Sea Level Anomaly trends in the South Atlantic around 10ºS

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Abstract. In this work, we analyze regional trends of altimetric Sea Level Anomalies (SLA), and the contribution of the steric component. We show evidences that for the region around 10ºS, the steric component cannot explain the altimetric SLA trends. On the western side of the region, the altimetric SLA trend is positive, while the steric component of the SLA has a negative trend. In the eastern side, both trends are positive, but the steric contribution is too small. Although the steric component of the SLA cannot explain regional trends of altimetric SLA, it is able to explain 45% of the decrease of subtropical gyre northward transport.

Palavras-chave: Sea level rise, steric contribution, altimetry, PIRATA

1. Introduction

One of the well known effects of the global warming is the sea level rise. It is subject of many studies in the past few years. Changes in sea level involve two processes: an increase of the mass of water in the oceans (the eustatic component), derived mainly from ice melting on land, and an increase of volume without mass change (the steric component), that is dominated by the thermal expansion of sea water (called thermostetic component). Based on long tide-gauge records, the global sea level rise is estimated to be 1.8±0.1 mm year^{-1} (Douglas, 1997; Zuo et al., 2007). Using Sea Level Anomalies (SLA) from altimetry, Chen et al. (2006) estimated a global averaged trend of 2.6±0.06 mm year^{-1} during the period of 1993–2004. Recent investigations, based on new ocean temperature data sets, indicate that the thermal expansion only explains about 0.4 mm year^{-1} (Antonov et al., 2002; Levitus et al, 2005; Ishii et al., 2005; Lombard et al, 2006). There is, still, much controversy about the relative contributions of steric and eustatic components for the sea level trend (Munk, 2002; Meier and Wahr, 2002; Munk, 2003). Another important point is that there is geographical variations in the sea level change as pointed out by Lombard et al. (2006), Chen et al. (2006), and Juncheng et al. (2009).

The objective of the present work is to study the sea level trend in a region in the South Atlantic around 10ºS combining altimetric sea level data, sea surface temperature from remote sensing, and observation from PIRATA moorings.

2. Data and Methods

In this work, we use SLA from multimission altimetry products produced by Ssalto/Duacs and distributed by AVISO (http://www.aviso.oceanobs.com/duacs/). The data set is gridded with horizontal resolution of 1/3-degree on a Mercator grid each seven days from October-1992 to November-2009. We also use optimally interpolated Sea Surface Temperature (SST) data from the TRMM Microwave Imager (TMI), carried on NASA's Tropical Rainfall Measuring Mission (TRMM) satellite. The resolution is 1/4-degree from 1998 to 2009 with daily files. The TMI data are produced and distributed by Remote Sensing Systems (www.remss.com) and sponsored by the NASA Earth Science MEaSUREs DISCOVER Project.

The hydrographic data used in this work are from the three buoys of the SW extension of the PIRATA (*Pilot Research Moored Array in the Tropical Atlantic*) array (Fig. 1).

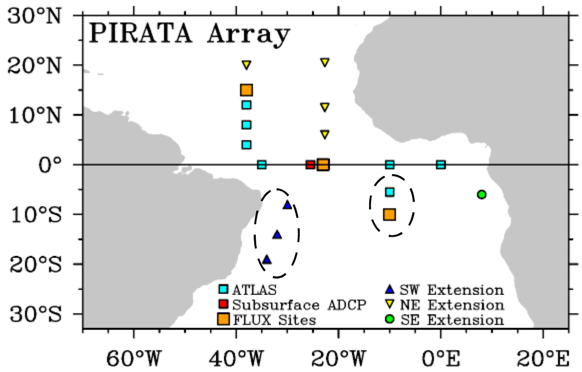

Figura 1. PIRATA array map. The circled sites are used in the present work. The blue triangles are the PIRATA SW extension sites.

In Fig. 2 we display our area of interest, the dotted rectangle R2 (10ºS-5ºS,35ºW-7ºE). The two sub-regions: R1 (10ºS-5ºS,35ºW-25ºW), and R3 (10ºS-5ºS,15ºE-7ºE) are used to obtain mean values of SLA (and SST) characteristic of the western basin and eastern basin, respectively.

