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Multi-decadal Variability of Sea Surface Temperature in the Northern Coast of Gulf of Guinea

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ABSTRACT

El Niño influences the climate over a broad region in the world and could shift the oceanic upwelling. The intensity of the upwelling at the northern coast of Gulf of Guinea (GG) is characterized by strong year-to-year variability with anomalous warming events that reach 1 or 2°C some years but how this event responds to natural climate-driven change in the physical environment still remains not well understood. The Sea Surface Temperature (SST) from the Reynolds datasets of the last 3 decades (1982-2010) was analyzed to evaluate the long term variability of the coastal upwelling in July-September of the northern Gulf of Guinea and the influence of El Niño-Southern Oscillation (ENSO) on this phenomenon. This major coastal upwelling of GG is important for the marine ecosystem and the fishery. It also influences the precipitation of the bordering countries. Lag relationship of 7-8 and 18 months was observed between the peaks of the strong El Niño (La Niña) events in the Pacific Ocean and the strongest warming (cooling) during summer at the northern coast of GG. Particularly, the strong cooling in July-September at the northern coast of GG occurred one year after the strong La Niña events in the Pacific Ocean. These results suggest that El Niño or La Niña events lead the SST variability at the northern coat of GG.

Key words: Guinea gulf, sea surface temperature, coastal upwelling, decadal variability, El Niño, time series

INTRODUCTION

The northern coast of the Gulf of Guinea (GG) experiences two seasonal upwellings occurring from December to March (minor upwelling) and from July to September (major upwelling) (Aman and Fofana, 1995, 1998). These upwellings are important for the marine ecosystem and the fishery in this area (Denis, 1982) and the major one influences the precipitation in the coastal area (Ali *et al*., 2011; Bakun, 1978). They extend (Fig. 1) from 2°N to the northern coast, between the Cape Palmas around 7°W at the border of Ivory Coast and Liberia and around 5°E at the east of Benin (Bakun, 1978). They are characterized by a strong year-to-year variability of their intensity and of their date of onset (Arfi *et al*., 1991). Many theories have been proposed to explain the mechanisms at the origin of these coastal upwellings (Roy, 1995) but up to now, no agreement is found between these theories.

The climatic variability such as El Niño could shift the Sea Surface Temperature (SST) in the area of the upwelling and could alter the upwelling systems (Fiedler, 1984; Kahru and Mitchell,

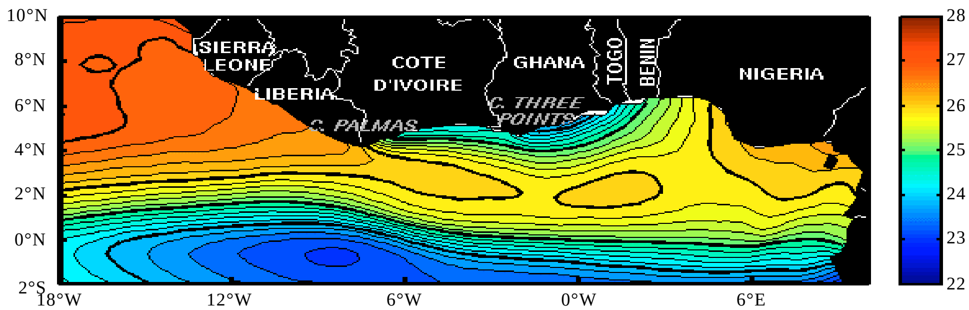

Fig. 1: Horizontal distribution of the mean July-August of SST calculated over 29 years (1982-2010) from weekly sea surface temperature (°C) of Reynolds datasets, Intervals between contours are 0.25°C and the bold lines represent integer values

2000). Is there any relationship between SST of the GG and El Niño-Southern Oscillation (ENSO) in the Pacific Ocean? It is shown that ENSO alters the sources of atmospheric heating, which then affects atmospheric circulation and climate on a global scale (Klein *et al.*, 1999; Oort and Yienger, 1996; Wang, 2002). The anomalous warming in the eastern equatorial Pacific during El Niño is at the origin of a warming signal in the troposphere, which then propagates rapidly eastward in the form of an equatorial Kelvin wave (Saravan and Chang, 2000; Yulaeva and Wallace, 1994). It could by example affect the tropical Atlantic through its impact on the trade winds over the Atlantic Ocean (Enfield and Mayer, 1997; Wu *et al.*, 2002) or on the zonal surface and subsurface currents (Lohmann and Latif, 2007). For example, one year after the strong El Niño event which developed during 1982-1983 with positive SST anomalies exceeding 3°C during many months in a broad area of the Pacific Ocean, a warm SST episode also occurred in the entire equatorial Atlantic with anomalies exceeding 2°C during the summer 1984 along the African coasts (Philander, 1986; Servain and Seva, 1987). This warm event in the Atlantic Ocean is partially initiated by atmospheric disturbance related to the major El Niño (Delecluse *et al.*, 1994; Horel *et al.*, 1986). Enfield and Mayer (1997) and Chang *et al.* (2006) didn't find significant correlations between SST in the Gulf of Guinea and the Pacific ENSO. The relationship between El Niño and the fluctuation in the equatorial Atlantic is fragile and inconsistent because of destructive interference between atmospheric and oceanic processes in response to El Niño (Chang *et al.*, 2006).

