Answer for referee 1

Dear Referee 1,

We very much wish to appreciate the time you took to go through our work in great detail. It is equally with great pleasure that we have been obliged to review and enact some necessary changes. This greatly added our insight into some of the various aspects of the phenomena discussed in there within.

We hope that we have, beyond doubt, answered all the questions adequately, so as to make the article much more solid.

Thank you.

The number of years has been increased (from 24) to 56. We observed that the percentage of the variance of EOF1 remains the same whereas that for EOF2 changes from 12% to 17%, (Fig. 11) showing that the variability of the second mode, which resembles the meridional mode, can change from year to year.

Because of the interest in the ACT phenomenon in the Atlantic Ocean, (cooling abrupt cooling appearing in the eastern tropical region); initially an empirical orthogonal analysis was made of tropical Atlantic data between (29°W–21°E, 25°S–7° N). Since we are studying the variability of SST in the tropical basin, one of the characteristics of the meridional mode will be missing in this space, as you mentioned that we did not talk about it. To identify and mention the meridional mode so as to strengthen our work, we extended the study area northwards. Therefore, to concentrate on the equatorial region, we chose to extend the area: (30°W–20°E, 26°S–22° N); which is that considered in the manuscript. Figs. 8 and 11, are just to show some differences between the results showing the first and second areas, if necessary, but not to be used in the manuscript.

Below are the step-by-step answers to individual questions or clarifications

1- **It is not clear if the asymmetry is due to real physical processes or due to the shortness of the time series used (only 24 years).**

We have now used a longer data set (1950-2005) that is for 56 years, which is the reconstruction sea surface temperature (ERSST) data set (Smith and Reynolds, 2003) from the NOAA National Climatic Data Center. A climatologically annual cycle was calculated by averaging the data for each calendar month, and monthly SST anomalies (SSTAs) were defined relative to this annual cycle.

The SSTA have long-term trends. In order to minimize the effect of these trends on the analysis, we have eliminated the linear trends from all datasets at each spatial location using the least squares technique. Thus, detrending the monthly anomaly, our primary dataset was formed.

The results, (Fig.1), show that the linearity is more pronounced using 56 years of data. The distribution of the original data points in each of the two-dimensional projections shown in Figures 1a–b are relatively a symmetric cloud of points, with only a amount of nonlinearity appearing in the PC2 versus PC3 plot in Figures 1c. The result is that the NLPCA mode 1 is a little bit coincident with the projection onto PC1 indicated by the green line in the plots.

And also, it is evident that the nonlinear solutions (red curve) approach to the input data (solid blue dots) most closely than the linear one (the green straight lines).

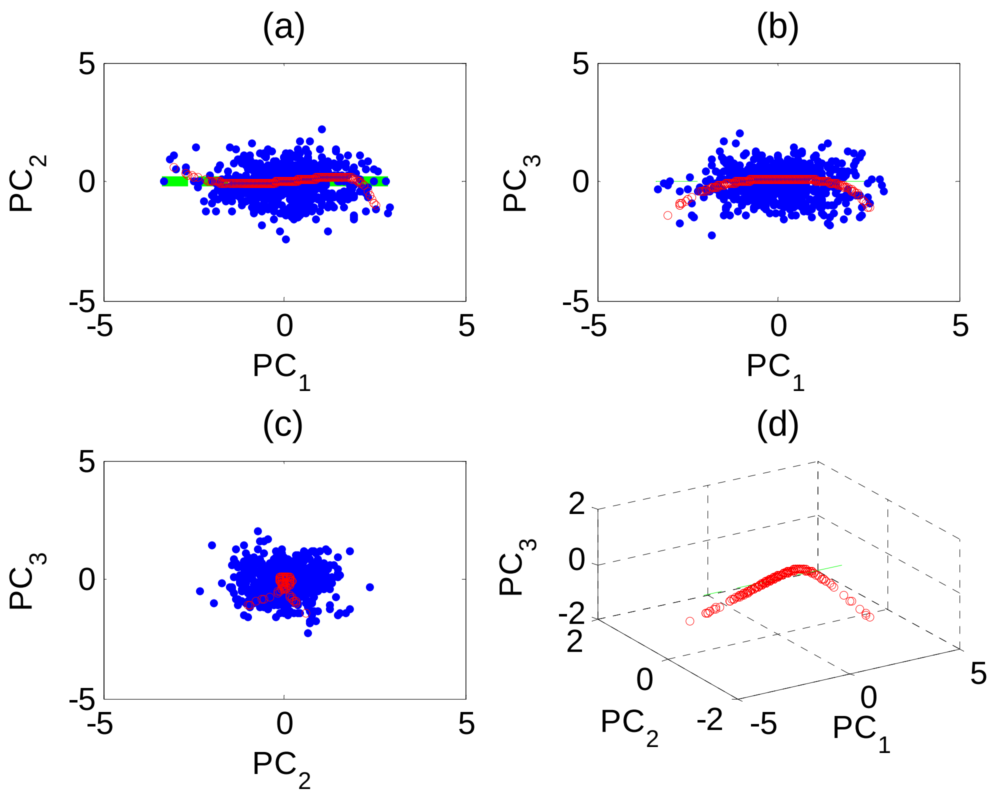


Figure 1: Scatter plot of the sea surface temperature anomaly (SSTA) data (shown as dots) in the principal component (PC1, PC2, and PC3) plane. The first mode NLPCA approximation to the data is indicated by the red circles, which traced out a *Wave*-shaped curve.

