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# The Salinity Front of the Río de la Plata - a numerical case study for winter and summer conditions

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**Abstract.** A 3-D baroclinic model has been applied to investigate the location of the salinity front of the Río de la Plata. River run-off, tides and mean winds for summer and winter conditions respectively were considered in order to find out the most important factors for the observed seasonal variability of this location. The results show that wind forcing is responsible for the observed variability in summer. In winter, wind forcing is not important, but the river discharge. The resulting surface salinity distributions show a surprisingly good agreement with the present knowledge from observations.

## 1. Introduction and background

The Río de la Plata is located on the eastern coast of South America at approximately 35°S, and drains to the Atlantic Ocean with a total average discharge larger than $22000 m^3 s^{-1}$ [*CARP*, 1989; *Nagy et al.*, 1997]. The river has a NW to SW oriented funnel shape, $320 Km$ long, and $230 Km$ wide at the open mouth. Comprehensive descriptions of this system have been given by *Framiñan and Brown* [1996] and *Guerrero et al.* [1997]. Due to the intense discharge, the estuary presents, when it meets the open ocean, an intense, extended and active salinity front followed by a fresh water plume, whose influence has been tracked up to 23°S [*Campos et al.*, 1999]. The front is not only important for fisheries, but also modifies the coastal circulation and mixing and convection conditions [*Piola et al.*, 2000] with important oceanographic implications.

Analysis of hydrographic data collected during the last 30 years [*Guerrero et al.*, 1997] show that the surface salinity front exhibits an intense variability in the seasonal scale, that seems to be controlled by the balance between onshore and offshore winds, the river discharge, the tides and the Coriolis force. There are two clearly different periods. During fall-winter, a NNE drift of estuary waters along the Uruguayan coast is observed; it has been related [*Guerrero et al.*, 1997] to a balance between onshore and offshore winds and a maximum in the continental drainage. Reciprocally, during spring-summer the presence of fresh water along the Argentinean coast up to 37°S and the penetration of Shelf waters up to Punta del Este have been attributed to onshore dominant winds and a minimum in the runoff. In this paper, by means of process oriented numerical experiments, the influence of the main driving forces on the surface salinity front variability is tested. The 3-D baroclinic primitive equations Hamburg Shelf Ocean Model [*Backhaus*, 1983, 1985] is applied. The isolated and combined effect of the forcings under realistic bathymetry and coastline is analyzed. Despite the idealistic conditions, the simulations are able to capture the most outstanding features of the observed variability.



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## 2. Description of numerical experiments

### 2.1. Model description

The HamSOM model used for our simulations is a widely used model developed at the University of Hamburg by *Backhaus* [1983, 1985]. It is a 3-D baroclinic primitive equation model, that has been applied to many shelf seas worldwide (see, for example, *Backhaus and Haimbucher*, 1987; *Rodriguez et al.*, 1991; *Stronach et al.*, 1993), showing to be very robust in studying the shelf sea dynamics. The domain chosen for the simulations, that spans from 31.5°S to 42°S and from 65.5°W to 51.5°W is shown in Fig. 1, together with the bathymetry and the coastline seen by the model. Given the fact that ETOPO5 bathymetry data display unrealistic very shallow features over the Continental Shelf, the topography has been built by combining this data set with data provided by the Servicio de Hidrografía Naval of Argentina for depths shallower than $200m$. The horizontal resolution has been set to 5′ in latitude and 6.66′ in longitude (approx. $9Km$), small enough to properly describe the problem involved dynamics and the bottom topography and coastline. Thirteen vertical levels, with bottoms at 6, 10, 15, 20, 40, 60, 100, 150, 250, 500, 1000, 3000 and $5500m$, have been used. The horizontal eddy viscosity has been set to $100 m^2 s^{-1}$; the vertical eddy viscosity is model computed following *Pohlmann* [1991]. The bottom friction factor of 0.0025 was reduced to 1/5 of this value at depths shallower than $50m$ at the Rincón de Bahía Blanca region; this change allows to reproduce better the tidal amplitudes observed in that area, characterized by a muddy bottom and large tidal flats. The timestep was set to 10 min for all of the runs.