In the region of the northern coast of GG, the impact of climate change on the long-term biomass has been studied by Wiafe *et al.* (2008). The variability of this costal upwelling has been supposed to be linked to the climate mode variability such as El Niño (Hardman-Mountford and McGlade, 2003; Wiafe *et al.*, 2008) and more precisely the warm year in the northern coast of the GG in 1984 is supposed to be associated to the 1982-1983 El Niño event (Hardman-Mountford and McGlade, 2003). As part of the variability of SSTs in the northern coast of GG is supposed to be driven by large-scale climate variability such as ENSO; establishing underlying links between these large scale patterns and by example the intensity of these upwellings will help to understand and predict the decadal changes of these upwellings in the context of natural variability.

The aim of this study is to analyze the long term trend variability of the major upwelling at the northern coast of GG and the possible impact of El Niño on this phenomenon. The 1×1° horizontal resolution and the period from 1982 to 2010 (29 years) of the weekly SST datasets from Reynolds provide more detail about the characteristic of the coastal upwelling.

MATERIALS AND METHODS

Sea surface temperature: A weekly 1×1° spatial resolution Optimum Interpolation (OI) SST produced by the National Oceanic and Atmospheric Administration (NOAA) was used to investigate the long term variability of SST along the northern coast of GG. These data are freely available (http://www.esrl.noaa.gov/psd/data/gridded/data.ncep.oisst.v2.html). Our study covers the period 1982-2010 (29 years) when both *in situ* and satellite data are available and included in this dataset (Reynolds *et al*., 2002). These data are widely been used for weather and climate monitoring and forecasting (Reynolds *et al*., 2002.) The major problem in retrieving SST from satellite is to eliminate cloud contamination. The algorithm used to correct the retrieval of SST datasets from cloud contamination is improved from the first version of optimum interpolation OI.v1) of this dataset to its second version (OI.v2). The global averaged difference among the different SST datasets and the improved version of SST used in this study is 0.05°C on decadal scales (Reynolds *et al*., 2002). The other problem in retrieving SST from satellite is recurrent in the Gulf of Guinea where the seasonal presence of the zone of confluence of the trade winds leads to the development of strong clouds. Such algorithm, improved to eliminate the cloud contamination, makes these SSTs the best as possible data available for the northern coast of the GG. The major coastal upwelling in the northern coast of GG is observed north of 2°N and between 7°W and 5°E (Bakun, 1978) from July to September. The weekly SSTs of Reynolds dataset (Reynolds *et al*., 2002) have been averaged spatially firstly in the box 7°W-5°E; 3°N-6°N. Then, a temporally average is performed on weekly dataset to construct the monthly time series used in this study.

El Niño-Southern oscillation index: The relationship between the low-frequency mode climate variability (El Niño-Southern oscillation) and the variability of SSTs at the northern coast of the GG was also examined through a combined analysis of the time series of SST in the GG and the time series of an indicator of El Niño. The El Niño-Southern oscillation index (Nino 3.4), an indicator of ENSO state (Trenberth and Stepaniak, 2001) is compiled by NOAA's Climate Prediction Center and is freely available at the web site ftp://ftp.cpc.ncep.noa.gov/wd52dg/data/indices/nino3.4. The Nino 3.4 region in the Pacific Ocean is centered on the equator between the latitudes 5°N and 5°S and between the longitudes 170°W and 120°W. In June 1997, the Nino 3.4 values were changed during the period 1950-1994 and also adjusted (ftp://ftp.ncep.noaa.gov). We decided to use the Nino 3.4 index because its area allows a better view of what SSTs are doing between Nino 3 and 4 regions.

Methodology: Cross-correlation analysis of the detrended time series of SST in the northern coast of GG and the filtered Nino 3.4 time series was performed to investigate the Relationships between El Niño in the Pacific and coastal upwelling of the northern boundary of GG. The monthly time series of SST was detrended by subtracting the best-fit line in the least-squares sense from the data. The linear trend typically indicates a systematic increase or decrease in the data. Removing the trend from the data enabled us to focus our analysis on the seasonal fluctuations of the warming or cooling during summer without the trend which can increase the warming or decrease the cooling. A 5-month running mean was used to filter the Nino 3.4 index.

