Continental Shelf Research 53 (2013) 102–109

Contents lists available at SciVerse ScienceDirect

Continental Shelf Research

journal homepage: www.elsevier.com/locate/csr

Research papers

Variability of chlorophyll-a in the Southwestern Atlantic from satellite images: Seasonal cycle and ENSO influences

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ARTICLE INFO

Article history:
Received 4 November 2011
Received in revised form
29 September 2012
Accepted 22 November 2012
Available online 30 November 2012

Keywords:
SeaWiFs
Southwestern Atlantic
Rio de la Plata
Chlorophyll-a
ENSO
Seasonal cycle

ABSTRACT

Seasonal and interannual satellite chlorophyll-a variability (CSAT) was assessed in the Southwestern Atlantic based on over 11 years (1997–2008) of Sea-Viewing Wide Field-of-View Sensor data. An Empirical Orthogonal Function analysis of the seasonal CSAT cycle showed strong variability and the spatial structure of the leading pattern revealed an opposite behavior over the continental shelf north and south of 37°S with low (high) biomass south (north) of 37°S during wintertime. This distribution is related to the lack of stratification of the water column in the southernmost region during winter due to heat loss to the atmosphere as well as wind induced and convective mixing, in contrast to a vertically stable water column north of 37°S induced by the fresh Río de la Plata discharge. High variability in CSAT between 47 and 51°S in the inner and outer shelves could be related to the southern Patagonian fronts. On interannual time scales the influence of El Niño-Southern Oscillation on CSAT during spring was estimated and related to wind stress, vertical velocities and Río de la Plata discharge. During El Niño events the continental shelf north of 45°S is characterized by high CSAT values (anomalies > 0.5 mg m^{-3}) while low values are found to the south (anomalies < -0.5 mg m^{-3}), except for positive anomalies near to the Malvinas Islands. The opposite pattern occurred in La Niña years. Conversely, the Brazil–Malvinas confluence has a lower CSAT in El Niño years in comparison with La Niña years. The higher chlorophyll-a of some areas over the shelf north of 45°S during El Niño was supported by increased Río de la Plata discharges, northerly winds anomalies and upwelling generated in the shelf between 33 and 39°S. The winds tend to retain the patch of high chlorophyll-a off Río de la Plata in spring, but advect it toward the Brazilian coast in summer. This result indicates the extreme importance of wind variability for the spreading or retention of phytoplankton in this area. No support was found for a mechanism linking Ekman pumping and CSAT variability over the continental shelf south of 45°S and in the Malvinas–Brazil confluence.

1. Introduction

Global ocean studies using ocean color satellite images have shown high chlorophyll-a concentration structures in the Southwestern Atlantic (SWA) (Yoder and Kennelly, 2003), a region that makes an important contribution to the global atmospheric CO_2 uptake by the ocean (Gregg and Conkright, 2002; Bianchi et al., 2009; Takahashi et al., 2009). Regional and international fishing fleets are attracted to the SWA by important fish and squid's populations inhabiting this area (Podestá, 1990; Jiménez et al., 2010).

The processes governing ecosystem functioning and variability in the SWA are still scarcely known despite the importance of the region. Limited space-time studies provided in situ data on phytoplankton biomass and productivity, mainly in the Rio de la Plata (RDP), Brazilian coast and in the Argentinean shelf break zone (Carreto et al., 1986; 1995; Ciotti et al., 1995; Brandini et al., 2000; Calliari et al., 2008; Lutz et al., 2010). More recently, availability of remote sensing technology allowed the identification of synoptic physical and biological patterns over that large area, and the analysis of their variability. Most studies have focused on the analysis of chlorophyll-a seasonal variability, while interannual variability remains less well understood because longer time series are needed (Saraceno et al., 2005;

Abbreviations: CSAT, satellite-derived chlorophyll-a; SWA, Southwestern Atlantic; RDP, Río de la Plata

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0278-4343/$ - see front matter © 2012 Published by Elsevier Ltd.
http://dx.doi.org/10.1016/j.csr.2012.11.014

Romero et al., 2006; Garcia et al., 2008; Garcia and Garcia, 2008; Lutz et al., 2010).

Hydrographic and ocean color satellite data indicated the correspondence between certain high average chlorophyll-a concentration areas in the SWA and nutrient-rich waters, fronts and river plumes (Carreto et al., 1995; Brandini et al., 2000; Bianchi et al., 2005; Saraceno et al., 2005; Romero et al., 2006; Calliari et al., 2008). In the open ocean, the strong thermal fronts resulting from the convergence of Malvinas and Brazil Currents (Fig. 1) frequently show high chlorophyll-a areas as a result of the stability provided by warm but nutrient-poor subtropical waters and the enrichment by subantartic waters in the transition zone (Gayoso and Podestá, 1996; Brandini et al., 2000; Garcia et al., 2004; Saraceno et al., 2005). Over the northern continental shelf high chlorophyll-a is related to RDP discharge, the subtropical shelf front, and areas where subantartic waters reach the euphotic zone (Ciotti et al., 1995; Calliari et al., 2008; Garcia and Garcia, 2008). On the southern shelf, high phytoplankton biomass is associated with the stratified side of the midshelf front and the Patagonian shelf break front (Fig. 1) (Carreto et al., 1995; Romero et al., 2006; Garcia et al., 2008). In situ studies confirmed elevated primary production in these areas (Garcia et al., 2008; Bianchi et al., 2005; Lutz et al., 2010).

