Thermal impacts of the coastal waves in the African upwelling areas at intraseasonal time scale

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Introduction

Although their strong social and economic consequences on surrounding countries, mechanisms for coastal upwellings along the tropical African coasts are not completely identified, in particular, competitions between local and remote (through coastal Kelvin waves) processes. Lagged correlations between sea level anomalies at the coast-equator and along the north and south coasts show that 25% of the variance in the upwelling areas is explained by the signal propagated along the coasts from the equator by the waves (Polo et al, 2007).

In this work, we are interested in the thermal impact of the coastal waves in the upwelling areas along the African coasts (Figs.1a, b). To discriminate local and remote effects, a specified experiment is lead. Using the mixed layer heat budget, coastal waves contribution to the horizontal advection and vertical diffusion of temperature can be evaluated. The thermal effect of the Kelvin wave is thus quantified.

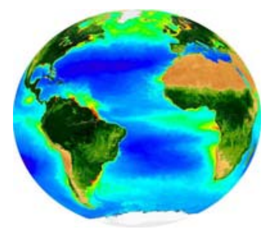

Fig.1a : Mean boreal summer SEAWIFS Chl (mg/m^3)

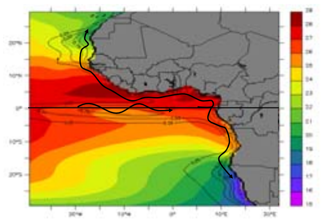

Fig.1b : Mean Reynolds SST (°C), ORCA05-PISCES Chl contours (mg/m^3); equatorial and coastal Kelvin waves trajectories are schematized

1 Models and Data

To characterize the thermal impact of the coastal waves along the African coasts, we first use Topex-Poseidon satellite data and then numerical runs to accede to the vertical distribution all along the waves trajectories and to calculate the mixed layer heat budget. The ocean model (ORCA025, coll C. Deltel) is forced with the DFS4 product (ERS wind stress and CORE data); the turbulent heat fluxes are computed with bulk formulae; it runs from 1988 to 2000; its horizontal resolution is 0.25° and there is 46 vertical levels (6 meters in the first 100m). The physical parameters are identical as in DRAKKAR simulations.

To visualize the wave propagation, we choose a 30-90 days time filter is applied to the SLA signal which is projected on the trajectory along the African coasts (Fig.2).

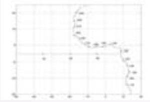

Fig.2 : Points defining the equatorial and coastal waves trajectories

2 Waves Periods along the African coasts

Both satellite and modeled SLA (Fig.3) shows equatorial and coastal waves along the African coasts until about 12°N and S with a 2 months periodicity, their amplitude varies between 1cm at the equator and 4cm at the coasts; their propagation phase speed is found to be in the range between the first and second Kelvin baroclinic modes (0.5 to 3m/s).

FFT analysis reveals significant signal in both data and model at different intraseasonal timescales (around 60, 70 and 90 days). The good agreement between wind stress FFT and SLA FFT at these scale strongly suggest the propagativ nature of these signals, until 10-12° N and S; poleward, the intraseasonal variability of local forcing dominates. Lagged correlations from T/P data (Figs.4) reinforce the propagativ nature of the signal with characteristic of equatorial and coastal Kelvin waves.

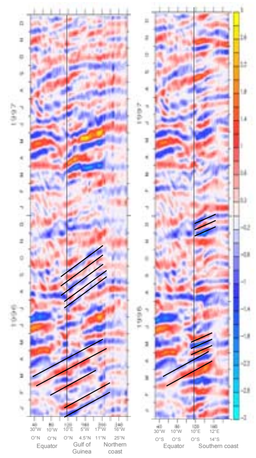

Fig.3 : Intraseasonal SLA along the equator, north (left) and south (right) coasts (cm)

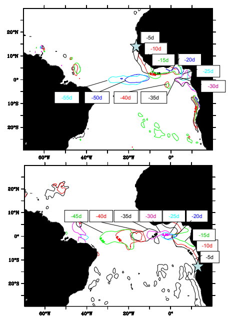

Fig.4 : Lag correlations (0.2 contours) between T/P SLA (*) and SLA in the whole basin

3 Numerical Experiment and simulated Kelvin wave

To quantify the thermal impact of the Kelvin waves, we need to discriminate local processes (heat fluxes, horizontal advection and vertical diffusion due to local wind stress) from remote one, due to Kelvin wave propagation, acting on temperature through horizontal advection and vertical diffusion. To succeed this challenge, numerical experiments are needed : a climatological "reference" runs is calculated with mean atmospheric forcing (1988-2000), a westerly wind burst is then added to the mean forcing and imposed to the oceanic model. The difference between both runs allows to isolate the Kelvin waves contribution.

The westerly wind burst characteristics (Figs.5), chosen from observations, are :

- horizontal extension : from 5°N to 5°S , bresilian coast to 10°W
- 2 months period, only positive phase
- phase speed of the first and second baroclinic mode in tropical Atlantic = 2.5 and 1.4 m/s (Illig et al, 2003), λ = 40° of longitude (deduced from observed wind stress variance); T= 2 months -> c = λ / T ≈ 1.6 m/s : combination of first and second modes at minimum
- wind burst imposed in January (to avoid TIWs)

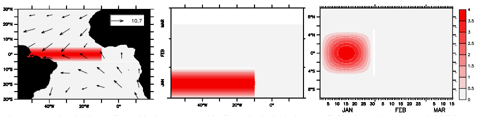

Fig.5 : westerly wind burst (in cm/s) : in January with climatological wind stress (left), along the equator (middle) and along 40°W (right)

=> The idealized winter downwelling intraseasonal wave (Figs.6) is very realist, the artificial wave characteristics are similar to observed ones (amplitude, phase speed, pathways, etc) : propagation from 30°W-eq to 12° N and S; v ≈ 1.9 m/s.

