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KELVIN WAVES ACTIVITY IN THE EASTERN TROPICAL ATLANTIC

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ABSTRACT

Tropical Atlantic intraseasonal variability is investigated in the framework of propagation of sea surface height anomalies along the equator and the West-African coastlines. We present a climatological analysis of the observed intraseasonal equatorial Kelvin wave activity and its coastally trapped extension signals. A OGCM simulation is used to provide the subsurface activity. The analysis focuses then on the wind activity that trigger the signal in the west equator and modulates it along the whole trajectories.

An about two months periodicity is found for the Kelvin wave signals and the winter season presents more activity The equatorial Kelvin wave propagates eastward along the equator until the African coast where the wave splits and travels polewards, coastally trapped. The propagation is clear until about 12 degree of latitude North and South where it encounters the oceanic fronts of the Mauritanian and Benguela upwelling regions. Beyond, local wind effects become predominant and control largely the ssha.

1. INTRODUCTION

The seasonal adjustment of the equatorial ocean to the wind stress forcing drives a cycle of consecutive Kelvin waves. The principal source of the equatorial Kelvin wave has been related to the western equatorial zonal wind changes (e.g.; Philander, 1990). In the Atlantic, as shown by Schouten et al. (2004), in winter, the relaxation of the trade winds at the equator generates apparent eastward propagations of positive ssha relative to the annual mean (February-march). In the summer, with the strengthening of the trade winds, an upwelling signal is observed instead (September-October). There are corresponding coastal poleward apparent propagations : two down-welling propagations (February-March and October-November) and an upwelling one (June-July) coinciding with the upwelling season in the Gulf of Guinea (Picaut 1983).
Kelvin wave propagation has been studied before from observational data, for the equatorial Atlantic (e.g.; Katz, 1990; Franca et al, 2003; Schouten et al, 2005), for the African coast (e.g.; Picaut, 1983), for the equatorial Pacific (e.g.; Cravatte et al., 2003) and for the coast of the Pacific related to the ENSO phenomenon (e.g.; Jacobs et al., 1994; Meyers et al., 1998; Vega et al., 2003). Other authors have revealed the importance of the Kelvin wave propagation. In the equator, the Kelvin wave is an important key for El Nino cycle (Suarez and Schopf, 1988). The coastal Kelvin wave propagation interacting with the coastal upwelling systems could be a way of producing SST anomalies which can affect the season of the fisheries (Picaut, 1985, Schouten et al., 2004, Florenchie, 2003). Also, the coastal Kelvin wave propagation could be responsible of the climate anomaly propagation between tropics-extratropics (Jacobs et al., 1994). However, the intraseasonal propagations along the West-African coasts, from the equator to the subtropics, has not yet been thoroughly described and explained. Several authors expressed difficulties at finding a clear signature of the equatorial and coastal Kelvin-type waves in the tropical Atlantic (Arnault et al., 1990, Handoh and Bigg, 2000, Illig et al., 2004), because of the small basin size and the presence of the North Brazil Current (NBC).

This paper describes the intraseasonal variability of the Kelvin wave propagation and proposes some mechanisms of the source and the consequences at subtropical latitudes. The paper is ordered as follows: first, the variables and data set are discussed, then we present a description and characterization of the Kelvin wave propagation along the equator and the African coast. A climatology of the intra-seasonal filtered anomalies is studied. Then, the causes of the Kelvin wave propagation are investigated in relation to the equatorial atmosphere. At last the SSH behavior in the tropical-subtropical coastal areas is explained.

2. DATASET

To investigate the Kelvin wave propagation, observational and model data is used. The observational resources used are: the TOPEX/Poseidon (T/P) SSHA (0.5 degrees latitude-longitude, and 7 days resolution) provided by the CNES-AVISO center and the Active Microwave Intrument-Earth Resources Satellite (AMI-ERS) zonal and meridional scatterometer wind stresses (5 days resolution). The ocean model used is the ORCA05 configuration of the OPA OGCM (Madec et al., 1998). The domain covers the tropical Atlantic with realistic coast lines and bathymetry, has also a 0.5 degrees latitude-longitude spatial resolution. It was forced over the 1992-2000 period by the same ERS wind stress, and bulk formulas were used to compute the air-sea heat fluxes from the NCEP reanalysis mainly. Model outputs are 5 days averages. Note that the weekly SSH from T/P is expected to have enough time resolution for the Kelvin wave description, since the theoretical first baroclinic mode Kelvin wave takes about 30-45 days to cross the Atlantic at the equator.