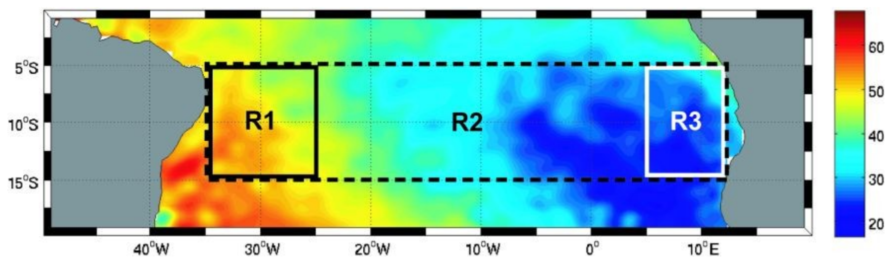

Figure 2. Absolute Sea Level map (in cm) from AVISO altimetry. The regions R1, R2, and R3 are used to calculate averages representative from western basin, whole basin and eastern basin around 10ºS.

3. Results and Discussion

Using altimetric data from AVISO, we calculate average values of SLA for each region in Fig. 2. The average SLA for regions R1, R2, and R3 are denoted SLA_{west}, SLA_{mean}, and SLA_{east}, respectively. The time series for SLA_{west}, SLA_{mean}, and SLA_{east} are displayed in Fig. 2. Its evident that there is a sea level trend in the three regions. The western side SLA trend is 2.02 mm year^{-1}, the eastern side SLA trend is 2.83 mm year $^{-1}$, while the whole area SLA trend is 2.22 mm year $^{-1}$. These values are in accordance with global SLA trends calculated by Cazenave and Nerem (2004) (2.8 mm year $^{-1}$), and Chen et al. (2006) (2.6 mm year $^{-1}$) . The interesting point here is that, although very close, the difference between the trend in the western and eastern basins has a profound implication.

The upper layer (with mean depth H) geostrophic meridional transport, can be estimated by

$$T = \frac{g}{2f}\left[\left(H+\eta_e\right)^2 - \left(H+\eta_w\right)^2\right] \sim -\frac{g}{f} H \, \Delta\eta \quad \left(\eta_e, \eta_w \ll H\right), \qquad (1)$$

where η_e , and η_w are the absolute sea level at the eastern, and western side of the basin, respectively, and $\Delta\eta = \eta_w - \eta_e$.

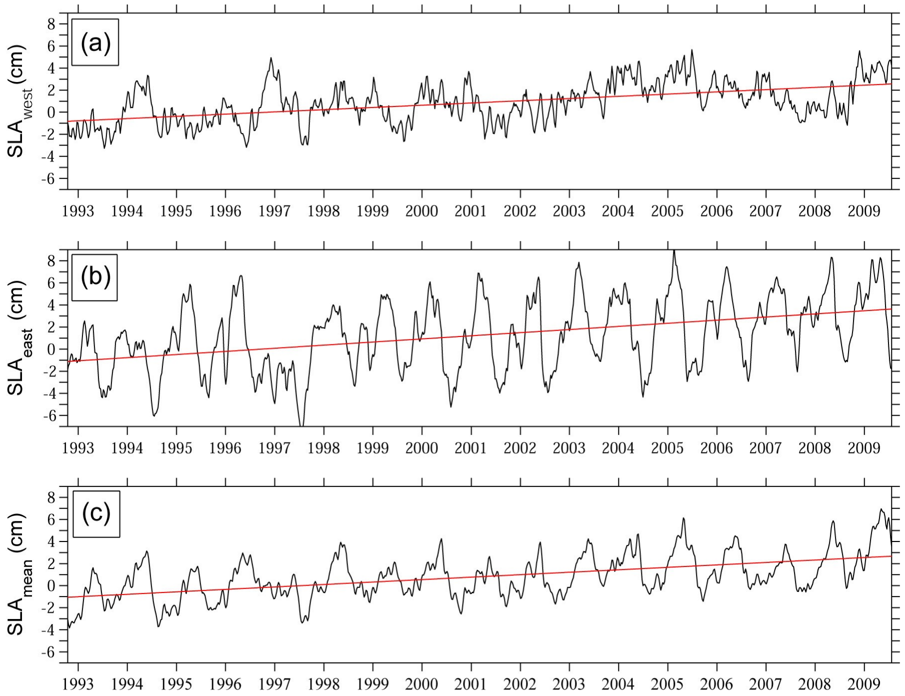

Figure 3. Sea Level Anomalies (SLA) averaged in the regions indicated in Fig.2: (a) In region R1, (b) in the region R3, and (c) in the region R2. The **red lines** are linear regression lines for each plot, with slopes 2.02, 2.83, and 2.22 mm year^{-1}, for (a), (b), and (c), respectively.