One important consequence of this is that spatial patterns of SST variation captured by the NLPCA mode 1 (Fig.3) are very symmetric between positive and negative temperature. Consequently, the long term data confirmed that the weak and strong regimes of the cold tongue are slightly asymmetric. The duration of the data set did not considerably affect the results. Even the results for the EOFs did not also change considerably (Fig.8).

2- **The discussion in section 3.2 is hard to follow and needs to be rewritten. Moreover, it is not clear that NLPCA gives different results than a simple composite using an SST index for the cold tongue to study the evolution of extreme warm and cold events.**

We shall rewrite section 3.2 as mentioned.

Also, the SST anomaly was note well computed. It is ok now. The patterns presented by the NLPCA now resemble those of the composite analysis (Fig.2).

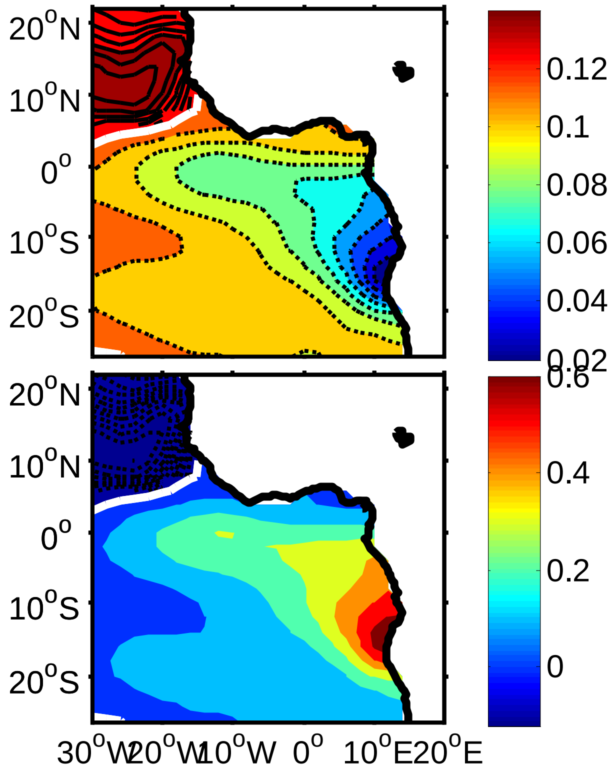


Figure2: Composite maps for average (a) cold ACT (upper) and (b) warm ACT (downer).Zero contours are white lines. Positive contours are black lines and negative contours are dashed black lines.

Although the correlation between ACT index and NLPCA is big, the ACT index only cannot allow us to determine if cold ACT and warm ACT are symmetric or not. Even if the method is complex, it has the advantage that it can show whether ACT is linear or not. NLPCA can also show different state.

3- **PCA and composite techniques are usually complementary because the latter allows to study the nonlinear behavior. It would be very useful to compare the results of compositing versus that of NLPCA: if authors can show that NLPCA is superior it would strengthen the manuscript substantially, and would prompt other authors to use this complex technique.**

Comparison of the eight sub-figures of Fig.3 (fig.3a-3h, respectively,) clearly show a similar pattern in the eastern part of the equatorial Atlantic. There are warm and cold SSTAs in this region, stretching further southwards along the coast of Central and South Africa. This is consistent with ACT development. There is no big spatial difference between a fully developed strong and weak ACT.

Comparing the patterns shown in Fig. 3a with that of the first EOF presented in Fig.6a, we observe that individual PCA modes represent only a single spatial pattern of the first mode of NLPCA with standing oscillations. Fig 6a is similar to Fig.3a, hence NLPCA mode 1 includes PCA mode 1. The strong and weak ACT states, (Figures 3a), (Figures 3h), respectively, are confined to the eastern part of the equatorial Atlantic. One of these patterns can be captured by a conventional PCA analysis but does not capture the symmetry presented by strong and weak ACTs.

At your request, the composite analysis method, for determining this symmetry between the weak and strong ACTs, is being used to compare with NLPCA.

The differences in strong/weak ACT symmetry in figure 3 can be compared to the spatial symmetry calculations. Composite analysis was conducted using the nonlinear principal component (NLPC). The simplest approach is, firstly, to compute the mean of NLPC. Warm and cold events are defined in each time series as events whose amplitudes are greater or less than the mean of NLPC; with the warm events having positive sign and the cold events negative signs respectively. Thereafter, we compute the mean of each group; i.e. for the warm or cold years during the ACT period (JJA). Then, here both methods are dependent, composite analysis is used to confirm the result of NLPCA .The mean for the strong ACT is represented by fig2.a and for the weak by Fig.2.b. The largest SSTA is located in the eastern part during average weak ACT events and centered in the same region during average strong ACT events. We may observe that the pattern of these two types of ACT is symmetric.

