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Space–time variability of the Plata plume inferred from ocean color

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ABSTRACT

Satellite ocean color and surface salinity data are used to characterize the space–time variability of the Río de la Plata plume. River outflow and satellite wind data are also used to assess their combined effect on the plume spreading over the Southwestern South Atlantic continental shelf. Over the continental shelf satellite-derived surface chlorophyll-*a* (CSAT) estimated by the OC4v4 SeaWiFS retrieval algorithm is a good indicator of surface salinity. The log (CSAT) distribution over the shelf presents three distinct modes, each associated to: Subantarctic Shelf Water, Subtropical Shelf Water and Plata Plume water. The log (CSAT) 0.4–0.8 range is associated with a sharp surface salinity transition across the offshore edge of the Plata plume from 28.5 to 32.5. Waters of surface salinity <31, derived from mixtures of Plata waters with continental shelf waters, are associated to log (CSAT)$>$0.5. In austral winter CSAT maxima extend northeastward from the Plata estuary beyond 30°S. In summer the high CSAT waters along the southern Brazil shelf retreat to 32°S and extend south of the estuary to about 37.5°S, only exceeding this latitude during extraordinary events. The seasonal CSAT variations northeast of the estuary are primarily controlled by reversals of the along-shore wind stress and surface currents. Along-shore wind stress and CSAT variations in the inner and mid-shelves are in phase north of the estuary and 180° out of phase south of the estuary. At interannual time scales northernmost Plata plume penetrations in winter (~1200 km from the estuary) are associated with more intense and persistent northeastward wind stress, which in the period 2000–2003, prevailed over the shelf south of 26°S. In contrast, in winter 1999, 2004 and 2005, characterized by weaker northeastward wind stress, the plume only reached between 650 and 900 km. Intense southwestward plume extensions beyond 38°S are dominated by interannual time scales and appear to be related to the magnitude of the river outflow. The plume response to large river outflow fluctuations observed at interannual time scales is moderate, except offshore from the estuary mouth, where outflow variations lead CSAT variations by about 2 months.

1. Introduction

Continental runoff discharges freshwater, sediments, organic material and dissolved substances onto the continental shelf producing a significant impact on the ocean's physical, chemical and biological properties. The Río de la Plata (Plata hereafter) drains nearly 20% of the surface area of South America and discharges about 23,000 $m^3 s^{-1}$ of freshwater on the western South Atlantic shelf at 35°S. The estuarine front is characterized by vertical nutrient fluxes, which produce fertilization and high chlorophyll-*a* (chl-*a*) concentrations near the estuary (Carreto et al., 1986), creating a nursery for coastal species (Acha et al., this issue). Several hundred kilometers northeast from the estuary the low salinity coastal waters derived from the Plata are also associated with high nutrient and chl-*a* concentrations, phytoplankton (Ciotti et al., 1995), benthic foraminifera (Eichler et al., this issue) and commercially important species (Muelbert and Sinque, 1996; Sunyé and Servain, 1998). Hydrographic, satellite and biological data collected over the shelf suggest that at times the Plata influence may extend northeastward beyond 1000 km from the estuary (e.g. Emilson, 1961; Campos et al., 1999) and may explain the observation of subantarctic species as far north as 22°S (Stevenson et al., 1998).

Changes from lower river outflow, and on-shore and upwelling winds in austral spring–summer to larger outflow, and offshore and downwelling winds in fall–winter, alter the upper layer salinity distribution within the estuary (Guerrero et al., 1997; Framiñan et al., 1999). Historical hydrographic data reveal that the meridional extension of the Plata plume undergoes large amplitude seasonal fluctuations. Based on the surface salinity distribution the Plata waters extend northeastward beyond 26°S in austral fall–winter and retract to about 33°S in spring–summer

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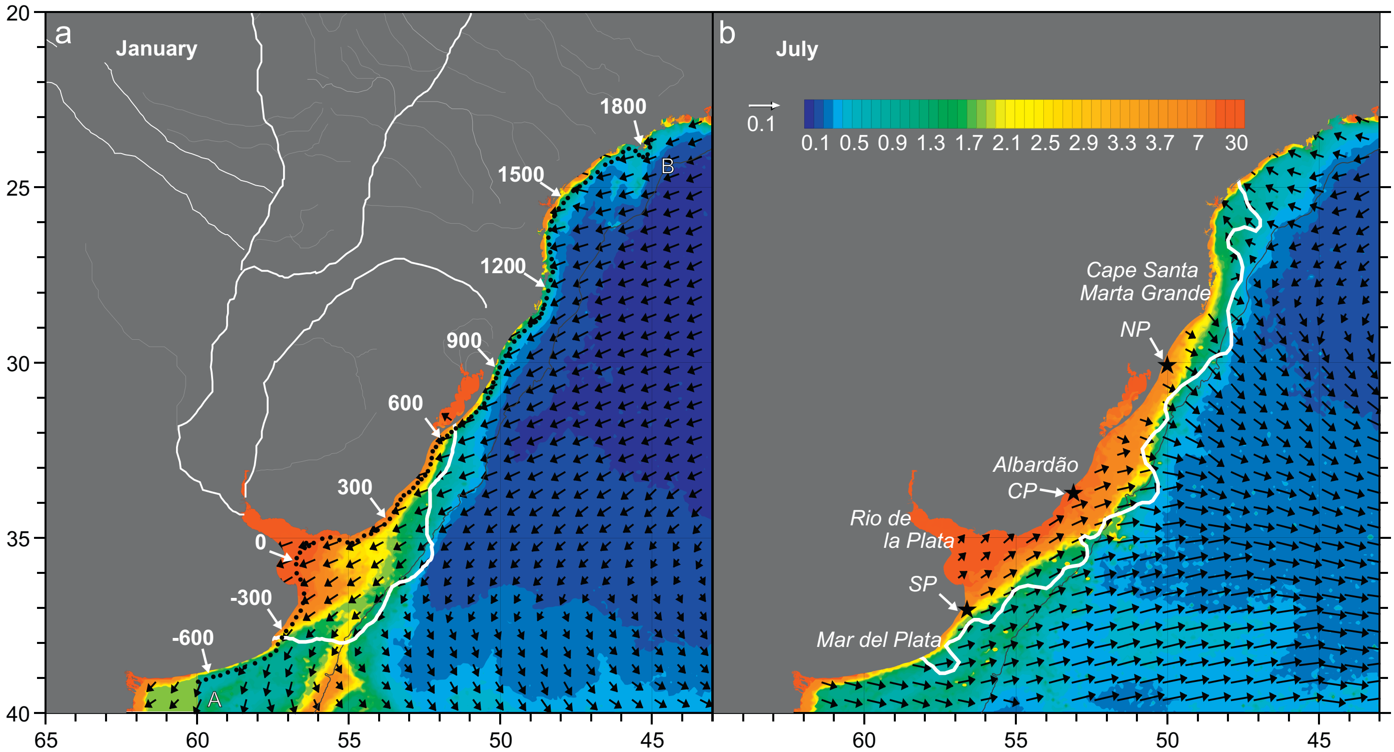

