Wavelet analysis of Brazil Malvinas Confluence variation forced by wind pseudostress in different locations

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Abstract: Brazil Malvinas Confluence (BMC) region is one of the most energetics of the world and presents a high variability. The latitude of the confluence is well marked by the annual cycle: it is found more to the north during the austral winter and more to the south in the austral summer. Many studies were made about the variability of BMC and its possible forcing mechanisms. Thus, the aim of this study is to better understand the confluence variability and its relation to wind stress forcing in different locations. The latitude of BC separation from the coast was used as a proxy of BMC. It was obtained through the interception point between 18ºC isotherm and 1000 m isobath. SST data was obtained from NOAA OISSTv2 and the zonal wind pseudostress data was extracted from CCMP project of NASA/GSFC/NOAA. The BC separation latitude presents a pronounced southward trend of 0.43º/year (±0,24), during the analyzed period. Both wind pseudostress series present negative trends too: - 2.4 m^2s^{-2}/year (±0,96) in CBM region and 0.36 m^2s^{-2}/year without significance in Drake Passage. The wavelet analysis was used for each time series, and the XWT and WTC was performed using the zonal wind pseudostress for the BMC and Drake Passage region with the BC separation latitude. The winds in BMC region could be related directly to the local annual variation, and the winds in Drake Passage are responsible for the interannual variation, and, after 2004, a significant semiannual variation.

Key-words: Southwest South Atlantic, Drake Passage, cross wavelet, wavelet coherence, remote sensing

1. Introduction

In the last decades, South Atlantic has been highlighted as an important area to regional and global climate system. According to the AR4 IPCC report, this region is one of the most affected in climate changes scenarios (Bindoff et al., 2007). Its main circulation is the South Atlantic Subtropical Gyre (SASG) composed by the eastward-flowing South Atlantic Current, the northward Benguela Current, the westward South Equatorial Current and the Brazil Current (BC) northward flow (Peterson and Stramma, 1991).

The southern limit of the SASG is dominated by the variability Brazil Malvinas Confluence (BMC), formed by the encounter of the southward BC and the northward Malvinas Current (MC) fluxes (Gordon and Greengrove, 1986). These region is one of the most energetics of the world and presents a high variability and mesoscale activities (Goni et al., 2011; Pezzi et al. 2016). In addition, confluence region plays also a principal role in water formation due to intense ocean-atmospheric interaction (Gordon, 1981).

Olson et al. (1988) were pioneers studying temporal variation in confluence zone. They showed that the separation of the Brazil and Malvinas current are not spatially coincident. Between them there are a mixture of waters from BC and MC. This band has up to 300 km and are filled by eddies. The same authors showed that variability of the separation latitude of BC and MC are different and possibly not forced by the same mechanisms. In one side the BC has a strong annual signal and in other side, MC present a semiannual component.

Usually, the BC front separates from the continental shelf break at around 36°S, and the MC at 38.8°S (Olson et al., 1988). The latitude of the confluence is well marked by the annual cycle: it is found more to the north during the austral winter and more to the south in the austral summer (Gordon and Greengrove, 1986; Olson et al., 1988). Matano et al. (1993) found that wind shear within the basin forces variations in BC and MC transports and consequently resulting in the north-south oscillation of the confluence in a seasonal scale.

Besides, Witter and Gordon (1999) discussed that the position of the BMC is also related with the SASG inter-annual variations forced by the large-scale wind. Indeed, recent studies shows that changes in the BMC are related to large-scale wind variations rather than the local wind shear and currents transport. Lumpkin and Garzoli (2011) and Goni et al. (2011) found a southward shift in the latitude of BC separation from the coast in the 1993-2008 period. According to these authors, these shifts are related to changes in the region of maximum wind stress curl due warm SST anomalies at the latitude of the BMC.

In a general view, the ocean-atmosphere interaction in regions of intense oceanic mesoscale activity (spatial scales of about 100-500 km and time scales of about 2-3 months) presents a positive correlation between the sea surface temperature (SST) and some meteorological variables, such as wind intensity and the heat and momentum. As reviewed by Pezzi, et al. (2016), this suggests that the ocean forces the atmosphere at the spatial and temporal scales related to the oceanic mesoscale.

There is a lot of studies about the variability of BMC and its possible forcing mechanisms but a lot of information still unknown especially because the lack of long temporal series. In this work, we look the BMC variability using the BC separation position as a proxy. The aim of this study is to better understand the confluence variability and its relation to wind stress forcing in different locations to see whether local winds or remote winds are more important to it.