### 2.2. Forcing

Three different forcing factors have been considered in our simulations: winds, river discharge and tides.

More than 97% of the total Río de la Plata water input is supplied by the Paraná and Uruguay rivers, which drain from two different basins. On very long periods, the mean

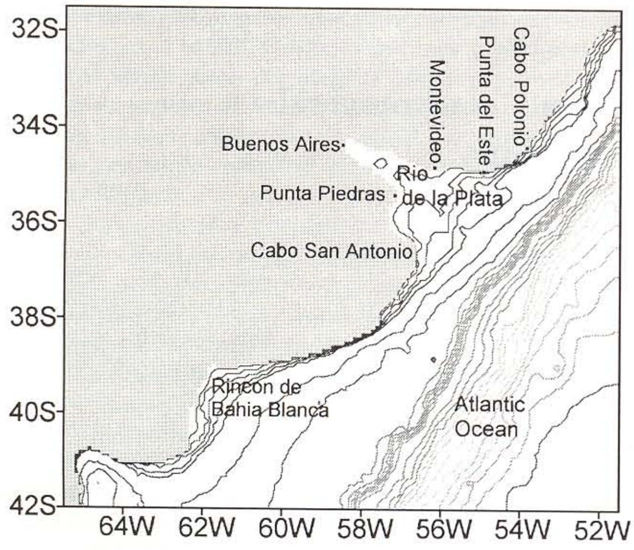


**Figure 1.** Location and bathymetry of the study area. Plotted isobaths start at $5m$, and go up to $25m$ every $5m$, up to $200m$ every $25m$ and up to $6000m$ every $250m$. The shaded zone represents the land and coast line as it is seen by the model.

does not exhibit a clear seasonal cycle; even though both rivers have a seasonal signal, the variation is moderate and the cycles are partly opposed and mutually compensated. Even though the historical mean flow of both rivers together is around $20000m^3s^{-1}$, during recent decades Paraná river flow has shown an increasing linear trend; since 1978 even relatively dry years have been wetter than the historical and 30 year mean and during the period 1983-1992, the mean discharge has been $25000m^3s^{-1}$, what represents an increment of 25% with respect to historical values [*Nagy et al.*, 1997]. Moreover, during this period, the discharge (shown in Fig. 2) exhibits a clearer seasonal pattern, with a minimum during the summer of around $20000m^3s^{-1}$ and a maximum of around $30000m^3s^{-1}$ in fall-winter. In the case study presented here these characteristic values have been chosen.

In order to characterize summer and winter winds, a climatology of the 1991-1995 period of NCEP wind stress reanalysis data has been used. Summer is defined as Jan-Feb and winter as Jul-Aug. An interpolation of this data to the model grid is displayed in Fig. 3; a large variation is evident from warm to cold season over the Río de la Plata. During the summer the mean winds are mainly from the E. In winter, as the result of almost a balance between offshore and onshore winds, the mean winds are small and from the NNW.

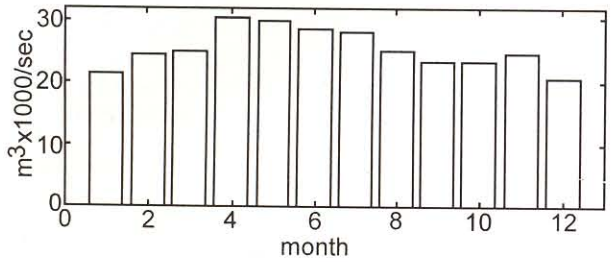


**Figure 2.** Freshwater total input to the Río de la Plata; monthly mean for the decade 1985-1994. Adapted from *Nagy et al.*, [1997].

