge.

3. NUMERICAL MODEL

A two-dimensional, depth averaged, computer code RMA-10 was used to model the fields of velocities and salinities for the Rio de la Plata. The model describes the variables of state pressure and velocity in three dimensions resolving an assembly of equations based on the combination of the equations of Navier Stokes, conservation of volume, advection-diffusion equation, and an equation of state that relates the density with the salinity, temperature and suspended sediment. In this model the friction stress, the effect of Coriolis and the wind inducing shear stress at the free surface also are represented. The basic equations, with appropriate boundary and initial conditions, are resolved numerical utilizing the method of the finite elements. With a Cartesian coordinate system in which the x-axis is directed toward the East and the y-axis is directed toward the North, the governing equations depth-averaged are (King, 1993):

The momentum equations:

$$\rho\cdot\left[h\cdot\frac{\partial u}{\partial t}+h\cdot u\cdot\frac{\partial u}{\partial x}+h\cdot v\cdot\frac{\partial u}{\partial y}-\frac{1}{\rho}\cdot\frac{\partial}{\partial x}\left(\varepsilon_{xx}\cdot h\cdot\frac{\partial u}{\partial x}\right)-\frac{1}{\rho}\cdot\frac{\partial}{\partial y}\left(\varepsilon_{xy}\cdot h\cdot\frac{\partial u}{\partial y}\right)+g\cdot h\cdot\left(\frac{\partial a}{\partial x}+\frac{\partial h}{\partial x}\right)\right]-g\cdot\frac{h^2}{2}\cdot\frac{\partial\rho}{\partial x}-h\cdot\Gamma_x=0 \tag{1}$$

$$\rho\cdot\left[h\cdot\frac{\partial v}{\partial t}+h\cdot u\cdot\frac{\partial v}{\partial x}+h\cdot v\cdot\frac{\partial v}{\partial y}-\frac{h}{\rho}\cdot\frac{\partial}{\partial x}\left(\varepsilon_{yx}\cdot\frac{\partial v}{\partial x}\right)-\frac{1}{\rho}\cdot\frac{\partial}{\partial y}\left(\varepsilon_{yy}\cdot\frac{\partial v}{\partial y}\right)+g\cdot h\cdot\left(\frac{\partial a}{\partial y}+\frac{\partial h}{\partial y}\right)\right]-g\cdot\frac{h^2}{2}\cdot\frac{\partial\rho}{\partial y}-h\cdot\Gamma_y=0 \tag{2}$$

$$\left(h\cdot\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}\right)+u\cdot\frac{\partial h}{\partial x}+v\cdot\frac{\partial h}{\partial y}+\frac{\partial h}{\partial t}=0 \tag{3}$$

The continuity equation:
The advection diffusion equation:
and the equation of state:

$$h\cdot\left(\frac{\partial s}{\partial t}+u\cdot\frac{\partial s}{\partial x}+v\cdot\frac{\partial s}{\partial y}\right)-\frac{\partial}{\partial x}\left(D_x\cdot h\cdot\frac{\partial s}{\partial x}\right)-\frac{\partial}{\partial y}\left(D_y\cdot h\cdot\frac{\partial s}{\partial y}\right)-\theta_s=0 \tag{4}$$

$$\rho-F(s)=0 \tag{5}$$

where t = time; u, v = depth-averaged velocity components in the horizontal x, y directions, respectively; h = water depth; a = bottom elevation; D_x, D_y = the eddy diffusion coefficients for salinity in x, y directions respectively; ε_{xx}, ε_{xy}, ε_{yx}, ε_{yy} = the turbulent eddy coefficients; g = the acceleration due to the gravity; ρ = water density; Γ_x, Γ_y = the external forces components in the horizontal x, y directions; and θ_s = the source/sink for salinity.

4. MODEL SETUP

The RMA-10 model is applied to the Río de la Plata. The area of study goes from Mar del Plata to the South, from La Paloma to the North, from the continental shelf to the East and from Uruguay and Paraná rivers to the West. The open boundary extends into the continental shelf until approximately the 200 m isobath. The quadrangular mesh used for this study is shown in Fig. 2. The average distance between mesh nodes is 30 km approximately in ocean boundary and 3 km approximately in the zone near to Montevideo city. A total of 1630 elements and 5113 nodes were used.