2 Data and Methods

2.1 Data

The latitude of separation of BC from the coast were obtained by the point of intersection of the 18ºC isotherm and the 1000 m isobath, which is the limit of continental shelf in the region (Olson, et al 1988; Goni et al., 2011). Such isotherm does not represent exactly the BC core, but the properties from mass water in surface, and can be used as a proxy to the BC waters influence in the BMC region (Olson et al., 1988). This method are not able to show strong seasonal variabilities due to summer warming and winter cooling, but is enough to represent long term variabilities.

The Sea Surface Temperature (SST) was obtained from the Optimum Interpolation SST analysis version 2 (OISSTv2, Reynold et al., 2002) maintained by the National Oceanic and Atmospheric Administration (NOAA, EUA). The analysis is produced weekly on a one-degree grid using in situ, satellite SST and simulated SST's by sea ice cover. The satellite data is adjusted for biases using the method of Reynolds (1988) and Reynolds and Marsico (1993). A more detailed description of the method can be found in Reynolds and Smith (1994). The monthly product cover the period between September 1981 to October 2016.

To analyze the influence of wind forcing it was used the zonal wind pseudostress (UP) from the Cross-Calibrated Multi-Platform (CCMP) project (NASA/GSFC/NOAA. 2009; Atlas et al., 2011). Pseudostress (P) is a vector in the direction of the surface wind and has a magnitude that is the square of wind speed. This quantity is commonly used because the uncertainties about the drag coefficient needed to compute the wind stress. The CCMP datasets includes cross-calibrated winds obtained from Remote Sensing Systems (REMSS) and uses a Variational Analysis Method (VAM) to combine them with *in situ* measurements, to produce a high-resolution (0.25 degree) gridded analysis. The P fields used in this work are referenced to a height of 10 meters and are in monthly files from 1988 to 2011.

The series of zonal wind pseudostress fields were calculated for two areas: The BMC region (30ºS-40ºS,45ºW-60ºW) and for Drake Passage region (55ºS-60ºS, 50ºS-70ºS). These areas are the same used in Silveira and Pezzi (2014) to study SST anomalies.

2.2 Wavelet

An important tool for time series studies is the wavelet analysis, by decomposing them into time-frequency space. Hence, it can localize power variations of a variable through time (Torrence and Compo, 1998). Also, the wavelet transform is used in analyses with nonstationary power at different frequencies (Daubechies 1990).

The result of a wavelet analysis has a characteristic cone of interest (COI), which corresponds to the region where edge effects are important and cannot be ignored. Thus, outside this cone edge effects can be negligible (Torrence and Compo, 1998, Grinsted et al. 2004). The limitation of the COI is a solution for the errors that occur at the beginning and the end of the wavelet spectrum due to the fact that time series are finite (Torrence and Compo, 1998).

For analyses of two multivariate time series it is indicated the use of wavelet function where both series will be compared at the same time. In this case, it is indicate the use of cross wavelet (XWT) and wavelet coherence (WTC), that can link both time series, highlighting which areas have the highest common powers and phase relationship between them (Grinsted et al., 2004; Maraun and Kurths, 2004).

Grinsted et al. (2004) proposed a methodology using XWT and WTC in geophysical time series, and developed a software package to facilitate the use of these functions, which can be found at http://noc.ac.uk/using-science/crosswavelet-wavelet-coherence. The method consists of the use of two continuous wavelet transform (CWT) to create a XWT and normalized both, time and scale WTC. The CWT expands each time series in time-frequency space and the oscillation can be interpreted in an intuitive way. The XWT highlight regions with high common power and WTC is the relationship between normalized by time and scale time series, and it evidenced events with lower intensity, which does not happen for the XWT (Torrence and Compo, 1998; Grinsted et al. 2004; Maraun e Kurths, 2004).

As proposed by Grinsted et al. (2004), for this study we used the Morlet wavelet for CWTs, because it is good in feature extraction of the series, and the method of Monte Carlo to determine the confidence of 95% for WTC.

At first, the CWT for each time series has been made, using all period available for each data. After that, the XWT was performed using the zonal pseudostress wind for the BMC and Drake Passage region with the BC separation latitude, using their common period of 1988 to 2011. The WTC has been done for the same time series combinations.

3. Results and discussion

The figure 1 shows the variation of BC separation latitude, the anomalies of zonal wind pseudostress for BMC region and for Drake Passage region. These series were treated with a

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Lanczos filter (Duchon, 1979) working as a low pass filter to eliminate periods lower than one years (13 months).

