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Suspended matter mean distribution and seasonal cycle in the Río de La Plata estuary and the adjacent shelf from ocean color satellite (MODIS) and *in-situ* observations

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ABSTRACT

The Río de la Plata is one of the largest and most turbid estuaries of the world, carrying a total of 160 million tons y^{-1} of suspended sediments. The knowledge of their spatial distribution and their scales of variability is fundamental for management and scientific reasons, but has been limited by the scarcity of observations. During 2009 and 2010, *in-situ* data (CTD and turbidity profiles, and water and bottom sediment samples) were collected at 26 sites during six repeated cruises and from three fixed instruments deployed in the frame of the FREPLATA/FFEM experiment. In this paper we complement the analysis of this *in-situ* data base with 10 years of daily intermediate resolution (1 km) MODIS-Aqua observations processed for surface suspended matter using the IFREMER algorithm for coastal turbid waters. The aim of this work is to provide a comprehensive characterization of the annual mean suspended matter concentration distribution, to study its variability on seasonal time scale and to identify the involved physical mechanisms. The comparison between the statistics of the direct and remote sensed data is satisfactory, showing a good agreement in the magnitude and spatial distribution of the mean suspended sediments concentration, its standard deviation, so as the seasonal variability. Our data show that all along the year the concentration of surface suspended matter maximizes along the southern coast of the upper and intermediate estuary and at the tips of Samborombón Bay. This fact is linked in part with the higher solid discharge of the Paraná River – flowing along the southern coast – compared to the Uruguay River which flows following the northern coast. The former receives most of the sediments load to the Río de la Plata from the Bermejo River. The observed mean pattern is also related to the stronger tidal currents along the southern coast of the estuary and at the tips of Samborombón Bay, which act re-suspending sediments near the bottom. Then, wind waves during storms enhance vertical mixing, increasing the surface concentration. The concentration of suspended sediments rapidly falls seawards the Barra del Indio shoal, in the area of the salt wedge. In the outer estuary, suspended matter concentration is also strongly associated to the wind-forced motion of the freshwater plume. Suspended matter concentration exhibits a maximum in winter and a minimum in summer, that cannot be fully explained in terms of the seasonal cycle of the solid discharge of the tributaries, but seems to be related to a raise in the frequency of the storms in winter, increasing the frequency of strong winds and higher wind waves, and the associated re-suspension and mixing.

1. Introduction

With a length of 320 km and a width more than 200 km at its mouth, the Río de la Plata (RDP, Fig. 1) is an extensive and shallow (< 20 m) estuary, located in the eastern coast of South America at approximately 35°S. It drains the second largest basin of South America, formed by the Paraná and the Uruguay rivers. They contribute to a joint mean runoff of 22,000 $m^3\,s^{-1}$, even though peaks as highs as 80,000 $m^3\,s^{-1}$ and as low as 8000 $m^3\,s^{-1}$ have been observed in association with the El Niño – Southern Oscillation cycles (Robertson and Mechoso, 1998; Jaime and Menéndez, 2002). Besides its geographical extension, the estuary is of large social, ecological and economical importance for the countries on its shores (Argentina and Uruguay). The capital cities of both countries (Buenos Aires and Montevideo) and a number of harbors, resorts and

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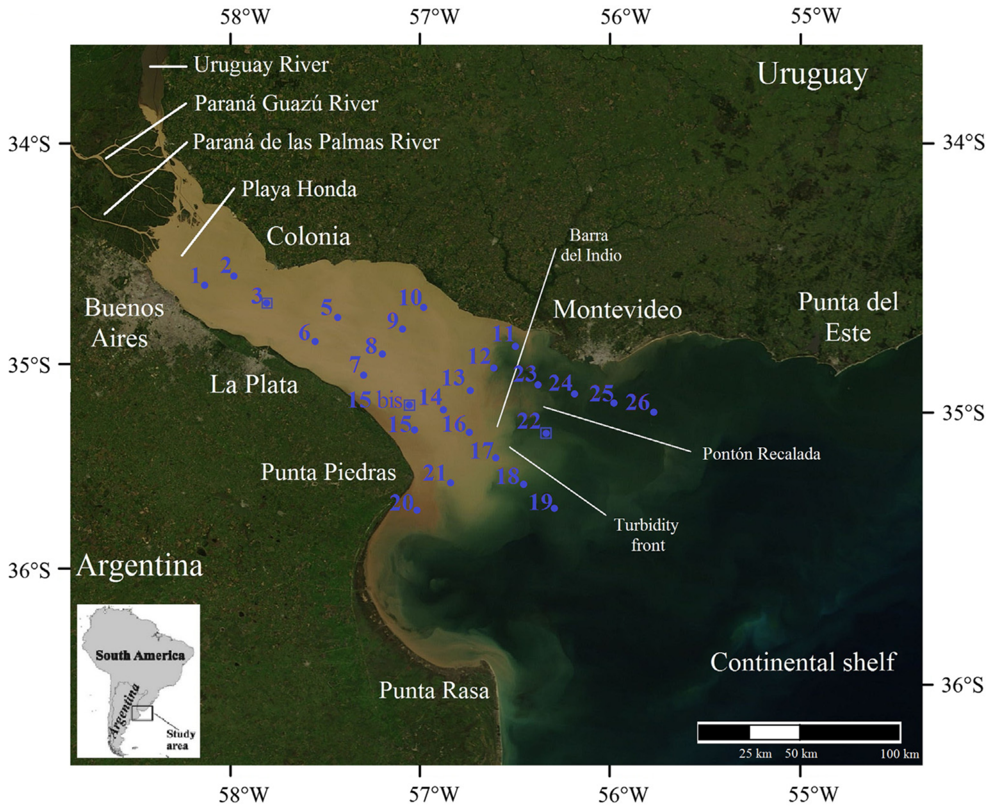