If we decompose the absolute sea level as a mean sea level plus SLA, we have

$$T' = -\frac{g}{f} H \Delta\eta' \quad \left(\Delta\eta' = \eta'_w - \eta'_e\right), \tag{2}$$

where the T' is the anomalous transport, η'_w , and η'_e are the SLA in Fig 3a,b, respectively. From (2), we see that the anomalous meridional transport is proportional to SLA_{west} - SLA_{east} ($\Delta\eta'$). Since, in the Southern hemisphere $f < 0$, it follows that T' and $\Delta\eta'$ have the same sign.

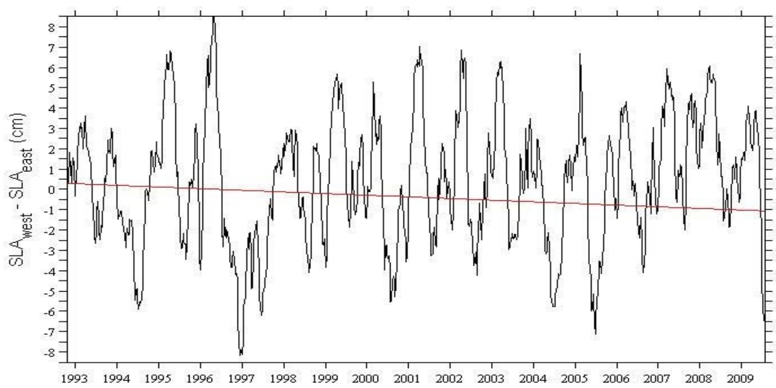

Figure 4. Difference between the SLA_{west} (average SLA in the region R1) and SLA_{east} (average SLA in the region R3) (Fig. 1). This quantity is proportional to the upper layer transport anomaly trough the zonal section at 10ºS. The **red lines** are the linear regression lines for each time series.

On Fig. 4, we plot SLA_{west} – SLA_{east} time series. There is a negative trend of -0.81 mm year^{-1}, what implies a decrease of 0.06 Sv year^{-1} in the meridional transport in the top 200 m, and from October-1992 to November-2009 this would give a total decrease of about 1 Sv. It should be noted that due to average precess, this decrease of 1 Sv is related with the gyre meridional transport that is estimated to be about 7 Sv.

On Fig. 5, we plot average TMI-SST for each region in Fig. 2. On the western region (Fig. 5a) there is a negative SST trend of -0.026 ºC year^{-1}, what is not consistent with the sea level rise in the same region (Fig. 3a). On the eastern side there is a small positive SST trend of 0.005 ºC year^{-1}, and the average SST on the whole region barely presents a trend. Considering that temperature variations are the major constituent of the steric sea level variations, it seems that the steric sea level variations cannot explain the altimetric sea level rise. In order to go deeper into this point, we analyze hydrographic data from PIRATA moorings sites indicated in Fig. 1.

