Use of satellite data to the Empirical Orthogonal Function Classification of the South Atlantic

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Abstract. This work is focused on the characterization of ocean dynamics in the South Atlantic in a space and time scale of ten years, between latitudes 2 ° S and 33 ° S, developing a classification study of the region, observing the variation of the physical and biological variables (temperature of the sea surface and chlorophyll) applying the empirical orthogonal function (EOF) method to visualize their variability and generate biogeographical regions. The results of analyses on normalized monthly fields (after temporal and spatial means were removed) show that sea surface temperature and chlorophyll data have similar mode 1 temporal and spatial patterns in these waters. Mode 1, which explains more than a half of the total variability in monthly images showing that shelf waters are out of phase with the Sub-tropical Gyre. The analyses are based on remote sense data provided by AVHRR – NOAA and SEAWIFS satellite sensors, representing a strong relation between the generated provinces and the currents systems.

keywords: Biogeographic Regions, Boundary Currents, Physical and Biological Parameters, Empirical Orthogonal Function

1. Introduction

The Brazilian coast is characterized according to the current influence of tropical waters and low latitudes where it is located in an area of humid tropical climate (Castro and Miranda, 1998). The confluence of different currents (i.e., Brazil and Falklands Currents - BC and FC, respectively) provides complex fluctuations in the physical, chemical and biological variation. Consequently, the presence of phenomena on a global scale (such as El Niño and La Niña) forms a network of remarkable features and information available for research.

There are various types of ocean variability that have been recently observed in different locations around the South Atlantic Tropical and Subtropical. The annual cycle is the biggest source of variability for the sea surface temperature (Avellaneda, 2005), which is explained by more than 90% in the continental platform, where the greatest amplitudes are founded (Podestá et al., 1991; Provost et. al, 1992; Lentini et al., 2001). Their mechanisms of force involve different dynamic processes such as changes in the wind, internal processes of the ocean and remote forces. The goal approach of this paper is to characterize the dynamic oceanographic and present a geographic classification of the zone between latitudes 2°S and 33°S utilizing the Empirical Orthogonal Function (EOF) analysis, which has become a standard statistical technique in the geophysical sciences of meteorology and oceanography (Preisendorfer, 1988; Emery and Thomson, 1997). Yoder et al., (2002) had also used this methodology to identify some variability () in the study area. A few points of control were selected in South Atlantic (SA), which, according to the literature reviewed, are affected by oceanographic phenomena characteristic of the region, i.e. upwelling, boundary currents, vorticity, etc. (Wilson and Adamec, 2001). The continental shelf is narrow gradually, allowing the influence of the Central Waters of the South Atlantic (CWSA) in the area (Castro and Miranda, 1998) and periodic intrusion of FC, which explains the appearance of coastal upwelling, resulting in a development of a suitable habitat for the creation of sardines and relevant

source of nutrients in the photic zone (Matsuura, 1986).
The focus of the study is to develop a descriptive analysis of the southwest Atlantic observing the variation of physical and biological variables. The compilation of two different tools of measurement is the main theme of the paper, combining sea surface temperature (SST) and ocean color (chlorophyll - CHL). The comparison of the patterns modes obtained provides enough information about ecological provinces showed in the area.

