INVESTIGATION OF THE INTRA-ANNUAL VARIABILITY OF THE NORTH EQUATORIAL COUNTERCURRENT EDDIES AND OF THE INSTABILITY WAVES OF THE TROPICAL ATLANTIC OCEAN

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Abstract - The western tropical Atlantic region houses energetic currents and instabilities. It is an important contributor to the inter-hemispheric oceanic transports associated with the meridional overturning circulation's upper limb. How much of this transport is due to eddy activity is still a pending question. This variability is investigated here using satellite altimetry, Sea Surface Salinities (SSS), and signal analysis methods such as the Empirical Mode Decomposition. Two regions of high variability are identified. The first one, between 3°N-11°N, is characterized by westward propagating structures linked to the North Brazil Current (NBC) retroflection in the North Equatorial CounterCurrent (NECC), near the Brazilian coast. This signal is frequency modulated shifting from large length scale structures (NBC/NECC instabilities and meanders) in October to smaller ones (eddies) in March. Consequently the number of "eddies" per year can be aliased, according to the time and location of sampling, and can impact the percentage they explain of the inter-hemispheric exchange of mass and heat. The second region reveals the presence of westward propagating instability waves centered north of the Equator (3°N-7°N) between 50°W-10°W. These instability waves also show a strong seasonal cycle with maximum amplitude around August. They clearly differ from the NBC/NECC instabilities.

Data and methods

Altimetric data (SLA)

AVISO Ssalto/ Duacs Sea Level Anomaly (SLA) merged products. Weekly, January 1993- September 2015, 1/4°x1/4°, 0°N to 15°N, 70°W to 20°E.

SMOS Sea Surface Salinity (SSS)

Weekly debiased V1 CATDS CEC LOCEAN products, January 2010 - December 2015, 1/4°x1/4°, 0°N to 15°N, 70°W to 20°E.

Methods

Complex Empirical Orthogonal Function (C-EOF), Singular Value Decomposition (SVD), Continuous Wavelet Transform (CWT), Hilbert Transform, Empirical Mode Decomposition (EMD)

Results

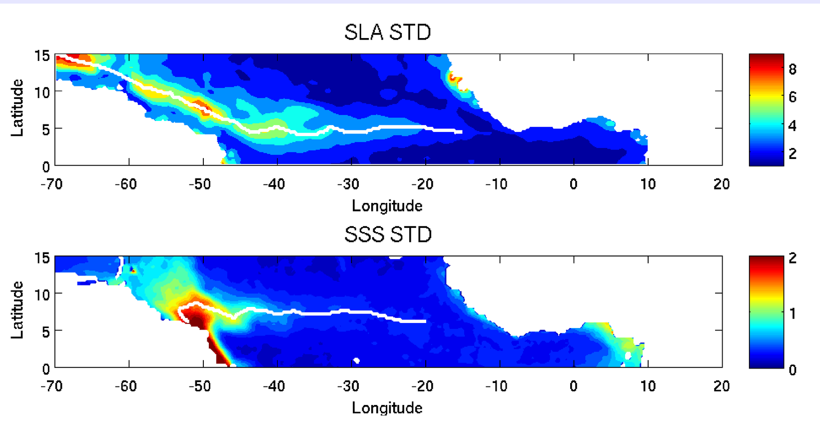

Fig. 1: Standard deviation of the SLA (up) and SSS (bottom) anomalies and ridge (white line).

Fig. 1 - The SLA STD is maximum between 15°N and 3°N, following the American coastline then extending eastward along ~5°N. The higher SSS STD is located mostly south of 10°N, although a northern extension is discernible. It reflects the Amazon river run off and advection.

Fig. 2 - A global CWT spectrum is calculated at each grid point of the SLA ridge in Fig.1. The western part of the ridge is, as expected, far more energetic than the eastern one. Both High and Low Frequencies (HF and LF) exist except in the center of the basin where only LFs seem to be present. HFs dominate near the Brazilian coast. The HF and the LF main periods remain rather stable along the ridge: around 5 to 7 weeks for the HF, between 10 and 16 weeks for the LF.

The processes can be analyzed in details if the SLA signals are decomposed in their HF and LF components. Frequency/amplitude modulations of these components are mathematically interpretable in a way that is representative of physical phenomena only if the HF and LF components are asymptotic => extraction based on EMD. Figure 3 gives an example of such decomposition along the ridge at 50°W.

Fig. 3 – The HF and LF components, once extracted and recomposed, explain more than 80 % of the raw SLA signal (a). The EMD envelopes show the HF and LF time distribution. The HF shows a strong seasonal cycle with maximum at the beginning of the year around February-March (b). The LF component is also seasonally modulated with a maximum activity in boreal fall, around October (c).