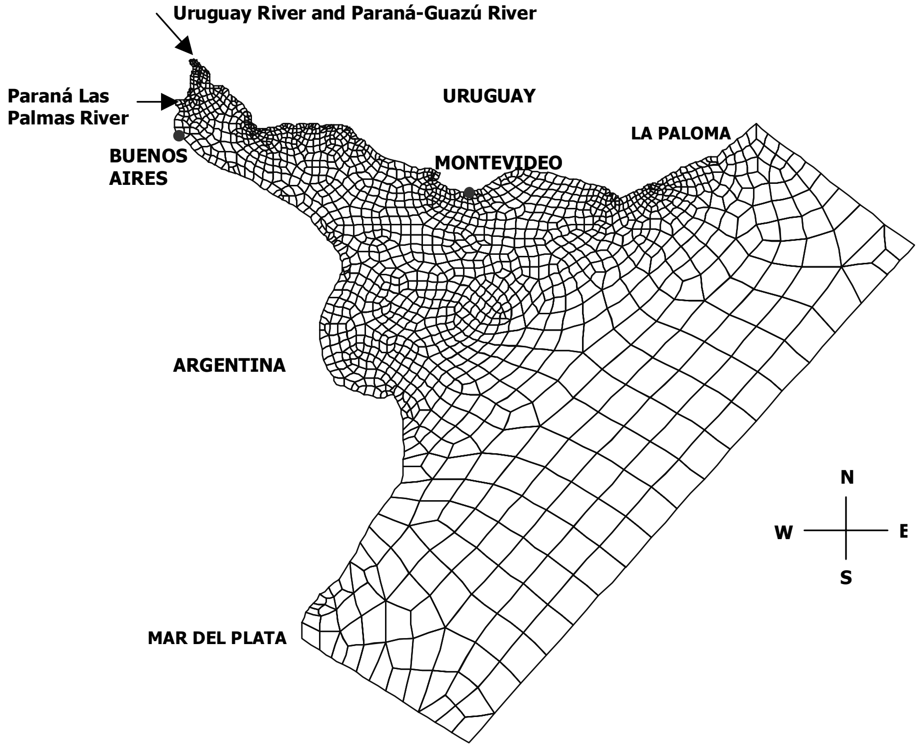

Fig. 2 Mesh of the Rio de la Plata for the RMA-10 model

Since the tidal range is the result of the co-oscillating tide, the momentum equations do not contain any forcing terms, thus, the modeled currents are forced by open boundary conditions. The open boundary conditions are prescribed giving the water surface elevation. The temporal variation of the river discharge, the tide and the wind were considered to make the simulations. The input flow is separated in two sections, one for the discharge of both: Uruguay river and Paraná Guazú river and the second for the discharge of Paraná-Las Palmas river. The model use hourly wind speed and wind direction recorded in a station located in Montevideo. The salinity boundary condition specified on the ocean boundary is a constant value of 34 ppt.

5. MODEL CALIBRATION

During previous studies, the hydrodynamic model was calibrated for the water surface elevation and velocities generated by astronomical tide and storm surges. In this study two parameters were adjusted to simulate the salt field: the scalar factors applied to diffusion coefficients D_x, D_y and the parameter Ψ. In the RMA-10 model the wind-induced shear stress at the free surface is expressed as:

$$\begin{aligned}\Gamma_x &= \Psi \cdot W^2 \cdot \cos(\theta) \\ \Gamma_{\bar{y}} &= \Psi \cdot W^2 \cdot \sin(\theta)\end{aligned} \tag{6}$$

where Ψ = parameter of calibration; θ = wind direction measure anti-clockwise from Easterly; and W = wind speed.

A set of accurate data is required to calibrate the numerical simulation model and to verify its capability to predict the flow and salinity distributions. In this case, different moments were selected: February of 1998 and March of 2000. In order to obtain a solution no dependent of the used initial salinity distribution, it was found necessary to simulate 60 days previous to each calibration period. The resulting calibration parameters were: scalar factors applied to the diffusion in the two horizontal directions 0.4 and a value of Ψ equal to 10×10^{-6}.

Fig. 3 shows the comparison of results with data from the Ramirez station in Montevideo along February 1998. In this case the flow discharge in the river is almost 49,000 m^3/s and the monthly average salinity value in Montevideo is 5 ppt. In general, good agreement was obtained between the model predictions and the measured data in all selected stations.