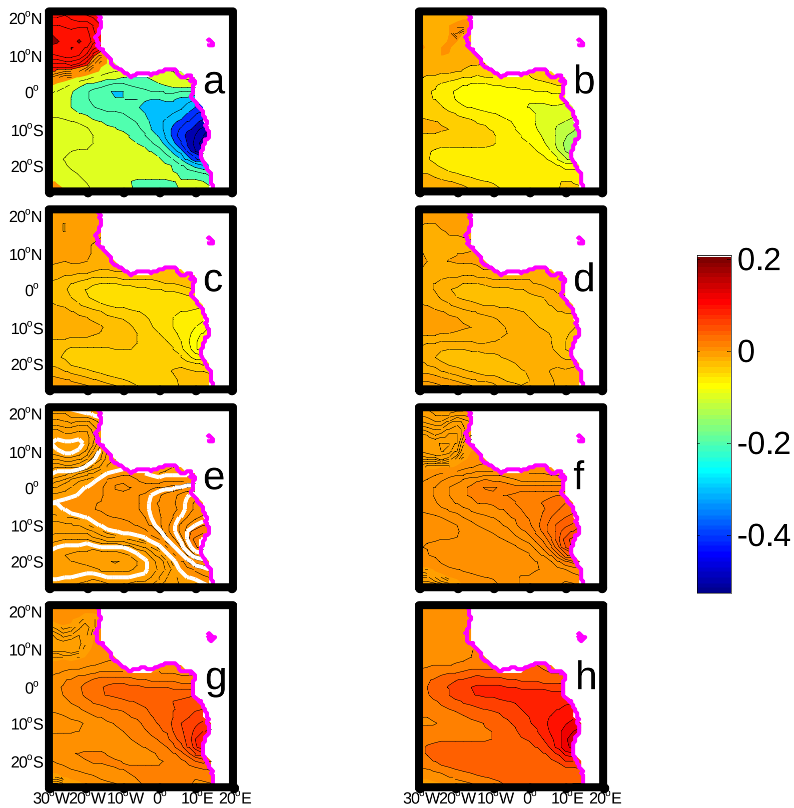
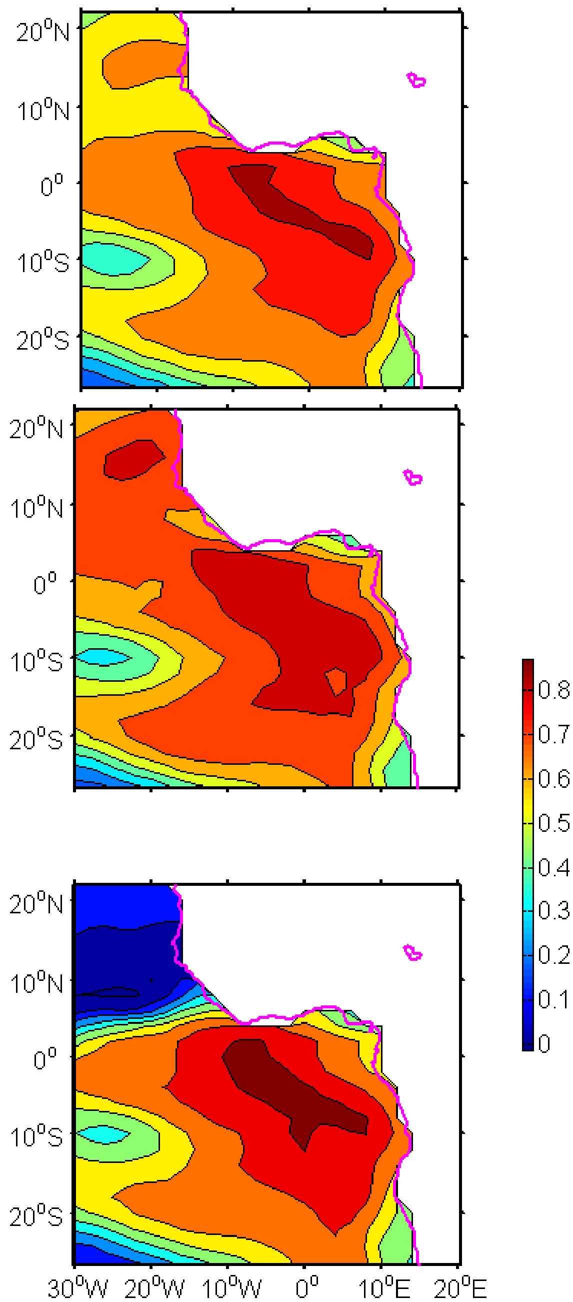


Figure 3: The SST anomaly pattern (in °C) of the first NLPCA mode u varies from (a) its minimum(strong Atlantic cold tongue), to (b) three-quarter its minimum, to (c) half its minimum, to (d)a quarter of its minimum, to (e) a quarter of its maximum, to (f) half its maximum, to (g) three-quarter its maximum and (h) its maximum (weak Atlantic cold tongue). Zero contours are white lines. Positive contours are black lines and negative contours are dashed black lines. The contours in pink color are the coast.

The symmetry determined by a composite analysis (Fig.2) shows just two steps of ACT. Since composite analysis is based on composite means, there will be difference of the micro-spatial patterns of strong and weak ACT from that of the NLPCA analysis. Composite analysis can show only the states of the means of the weak and strong ACTs separately. But NLPCA shows different states of ACT; isolating different patterns and their associated amplitudes which may be missed by the means or averaging. The NLPCA, therefore, has the nice feature of capturing a range of variability between the symmetry of different ACT states, something that is difficult to obtain using index-based SST composites. NLPCA improves on PCA by allowing low-dimensional approximations to have a structure other than that of simple standing oscillations. Both the NLPCA mode 1 and the composite analysis describe the symmetry between averages of warm and cold ACT events. However, NLPCA has the advantage of no *a priori* specification of a time series (e.g. periods) over which to composite, and provides a full 1D approximation to the data, in contrast to the absence of approximation in composite analysis. The latter can only give the mean state of ACT but PCA and NLPCA can approximate the real state. The fact that we found that ACT is almost linear gives the impression that NLPCA is not necessary, but the implementation of linear PCA only could hide this nonlinearity. The warm events (Atlantic Niños) are associated with reduced cold tongue development (Carton and Huang 1994). The weak ACT can be regarded as the conventional El Niño.