Fig. 4 – The HF C-EOF1 pattern shows westward propagating "eddies" close to the Brazilian coast, c ~ 19 cm/s, λ ~280 km (a). The LF one shows larger scale propagating structures between ~30°W and ~50°W, c ~ 19 cm/s, λ ~550 km (b). The HF C-EOF3 pattern shows westward propagating instability waves from ~10°W to ~35°W, c ~ 44 cm/s, λ ~1000 km (c).

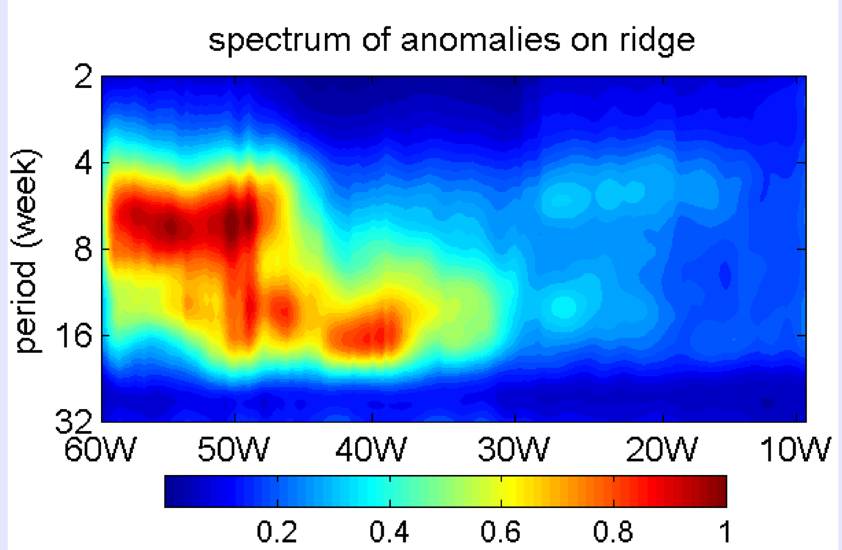

Fig. 2 : CWT spectrum of the SLA along the ridge in Fig. 1

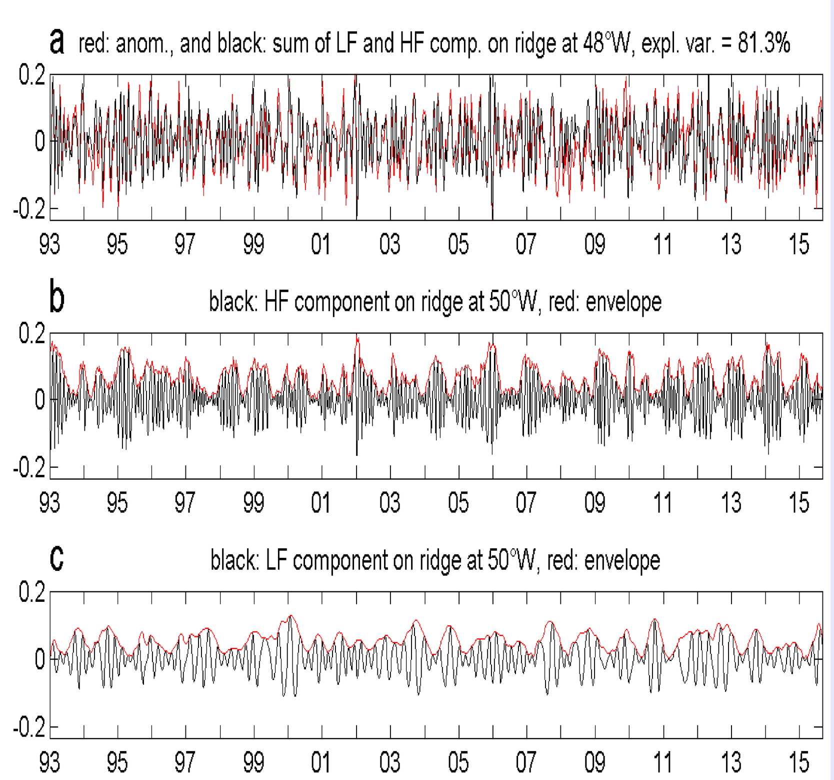

Fig.3 : SLA on the ridge of Fig. 1 at 50°W (red), HF+ LF components (black). (b) HF (black) and its envelope (red). (c) same as (b) but for the LF component.