2. Methodology

The data processing was carried out using the MatLab 7.0 programming language. The products used in this study are monthly global data such as AVHRR sensors for the measurement of SST (Sea Surface Temperature) at 4 Km resolution, Version 3 SeaWiFS images corresponding to the concentration of chlorophyll at 9 Km (Hooker and Mcclain, 2000), completing a study conducted over a period of 10 years (from January of 1998 until December of 2007). To the set of data normalized by the correspondent standard deviation, were applied some of basic statistics analyses, as the Empirical Orthogonal Function application (EOF), in order to study variations in time and space.
All values were estimated for each image, considering the possible errors by missing data due to cloud cover. To treat this type of problem was applied a filter for a window of 0.5° X 0.5 ° resolution, running the failed region represented by the images, followed by the average of nearest neighbors in the fields. Under no circumstances mean field was used to fill empty areas in more than three consecutive times. As the two databases used with different degrees of resolution, was considered resolution data of ocean color as a basis to remodel the remaining sets monthly images of 0.09 °X 0.09 °, resulting in arrays of 700 x 360 pixels (Figure 3.1).
In the SST data was applied the interpolation method proposed by Gigliotti et al (2009) to fill gaps. In the matrices was applied the transformation of digital levels of surface temperature by multiplying their values by the scaling factor and then adding the error. Those concerning the concentration of chlorophyll can be approximated to a lognormal distribution of base 10. In terms of zoning under study in the South Atlantic region, was originally considered in the classification between coastal region and tropical twist Longhurst (1998) for ecological provinces based on a sub-classification. According to the criterion noted in Vantrepotte and Mélin (2009), was took into account the possible influence of two other provinces suggested (ETRA - Eastern Tropical Atlantic and Benga - Benguela Current) to carry out clustering analysis. Like that the variability analysis was performed through the application of the Empirical Orthogonal Functions, which, as well as the methods of singular value decomposition (SVD), calculates the temporal amplitudes, the spatial oscillation modes and their corresponding eigenvalues (Yoder et al., 2002). This procedure enables a reliable analysis of the anomaly fields, extracted and normalized after classification zones and the subtraction of the climatology of the original series of data. According to Yoder and Kennelly (2003), the vector amplitude time series associated with the spatial pattern of each mode is dimensionless and represents the evolution of spatial mode in time. Thus, the values deviate significantly from the overall average pattern, i.e. are out of phase with the same, the pixels in the spatial modes have similar values, however, present different signals (ranging between positive, negative). In Section 3.1, the dimensionless amplitudes of the time series are exhibit, which describe the changes for each mode of oscillation and spatial patterns and identify certain areas of the ocean.

3. Results and discussion

For all chlorophyll and SST data sets, more than 98% of the variability is contained in the seasonal signal, so the first mode overwhelms the lesser modes. By removing the temporal and spatial means, the dominant seasonal signal was reduced (Yoder et al., 2002). Normalization was applied by dividing each pixel by its standard deviation (Davis 1973), which reduces the extremes in areas of high variability relative to areas of low variability without completely damping out the anomalies, and allows the comparison of results on chlorophyll and temperature. One characteristic and advantage of a combined EOF is that the two variables will have the same time-varying amplitudes, thus making it very easy to detect and interpret common seasonal patterns (Bretherton et al. 1992).

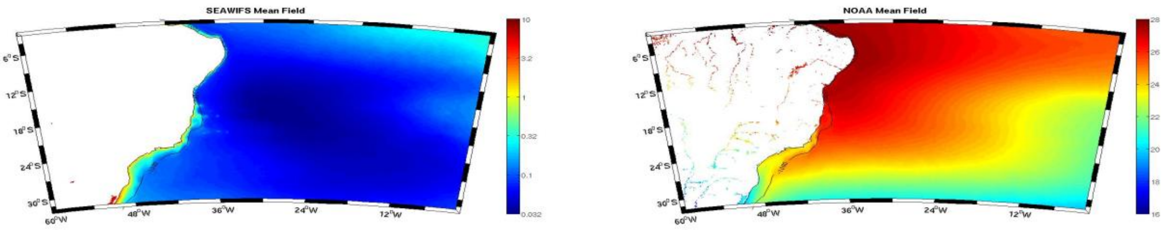

Figure 3.1: 10-year mean chlorophyll from SeaWiFS sensor (left) and sea surface temperature form NOAA (right); black thick line refers to 1000m isobath.

The EOF method was applied to the chlorophyll original data set in order to classify the whole area in the 6 smaller study points. From them were extracted the anomalies fields (from both variables), which have the most important content to variability study. The anomaly analyses, when applied to middle latitudes, allows the study of variations with time scale in months and few years (2-3 years), even if the pattern repeats every 12 months to explain much of the variability in most cases. The annual cycle of weather patterns can mask low frequency, thus removing the dominant seasonal signal, allows the analysis of smaller fluctuations associated with climate change.