4- **Figure 9 suggests that PCA and NLPCA might be complimentary as they have maxima over different regions. It seems to me that the NLPCA is more localized in space and therefore seems to be able to isolate different processes. On the other hand, it is well known that PCAs should be rotated to better reflect physical processes as they only try to explain maximum covariance over the region. The rotated PCAs are usually more localized. Is it possible that the leading rotated PCA would have a similar pattern of correlation as the leading NLPCA?**

There are many possible schemes for rotation of PCA, (RPCA); the varimax (Kaiser, 1958) being the most popular. Both RPCA and NLPCA take the PCs from PCA as inputs. There is an important difference between PCA and rotated PCA methods; as it is generally impossible to have a simultaneous solution: explaining maximum global variance of the data and approaching pattern recognition. NLPCA can give both information, thus the nonlinearity in NLPCA unifies the PCA and rotated PCA approaches (Hsieh, 2001). In this work, in terms of variance, the first NLPCA mode explained 38.3% of the variance, versus 36% by the first PCA mode, and 31% by the first rotated PCA mode. We may see that the leading rotated PCA has a similar pattern of correlation as the leading NLPCA; except above latitude 5°N, where PCA shows a good correlation. The correlation is maximum in the ACT surface for the case of NLPCA than the RPCA and PCA. Therefore, NLPCA, RPCA and PCA are complementary.



20⁰N
10⁰N
0⁰
10⁰S
20⁰S
30⁰W 20⁰W 10⁰W 0⁰ 10⁰E 20⁰E
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0

Figure 4: Maps of pointwise correlation coefficients between observed SSTA and a) RPCA,(b) 1D PCA approximation and (c) 1D NLPCA approximation.

The correlation between the rotated PCA and SSTA shows greater resemblance to the correlation between unrotated PCA and SSTA than NLPCA. The RPCA method generally improves more in the entire region, but in the ACT zone, the NLPCA is the best candidate and also remains the best method to study the spatial variation of ACT.

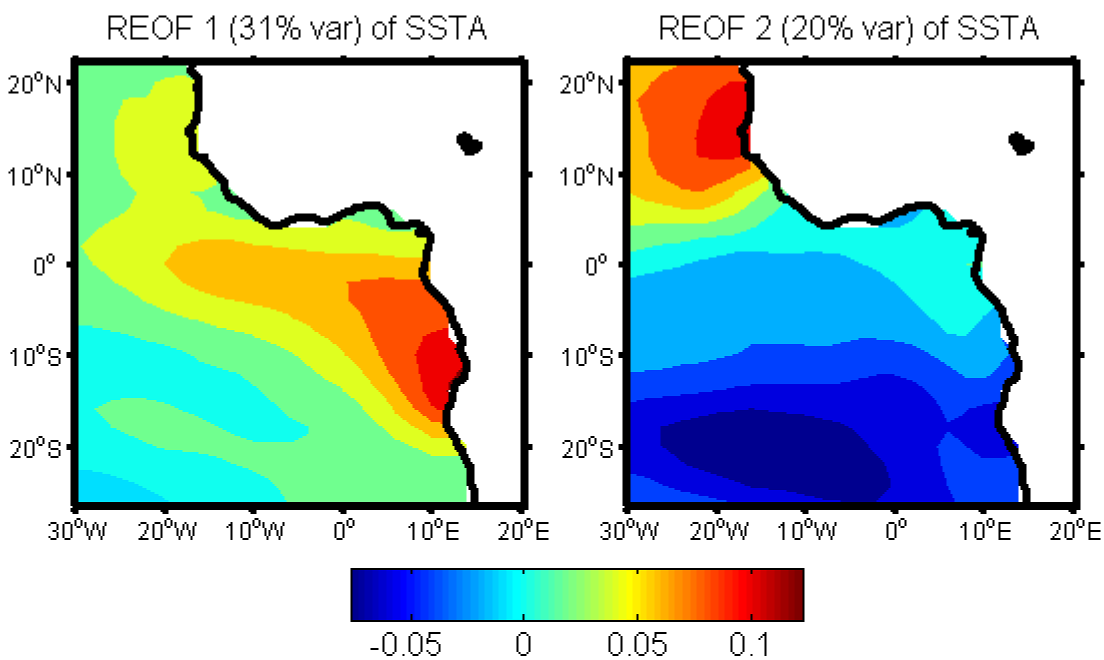


Figure5: The rotated PCA (RPCA) eigenvectors using the varimax method of detrended monthly sea surface temperature (SST) Anomalies. EOF1 mode (left) and EOF2 mode (right) with their explained variance shown in parenthesis.

The first PCA exhibits a more accurate description of the ACT (Fig.6a) than the first RPCA mode (Fig.5a), which represents high variance from the Angolan coast to the Senegal coats. In our opinion it is not necessary to study RPCA since neither of PCA and RPCA can represent the two states of ACT simultaneously. In contrast, the first NLPCA mode successfully passes through the strong and weak states as NLPC varies continuously from its minimum to maximum value. Therefore the rotated eigenvectors does not improve much on the unrotated eigenvectors for the study of ACT.

Finally, the manuscript is not very clearly written and there are paragraphs that are difficult to follow because of the language and because the content is all mixed. For example the last paragraph of page 239 and first paragraph of page 240 in the introduction is quite confusing. The authors review here the literature on the seasonal cycle and inter-annual variability and compare the tropical Atlantic with the Pacific:

Here, we did a literature review on the Pacific just to show that the method used in the manuscript had also been used in Pacific Ocean to study a particular phenomenon; the El Niño. The Atlantic Cold Tongue is also another phenomenon but in the Atlantic Ocean. In the manuscript we are not making any linkage between the two phenomena but we talk about the similarities.