3. DESCRIPTION OF EQUATORIAL AND COASTAL PROPAGATIONS

A wave track has been defined as in Figure 1, starting at the western equatorial Atlantic, following the equator and African coasts. To follow the Kelvin wave propagation, a wave track has been defined along the equator and the African coast. It is important to notice tracking the Kelvin wave propagation on different isobaths (0, 200, 400, 1000 meters) does not make substantial differences and no remarkable properties changes are found.

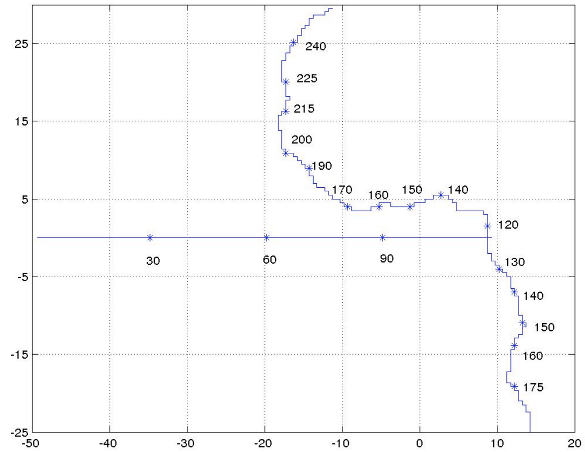

Figure 1. Map of the Grid points along the Equator and the African coast used in the study.

3.1. Intra-seasonal variability

In order to clarify the picture of what is phenomenon at intraseasonal scales, a 25 to 95 days band pass filter has been applied to the T/P and model SSH data based on a Hanning filter. Periodicity peaks at intraseasonal scales for the Kelvin waves from observational data has been described before. They range from 20 to 60 days for the equatorial Atlantic (Katz, 1990), and from 60 to 120 days in the equatorial Pacific (Kessler et al., 1995; Cravatte et al., 2003). Accordingly, our filter retains periodicities in these ranges. The Figure 2 shows the result for the T/P SSH data in the entire period along the Northern track. The Hovmuller diagram for the filtered signal shows downwelling and upwelling propagation with a period of about 2 months, propagations are seen all year for all the years, the continuity of the eastward equatorial Kelvin wave and the coastal propagation is sometimes broken. The clearest propagation of a downwelling equatorial and coastal Kelvin wave appears in September, December and March, and upwelling equatorial and coastal Kelvin waves appear in November, July and February. This pairs of upwelling and downwelling signals, November-December, February-March and July-September are characterizing most of the years. However an interannual modulation of the intraseasonal variability is also clear.

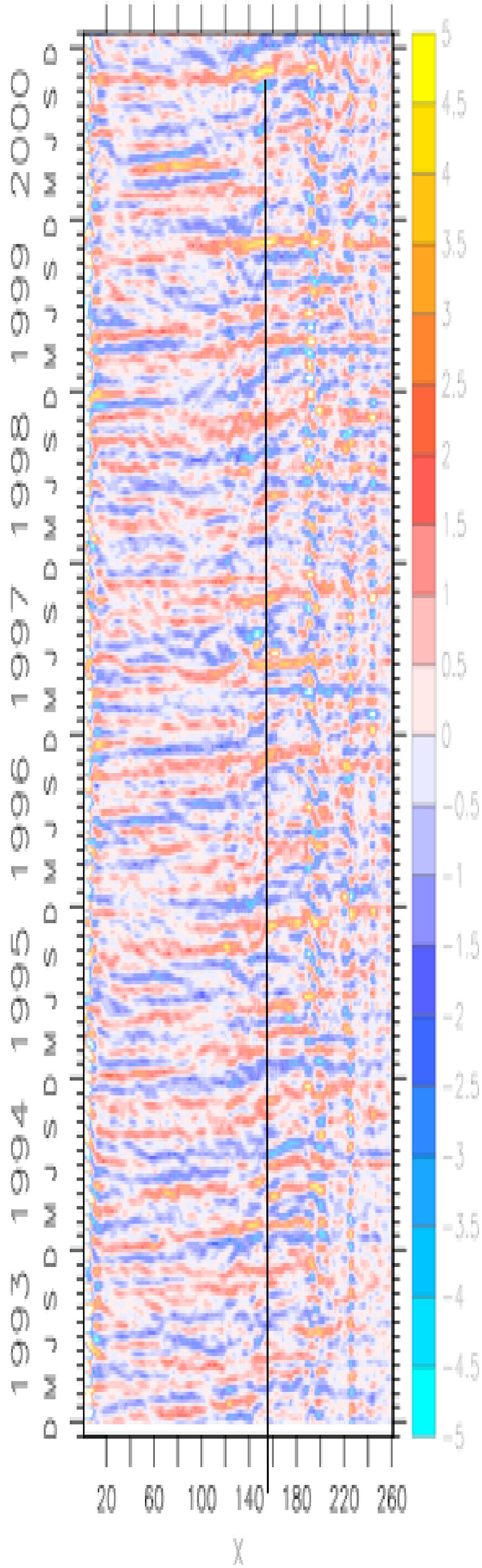

Figure 2. Hovmuller diagrams for the time-filtered SLA T/P anomalies (in cm), following the track of figure 1, for the equator and the northern African coast.