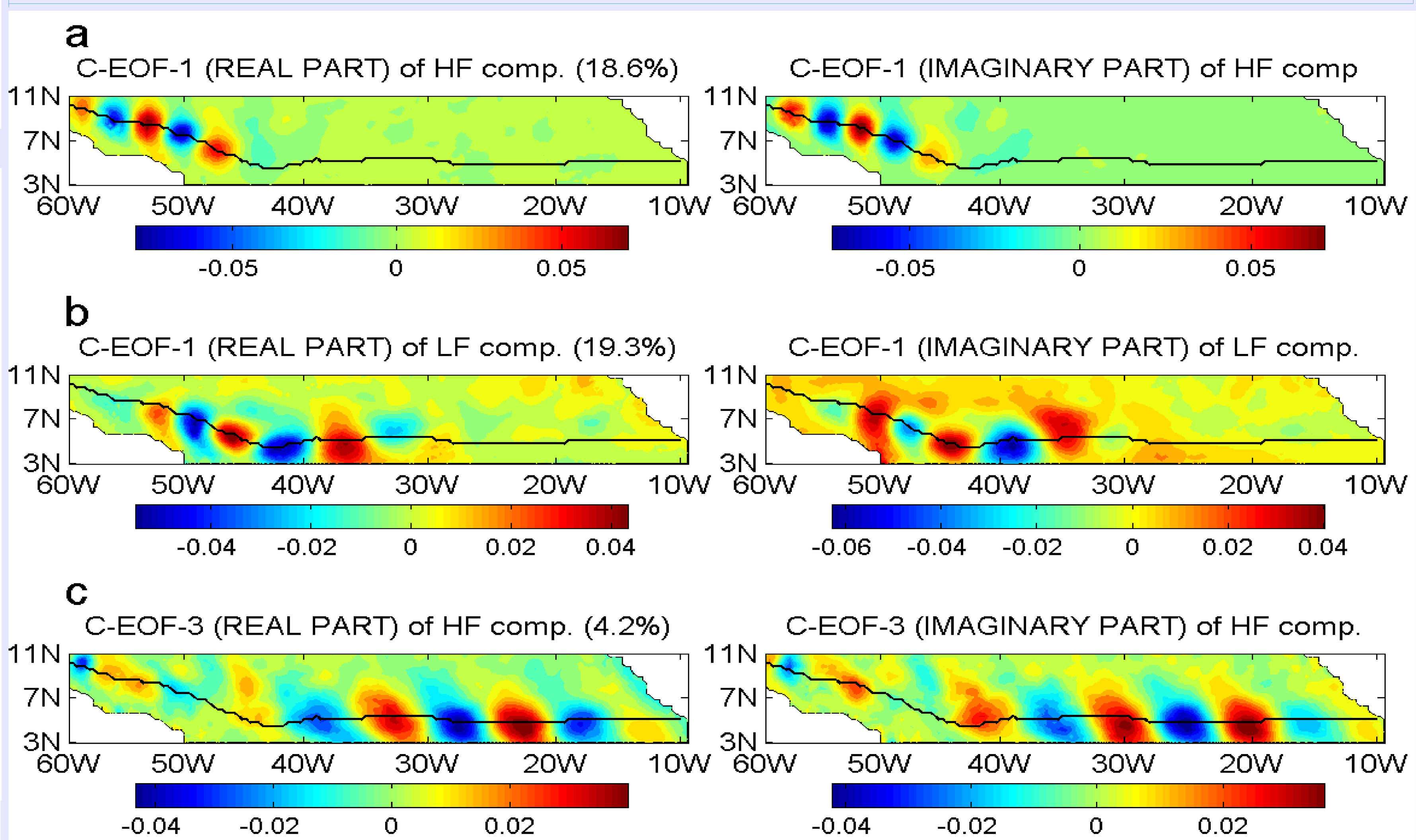

Fig. 4: (a) real part (left) and imaginary part (right) of the first C-EOF of the SLA HF components between 3°N and 10°N. (b) same as (a) but for the LF component. (c) same as (a) but for the third C-EOF of the HF components.