5- **(1) Why is the meridional mode at all mentioned? It peaks in MAM and is not considered later in the study,**

In the manuscript, we used the space (29°W–21°E, 25°S–7° N) for which the PCA was unable to capture the meridional mode because of the limitation of space but was able to after increasing it northwards, ie (30°W–20°E, 26°S–22° N). Since the space was insufficient for observing characteristic of Atlantic dipole. This meridional mode (Figure 9) is exhibited in the second mode of NLPCA and we see that the asymmetry of the variability of the meridional mode is more asymmetric (Fig. 10a) than that of the ACT. Fig.9b, c, d show the displacement of southern counterpart of the dipole, which confirms the asymmetry of the meridional mode.

6- **(2) the Atlantic Nino peaks in JJA as mentioned, but ENSO in the Pacific peaks in DJ, which suggests that in the Atlantic interannual variability is directly linked to the seasonal cycle while in the tropical Pacific this connection is more indirect; this is not mentioned. This has to do apparently with the different connection between SSTa and thermocline depth anomalies in both oceans (Li and Philander 1997, Burls et al2011).**

In this study the connection between these two events is not our objective as mentioned above. Some studies show that the El Niño is nonlinear. So, we just wanted to see if the inter-annual spatial variability in the Gulf of Guinea is more unstable, or not, than that of the tropical Pacific Ocean.

Anyway, I will then add the following paragraphs in the introduction:

The tropical Atlantic Ocean exhibits two primary modes of inter-annual climate variability: the equatorial and meridional modes. The equatorial mode is responsible for warm sea surface temperature (SST) events, mainly in the Gulf of Guinea, and is identified by abnormal changes in the equatorial thermocline slope; resulting from zonal-wind anomalies in the western tropical Atlantic. The meridional mode is characterized by a north-south inter-hemispheric gradient of SST anomaly (Jacques Servain, 1999). Many studies emphasize the similarity between the equatorial Atlantic cold tongue and the El Niño in the Pacific Ocean (Philander 1986; Horel et al.1986, Carton and Huang 1994, Delecluse et al. 1994). The meridional mode does not exist in the Pacific Ocean (Jacques servain, 1999).A relationship between the Atlantic Niño mode and Pacific variability has also been suggested by some studies; (Servain 1991, Carton and Huang 1994). They suggest a relaxation of the trade winds in the western Atlantic leads to an accumulation of warm water. Xie and Tanimoto (1998) also demonstrated how wind forcing induces the meridional mode. Specifically, when the trades intensify (weaken) in the western Atlantic, the equatorial thermocline slope increases (decreases) and negative (positive) SST anomalies develop in the equatorial ocean, particularly in the Gulf of Guinea (Servain and Arnault, 1995). In the east, warm (cold) SST is associated with a deep (shallow) thermocline, and in the west, warm (cold) SST is associated with a shallow (deep) thermocline. Because the thermocline shallows throughout the eastern ocean, cool subsurface water is able to upwell to the surface, creating cold SST anomalies in the region. This type of dynamical response is found in Moore et al. (1978), Picaut (1983), and Katz (1987, 1997) and the relevant theory in Zebiak (1993) and Servain and Arnault (1995). In the eastern tropical Pacific, large changes in SST are highly correlated with changes in the depth of the thermocline on inter-annual but not on seasonal time scales. The thermocline depth along the equator does not vary much seasonally (McPhaden et al., 1998), with the largest seasonal temperature variations confined to the surface mixed layer (McPhaden et al., 1998). The ocean atmosphere interactions that determine the oscillations between El Niño and La Niña are entirely different from those that influence the seasonal cycle. In the Atlantic, the seasonal cycle involves substantial vertical movements of the thermocline and while seasonal SST fluctuations are large, inter-annual variations in the Atlantic are modest in amplitude (Li and Philander 1997). The strongest amplitude of equatorial mode appears from May to July while the meridional mode is most pronounced during the equatorial warm season March-May (Clara Deser, 2010). Previous studies show that this meridional mode, especially in the Northern Hemisphere is significantly influenced by ENSO (Czaja et al. 2002). Particularly for ENSO, many observational (Enfield and Mayer, 1997) and modeling (Alexander and Scott 2002; Huang et al. 2002) studies have shown that the ENSO influence on the tropical Atlantic is strongest in the North Tropical Atlantic, with Atlantic warming occurring 4–5 months after the mature phases of Pacific warm events (Xie and Carton, 2004).

Other corrections and comments:

7- **page 239, last sentence: 10E**

It is 10°W

8- **page 240, line 22: what does it mean: "weakening of the ocean circulation in the Atlantic..."**

Ping et al. (2008) show that when the North Atlantic thermohaline circulation is weakened then African summer monsoonal winds and rainfall over West Africa are reduced. The "weakening of the ocean circulation in the Atlantic" means that the general circulation of the Atlantic Ocean, which is the North Atlantic thermohaline circulation is reduced. This ocean circulation change may be a major contributing factor to the rapid shift in the African monsoon. We are talking about the weakening of the Atlantic thermohaline circulation. See also (Zhang et al., 2005).

9- **page 245, last sentence: 256?**

It is 25°S and not 256.

10- **page 246: why are the PCA of the total SST presented?**

It is true that this figure is not necessary since it is not used in the next session. However, with this figure I just wanted to show the pattern of equatorial mode. Hence, I will remove it.

11- **It is not clear Figure 2 is necessary. Also, how do we know that EOF2 describes the equatorial mode? It has a different structure than the leading EOFa.**

Fig. 6a,6b and 6c show the three modes and their corresponding principal components (PCs). The other components explain less than 10% of the total variance and will not be discussed further. EOFs provide a series of eigenvectors, each of which contains a percentage of the temporal variability of the data. The three EOF modes together account for 64.11% of the total monthly SSTA variance. Individually, they explain, respectively, 36, 16 and 14% of the total variance of SSTA. Eigenvectors with the largest percentages are usually associated with physical processes. The first two modes differ in their spatial expressions. The first and third have a similar pattern.