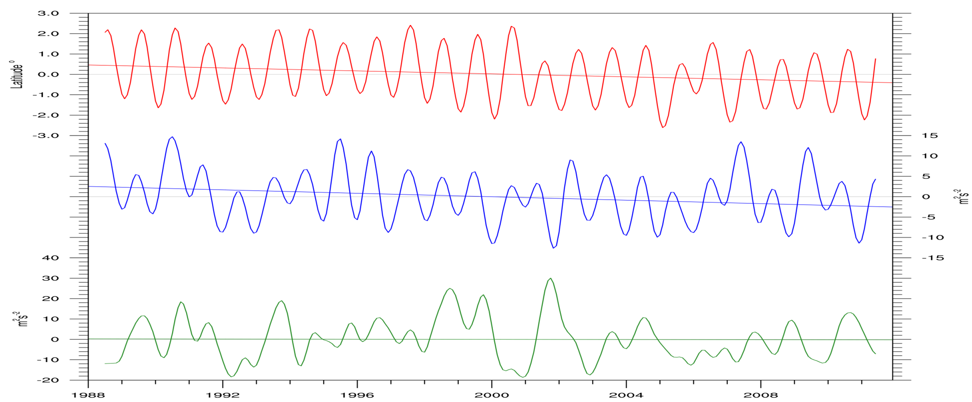

Figure 1: Variability of BC separation latitude (red), the anomalies of zonal wind pseudostress at BMC region (blue) and at Drake Passage region (green), with the 13 months pass filter and trend in dashed line.

The BC separation latitude presents a pronounced southward trend of 0.43º/year (± 0.24) per year, during the analyzed period. This trend was obtained using least squares adjustment and it is almost ten times bigger than the tendency found by Goni et al. (2011) and Lumpkin and Garzoli (2011). Although the method to get the BC separation latitude is different than the above studies mentioned before, these cannot justify the observed discrepancy in the time series trend.

Both zonal wind pseudostress anomalies series showed negative trends too: -2.4 m^2s^{-2}/year (± 0.96) in BMC region and 0.36 m^2s^{-2}/year in Drake Passage, but the last one without significance. For UP series, the negative trend is related to an increase in westward winds. In BMC region, the westward winds are associated to a possible BC intensification and consequently, a southward shift of the BMC. At Drake Passage region, this tendency is not significant considering this period.

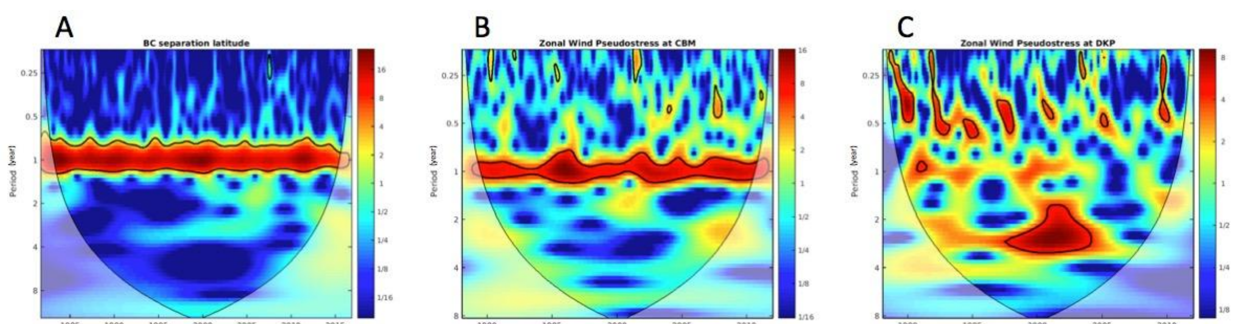

Figure 2: Continuous wavelet transform for, a.) latitudinal variation of BC separation; b) zonal wind pseudostress at CBM region; and, c) zonal wind pseudostress at Drake Passage region.

The wavelet analysis is presented in figures 2 and 3. The COI are shaded and features outside this area must be ignored due edge effects, as explained before. The continuous lines around some edges mark regions statistically significant, and it is related with significance level pre-selected in the null hypotheses (Grinsted et al. 2004), in the case of this work, it is 5%

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significance level. The y-axis represents the period in years and the x-axis the period used for the analysis (1988-2011).