RESULTS

This study analyses the three decade variabilities of the annual major coastal upwelling along the northern coast of the GG and how this event responds to the El Niño. The monthly and annual time series of SST at the northern coast of GG are shown in Fig. 2 and 3. These figures show an

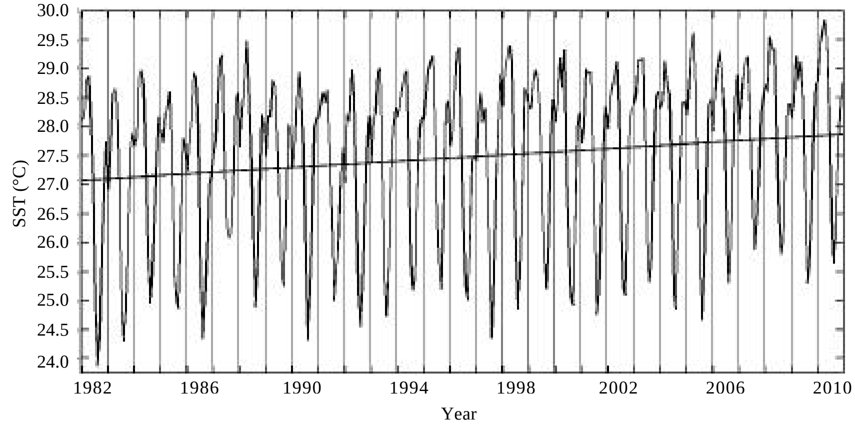

Fig. 2: Temporal evolution of monthly SST averaged within 7°W-5°E; 3°N-6°N. The weekly SSTs of Reynolds datasets have been averaged in monthly time series for the period 1982-2010. The best-fit line in the least-squares sense representing the trend of the data was added

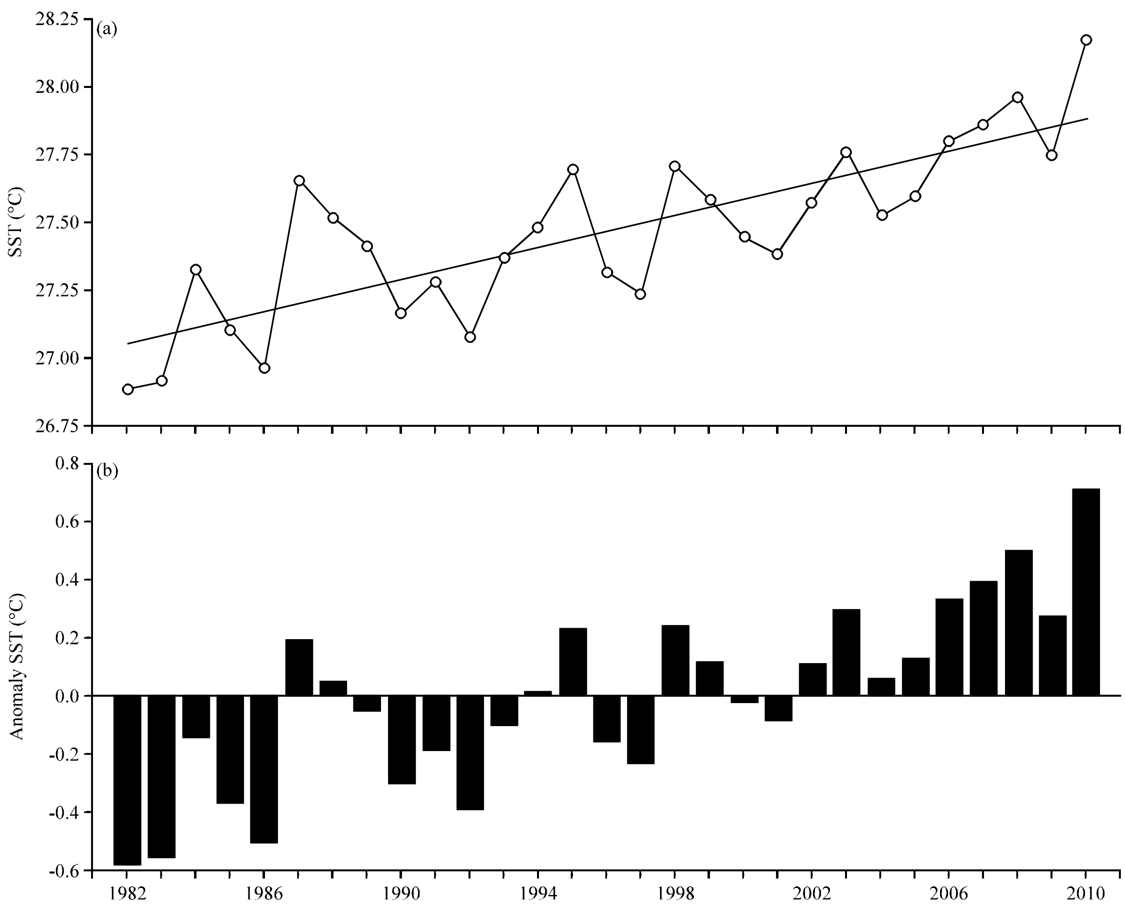

Fig. 3(a-b): (a) Evolution of the annual mean of SSTs the 12 calendar months of the time series used in Fig. 1 and (b) Anomaly of SST derived from this annual mean increase of SST in the northern GG. This warming is also observed during the major upwelling (Fig. 4). The close analysis of the El Niño in the Pacific Ocean and the major coastal upwelling of the northern coast of GG (Fig. 5, 6) suggest that El Niño leads the variability of the intensity of this upwelling.