To quantify how realistic is the model along the wave track, the correlation between the model and the T/P

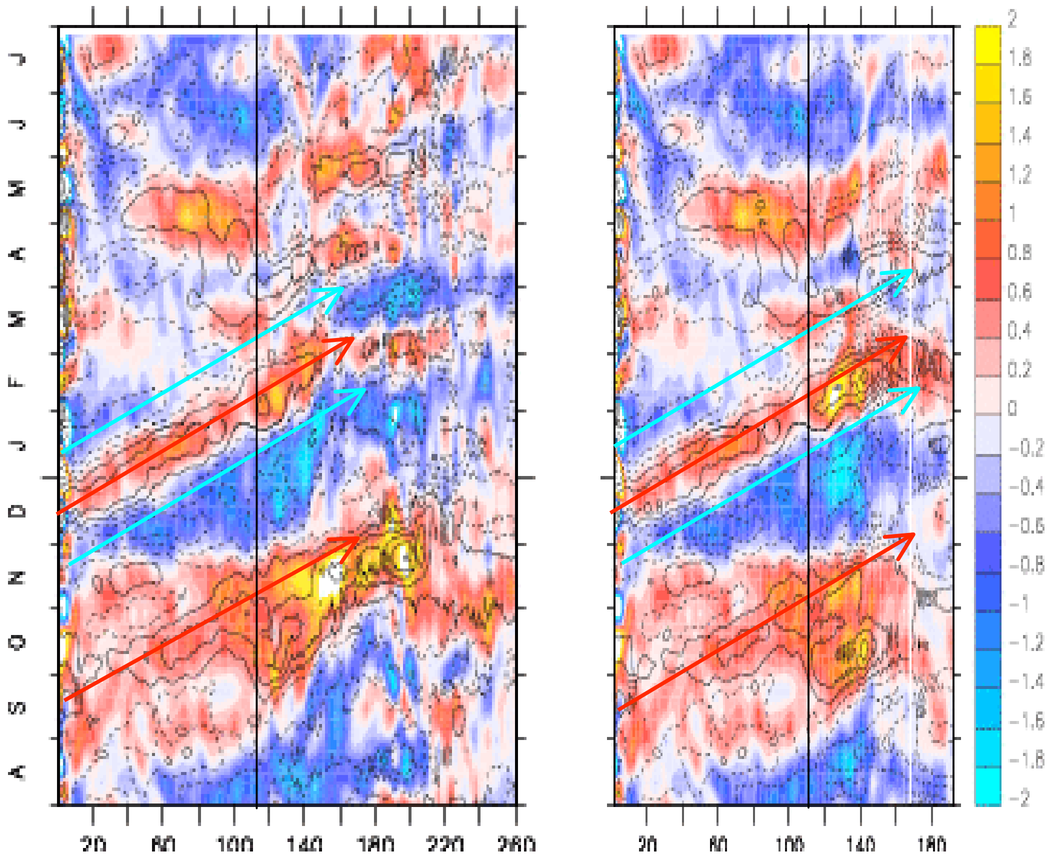

Figure 3. Climatology of the SSH intraseasonal anomalies (in cm), for observations (shaded areas) and the model (contour lines), along the northern track (left) and the southern track (right).

data at intraseasonal scales has been performed. Along the equator the correlation is larger than 0.5 (not shown). Along the coast, the correlation is good for most of the points, decreasing northward and southward. The variances for the model and for the observation indicate that the amplitude of the observations is always larger than the model (not shown), but the model is suitable to study the intraseasonal variability of the SSH at the equator and the African coast.

4. CLIMATOLOGY OF THE INTRA-SEASONAL VARIABILITY

4.1. Description

To clarify the propagation properties seen above, the climatology of the time-filtered signal of the period 1993-2000 has been computed. Figure 3 (upper panel) displays clearly two downwelling (positive ssha) Kelvin waves, one starting in the West in September and a second in December, as well as a November and a January upwelling Kelvin waves. There is a two months periodicity of these signals. The continuity, often visible on Figure 2 along the coastal track is not well seen here. The correlation between the model and the observations is evidenced by the Figure. The z18 anomalies (not shown). exhibit continuity from the equator to the coast, even further north and south than the SSH.