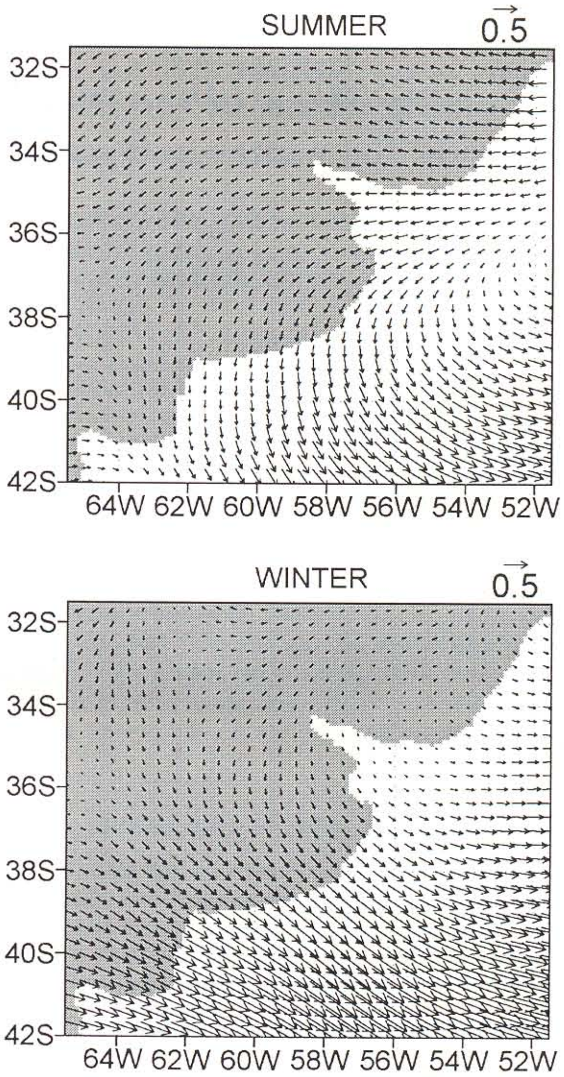


**Figure 3.** Summer and winter mean wind stress for the area of study derived from NCEP reanalysis data for the period 1991 – 1995. Only one every four vector is shown; units are $dyn\ cm^{-1}(10^{-1}\ N\ m^{-2})$.

## 2.3. Results

In a first set of numerical experiments, the effect of the river discharge seasonal variation was analyzed. Two different runs were conducted, starting with an overall salinity of 33, characteristic of the outer shelf waters [*Guerrero et al.*, 1997], the temperature field fixed to 10°C, and different river discharges of $20000m^3s^{-1}$ (summer case) and $30000m^3s^{-1}$ (winter case). On the boundaries, salinity is clamped to 33 and the sea surface elevation set to zero. The so obtained first layer salinity after 5 months of integration is shown in Fig. 4 a and b. After that period, the fresh water has fulfilled the upper part of the estuary and a meandering and clearly topography influenced front has been established. The fresh water plume extends northward along the coast, forced by the Coriolis force, deviating to the left on the Southern Hemisphere. Even though some degree of difference is observed between the summer (Fig. 4 a) and winter (Fig. 4 b) cases, being in this last case the plume more extended to the N and to deeper waters, the difference cannot account for the observed variability.