The Gulf of Guinea is identified by abnormal changes in the equator and eastern part. The SSTA signature of the first mode is mainly confined to the eastern equatorial region. This first mode presents a structure for which the pattern is more closely confined to the eastern basin and spanning a range of latitudes (Zebiak, 1993) near the Angola coats. This spatial structure is characterized by a zonal pattern symmetric about the equator, with warm or cold SSTs appearing in the eastern equatorial basin to the south and north of the equator. The pattern of the first mode captures the zonal mode pattern in the tropical Atlantic (Zebiak 1993; Carton and Huang 1994; Huang and Shukla 1997; Handoh and Bigg 2000; Ruiz-Barradas et al. 2000). By combining EOF1 with its related PC, we observe some typical ACT cold years, such as 1990, 1992, 1997, 2005 and warm years 1984, 1987 and 1998 (Caniaux et al., 2001). This mode mainly presents interannual variability in the tropical Atlantic. Hence, this picture resembles the equatorial mode. On the other hand, the strong Atlantic signal (fig.6a), which appears in the eastern equatorial Atlantic, is mostly located south of the equator, with a longitudinal maximum variance extending from the African coast to almost 20°W.These entire characteristic is consistent with the ACT phenomenon (Caniaux et al., 2011).Therefore, this picture resembles the ACT; thus we refer this first mode as the Atlantic cold tongue. A north-south inter-hemispheric gradient of SST anomalies is observed (Jacques servain, 1999) in the second mode, which is consistent with the Atlantic dipole.

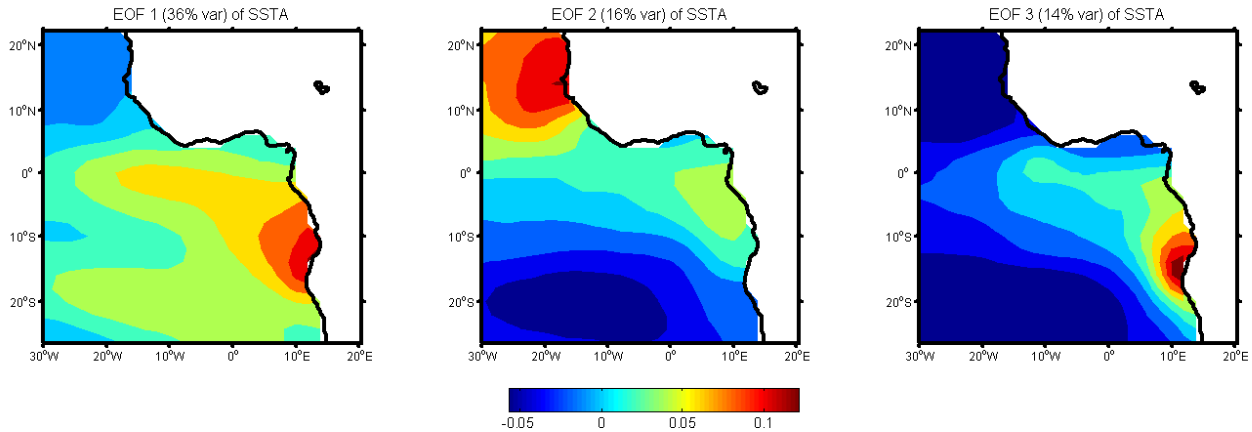


Figure 6: Empirical orthogonal function (EOF) of detrended monthly sea surface temperature (SST) Anomalies. A) EOF1 mode (left) and b) EOF2 mode (right) with their explained variance in parenthesis.

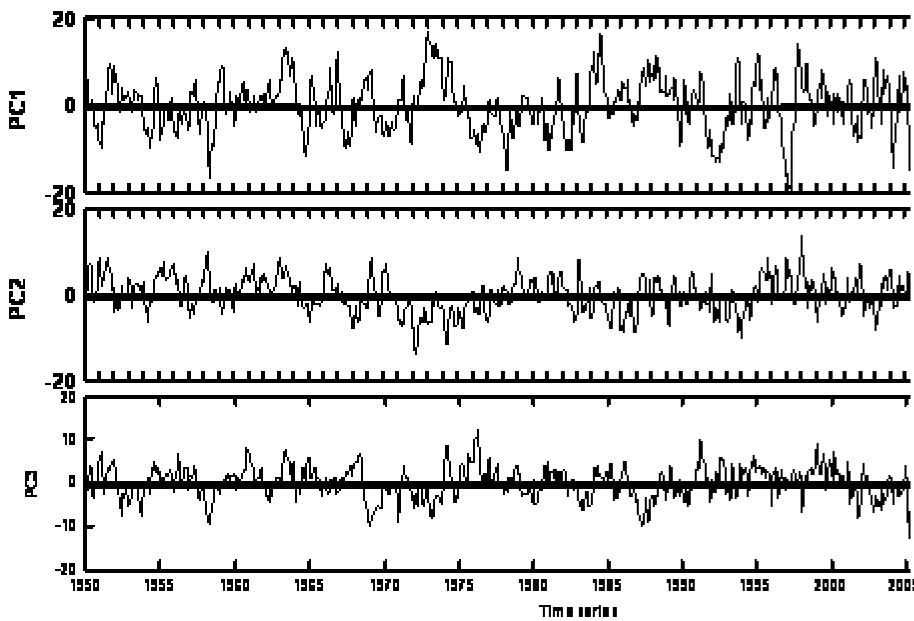


Figure 7: The corresponding time coefficients. Vertical lines in the time series correspond to January of the respective years, starting in January 1950 and ending in December 2005.