The signal appears to be amplified at the Guinean coast (140-200 north track points) and the southern coast (120-160 south track points). The discontinuity and amplification of SSH signal around 135 south track point is likely related to the Congo river run-off. The propagation pattern disappears poleward of points 215 north and 170 south, beyond these points (near subtropics) the signal seems to be stationary.

4.2. Estimate of the propagation phase speed

The Atlantic Kelvin equatorially trapped wave propagation has been presented for observations and linear theory as characterized by an about 2.4 m/s velocity for the first baroclinic mode, a 1.4 m/s velocity for the second mode and 0.8 m/s velocity for the third mode (Philander, 1990; Katz, 1997; Franca et al, 2004; Illig et al., 2004). Here we computed the velocity of the propagation as the linear regression slope of the maximum (in time-track points) lagged correlation for a number of points for the northern and the southern tracks and for the model and the observations (not shown). The resulting mean phase speed is 1.8 m/s.

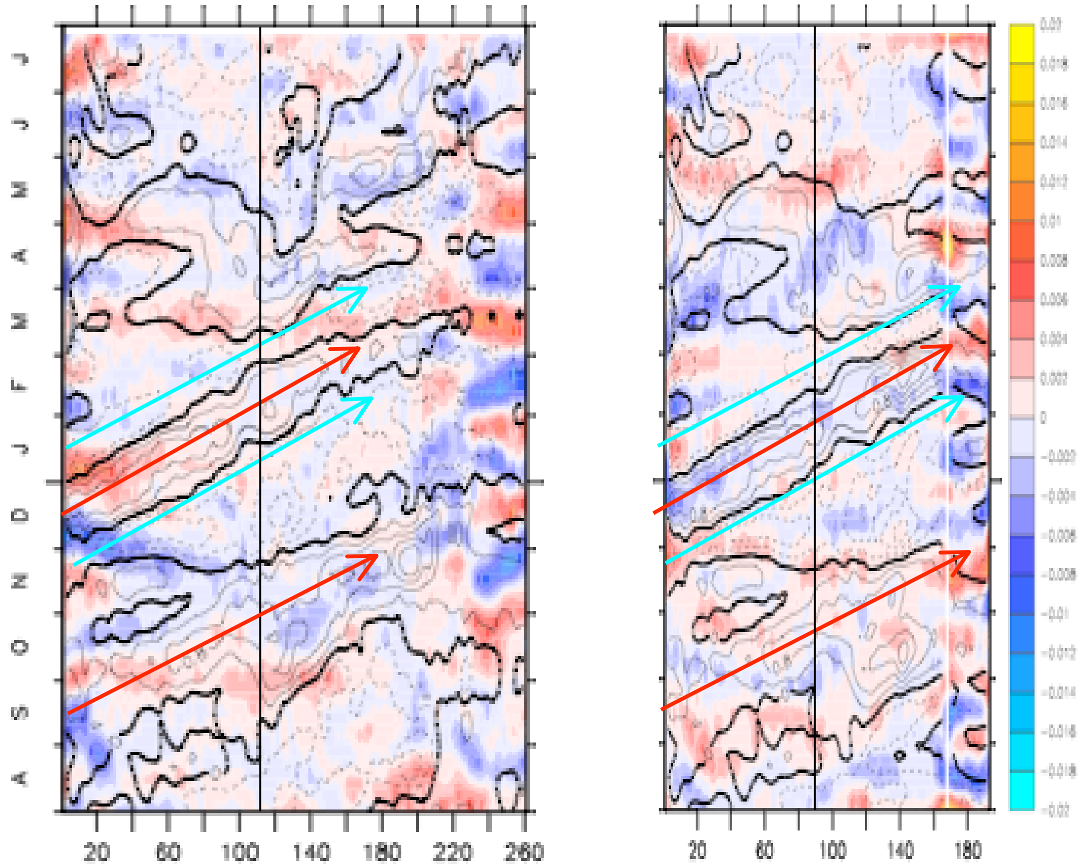

Figure 4. Climatology of the observed intraseasonal wind stress anomalies (time-filtered) for the zonal component along the northern track (left panel) and the meridional component along the southern track (right panel) (shaded, in N m-2), and corresponding time-filtered model SSH (contours, in cm CI=0.4)