The equatorial zone represented by the Figure 3.1 is characterized by the abundance of warm water, therefore small differences are observed in temperature in accordance with the changing seasons of the year (not represented). Locations near to northeastern Brazil are under influence of Convergence Zone and other Amazon’s river discharges. As the east coast of the country with constant influence of the Brazilian Current (BC) and its proximity to the 'National Marine Park of Abrolhos' perhaps accuse some signal into the data set. The proximity of Cabo Frio – RJ (41.75 ° W / 25.375 ° S), belongs to the Southeastern Brazilian Bight (SBB), break of the coastline, this region has numerous islands and discharge of rivers (such as the Complex Estuarine Paranaguá-Cananeia). It is also the area of migration of different economically important species related to the current regime, which is influenced by BC and also the seasonal intrusion of FC. Previous studies claim eddies formation from its boundary currents (Ciotti and Kampel, 2001). Known as one of the main areas of upwelling on the Brazilian coast, is the point of outcrop waters laden with nutrients, thus presenting a rich ecosystem. In the region located near the Cabo of Santa Marta (coordinates 56.75°W and 30.375°S), near the island of Florianopolis, the mechanism of mass transport of cold water originating from offshore is poorly understood. There is an important relationship with the Patos Lagoon deal with the existence of several discharged of rivers around. The set makes this area grow richly diverse ecosystems, and the presence of endemic species is favorably to a deeper study.

3.1 Oscillation Modes

From the ocean color data set analyzed it was possible to observe four relevant patterns of oscillation that represents around 78% of total variability in the entire region. The fact of the variability been explained only by a few oscillation modes, is consistent with the simplicity and coherence of those patterns modes which describes the zone. The first mode, with a 68.7% of the variability explained turns around the annual cycle, represented in Figure 3.2 It is clear the division in two principal variability areas: coastal and Southeastern Equatorial zones, which contrasts with the oligotrophic zone from the Subtropical Gyre. In the second mode, represented in 5.63% of total variance, it is easily to identify some of the principal variability zones used in the present study. The third mode (Percent of Variance Explained - PVE 2.39%), which reaches the 77% of variance explained, shows a representation of a variability in phase between southern platform area and the rest of the ocean zone. For the SST results, more than 99% of the variability is explained by the first mode, describing the seasonal pattern. According to Gigliotti et al. (2009) the senoidal pattern is appropriate because it describes the behavior of the approximate mean cycle of SST. Others patterns are showed, even if they appears to be irrelevant to the present study.