12- Page 249, line 19-21: it is not clear how it is possible to conclude that: "Unlike in the Pacific ocean, the spatial variability of this equatorial mode... than the latter." Where does this conclusion come from?

From Hsieh (2004), EL NIÑO is asymmetric, and we know that the ACT is modestly asymmetric. That is why we concluded that unlike in the Pacific Ocean, the spatial variability of this equatorial mode in the Atlantic Ocean, which is similar to El Niño/Southern Oscillation (ENSO) in the Pacific, is less linear than the latter.

13- Page 250, line 26: "the type of ACT depends on SSTa activity". What does this mean? What kind of SSTa activity? Where? What kind of physical process are we talking about?

It is a mistake; it is ACT activity and not SSTa activity, meaning that the amplitude of the ACT depends on its previous step. Hence, it shall be corrected.

14- Page 251, line 9: papers from 1977 and 1983 can not be referred as "recently".

It is true. I will cancel "recently" and replace it with:

Some authors (Hastenrath and Lamb, 1977; Houghton, 1983) showed that …………………

15- Page 251, line 26: 1D(?) NLPCA

It is "1D NLPCA approximation ".

(Fig. 8 is just to show the results for EOF for 56 years without adding the northward spatial enlargement. Hence, we shall instead consider Fig. 6.)

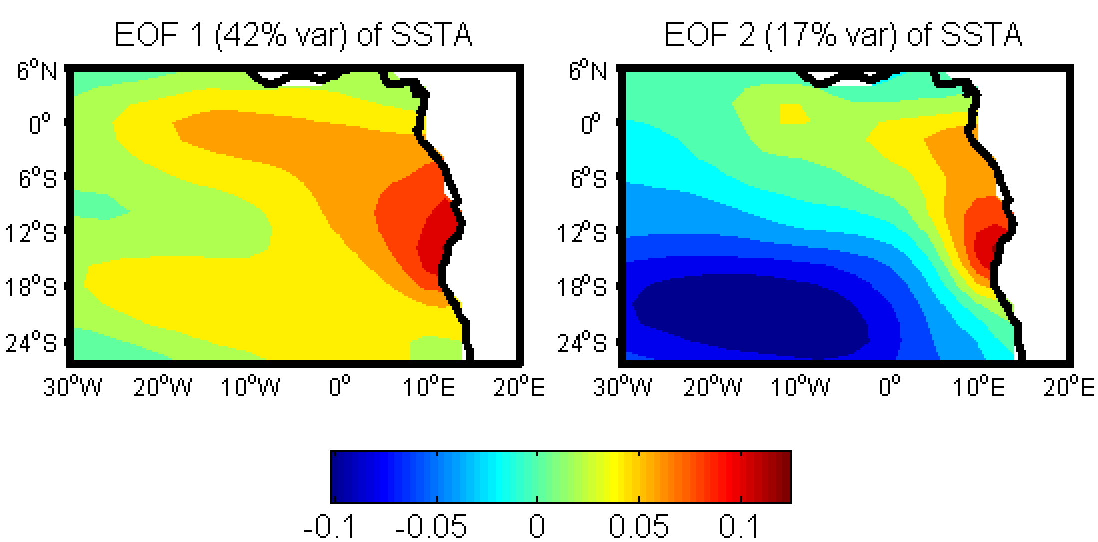


Figure 8: Empirical orthogonal function (EOF) of detrended monthly sea surface temperature (SST) Anomalies. EOF1 mode (left) and EOF2 mode (right) with their explained variance shown in parenthesis.

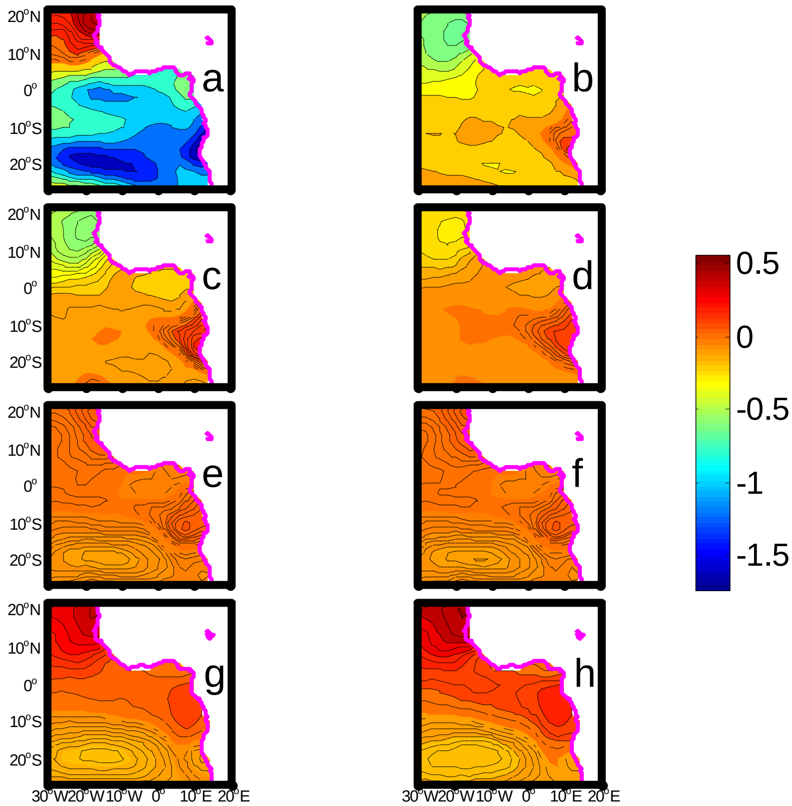


Figure 9: The SST anomaly pattern (in °C) of the second NLPCA mode varies from (a) its minimum (strong gradient between north and South), to (b) three-quarter its minimum, to (c) half its minimum, to (d)quarter of its minimum, to (e) quarter its maximum, to (f) half its maximum, to (g) three-quarter its maximum and (h) its maximum (weak gradient between north and South). Zero contours are white lines. Positives contours are black line and negative contours are dashed black line. The contours in pink color are the coast.