Long term variability of the sea surface temperature in the northern coast of GG: Figure 2 shows the monthly time series of the SST between 7°W-5°E and 3°N-6°N and the related best-fit line. The weekly data have been averaged to obtain unfiltered monthly data. This time series was characterized by two minima in summer and in winter which correspond to the major and the minor upwelling, respectively (Aman and Fofana, 1995, 1998). The major upwelling characterized by lowest SST showed a strong year-to-year variability (Arfi *et al.*, 1991). The time series of SST showed also a faster annual oscillations (Fig. 2). The trend of the SST was positive and indicated a SST warming of about 0.03°C year^{-1}.

Figure 3 shows the annual mean and anomalies of SST. An increase of the annual mean of the SST of about 0.03°C year^{-1} was observed between 26.5 and 28.25°C during the period 1982-2010 (Fig. 3a). Figure 3b exhibits two periods of SST anomaly: the first period of cold SST which extended from 1982 to 2001 and was characterized by negative anomaly. The second period of

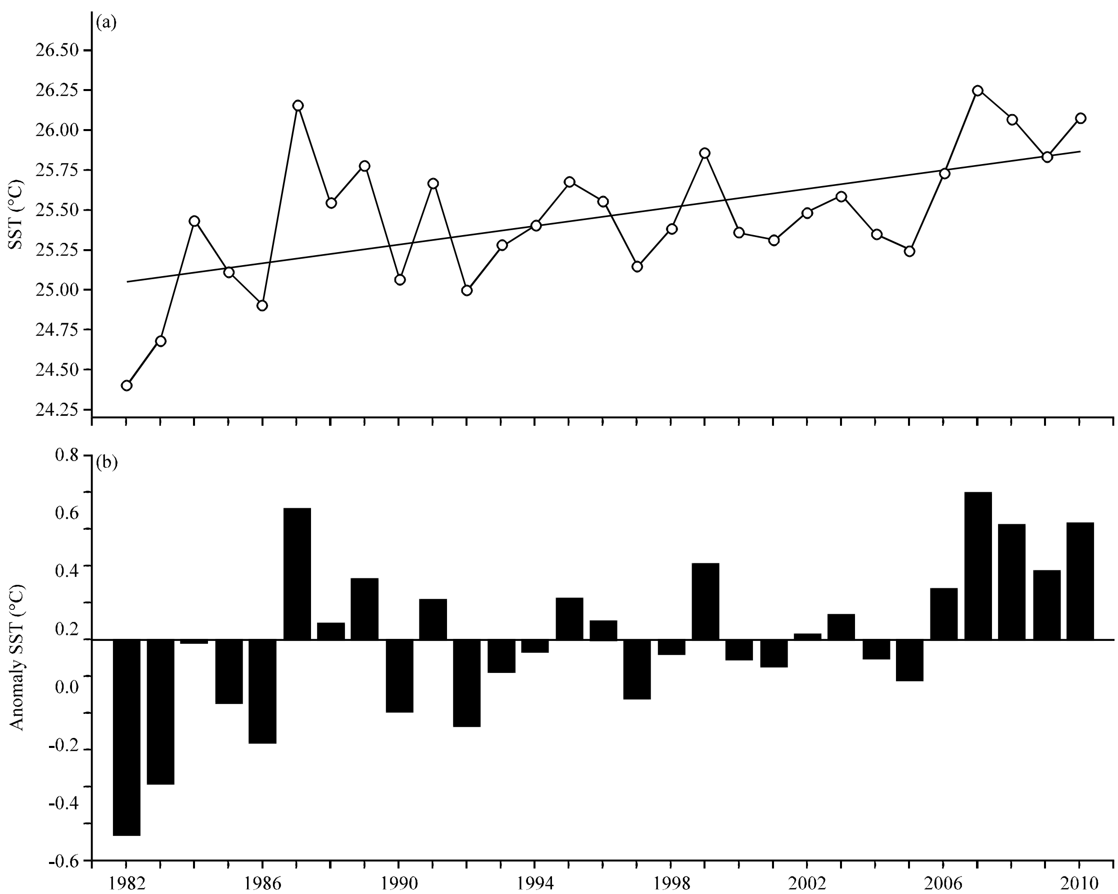

Fig. 4(a-b): (a) Annual evolution of the seasonal (July-August-September) average of the SSTs time series of the northern coast of GG for the period 1982-2010 and (b) the annual anomaly of the July-August-September mean derived from the seasonal mean

