

The influence of the Plata River discharge on the western South Atlantic shelf

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[1] The influence of the Plata, the second largest river in South America, extends along a coastal strip of 1300 km. Historical hydrographic and wind data and numerical simulations are combined to determine the seasonal and interannual variability of the Plata plume and its relationship to the magnitude of the river discharge and the intensity and direction of the wind stress. Our results indicate that the seasonal variability of the river plume is controlled by the alongshore component of the wind stress. During El Niño the effects of the wind and precipitation anomalies tend to compensate each other, preventing anomalous northeastward plume extensions associated to large outflow events. Numerical experiments confirm this finding and indicate that during El Niño the discharge from the Plata River spreads offshore. **Citation:** Piola, A. R., R. P. Matano, E. D. Palma, O. O. Möller Jr., and E. J. D. Campos (2005), The influence of the Plata River discharge on the western South Atlantic shelf, *Geophys. Res. Lett.*, 32, L01603, doi:10.1029/2004GL021638.

1. Introduction

[2] The Plata basin is the fourth largest in the world and covers 20% of the surface of South America (Figure 1). This hydrographic system extends from the subequatorial zone through the tropics, funneling its numerous tributaries into the Plata river (Plata hereafter) whence $22,000 \text{ m}^3 \cdot \text{s}^{-1}$ are discharged into the South Atlantic Ocean and spread along the coasts of Argentina, Uruguay and Brazil (Figure 1). This outflow influences the near-shore ecosystem [Ciotti *et al.*, 1995; Muelbert and Sinque, 1996; Sunyé and Servain, 1998] and is an important vector for the export of carbon from the continent into the sea [Degens *et al.*, 1991]. In spite of its importance, however, there is only scant information about the fate of the Plata plume after it is entrained into the continental shelf. Historical hydrographic data suggests that in the austral winter (JAS) the Plata plume reaches Cape Santa Marta Grande ($\sim 28^\circ\text{S}$), while in the summer (DJF) it retracts to 32°S [Piola *et al.*, 2000]. There is strong evidence that large precipitation anomalies

associated with El Niño (EN) [Ropelewski and Halpert, 1987; Kiladis and Diaz, 1989] events significantly increase the river discharge [Depetris *et al.*, 1996; Mechoso and Pérez-Iribarren, 1992]. The effect of these anomalies on the path of the river plume, however, remains undetermined. We use hydrographic observations, atmospheric reanalysis winds and numerical experiments to discuss the seasonal and interannual variations of the path of the Plata plume over the southwestern Atlantic.

2. Data and Methods

[3] We use historical hydrographic data collected after 1950 and Plata monthly discharge data (Q) for the period 1931–2001 [Jaime *et al.*, 2002]. Wind stress data are from global reanalysis (NCEP [Kistler *et al.*, 2001] and ECMWF [Trenberth *et al.*, 1989]). To validate these global data sets we used wind data from a coastal station at Chui ($\sim 33^\circ\text{S}$). Wind stress was decomposed in cross-shore (τ_x , 125°T) and along-shore (τ_y , 35°T) components. These three wind stress estimates show positive (northeastward) mean values during the austral winter, and negative (southwestward) mean values during the summer.

[4] The numerical experiments were done with the Princeton Ocean Model [Blumberg and Mellor, 1987], a 3-D nonlinear primitive equation model with a curvilinear orthogonal coordinate system in the horizontal and a bottom-following (sigma) coordinate in the vertical. The model domain extends from 20 to 55°S and from the coast to 40°W . The model has 25 sigma-levels and a horizontal resolution of ~ 4 km near the coast. The model included a realistic representation of the bottom topography, was initialized with climatological mean values of temperature and salinity and forced with NCEP winds. The inflows and outflows of the Malvinas (Falkland) and Brazil Currents were obtained from the Parallel Ocean Climate Model (experiment 4C [Tokmakian and Challenor, 1999]). The amplitude and phase of the principal tidal constituents are from the Oregon State University TPXO.5 tidal model [Egbert *et al.*, 1994]. The model was spun-up for an initial 3-year period followed by an additional 1-year run for analysis.