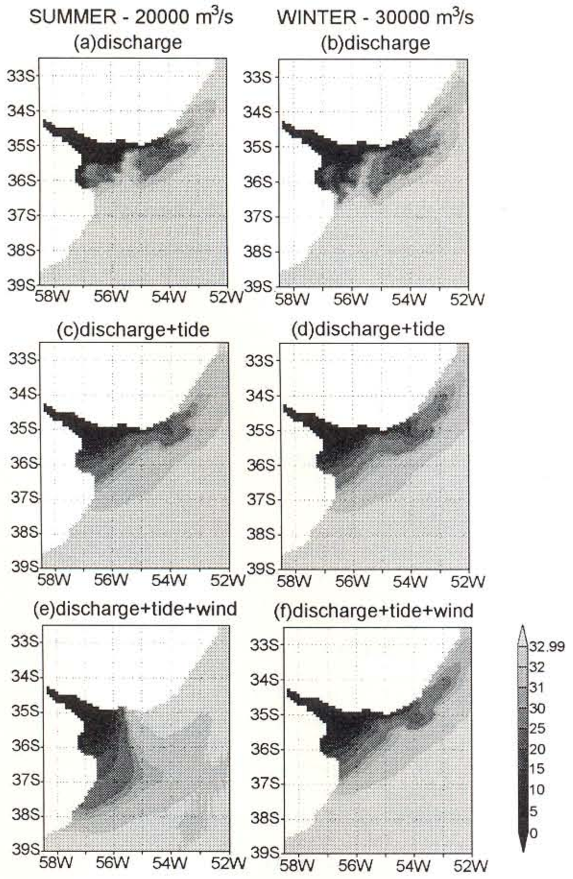


**Figure 4.** Results of the three sets of experiments forced with river runoff (upper panel), runoff and tides (central panel) and also winds (lower panel); the figures display the first layer simulated salinity. Note that contour intervals are not regular.

In order to evaluate the effect of the tides, two additional numerical experiments were carried out. On them, an extra boundary condition for the sea surface elevation is imposed. It varies according to the amplitude and phase of the $M_2$ tidal component, that explains for most of tidal variability in the region, as it is given by a larger scale shelf model [*Simionato et al.*, 2000]. At the Río de la Plata entrance the $M_2$ amplitude amounts to $65cm$ in the south and few centimeters in the north, whereas the $S_2$ amplitude is approximately 1/6 of those values. The results for the first layer salinity of these runs are shown in Fig. 4 c and d. In the wake of the tidal wave and the related mixing, the frontal zone has spread and its influence is seen farther away along the northern coast of Uruguay. Even though the summer (Fig. 4 c) case is very different compared to observations, the winter (Fig. 4 d) case exhibits most of the characteristics displayed by the historical data. Important features are the position of the 25 and 30 isohalines at the Argentinean (western) coast, and the bathymetry related "curvature" of the salinity front in front of Punta del Este - Cabo Polonio (see *Guerrero et al.*, 1997, Fig 4 a). Given that the winter wind is almost zero, this result is merely anticipating that the wind does not play a dominant role during this period.

In a third set of experiments the wind forcing is included. Results for first layer salinity are shown in Fig. 4 e and f. For the summer case (Fig. 4 e), the effect of the easterly preponderant winds is to produce an Ekman transport to the S that displaces the surface salinity front to the W along the Uruguayan coast and to the S along the Argentinean coast. The general qualitative and (despite the simplicity of our simulations) quantitative resemblance between the model and data derived pictures is outstanding (see *Guerrero et al.*, 1997, Fig 5 a). The 25 and 30 isohalines are located slightly west of Punta del Este and slightly south of Punta Rasa. This last result suggests that the influence of outer current systems is not relevant for the location of the mean position of the front along the year. The only feature observed from data and not well described by our simulations is the presence of a second fresh water plume along the northern Uruguayan coast. It has been suggested [*Guerrero et al.*, 1997] that it is due to a southward coastal drift of fresh water along the Brazilian and Uruguayan coasts, originated in Lagoa dos Patos (32°S, not included into our simulations) a coastal lagoon with a net average outflow of $8600m^3s^{-1}$ during 200 days a year [*Herz and Mascarenhas*, 1993], and maintained by the spring-summer prevailing winds [*Pereira*, 1989]. The winter case (Fig. 4 f), in turn, does not exhibit a significant difference when wind is included (compare to Fig. 4 d). This last result suggests that the winter regime is mainly explained by a combination between the amount of the discharge and the Coriolis effect that deflects the fresh water plume to the N along the coast. As long as the average wind intensity is very small during this season but its direction is almost from the N, the induced Ekman drift has a positive but small influence on the plume extension. The qualitative and quantitative resemblance between model and data is surprising, being the model able to properly reproduce the position of the front related (25 and 30) isohalines and their shape. Outstanding features are the presence of a tongue with salinity lower than 25 in front of Cabo Polonio (probably related to the bathymetry) and the location of the 250 and 30 isohalines near Cabo San Antonio respectively (see *Guerrero et al.*, 1997, Fig. 4 a).