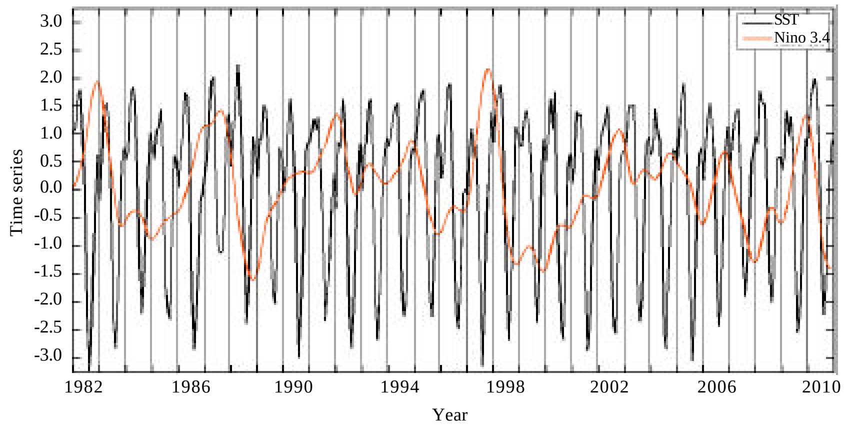

Fig. 5: Monthly evolution of the detrended SSTs from the monthly time series of SSTs in the northern coast of GG (black curve) and the Nino 3.4 index, The best-fit line in the least-squares sense was removed from the time series data to compute the detrended SSTs. A 5 month running mean was applied to the Nino 3.4 time series

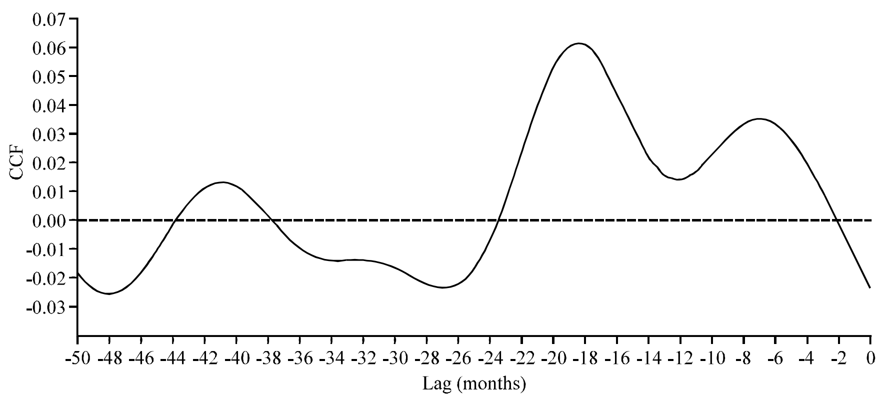

Fig. 6: Cross-correlation function of detrended time series of SSTs from the northern coast of GG and the Nino 3.4 index, The Nino 3.4 time series was filtered with a 5 month running mean

warm SST (from 2002 to 2010) showed positive anomaly. The coldest SST anomalies (<-0.2°C) were observed in 1982, 1983, 1985, 1986, 1990 and 1992; whereas the warmest (>0.2°C) were recorded in 2003 and from 2006 to 2010 with maxima in 2008 and 2010 where SST anomalies exceeded 0.3°C.

Figure 4 shows the July-to-September annual evolution of SST during the major upwelling season. A strong year-to-year variability with 0.62°C of standard deviation was observed in the annual evolution of the seasonal SST with a gradual increase (Wiafe *et al*., 2008). The slope of the best fit line (~0.03°C year^{-1}) is significant at 95% level and was closed to that calculated for the annual mean (Fig. 3a). This suggests that the seasonal warming observed during the major upwelling season followed the annual warming at the northern coast of the GG. The seasonal anomaly derived from the seasonal mean of the major upwelling season in July-August-September showed a strong variability between negative and positive values (Fig. 4b). The periods 1982-1986 was characterized by negative anomaly while the period 2006-2010 showed positive anomalies. The years 1982, 1983 and 1986 recorded the minimum anomalies while 1987, 1999, 2007 and 2009 had the maximum ones.

Potential connection of SST in the northern coast of GG to El Niño in the pacific ocean: Figure 5 shows the detrended monthly time series of SST and the index of El Niño-Southern oscillation (Nino 3.4). The time series of SST was detrended by removing the mean value from the monthly variability in the aims to detect the peak-to-peak of the summer minimum or maximum not due to the global trend characterized by an increase of SST over the decades. The Nino 3.4 index was filtered by applying a 5 month running mean. The Figure 5 shows minimum SSTs during the coastal upwelling of the northern coast of GG during summer of the years 1982, 1983, 1986, 1990, 1992, 1997, 2001 and 2005. The warm summers off Ivory Coast and Ghana were observed in 1984, 1987, 1989, 1994, 1995, 1999, 2003 and 2007. The Nino 3.4 time series (Fig. 5) showed a 3.5, 4 to 7 year period time variability in the peak of its maximum and minimum values. The maximum values of the Nino 3.4 index corresponding to El Niño events were observed in 1982-1983, 1986-1987; 1991-1992, 1997-1998, 2009-2010. The 1982-1983 and 1997-1998 El Niño events are the strongest abnormal climatic events observed during these last decades (Chang *et al.*, 2006). Negative minimum Nino 3.4 index values corresponding to La Niña events were also observed with their peaks in 1984-1985, 1988-1989, 1995-1996, 1998-2000, 2007-2008.