Fig. 4 shows a comparison of computed and measured salinity time series in Ramirez beach in Montevideo along March 2000. The discharge flow varies between 10,000 and 15,000 m^3/s. The results show that the numerical model can favourably determine the trend of salinity distribution. The same comparison carried out in other stations of Montevideo (data not shown) presents similar results. The model reproduces salinity values rather accurately.

Fig. 5 and 6 shows the salinity field in a specific time for both situations, February 1998 and March 2000, respectively. The first case corresponds to correspond to February 15 at 1:00 a.m. and the salinity front is not located in Montevideo, it is toward the East. Fig. 6 correspond to March 20 at 1:00 a.m. and the salinity front is located around Montevideo.

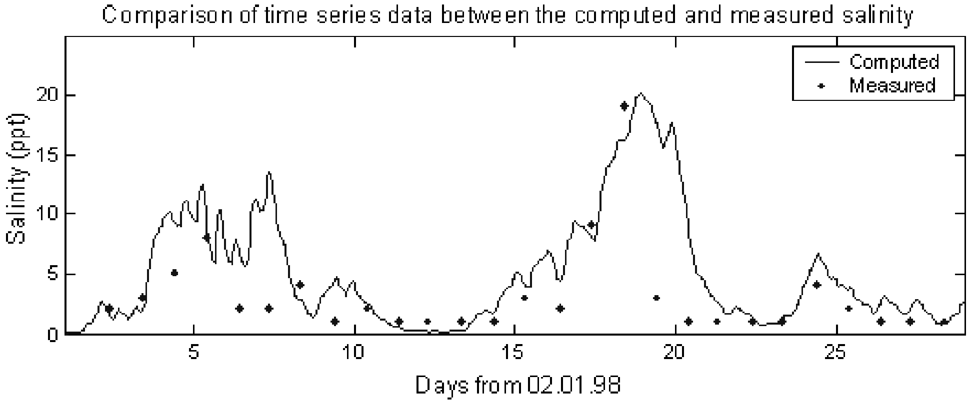

Fig. 3 Time series of computed and measured salinity in Montevideo on February 1998

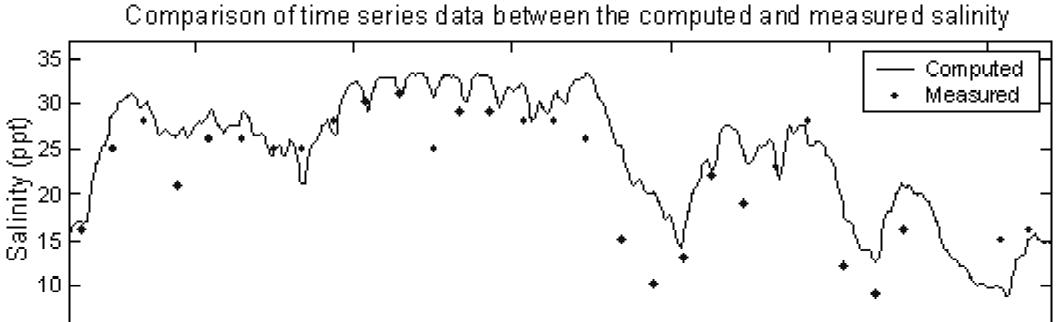

Fig. 4 Time series of computed and measured salinity in Montevideo on March 2000

6. MODEL VERIFICATION

Two situations were simulated to verify the model, June 1997 and January 1999. In both cases the flow discharge is between 15,000 and 30,000 m^3/s.

Fig. 7 shows a comparison of computed and measured salinity time series in Ramirez beach along June 1997. From 06.09.97 the model reproduce acceptably the salinity data although in some cases the difference between calculated and measured salinity is almost 10 ppt. Fig. 8 shows the computed and measured salinity along January 1999 in Ramirez station. The results show that the model reproduces favourably the trend of salinity data.