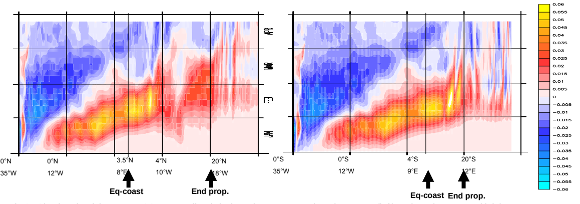

Fig.6 : Simulated Kelvin waves : SSH anomalies (m) along the equator and northen coast (left) and southern coast (right).

4 Thermal Impact

The coastal waves can play a role on mixed layer heat budget in the horizontal advection and vertical diffusion terms, acting together in the coastal upwelling regions. Their influences on the temporal temperature evolution can only be significativ in the regions of strong vertical and horizontal temperature gradients. Therefore, these intraseasonal processes are extensively conditionned by the seasonal cycles of coastal upwelling .

The simulated Kelvin wave can be responsible of strong SST anomalies in coastal upwelling areas (Figs.7) : a 6cm SLA anomalies can create a 1.5°C SST anomalies in coastal upwellings areas on 10° extension and during more than the period of the wave (>1month), as in observations.

The mixed layer heat budget, calculated by the model, allows to determine how the waves act onto SST :

$$\partial_t T - Q \approx -u.\partial_x T - v.\partial_y T + \partial_z (K_z.\partial_z T) \approx \partial_t T_{ocean}$$

The processes of thermal impact of the Kelvin wave (Figs.8) are similar along the Angola and Senegal coasts :

2/3 horizontal advection + 1/3 vertical diffusion

and have opposite effects in the Gulf of Guinea upwelling :

3/4 vertical diffusion - 1/4 horizontal advection

The horizontal advections decomposition (not shown) show the predominance of the mean zonal current by the zonal temperature gradient, and the currents anomalies by the mean temperature gradient.

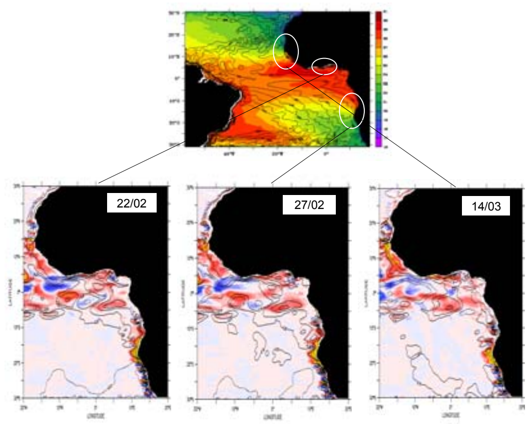

Fig.7 : Upper : climatological february SST (°C) and D18 (contours, m); Lower : SST anomalies (°C) and SSH anomalies (contours, m).

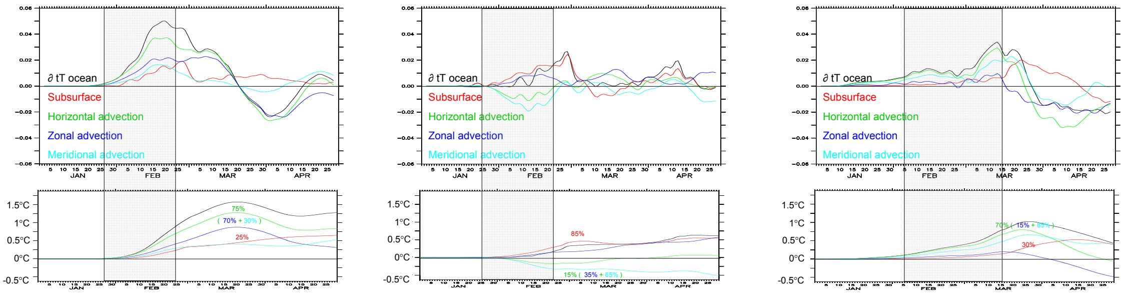

Fig.8 : Total (°C/month, upper) and time integrated (°C, lower) mixed layer heat budget trends, in the Angola upwelling area (left), Golf of Guinea upwelling (middle) and Senegal upwelling (right). Percents give each contribution term to the total temperature evolution. Dash boxes represents the Kelvin wave passage into the upwelling areas.

References and Acknowledgments

- Peter, A.C., and A. Lazar, 2009 : Thermal impacts of the coastal waves in the African upwelling areas at intraseasonal time scale, in prep.
- 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., 113, C07009, doi:10.1029/2007JC004495.
- Polo, I., A. Lazar, B. Rodriguez-Fonseca, 2009: Oceanic Kelvin Waves and Tropical Atlantic intraseasonal Variability. Part II: Mechanisms and Impacts, in preparation.

- Numerical simulations run on IDRIS computers and has been configured by A.C Peter and C. Deltel.