Earlier studies of phytoplankton in the SWA showed a strong seasonal cycle, wider over the shelf (sd >4 mg m^{-3}) than in the open ocean (sd <1.5 mg m^{-3}) (Saraceno et al., 2005; Romero et al., 2006). A region of relatively high chlorophyll-a is found during winter associated with warm subtropical and coastal waters (Romero et al., 2006). On the other hand, the lack of stratification during the colder months caused by heat loss toward the atmosphere and by wind induced mixing limits the primary production and phytoplankton biomass during winter south of 37°S (Carreto et al., 1995; Rivas and Piola, 2002; Bianchi et al., 2005). A pronounced bloom occurs in the spring over the continental shelf associated with the stratification of subantartic waters and enhanced light availability (Saraceno et al., 2005; Rivas et al., 2006; Romero et al., 2006; Garcia et al., 2008; Garcia and Garcia, 2008).

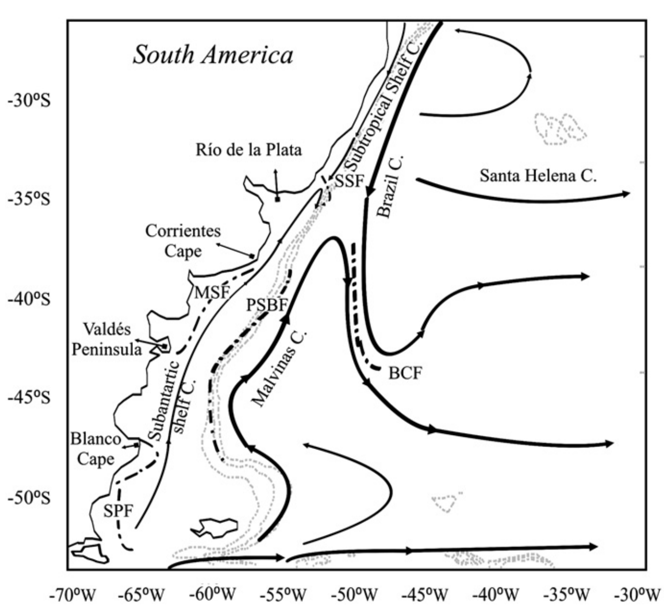

Fig. 1. Schematic surface circulation (black arrows) in the Southwestern Atlantic and geographical locations referred to in the text. The 500, 1000 and 1500 m isobaths are included in the figure (grey dotted lines). Also the fronts are indicated (black dotted lines): Brazil/Malvinas Front (BCF), Subtropical Shelf front (SSF), Midshelf Front (MSF), Patagonian Shelf-Break Front (PSBF), and Southern Patagonian Front (SPF).

Year to year chlorophyll-a variability has also been reported over large areas. Hypothesis such as wind anomalies leading to upwelling events and changes in the positions of fronts, as well as anomalies in the discharges of large rivers have been put forward to explain the observed anomalies (Saraceno et al., 2005; Romero et al., 2006; Garcia and Garcia, 2008).

El Niño-Southern Oscillation (ENSO) has a strong effect on the precipitation in Southeastern South America, particularly in spring (Grimm et al., 2000). Consequently, the freshwater discharges to the ocean from large point sources such as RDP and Lagoa dos Patos increase during El Niño events-with an historic high ca. $\sim$82000 m^3 s^{-1} in RDP flow during the winter of 1983- and decrease during La Niña events with values smaller than 5000 m^3 s^{-1} (Mechoso and Pérez Iribarren, 1992; Barros et al., 2002; Borus et al., 2006; Piola et al., 2008). Chlorophyll-a was observed to increase in shelf waters adjacent to the RDP during the moderate 1987 and the strong 1997 El Niño events, presumably resulting from a higher extent of the river plume and nutrient fluxes to the shelf (Carreto et al., 1995; Garcia and Garcia, 2008). In addition, ENSO has global effects on winds (Li and Clarke, 2004) which could potentially affect the chlorophyll-a distribution in the SWA.

Previous studies that focused in chlorophyll-a variability in the SWA had restricted time coverage because of limitations in the length record of satellite imagery, especially important to analyse the ENSO influence. Moreover, most studies have addressed the impact of El Niño (Ciotti et al., 1995; Garcia and Garcia, 2008) and little is known about that of La Niña events.

In this work we focus on a large area in the SWA to evaluate an 11-year record of satellite derived chlorophyll-a (CSAT) variability and its connection to regional processes and ENSO dynamics. Based on earlier evidence reviewed above, we expected to find significant CSAT variability at different time-scales associated to seasonal cycles, RDP freshwater flows and wind forcing. Changes in chlorophyll-a during opposite ENSO phases are analyzed using composite analysis. To summarize, the objective of this paper is threefold (1) to describe the seasonal CSAT variability in the Southwestern Atlantic over the period 1997–2008; (2) to determine the influence of El Niño/La Niña in chlorophyll-a distribution; (3) to evaluate the relative importance of river outflow and Ekman pumping on chlorophyll-a variability during ENSO events.

2. Data and methods

2.1. Satellite data

Analyses are based on CSAT time series in the SWA region [25–55°S, 70–30°W] estimated by the OC4v4 Sea-viewing Wide Field-of-view Sensor (SeaWiFs) retrieval algorithm (Fig. 1). Given the extension of the area considered and the focus on large scale processes, we considered images of monthly average CSAT with a 100×100 km spatial resolution obtained from 〈http://reason.gsfc.nasa.gov/OPS/Giovanni/ocean.seawifs.2.shtml〉. The RDP proper was excluded from the analysis because chlorophyll-a could be overestimated due to the large amount of sediments within the estuary (Armstrong et al., 2004; Martinez et al., 2005).

2.2. Reanalysis data

To characterize the mechanical forcing of the ocean by the atmospheric circulation anomalies monthly surface winds and wind stress from the NCEP Reanalysis CDAS-1 were used (Kalnay et al., 1996) during the same period as the CSAT data. These data were obtained from 〈www.cdc.noaa.gov/data/gridded/data.ncep.reanalysis.html〉.