Fig. 1. January (a) and July (b) climatological CSAT (mg m^{-3}) distributions derived from monthly mean SeaWiFS images of 9 km spatial resolution (1998–2005). Also shown are climatological wind stress fields derived from monthly mean QuikSCAT winds from July 1999 to December 2005. The black dotted line in (a) shows the location of along-shore section AB (see Fig. 6a and b), also shown are distances to estuary (in km) along this line and the major Plata tributaries. SP, CP and NP shown in (b) are the locations selected to depict the seasonal and interannual variations of CSAT and wind stress. The white line in each plot is the climatological position of the 33.5 isohaline derived from historical hydrographic data.

(Fig. 1, Piola et al., 2000). At 30°S the seasonal variability in the distribution of the Plata plume causes large temperature (~3 °C, Campos et al., 1999) and salinity fluctuations (~4, Piola et al., 2005). The seasonal fluctuations of the Plata plume were recently confirmed by high-resolution synoptic surveys carried out over the shelf and slope in 2003 and 2004. In winter 2003, mixtures of about 5% of Plata waters were observed 1200 km (~28°S) from the estuary, while in summer 2004 the 5% mixture retracted to 330 km from the estuary (34°S) and expanded offshore beyond the shelf break (Möller et al, this issue).

Historical data, together with reanalysis wind stress data and numerical simulations suggest that changes in the along-shore wind stress are the main factor affecting the distribution of low salinity waters over the shelf (Piola et al., 2005). Numerical simulations of the Plata plume suggest that near the estuary wind forcing is mostly important during the summer, when prevailing easterlies force low salinity waters southward, while in winter the northeastward plume development is due to the combined effect of river discharge and the Coriolis force (Simionato et al., 2001; Huret et al., 2005). Other simulations of the Plata plume (Pimenta et al., 2005) and simplified models (Palma and Sitz, 2005) explored the role of large-scale wind forcing over the entire shelf area, concluding that wind forcing plays a central role in determining the along-shore plume extent.

There is strong evidence that large precipitation anomalies over central South America, associated with El Niño (EN, Ropelewski and Halpert, 1987; Kiladis and Diaz, 1989) events, significantly increase the discharge of the major Plata tributaries (Depetris et al., 1996; Mechoso and Perez Iribarren, 1992). Consequently, the Plata outflow presents large interannual variability, with maxima beyond 80,000 m^3 s^{-1}, and minima of about 11,000 m^3 s^{-1}. Theoretical arguments and numerical experiments indicate that high river discharges should lead to increased plume penetrations (Kourafalou et al., 1996; Garvine, 1999). However, surface salinity observations from the southern Brazil continental shelf suggest that the large discharge events do not lead to stronger northeastward plume penetrations (Piola et al., 2005). The apparent decoupling of the northeastward plume penetration from the river discharge is explained by anomalous northeasterly winds frequently prevailing during EN episodes, which effectively oppose to the northward spreading of low salinity waters (Piola et al., 2005).

Continental runoff introduces suspended material and yellow substances (colored dissolved organic matter), which alter the optical properties of the coastal ocean (e.g. Binding and Bowers, 2003). These substances enhance the upward water-leaving radiance and lead to an overestimation of continental shelf satellite-derived surface chl-*a* (CSAT) in coastal waters by standard retrieval algorithms (IOCC, 2000; Hu et al., 2000). Consequently, chl-*a* in the Plata influenced region is highly overestimated by satellite color measurements (Armstrong et al., 2004; Garcia et al., 2005, 2006). Based on CSAT distributions the area influenced by the Plata discharge has been identified as a distinct biogeographical region characterized by high surface reflectance (Gonzalez-Silvera et al., 2004). Therefore, a relation between salinity and CSAT may be expected in near coastal waters influenced by the river outflow. A preliminary analysis of CSAT vs. surface salinity based on historical data showed that near 30°S, where there are large seasonal salinity variations on the continental shelf, sea surface salinity monthly minima are linearly correlated with CSAT ($r^2 = 0.78$, Piola and Romero, 2004).

Though the Plata outflow and the variability of the distribution of low salinity waters produce a strong impact on the near-shore ecosystem, there is limited understanding of their variations from