In the figure 2 are the CWT from latitudinal variation of BC separation and the pseudostress wind for CBM and Drake Passage region, respectively.

The CWT from the variation of BC separation latitude has a well-defined power in annual period, due to seasonal variation through the years, what is already expected and mentioned before (Matano et al., 1993, Goni et al., 2011). It is also noticed a weak variation biannual from 2000 to 2007, but with no significance. In the zonal pseudostress wind for the CBM region the CWT has a biannual variation during the period from 1998 to 2004 not significant, besides the high power in the annual variation. For the Drake Passage region, the CWT shows a semiannual variability well marked and a high power significant from 1997 to 2004, that is clearly extend to other years, so the hole sign can be considered from 1993 to 2007.

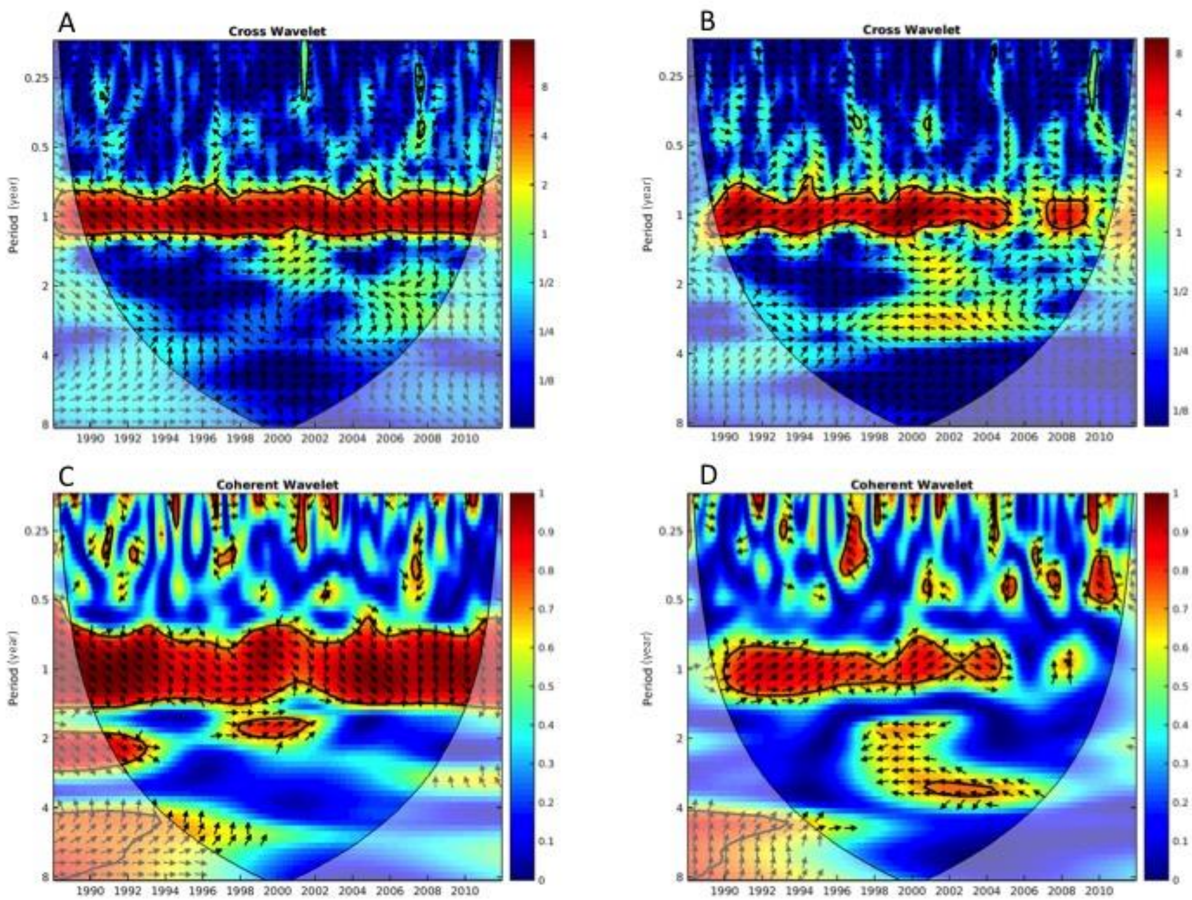

Figure 3: Cross-wavelet and wavelet coherence for a) zonal wind pseudostress at CBM region and BC separation latitude series, b) zonal wind pseudostress at Drake Passage region and BC separation latitude series; wavelet coherence for c) zonal wind pseudostress at CBM region and BC separation latitude series, d) zonal wind pseudostress at Drake Passage region and BC separation latitude series.