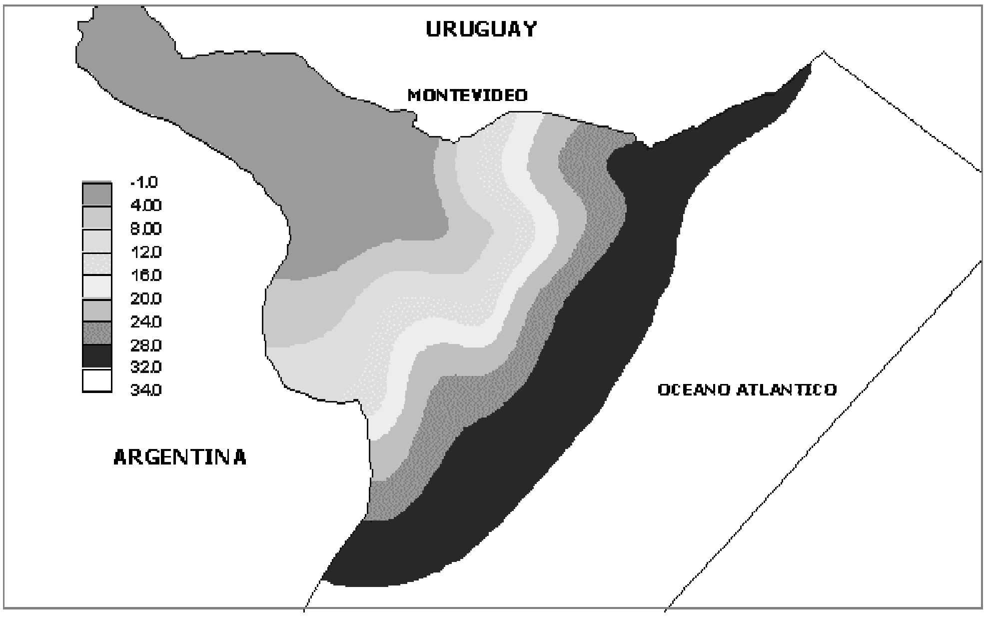

Fig. 5 Salt field (ppt) modeled for 02.15.98 1:00 a.m.

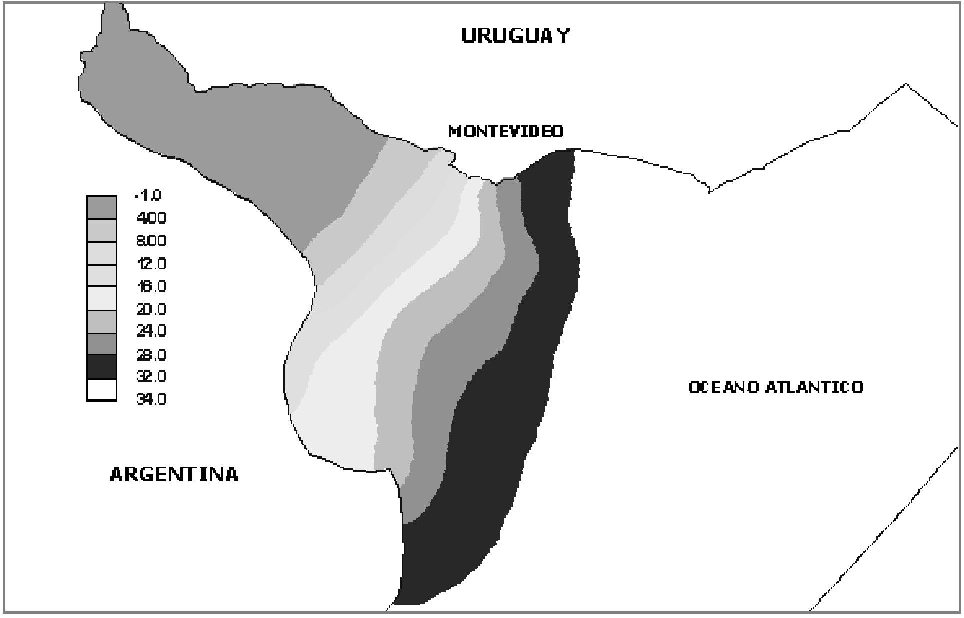

Fig. 6 Salt field (ppt) modeled for 03.20.00 1:00a.m.