4.3. Perturbation source in the western equatorial Atlantic

To find the cause of the equatorial intraseasonal Kelvin wave, the zonal and meridional time-filtered wind stress climatology over-imposed on the time-filtered SSH is shown in Figure 4. The western equatorial Atlantic (from 0 to 20 track points) zonal wind stress anomalies (Figure 4a) shows a negative relationship with the SSH. During winter in particular, before the downwelling (upwelling) Kelvin wave starts, a negative (positive) zonal wind stress anomalies occurs in the West, corresponding to a coastal downwelling (upwelling) at the American coast. The positive (negative) SSH anomaly propagates eastward as a Kelvin wave. Simultaneously, the meridional wind stress (Figure 4b) is positively correlated with the SSH. Interestingly, this positive correlation lasts for a few weeks, evidencing an eastward propagation of the wind anomaly, coupled or forced by the sea surface temperature anomaly (not shown) of the Kelvin wave.

To identify further the atmospheric processes linked to this quasi-bimonthly wind stress oscillation at the Brazilian coast, the troposphere winds (from 1000 to 100 mb) and the OLR at this location were analyzed. The filtered atmospheric variables show surface wind convergence (divergence) at the western equatorial area (5S-5N; 50W-40W). A very deep structure in the atmospheric column (not shown) is found to coincide with negative (positive) OLR anomalies between 60W and 40W (Amazonas), before an upwelling (downwelling) SSH perturbation at the western equatorial Atlantic in winter.

Other authors have suggested a possible mechanism for an interannual tropical Atlantic variability mode, involving the OLR anomalies which changes the zonal winds at the equator, perturbing later the SSH, causing a Kelvin-like equatorial propagation (Handoh and Bigg, 2000). Also the equatorial Pacific Kelvin waves at the intraseasonal scales has been related to the OLR anomalies via Madden Julian Oscillation (MJO) (Kessler and McPhaden, 1995). The MJO is stronger in boreal winter and has a period rangin from 30 to 60 days (Madden and Julian, 1994). Its influence on the Amazon region and its interaction with the South American deep convection is well established (Kayano and Kousky, 1999). Foltz and McPhaden (2004) have shown a MJO index regression onto the Atlantic winds, which is significant at the western equatorial Atlantic for the zonal wind. Moreover, the consistency between the convergence, precipitation and wind velocity at 50-60 days periodicity in the western tropical Atlantic (northern ITCZ), has been shown by Foltz and McPhaden (2005).

Since the wind stress anomalies at the middle of the basin are lighter than in the western equatorial and the subtropical Atlantic, their impact seems to be a reinforcement of the SSH along the coastal track. This kind of behavior is illustrated in Figure 5 for the zonal wind stress anomalies at the Guinea Gulf (120 to 180 north track points) and the southern African coast (120 to 140 south track points) from October to November.

4.4. Behavior in the subtropics

Poleward of 12 degrees of latitude, the wave seems to not propagate, and the correlation between the SSH and the alongshore wind-stress anomalies become significant (not shown). The wind anomalies there exhibit strong anomalies (poleward of the 200 north and 160 south track points). The spatial structure of the oscillation at the north and at the south is large scale, involving the entire basin width. These wind oscillations have a period of about 60 days, and correspond to trade wind changes around the Azores and Santa Elena High for the north and the south respectively. These oscillations represents the main percentage of the intraseasonal variability for both (50% fraction of variance from EOF analysis, not shown). However, no significant coherence is found between both hemispheres wind oscillations at any lag (not shown). The quasi-bimonthly oscillation of this winds in the northern subtropics could be associated with a described 120 days period SLP differences between Casablanca and Cape Blanc. Also Foltz and McPhaden (2004) have shown a significant correlation between the MJO and the North Atlantic SLP and winds.

5. CONCLUSIONS

We have evidenced Kelvin-like wave activity in the T/P sea level anomalies along the equator and the west-African coasts thanks to appropriate time-filtering. In the climatology of this signal, the Kelvin wave signal peaks in boreal winter. The periodicity (around two months) of the wave seems to be very coherent with the atmospheric variables.

Regarding the causes of the equatorial waves, the source of the equatorial Kelvin wave seems to be the zonal wind stress at the equatorial western Atlantic associated to an atmospheric Oscillation (i.e. MJO). This anomalously deep convection at the western Atlantic and the surface winds divergence appear before the SSH perturbation starts to propagates, which seems to indicate that the atmosphere is leading the phenomenon.

From the western basin, a typical Kelvin wave propagates eastward along the equator and splits along the African coast, where it propagates polewards at a varying speed (1.8 m/s in average over the tracks). The propagation seem to stop at about 12 degrees of latitude north and south. There, the periodic oscillations of the alongshore winds become more important and the wave has less impact on the SSH.

This is an ongoing work, further analyses will be presented in a future publication.

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