The XWT and WTC analysis shows arrows pointing to the relative phases between the variables: arrows to left indicate that variables are in anti-phase, to right they are in-phase, arrows downward show that the zonal wind pseudostress leads/lag the latitudinal variation of isotherm by 90° and upward, the BC separation latitude variation leads/lag the pseudostress winds 90°. But for this last case it makes more sense to interpret the upward arrow as a lag of 270° or a lag of 90° relative to the anti-phase (Grinsted et al. 2004).

The figure 3 shows the XTC and WTC for the zonal wind pseudostress of CBM region and the variation of BC separation latitude and, zonal wind pseudostress of Drake Passage region and the variation of BC separation latitude.

For the zonal pseudostress wind from CBM region with latitudinal CB separation, the XWT (figure 3a) shows a high significant annual power and the variables are in-phase, with a tendency of the zonal wind pseudostress leading the variation of BC separation, indicating that the annual variation in the CBM is mainly caused by the local winds. The WTC of this variables (Figure 3c) shows a significant and high biannual variation in phase from 1997 to 2002, that appears in XWT too, but as a weak and non-significant signal. These may be associated to the strong 1997/1998 El-Niño event, and this same signal is also present in XWT and WTC from Drake Passage UP and BC separation latitude, but without significance. Although, there are others El-Niño events in analysis period that does not appear in those wavelets. Soppa et al. (2011) found a relation between SST anomalies in CBM region and ENSO, but this relation has an instable behavior. Some ENSO events does not influence CBM region, probably because the interference of others variabilities modes (Soppa et al., 2011).

For zonal wind pseudostress at Drake Passage region and BC separation latitude, the XWT (figure 3b) has an interannual high power, with a tendency of lag between the variations, which could be cause for the different wind direction, that came from the west. It is possible to see a soft sign in the period of 3 to 4 years, that appears significant in they WTC (figure 3d), where the variables are in anti-phase, and can be related with the Antarctic Oscillation (AAO).

Thus, the zonal wind pseudostress from Drake Passage appears to interfere in a interannual variability of the BC separation, in agreement to past studies (Witter and Gordon , 1999). It is also possible to note that after 2004 there is a break in the pattern of the WTC and XWT. Both of them have presents an interruption of the annual signal and in WTC becomes clear a semiannual signal with significant meaning. Combes and Matano (2014) suggest that after 2000 there was an abrupt change in South Ocean circulation due changes in westerlies, causing weakening of the northern branch of the Antarctic Circumpolar Current (ACC). These changes can possibly modify relationship between the westerlies in Drake Passage and BC separation latitude through some remote mechanisms.

4. Conclusions and future recommendations

The wavelet analysis is an important tool to time series studies, where it is possible to conjugate two time series in just one analyses, and observe not just the highest events as in the CWT and XTC, but also those that are significant masked by a low power, as shown in the WCT.

The zonal wind pseudostress at CBM and Drake Passage region forces the BC separation from the coast latitude in different ways. The winds in CBM region could be related directly to the local annual variation, and the winds in Drake Passage are responsible for the interannual variation, and, after 2004, a semiannual variation. It is possible to conclude that influence of Drake Passage winds in confluence zone presents a considerable lag. This result consolidates the knowledge of annual and interannual forcing mechanisms in confluence zone (eg. Matano et al., 1993; Witter and Gordon (1999). Combes and Matano (2014), shows a generalized weakening of westerlies in Drake Passage region in last decades. According to them, this has an influence the Southern Ocean circulation and consequently the MC, allowing BC waters penetrate southward.

Other interesting fact raised by those authors is that the westerlies changes promote a weakening in the Patagonian shelf break upwelling, what can increase the SST of the confluence region too. All those factors contribute to an increase in SST of CBM zone, observed by recent studies (Lumpkin and Garzoli, 2011; Silveira and Pezzi, 2014). So, the analyses made in this work can be suffering interference of this warming, as long as a fixed isotherm is used as criteria to the location of BC separation point. This fact can be a good explanation to the high negative trend found. The BC separation latitude series is representing not only the BC waters influence, but the warming process at CBM due the changes explained by Combes and Matano (2014).

Therefore, both regions are important and have a significant influence at the confluence variability due to different features, where the local winds contribute for the annual and, the remote region, to the interannual and semiannual variations.

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