Fig. 1. Study area and geographical references superimposed over a true color MODIS image from Visible Earth (http://visibleearth.nasa.gov). Blue dots indicate the 26 sampling sites during the oceanographic cruises, whereas blue squares show the location of the fixed instruments. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

industrial centers are located on its margins and influence zone. The estuary constitutes the main source of drinking water for the millions of inhabitants in the region, for whom it is also an important recreational area. The RDP is rich in nutrients and, therefore, has an abundant and diverse fauna. It has important fisheries and has the unusual feature of being a spawning and nursery area for several coastal species (Cousseau, 1985; Boschi, 1988; Macchi et al., 1996; Acha et al., 1999; Acha and Macchi, 2000; Berasategui et al., 2004, 2006; Rodrigues, 2005). The life cycles of these fishes seem to be strongly linked with turbidity (Jaureguizar et al., 2003a, 2003b, Dogliotti et al., 2011). This association is not completely understood yet, but it could be connected to feeding benefits due to an increase of prey abundance due in part to the retentive properties of the system (Simionato et al., 2008, Acha et al., 2012), or to protection from avian predation (Jaureguizar et al., 2003a, 2003b). Samborombón Bay is one of the most important wetlands of Argentina and is home to a number of species of fishes, turtles, crabs and migratory birds (Lasta, 1995; Canevari et al., 1998). The fresh water plume of the RDP impacts the shelf in a distance of more than 500 km (Campos et al., 1999).

The sedimentological features of the RDP have been described by Ottmann and Urien (1966), Urien (1972), Ayup (1986, 1987), Parker et al. (1986a, 1986b, 1987), Cavallotto (1987), López Laborde (1987, 1997), Parker and López Laborde (1988, 1989), López Laborde and Nagy (1999), Guarga et al. (1991) and Cavallotto and Violante (2008). The sediments that reach the estuary come mainly from the Paraná River and from the drainage of a number of small tributaries along the Argentinean coast. These rivers, carry high amounts of nutrients, suspended particulate and dissolved organic matter to the estuary and, therefore, to the adjacent shelf waters. The amount of sediments transported by the RDP has been estimated in more than 160 million tons y^{-1} (Simionato et al., 2011b). As a consequence, it is one of the most turbid estuaries in the world, with extreme concentrations more than 400 g m^{-3} (Framiñan and Brown, 1996).

The issue is important because many environmental questions in the RDP and the adjacent shelf are linked to the high sediments load of this estuary. The most significant topics include optimization of dredging operations (Cardini et al., 2002), understanding geomorphological change (Codignotto et al., 2012; Dragani et al., 2012), contamination (Colombo et al., 2005, 2007), bentonic ecology (Gomez-Erache et al., 1999), primary productivity (Gómez-Erache et al., 2004; Huret et al., 2005), fisheries (Jaureguizar et al., 2003a, 2003b, 2008), evaluating fluxes of particulate organic carbon to the sea and biogeochemical modeling (Huret et al., 2005). Nevertheless, the problem of the suspended sediments in estuaries and coastal seas is intrinsically difficult, because sedimentological processes are not only numerous and complex but also highly site dependent and variable over a broad spectrum of time and space scales. This variability renders the most traditional field sampling methods as inadequate in studies to resolve sediment dynamics in complex coastal waters (Miller and McKee, 2004).

In the particular case of the RDP, the lack of observations has been historically the main limitation to the knowledge of the sedimentological processes. The previous works which dealt with the suspended matter (SM) distribution and the involved physical processes in the estuary have been summarized by López Laborde and Nagy (1999). Most of what is known is based on the work by Ottmann and Urien (1966), who analyzed data collected along three legs across the very upper estuary, one leg along the navigation channel from Buenos Aires to Pontón Recalada and three legs at the exterior estuary, from Punta Rasa to Punta del Este. Based on those observations the authors classified the RDP into three geographical zones, which they postulated corresponded to three different sedimentological regimes: (i) an upper zone, upstream