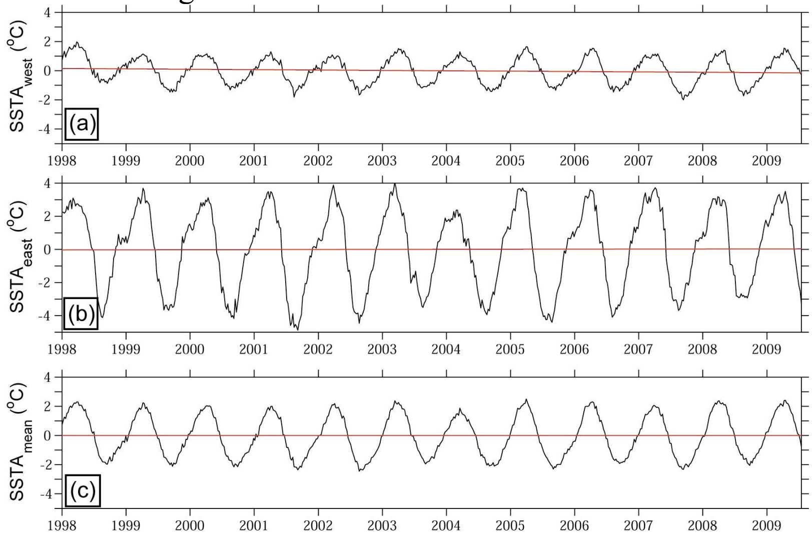

Figure 5. Sea Surface Temperature Anomalies (SSTA) averaged in the regions indicated in Fig. 2: (a) In region R1, (b) in the region R3, and (c) in the region R2. The red lines are linear regression lines for each plot, with slopes -0.026 ºC year^{-1}, 0.005 ºC year^{-1}, and 4.8x10^{-5} ºC year^{-1}, respectively.

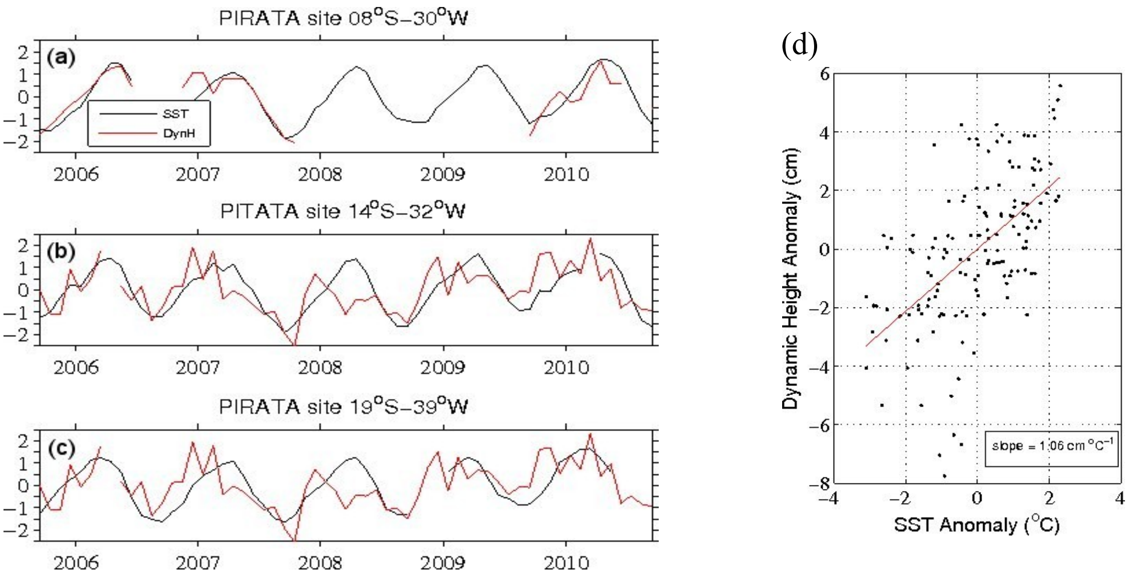

Figure 6. (a)-(c):Normalized SST (**black line**) and Dynamic Height (**red line**) at the three PIRATA buoys in the SW extension.. (d) Scatter plot of SST anomalies versus Dynamic Height anomalies from the three PIRATA buoys in the SW extension all together. The **red line** is the linear regression line with slope 1.06 cm ºC^{-1}.

In Fig. 6a-c, we plot normalized SST (SST divided by its variance) and normalized dynamic height relative to 500 m at each one of the sites in the PIRATA SW extension. There are high correlations between SST and dynamic height on all sites, what shows that variations in SST are compatible with variations in dynamic height. Fig. 6d shows a scatter plot of SST anomalies against dynamic height anomalies using all data for the three sites. The linear regression line has a slope of 1.06 cm $^{o}C^{-1}$. Considering that the dynamic height is the steric component of sea level, we see that variations of SST, in this region, are very good proxies for dynamic height variations. Using the regression coefficient between SST and dynamic height anomalies, we estimate a steric SLA trend of -0.27 mm year^{-1} from SST data, what cannot explain the positive altimetric SLA trend.