3. Analysis

[5] To characterize the seasonal migrations of the Plata over the southwestern Atlantic shelf we compiled sea surface salinity (salinity hereafter) data from a region close to Cape Sta. Marta (Figure 2). Although the seasonal variations of Q are relatively small, the salinity time series shows a distinct seasonal change with a minimum during the winter and a maximum in summer. Since there is no

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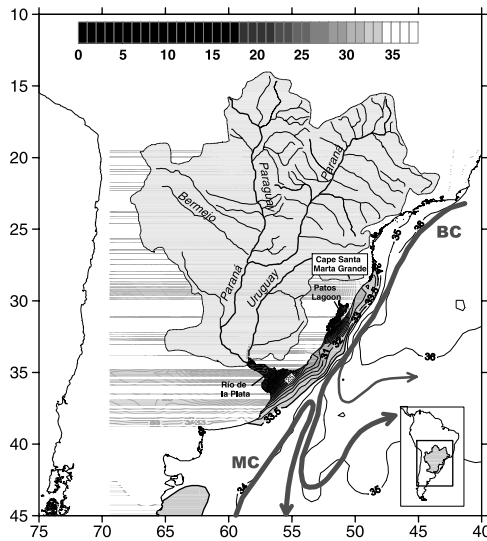


Figure 1. The Plata basin indicating the major tributaries and mean winter surface salinity in the southwest South Atlantic. Contour interval is 1. Salinity < 33.5 is shaded in gray. The Brazil Current (BC) and Malvinas Current (MC) are shown schematically.

significant local runoff, and the Patos influence is limited to the region near the mouth [Zavialov *et al.*, 2003], the salinity minimum observed in the bottom panel of Fig. 2 is associated with a northward penetration of the river plume, and the maximum with a retraction. Since the lowest salinities (~ 30) correspond to periods of southwesterly

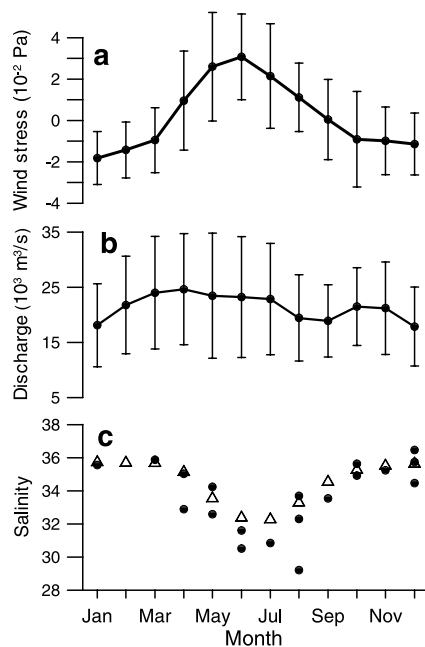


Figure 2. Seasonal variation of (a) alongshore wind stress (Pa), (b) Plata outflow ($\text{m}^3 \text{s}^{-1}$) and (c) sea surface salinity near Cape Santa Marta Grande from data (\bullet) and model (Δ). The monthly mean values of river outflow and wind stress correspond to the period 1949–2001. The vertical bars indicate standard deviations.

winds (MJJ), and the highest (~ 35) to periods of northeasterly winds (DJF), the hydrographic data suggest that the migrations of the Plata plume are highly influenced by the seasonal changes of the wind stress.

[6] To estimate the influence of the magnitude of the Plata discharge on the meridional penetration of its plume, we computed meridional distributions of nearshore salinity during periods of high and low river discharges (Figure 3). To account for the propagation of the salinity signal associated to outflow variations, based on the results of Pimenta [2001], the outflow data was lagged as a function of outflow magnitude and distance to the river mouth. During the periods of high precipitation Q reached $42,000 \text{ m}^3 \cdot \text{s}^{-1}$ (with peaks $> 60,000 \text{ m}^3 \cdot \text{s}^{-1}$). Conversely, during periods of low precipitation Q decreased to $< 12,000 \text{ m}^3 \cdot \text{s}^{-1}$. Theoretical arguments indicate that high river discharges should lead to increased plume penetrations [Garvine, 1999]. Surprisingly, however, and in spite of the significant discharge variations, the data show similar salinity distributions for the periods of high and low outflow (Figure 3).

[7] The meridional penetration of a river plume is largely controlled by the magnitude of Q and the direction and amplitude of the wind stress forcing [Kourafalou *et al.*, 1996]. To illustrate these relations we computed τ_y and Q for the period 1949–2001 (Figure 4). To eliminate the strong seasonal signal contained in the wind stress, the data was low-passed filtered using a Kaiser filter [Hamming, 1977] with a cutoff frequency of 1/14 months. During the period considered there were seven events of high river discharge ($Q > 30,000 \text{ m}^3 \cdot \text{s}^{-1}$), five of which were associated with EN events (all but 1959 and 1990). Of these events only one, in 1992, had wind stress conditions favorable for a northward spreading of the river plume. During all the events the wind forcing either opposed the penetration of the plume or was negligible.