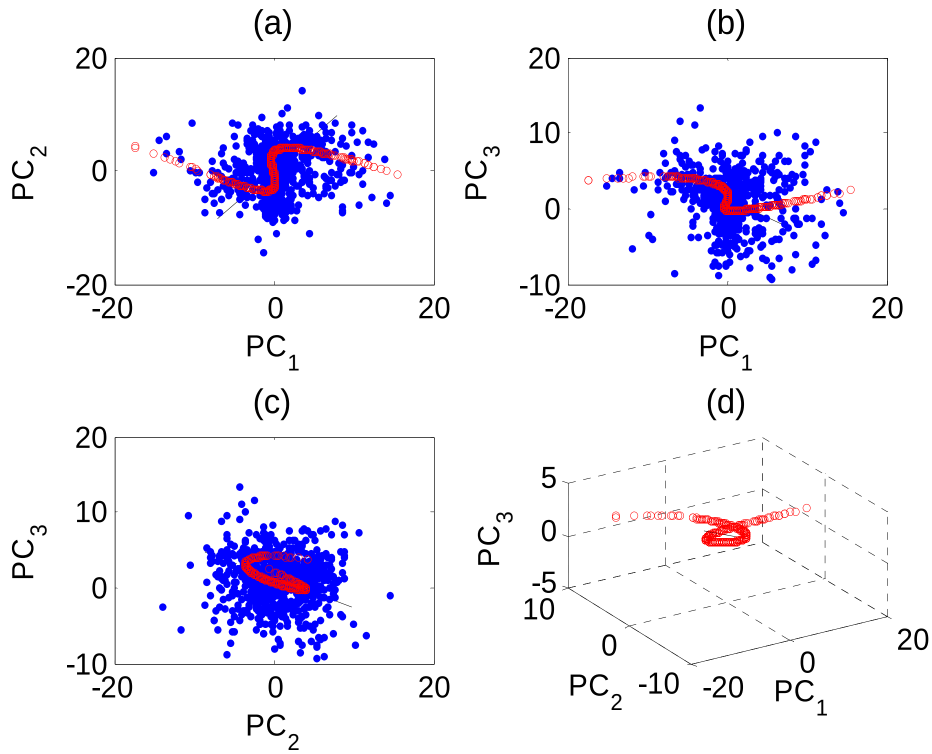


Figure 10: Scatter plots of the sea surface temperature (SST) anomaly (SSTA) data (shown as dots) in the principal component (PC1, PC2, and PC3) plane. The dots show the residual data after the NLPCA mode 1 has been subtracted.This second mode NLPCA approximation to the data is shown by the reds circles, which trace out a *Wave*-shaped curve. (The linear solution to the dataset after NLPCA mode 1 has been removed is not the same as PCA mode 2, which is the linear solution to the dataset after PCA mode 1 has been removed.)

The NLCCA mode 2 (circles) in the SLP PC-space (where PC1, PC2, and PC3 of the 6 SLP PCs are shown). The dots show the residual data after the NLCCA mode 1 has been subtracted. The linear solution is shown as the thin straight line. (This linear solution to the dataset

after NLCCA mode 1 has been removed is not the same as CCA mode 2, which is the linear solution to the dataset after CCA mode 1 has been removed.)

Find below the figure of the Rotated PCA when considering the previous space (29°W–21°E, 25°S–7° N).

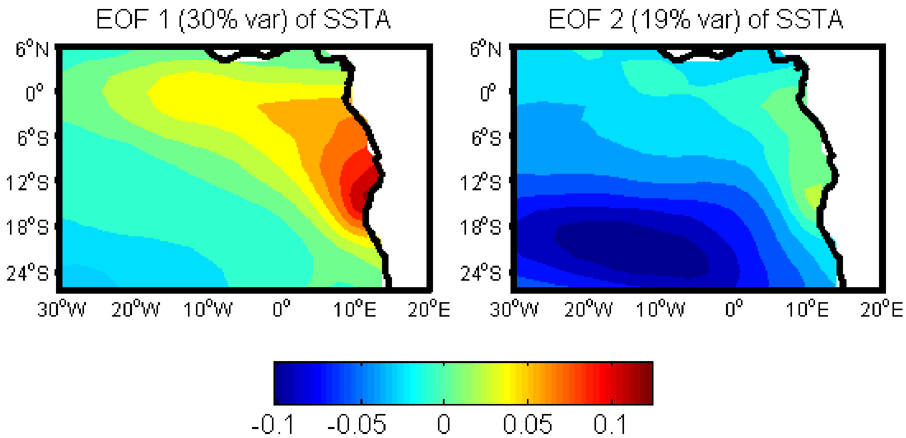


Figure11: The rotated PCA (RPCA) eigenvectors using the varimax method of detrended monthly sea surface temperature (SST) Anomalies. EOF1 mode (left) and EOF2 mode (right) with their explained variance shown in parenthesis.