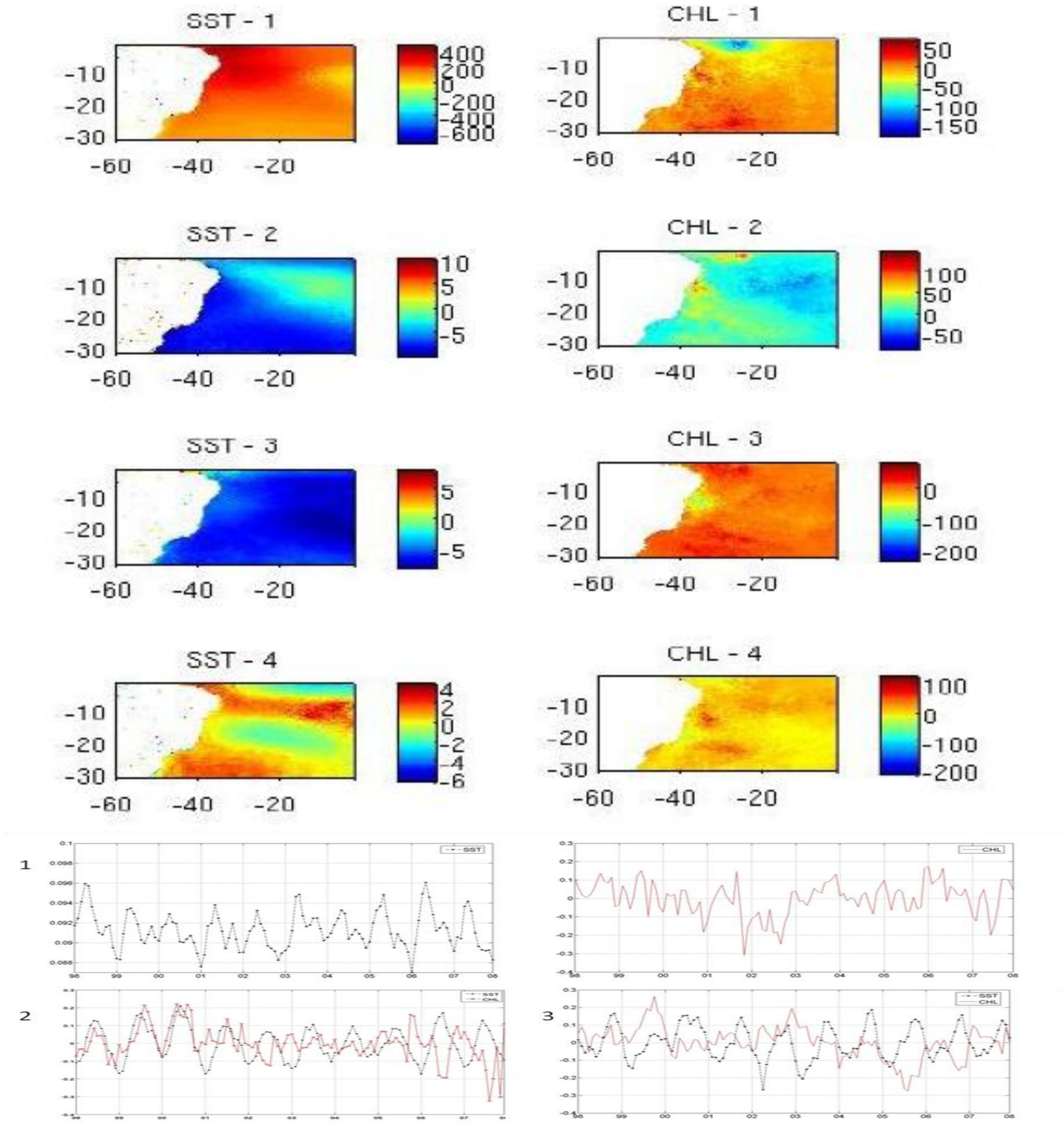

Figure 3.2: oscillation modes (1 to 4) originated from the EOF applied in the SST and CHL data set. Graphs of amplitudes are represented by Time in years; spatial patterns in Degrees for SST values and Log10 units - final values must be exponent in base 10.