The warm summers in the northern coast of GG during the years 1984 and 1999 were observed one year after (approximately 17 months after the peaks of the El Nino in December-January) the strong El Niño observed in the Pacific respectively in 1982-1983 and 1997-1998. Also, some warm summers in the northern coast of GG were observed in 1994, 1995 during the extended El Niño event of 1990-1995 in the Pacific Ocean. The strong warm summer of 1987 in the northern coast of GG occurred during an extended El Niño event started in spring 1986 and peaked from December 1986 until fall 1987. The warm summer events in the northern coast of GG during the years 2003 and 2007 were observed 6 months after the respective peak of the El Niño events of the years 2002-2003 and 2006-2007. In general, the warm summer upwellings in the northern coast of GG were observed one year (i.e., 17-18 months after the peaks of the Nino 3.4 index) or 6 to 8 months after the El-Niño events in the pacific ocean. The strong cooling during summer of the years 1986, 1990, 1997, 2001 and 2009 were observed respectively one year after the La Niña events. Strong cooling events occurred in 1982 and 2005 in the northern coast of GG that were not observed after La Niña events.

Previous studies have already connected the warm event of 1984 in the Atlantic Ocean to the strong 1982-1983 El Niño event in the pacific (Delecluse *et al.*, 1994). Also our previous results suggested warm events during summer upwelling at the northern coast of GG could be associated to El Niño events in the pacific ocean in some unspecified way. What is the correlation between the ENSO index (Nino 3.4 time series) and the SST time series of the northern coast of GG?. Figure 6 shows the Cross-correlation Function (CCF) between the detrended time series of SST of the northern coast of GG and the time series of Nino 3.4. The cross-correlation function peaked at time +7-8 months, at time +18 months and at time +41 months. The value of the correlation was positive and also weak as observed by Chang *et al.* (2006), with the maximum one observed at time lag +18 months. The sign of the CCF was positive, leading to the conclusion that the two phenomena, i.e., the El Niño in the Pacific and the SST at the northern coast of GG, move in the same direction:

A warming (cooling) in the Pacific corresponding to an El Niño (La Niña) event leads to a warming (cooling) of the SST off Ivorian-Ghanaian coast, particularly the warming (cooling) of the summer coastal upwelling of the northern coast of the GG.

DISCUSSION

This study Focused on the variability of SST along the northern coast of GG and Nino 3.4 index in the Pacific Ocean during 1982-2010. It provides insight into the long term variability of the boreal coastal upwelling along the northern boundary of GG and the relationship between this upwelling and the El Niño occurring in the Pacific Ocean. Two upwelling periods are observed: the minor upwelling during winter and the major one in summer (Aman and Fofana, 1995, 1998; Bakun, 1978). Over the last three decades, SSTs increased concomitantly with the major upwelling (Wiafe *et al.*, 2008).

The annual mean anomaly of SST shows a strong cooling period from 1982 to 1992, a period of strong interannual variability between cold and warm years in 1992-2002 and a warm period from 2002 to 2010. The three periods lasted on average 10 years. These results are in agreement with those of Koranteng and McGlade (2001) who also observed a decadal change in the SST.

Annual variability of the cooling during summer was observed over these decades. The SSTs was warm for some summers and cold for others. A lagged correlation analysis was performed to investigate the remote forcing of El Niño in the Pacific Ocean onto the major coastal upwelling of the northern GG (Huang *et al.*, 2002). Important correlation between SST time series and Nino 3.4 time series was observed at lag 7-8 months and 18 months. This suggests that El Niño (La Niña) events enhance the warming (cooling) of the water during the major upwelling in the northern coast of GG. This finding is an agreement with many studies which have shown that SST fluctuation in the Atlantic Ocean is associated to El Niño (Chiang *et al.*, 2000; Curtis and Hastenrath, 1995; Enfield and Mayer, 1997; Latif and Barnett, 1995; Latif and Grotzner, 2000; Saravan and Chang, 2000). For instance, Hardman-Mountford and McGlade (2003) suggested that the warm events at the northern coast of GG and specially the warm upwelling event in 1984 are associated to El Niño type forcing.