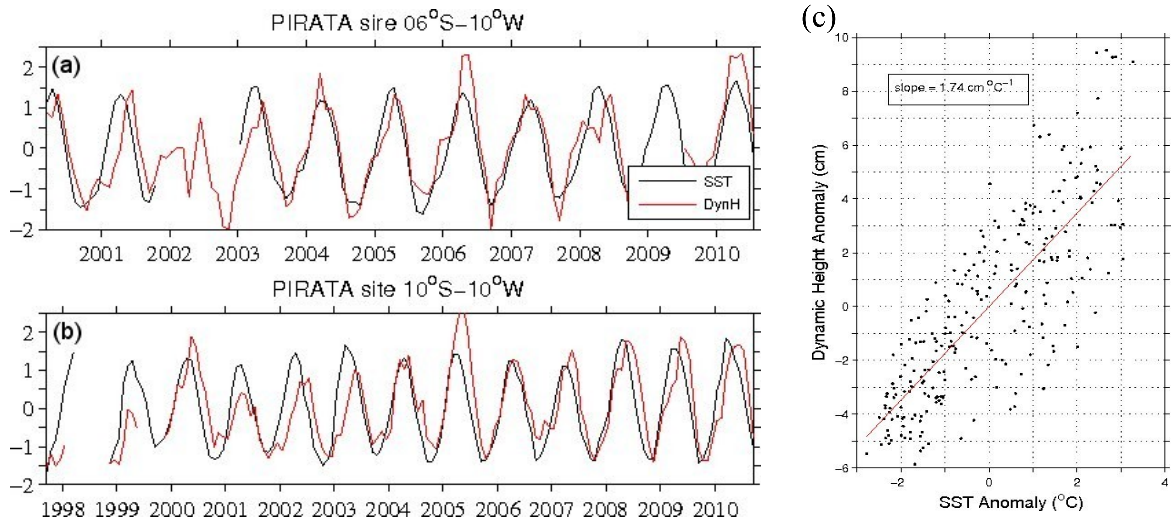

Figure 7. (a)-(b):Normalized SST (**black line**) and dynamic height (**red line**) at the two PIRATA buoys in the center of our study region. (c) Scatter plot of SST anomalies versus dynamic height anomalies from the two PIRATA buoys in the SW extension all together. The **red line** is the linear regression line with slope 1.74 cm $^{o}C^{-1}$.

Since there is no PIRATA mooring in our eastern region R3 (Fig. 2), we analyzed two sites located in the center of our region of study (Fig. 1). A comparison between SST and dynamic height for these sites is plotted in Fig. 7a,b. Again, dynamic height variations are related with SST variations, and the regression between SST anomalies and dynamic height anomalies has a slope of 1.74 cm $^{o}C^{-1}$ (Fig. 7c). So, using this estimate for the eastern basin, the trend in dynamic height would be about 0.09 mm year^{-1}, what cannot explain the trend of 2.83 mm year^{-1} of the altimetric SLA.

Although, dynamic height trends cannot explain the regional trends of SLA, they can explain a substantial amount of the meridional transport trend. In fact, the trends of -0.27 mm year^{-1}, and 0.09 mm year^{-1} for dynamic height would give a trend of -0.36 mm year^{-1} for the steric component of $SLA_{west} - SLA_{east}$, what is about 45% of the -0.81 mm year^{-1} for altimetric SLA.

4. Conclusions

In this work, we analyze regional trends of altimetric Sea Level Anomalies, and the contribution of its steric component. We show evidences that for the region around 10ºS, the steric component cannot explain the altimetric SLA trends. On the western side of the region, the altimetric SLA trend is positive, while the steric SLA component has a negative trend. In the eastern side, both SLA trends are positive, but the steric contribution is too small.

On the other side, the difference between altimetric SLA calculated on western side and on the eastern side has a negative trend. Since this quantity is proportional to the upper layer zonal transport, we show evidence that the subtropical gyre northward transport is decreasing in a rate of 0.06 Sv $year^{-1}$ (in the top 200 m). Although steric component of the SLA cannot explain regional trends of altimetric SLA, it is able to explain 45% of the decrease of subtropical gyre northward transport.

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