4. Numerical Simulations

[8] The above discussion indicates that at interannual time scales the salinity structure in the nearshore region is determined by a balance between the wind stress forcing and the magnitude of the river discharge numerical experiments forced by mean monthly winds show salinity variations in good agreement with the observations. To

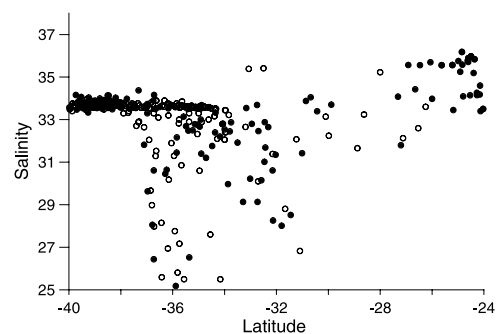


Figure 3. Winter sea surface salinity over the continental shelf as a function of latitude for periods of high river discharge (\circ , $> 30000 \text{ m}^3 \cdot \text{s}^{-1}$) and low discharge (\bullet , $< 15000 \text{ m}^3 \cdot \text{s}^{-1}$). Outflow data was lagged to account for the delay in propagation of the low salinity signal along the shelf.

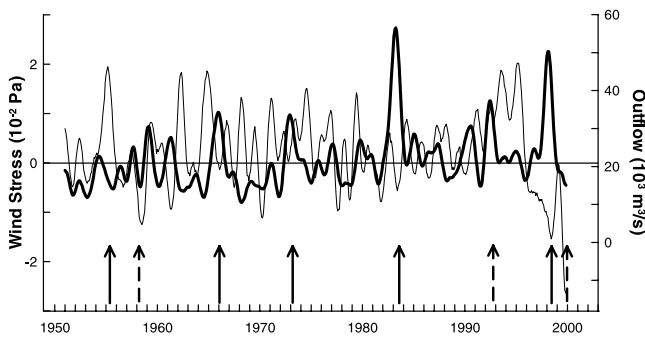


Figure 4. Time series of low frequency river discharge (heavy line, m^3s^{-1}) and along-shore wind stress (thin line, Pa). These data have been low passed filtered to eliminate the strong seasonality in the wind stress. Solid arrows mark periods of large, out of phase fluctuations, and dashed arrows periods of in-phase fluctuations.

investigate the interannual variability we did two numerical experiments. The first experiment emulated the conditions of the 1978 La Niña (LN), during which $Q = 12,950 \text{ m}^3\text{s}^{-1}$ and $\tau_y = 0.05 \text{ Pa}$. The second experiment emulated EN conditions from the 1998 event during which Q reached $65,000 \text{ m}^3\text{s}^{-1}$ and $\tau_y = -0.025 \text{ Pa}$. The experiments show the strong control of the wind on the spreading of the river plume (Figure 5). In the LN simulation there is a relatively low salinity coastal strip that extends into the South Brazil Bight ($\sim 24^\circ\text{S}$), about 1400 km from the estuary. In contrast, the simulation replicating EN conditions shows a wider plume that only reaches to 32°S . In this experiment the alongshore spreading of the plume is arrested by the effect of the opposing winds that force the low salinity waters to flow in the offshore direction. In agreement with our data analysis, therefore, the simulations indicate that the meridional spreading of the Plata plume is largely controlled by τ_y .

5. Discussion and Conclusions

[9] The scale of the along-shore plume penetration (L_y) against the opposing summer northeasterly winds can be

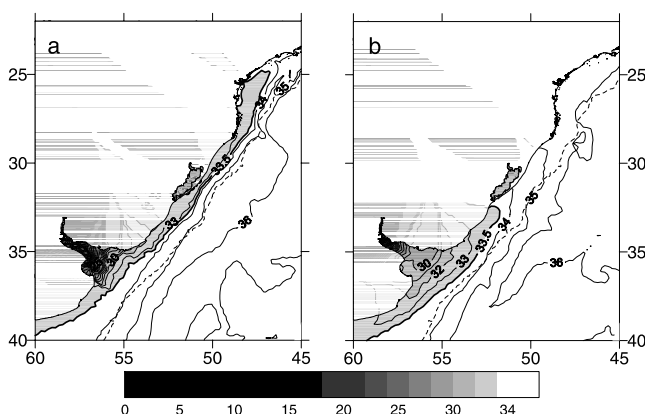


Figure 5. Snapshots of sea surface salinity from the numerical simulations (a) from fall of 1978 and (b) from fall of 1998. Salinity < 33.5 is shown in grayscale. The dashed line is the 200 m isobath.