Our results suggest that at lag of 18 months, El Nino explain 6% of the variability of the SST at the northern coast of GG and particularly during the major coastal upwelling. El Niño has a remote impact on climate variability in the tropical Atlantic Ocean with the robust influence in the northern tropical Atlantic (Enfield and Mayer, 1997). Min (2002) mentioned that ENSO induces 10-15% of total variance of the SST anomalies in the tropical Atlantic Ocean. Our value is less than that mentioned by Min (2002) and could be explained by some process. For example, the coastal upwelling of the northern GG is characterized by complex mechanisms. Besides, the local coupling impacts SST in the Atlantic Ocean (Chang *et al.*, 1997; Zebiak, 1993). Moreover, Atlantic Niño has an impact on the SST over a broad area in the Gulf of Guinea. But up to now, the relation between the variability of equatorial SST and coastal SST along the northern coast is discussed (Colin, 1988; Roy, 1995). The equatorial area in the Atlantic Ocean could force the coastal SST of the northern coast through a remote forcing (Picaut, 1983; Moore *et al.*, 1978) due to the propagation of equatorial Kelvin waves in the GG observed by Polo *et al.* (2008).

The SST in the Atlantic Ocean and particularly at the northern coast of GG doesn’t respond linearly to the El Nino signal. It is a complex response involving the Pacific remote influence (Chang *et al.*, 1997; Zebiak, 1993) and the Atlantic Ocean-atmosphere interaction (Enfield and Mayer, 1997). Also, the wind respond depending to atmospheric heating structure and duration can vary considerably depending of each El Niño (Chang *et al.*, 2006). The local ocean-atmosphere interaction in the Atlantic Ocean would consequently depend of the variability of the duration of the El Niño events, e.g., the warm upwelling of 1994 was of same magnitude as those observed in 1984 and 1999 in the northern coast of GG. The warm upwelling of the year 1994 occurred during an El Niño event of 1990-1995 (Trenberth and Stepaniak, 2001) which lasts long time compared to the strong El Niño of 1982-1983 and 1997-1998.

Our results highlight that El Niño influences the major coastal upwelling at the northern coast of GG. These results deserve to be confirmed by model calculations in order to better understand the physical mechanisms by which this connexion is made.

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REFERENCES

Ali, K.E., K.Y. Kouadio, E.P. Zahiri, A. Aman, A.P. Assamoi and B. Bourles, 2011. Influence of the Gulf of Guinea coastal and equatorial upwellings on the precipitations along its Northern coasts during the boreal summer period. Asian J. Applied Sci., 4: 271-285.

Aman, A. and S. Fofana, 1995. Temperature as Detected by Meteosat satellite and received at the University of Abidjan. In: Dynamics and Use of Sardinella Resources from Upwelling off Ghana and Ivory Coast, Bard, F.X. and K.A. Koranteng (Eds.). ORSTOM Editions, Paris, pp: 52-59.

Aman, A. and S. Fofana, 1998. Spatial Dynamics of the Upwelling of Cote d'Ivoire. In: Global Versus Local Changes in Upwelling Systems, Durand, M.H., P. Cury, R. Mendelssohn, C. Roy, A. Bakun and D. Pauly (Eds.). ORSTOM Editions, Paris, pp: 139-147.

Arfi, R., O. Penzennec, S. Cissoko and M. Mensah, 1991. Variations Spatiale et Temporelle de la Resurgence Ivoiro-Ghaneenne. In: Pecheries Ouest-Africaines: Variabilite, Instabilitie Changement, Cuiv, P. and C. Roy (Eds.). ORSTOM, Paris, pp: 162-172.

Bakun, A., 1978. Guinea current upwelling. Nature, 271: 147-150.

Chang, P., L. Ji and H. Li, 1997. A decadal climate variation in the tropical Atlantic Ocean from thermodynamic air-sea interactions. Nature, 385: 516-518.

Chang, P., Y. Fang, R. Saravanan, L. Ji and H. Seidel, 2006. The cause of the fragile relationship between the Pacific El Nino and the Atlantic Nino. Nature, 443: 324-328.

Chiang, J.C.H., Y. Kushnir and S.E. Zebiak, 2000. Interdecadal changes in eastern Pacific ITCZ variability and its influence on the Atlantic ITCZ. Geophys. Res. Lett., 27: 3687-3690.

Colin, C., 1988. Coastal upwelling events in front of the ivory coast during the FOCAL program. Oceanol. Acta, 11: 125-138.

Curtis, S. and S. Hastenrath, 1995. Forcing of anomalous sea surface temperature evolution in the tropical Atlantic during Pacific warm events. J. Geophys. Res., 100: 15,835-15,847.

Delecluse, P., J. Servain, C. Levy, K. Arpe and L. Bengtsson, 1994. On the connection between the 1984 Atlantic warm event and the 1982-1983 ENSO. Tellus, A, 46: 448-464.

Denis, B., 1982. Influence of the climate variation on the fishery of Sardinella aurita off Ivorian-Ghanaian coast: Relation drought-overfishing. Oceanol. Acta, 5: 443-452.

Enfield, D.B. and D.A. Mayer, 1997. Tropical Atlantic sea surface temperature variability and its relation to El Nino-Southern Oscillation. J. Geophys. Res., 102: 929-945.