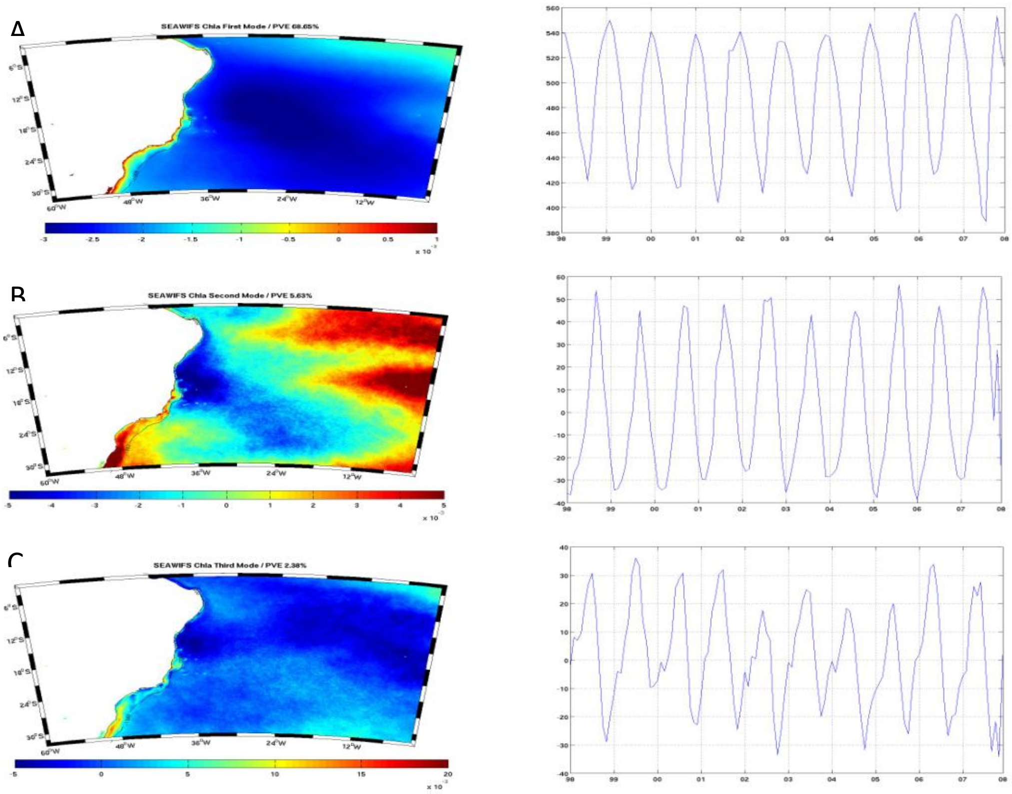

Figure 3.3: oscillation modes originated from the EOF applied in the original CHL data set. Graphs are represented by Time in years; spatial patterns in Log10 units - final values must be exponent in base 10. Black thick line refers to 1000m isobath.

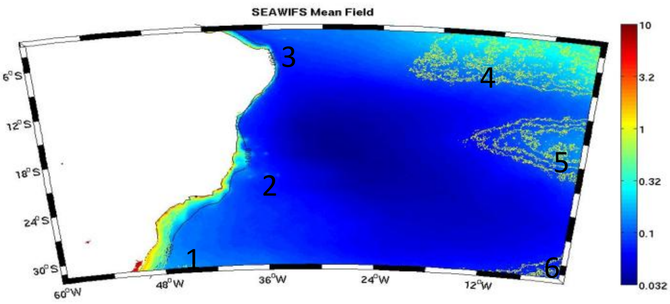

Figure 3.4: year mean chlorophyll from SeaWiFS sensor. Yellow lines represent EOF method classification, while black thick line refers to 1000m isobath. Representation of biogeographic zones.

In what concerns the dimensionless amplitudes series, there's a periodicity relative to annual, semi-annual and smaller cycles correspondents to a few months (Figures 3.2 and 3.3). In the first mode of the chlorophyll (Figure 3.3.A and Figure 3.4), the variability pattern represented has the same sign, i.e. positives or negatives variations related to the mean field are in phase. The amplitude of this mode, as the third one, might reveal a strong association with the intrusion of cold masses of water in the platform at south of the scene. Pixels in the second and third modal spatial pattern have similar values, but different signs. What means that deviations from the mean global pattern are out of phase. Positives values in the second mode, are located in four different areas; coastal zone from the south of the scene up to the Abrolhos region, taken the whole platform location. As the

Northeastern Equatorial zone probably influenced by the Benguela current and the African coast. Negatives values are associated to the subtropical gyre, and the east Brazilian coast. The time series from this mode appears to be related to inter-annual oscillations, with winter peaks. As the second one, the third spatial mode presents oscillations in phase, with the biggest amplitudes in the southeastern of the scene and some upwelling zones. The amplitude can be associated to a few months variability, as showed by two different peaks in the time series oscillation.

The normalized set amplitudes reveal values characteristic of the strong seasonal cycle, with variability in the Northwest of the scene. In second and third modes opposite oscillations between SST and CHL amplitudes are relevant in the years 2001 to 2003 and 2006 to 2008. This might be related to ENSO index (Figure 3.2 and 3.3). Common eigenfunctions and time-varying amplitudes for all data sets are evidence that the variables forcing were probably very similar in periods analyzed.

From EOF results, it is possible to classify the entire zone of the SA in representative areas from their variability (Figure 3.4). A space average of CHL and SST data in each zone will be applied to the basic statistical analyses, and the seasonal component removed from its time series by a three harmonic Fourier component, resulting in series of CHL (CHLA), sea level (SLA), SST anomalies (SSTA), which will be the basis for subsequent studies. For SST data is considerable further study of its anomalies, which may be possible to observe variability at other scales.

4. Conclusions

To classify the whole South Atlantic region in biogeographic regions is a study that requires more statistical analyses and the correlation of two variables is a valid procedure, which could reveal knowledge enough to appoint exchanges of information between the existed zones.

Even under the strong influence of different Currents as the Subequatorial and Falklands, some of local phenomena as upwelling events and the eventual effects of Brasil-Malvinas systems, the area can be generally classified by a oligotrophic zone in the Subtropical Gyre rounded by euphotic provinces located most of all in the Brazilian platform.

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