determined from a simple mass balance between river discharge and the offshore Ekman flow ($Q = \tau_y L_y H_p / D \rho f$). $Q = 23,000 \text{ m}^3\text{s}^{-1}$, ρ the mean water density ($1023 \text{ kg}\cdot\text{m}^{-3}$), f the Coriolis parameter ($7.7 \times 10^{-5} \text{ s}^{-1}$), D the Ekman depth (30 m), H_p the plume thickness (10 m) and $\tau_y = -0.02 \text{ Pa}$. Our balance assumes that the fraction H_p/D of Ekman transport is composed of river water. This simple calculation yields $L_y = 270 \text{ km}$, which is a reasonable approximation to the observed extent of the plume. The above results indicate that the meridional migrations of the Plata plume are regulated by the along-shore component of the wind stress forcing. During EN years, Q is significantly augmented by large precipitation anomalies over the river basin. These increases, however, do not lead to a significant northward penetration of the plume due to the arresting effect of τ_y . During these periods, the low salinity waters are displaced offshore. The out-of-phase relation between Q and τ_y anomalies is not fortuitous. The high precipitation anomalies over South America and the northeasterly wind anomalies over the southwestern Atlantic are related to the intensification of the western portion of the South Atlantic high pressure center [Barros *et al.*, 2002; Silvestri, 2004]. This intensification leads to low-level, southward advection of warm air along the eastern slope of the Andes, related to the high precipitation anomalies [Grimm *et al.*, 2000] and to the development of southwestward wind anomalies over the southwestern Atlantic shelf (Figure 6).

[10] Although the out-of-phase relation between τ_y and Q is a ubiquitous characteristic of the observations, during a few events they were in phase. During the fall and early winter of 1992, for example, there was a combination of $Q = 43,300 \text{ m}^3\text{s}^{-1}$ and $\tau_y = 0.035 \text{ Pa}$. In contrast, in summer of 1999–2000 Q decreased to $12,650 \text{ m}^3\text{s}^{-1}$ and $\tau_y = -0.033 \text{ Pa}$. These events must have led to exceptionally large fluctuations of the water mass structure. The later is the probable explanation for the anomalous plankton and fish distribution observed in the summer of 2000 [Mianzan *et al.*, 2001]. During the winter of the 1993 EN in-situ observations indicated the existence of a low sea surface temperature ($< 17^\circ\text{C}$), salinity (< 34), and a persistent northeastward surface drift in the South Brazil Bight [Campos *et al.*, 1996]. The hydrological data indicates that at that time the Plata discharge was only $20,300 \text{ m}^3\text{s}^{-1}$. The alongshore

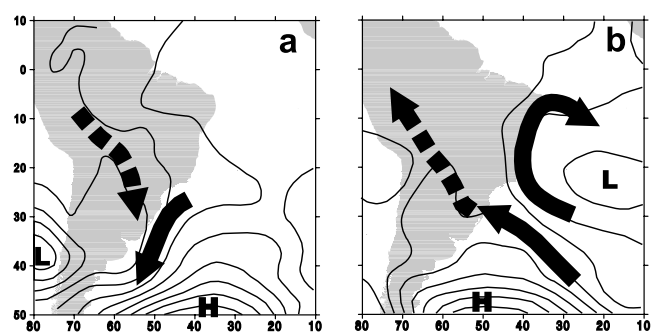


Figure 6. Schematic diagrams of low level atmospheric circulation anomalies relative to neutral periods based on the NCEP reanalysis for the period 1963–1999 associated to (a) EN and (b) LN in AMJ. Arrows indicate wind anomalies and contours geopotential anomalies at 1000 hPa, plotted every 3 gpm.

wind stress anomalies instead were the third largest of the period 1949–2001, only exceeded in the late summer of 1955 and the early fall of 1995, suggesting that the anomalous conditions observed in the South Brazil Bight during the winter of 1993 were associated with southwest-erly anomalies in the wind stress forcing.

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