Fiedler, P.C., 1984. Satellite observations of the 1982-1983 El Nino along the U.S. Pacific coast. Science, 224: 1251-1254.

Hardman-Mountford, N.J. and J.M. McGlade, 2003. Seasonal and interannual variability of oceanographic processes in the Gulf of Guinea: an investigation using AVHRR sea surface temperature data. Int. J. Remote Sens., 24: 3247-3268.

Horel, J.D., V.E. Kousky and M.T. Kagano, 1986. Atmospheric conditions in the Atlantic sector during 1983 and 1984. Nature, 322: 248-251.

Huang, B., P.S. Schopf and Z. Pan, 2002. The ENSO effect on the tropical Atlantic variability: A regionally coupled model study. Geophys. Res. Lett., Vol. 29.

Kahru, M. and B.G. Mitchell, 2000. Influence of the 1997-98 El Nino on the surface chlorophyll in the California Current. Geophys. Res. Lett., 27: 2937-2940.

Klein, S.A., B.J. Soden and N.C. Lau, 1999. Remote sea surface temperature variations during ENSO: Evidence for a tropical atmospheric bridge. J. Climate, 12: 917-932.

Koranteng, K.A. and J.M. McGlade, 2001. Climatic trends in continental shelf waters off Ghana and in the Gulf of Guinea, 1963-1992. Oceanol. Acta, 24: 187-198.

Latif, M. and A. Grotzner, 2000. The equatorial Atlantic oscillation and its response to ENSO. Climate Dyn., 16: 213-218.

Latif, M. and T.P. Barnett, 1995. Interactions of the tropical oceans. J. Climate, 8: 952-964.

Lohmann, K. and M. Latif, 2007. Influence of El Nino on the Upper-ocean circulation in the tropical Atlantic Ocean. J. Climate, 20: 5012-5018.

Min, D., 2002. A numerical investigation of the remote influence of Pacific ENSO on variability in the tropical Atlantic Ocean. Texas Aand M University, Pages: 218.

Moore, D., P. Hisard, J. McCreary, J. Merle and J. O'Brien *et al*., 1978. Equatorial adjustment in the Eastern Atlantic. Geophys. Res. Lett., 5: 637-640.

Oort, A.H. and J.J. Yienger, 1996. Observed interannual variability in the Hadley Circulation and its connection to ENSO. J. Climate, 9: 2751-2767.

Philander, S.G.H., 1986. Unusual conditions in the tropical Atlantic ocean in 1984. Nature, 322: 236-238.

Picaut, J., 1983. Propagation of the seasonal upwelling in the Eastern equatorial Atlantic. J. Phys. Oceanogr., 13: 18-37.

Polo, I., A. Lazar, B. Rodriguez-Fonseca and S. Arnault, 2008. Oceanic Kelvin waves and tropical Atlantic intraseasonal variability: 1. Kelvin wave characterization. J. Geophys. Res., Vol. 113.

Reynolds, R.W., N.A. Rayner, T.M. Smith, D.C. Stokes and W. Wang, 2002. An improved in situ and satellite SST analysis for climate. J. Climate, 15: 1609-1625.

Roy, C., 1995. The Cote d`Ivoire and Ghana Coastal Upwellings: Dynamics and Changes. In: Dynamics and Use of Sardinella Resources from Upwelling off Ghana and Ivory Coast, Bard, F.X. and K.A. Koranteng (Eds.). ORSTOM, Paris, pp: 346-361.

Saravan, R. and P. Chang, 2000. Interaction between tropical Atlantic variability and El Nino-Southern Oscillation. J. Climate, 13: 2177-2194.

Servain, J. and M. Seva, 1987. On relationships between tropical Atlantic sea surface temperature, wind-stress and regional precipitation indices: 1964-1984. Ocean-Air Interactions, 1: 183-190.

Trenberth, K.E. and D.P. Stepaniak, 2001. Indices of El Nino evolution. J. Climate, 14: 1697-1701.

Wang, C., 2002. Atmospheric circulation cells associated with the El Nino-Southern Oscillation. J. Climate, 15: 399-419.

Wiafe, G., H.B. Yaqub, M.A. Mensah and C.L.J. Frid, 2008. Impact of the climate change on long-term zooplankton biomass in the upwelling of the Gulf of Guinea. J. Mar. Sci., 65: 318-324.

Wu, L., Q. Zhang and Z. Liu, 2002. Searching for the role of ENSO in tropical Atlantic variability using a coupled GCM. CLIVAR Exchanges, 7: 20-24.

Yulaeva, E. and J.M. Wallace, 1994. Sensitivity of seasonal climate forecasts to persisted SST anomalies. J. Climate, 7: 1719-1736.

Zebiak, S.E., 1993. Air-Sea interaction in the equatorial Atlantic region. J. Climate, 6: 1567-1586.