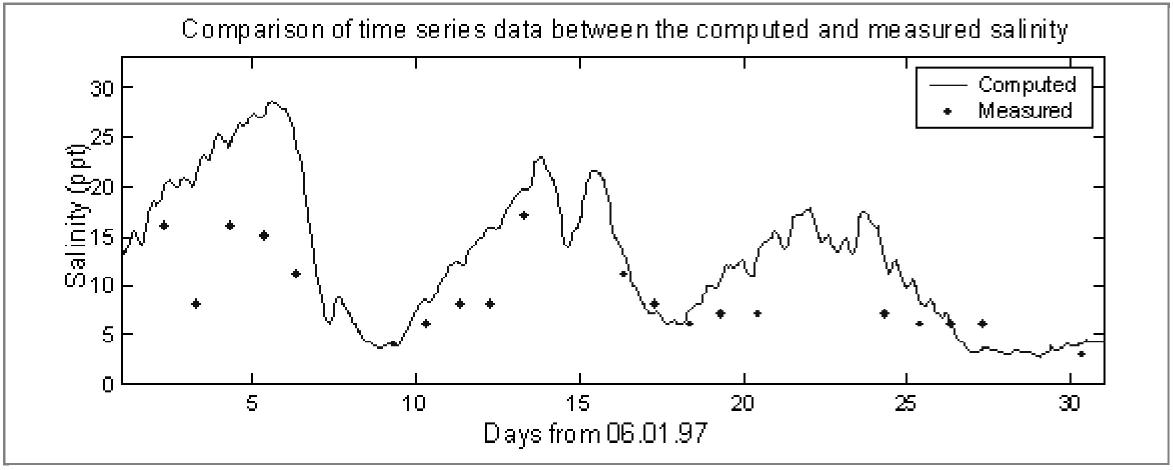

Fig. 7 Time series of computed and measured salinity in Montevideo on June 1997

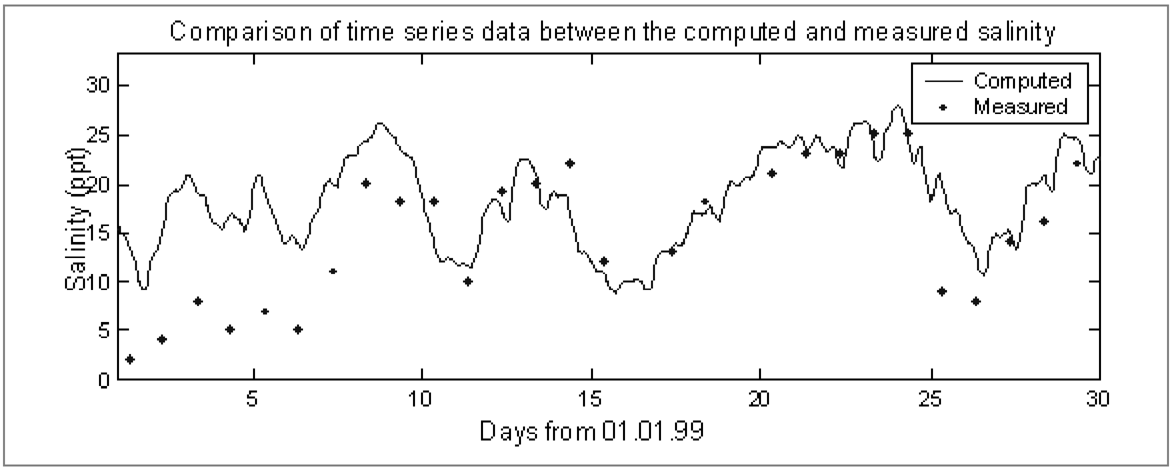

Fig. 8 Time series of computed and measured salinity in Montevideo on January 1999

7. CONCLUSIONS

A two-dimensional, depth-averaged numerical model has been applied to study the circulation and salinity front in the Río de la Plata. The salinity predictions of the model are in good agreement with salinity measured in Montevideo coast. The model results are compared with the recorded data in four different situations. Comparison shows that the model is able to predict the salt field with a reasonably accuracy.

Along this study, satisfactory results have been obtained. Although in some cases, the model does not reproduce some variations of the salinity data. Further effort is needed in order to improve the simulations of the salinity front.

ACKNOWLEDGMENTS

This study was supported by the Project FREPLATA: Protección Ambiental del Río de la Plata y su Frente Marítimo.

REFERENCES

Climatology and Hydrology of the la Plata Basin: A Document of VAMOS Scientific Study Group on the la Plata Basin, 2001. http://www.clivar.org/organization/vamos/index.htm.

C.A.R.P., 1989. Estudio para la evaluación de la contaminación en el Río de la Plata. Comisión Administradora del Rio de la Plata.

Framiñan Mariana B., Brown Otis B., 1996. Study of the Río de la Plata turbidity front, Part I: spatial and temporal distribution. Continental Shelf Research, Vol. 16, No. 10, pp 1259-1282.

King, Ian P., January 1993. RMA-10 A finite element model for three-dimensional density stratified flow. Department of Civil and Environmental Engineering, University of California, Davis.