Since the river discharge seems to be the leading force during the winter, and historical data do not exhibit an in-

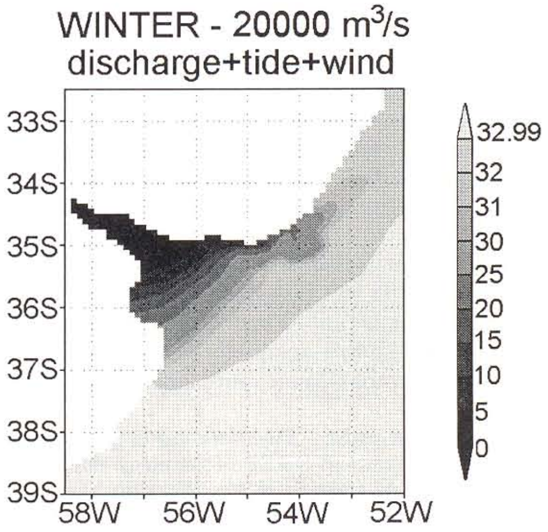


**Figure 5.** Simulation for winter winds, tides and a discharge of $20000m^3s^{-1}$; the figure displays the upper layer salinity.

tense variation of this parameter along the year, except during the last part of 20$^{th}$ Century, a relevant question is how much the winter mean condition is affected by a reduction of the river outflow. In an attempt to provide an indication for that, another experiment in which the model was run for tides and winter wind forcing, but the discharge was reduced to $20000 m^3 s^{-1}$ was carried out. The surface modeled salinity obtained from this numerical experiment is shown in Fig. 5. When comparing this figure to the $30000 m^3 s^{-1}$ case (Fig. 4 f) and with observations it is seen that even though the qualitative picture is preserved, the location of the frontal related isohalines as well as the tongue in front of Cabo Polonio, are better represented for the $30000 m^3 s^{-1}$ case. In the case of reduced discharge the low salinity tongue is not able to penetrate as far as is suggested by the observations. Because most of the observations correspond to the last period of 20$^{th}$ Century [*Guerrero et al.*, 1997] this is in any case a consistent result that reaffirms our conclusions.

A remaining question is how much our results are influenced by the election of the outer salinity conditions. In order to account for that, a last set of simulations was performed in which the initial and boundary conditions for salinity were set to 35 instead of 33. The results (not shown) do not exhibit any important departure with respect to the former case, suggesting that the system seasonal variability is not dependent upon this factor, but mainly determined by the tides, winds and river outflow.

## 3. Summary and conclusions

The 3-D baroclinic numerical experiments indicate that most of the seasonality of the surface salinity front is due to the winds seasonal variation, meanwhile the change of the river discharge exhibits a much smaller influence. The tides play an important role on producing mixing and extending the influence of the fresh water plume to the N. The winter condition is mainly explained by a combination between the amount of the discharge and the Coriolis effect, which deflects the fresh water plume to the N along the coast. Since the average wind intensity is very small during this season but its direction is offshore, it has a small but positive effect on the plume extension to the ocean. During the summer, even though the amount of the river discharge is large enough to produce a similar picture to the one observed in winter, the predominant easterly winds inhibit the plume extension and force the fresh waters to the W along the Uruguayan coast, and SW on the Argentinean side. Even though historical data do not exhibit an intense seasonal variation on the river outflow, except during the last part of 20$^{th}$ Century, our results compare better to data when this variation is included into the simulation. This last is probably due to the fact that most of the observations were taken during that period. Finally, the influence of the exterior mean condition is analyzed; results suggest that the system-analyzed variability is quite independent from it.

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