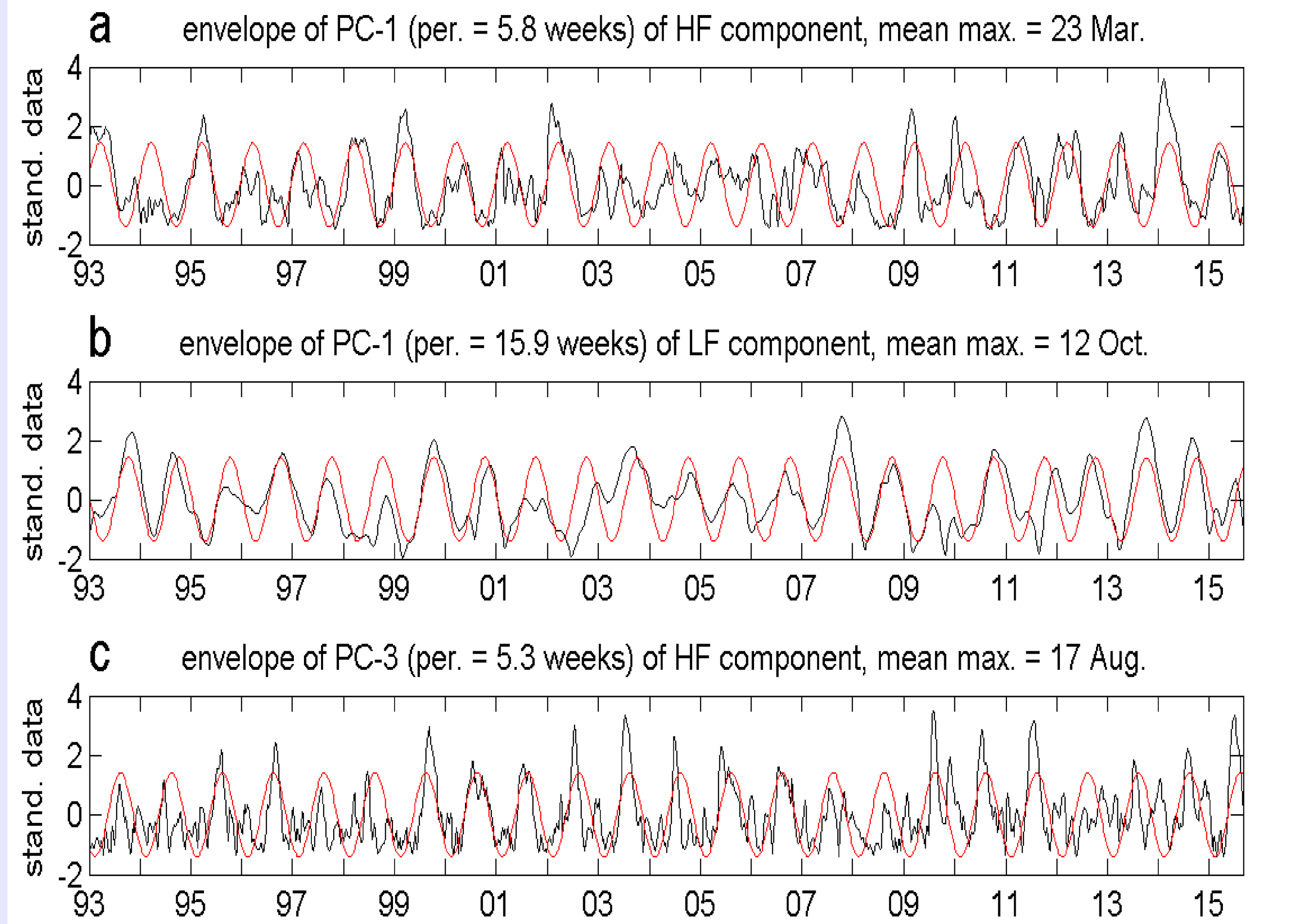

Fig. 5: (a) to (c) : envelopes (black) of the PCs of the C-EOFs in Fig. 2 and fitted sine wave with a one year period (red).

Fig. 5 - The envelopes of the C-EOF Principal Components (PCc) display a strong seasonal cycle. The envelope of PC-1 of the HF component is maximum in March (a) and in October for the LF (b). These signals are thus frequency modulated: they are composed of oscillations shifting from LF in October, which are due to NECC/NBC meanders, to HF in March due to eddies. Consequently the number of NECC structures varies from ~4 per year in October to ~9 per year in March. The instability waves also shows a strong seasonal cycle with maximum amplitude around August (c). They are generated by the shear between the NECC and the South Equatorial Current and follow the local wind intensifications.

What about SSS ?

As the SSS series is shorter than the SLA one, we first investigate the common pictures between the 2 data sets using SVD analysis over the 2010-2015 period and restricted to the zone West of 30°W..

Fig. 6 – The SVD analysis performed on the SLA and SSS series presents patterns and PCs in quadrature revealing the westward propagation of the structures.

The analysis of the HF components show SLA eddy structures along the Brazilian coast associated with similar patterns in SSS (a and b). The 2 SVD when combined, explain more than 50 % of the total HF variability.

The SVDs of the SLA and SSS LF components indicate larger scale processes clearly associated with the NBC retroflection in the NECC and their instabilities (c and d). They account for more than 60 % of the signal.

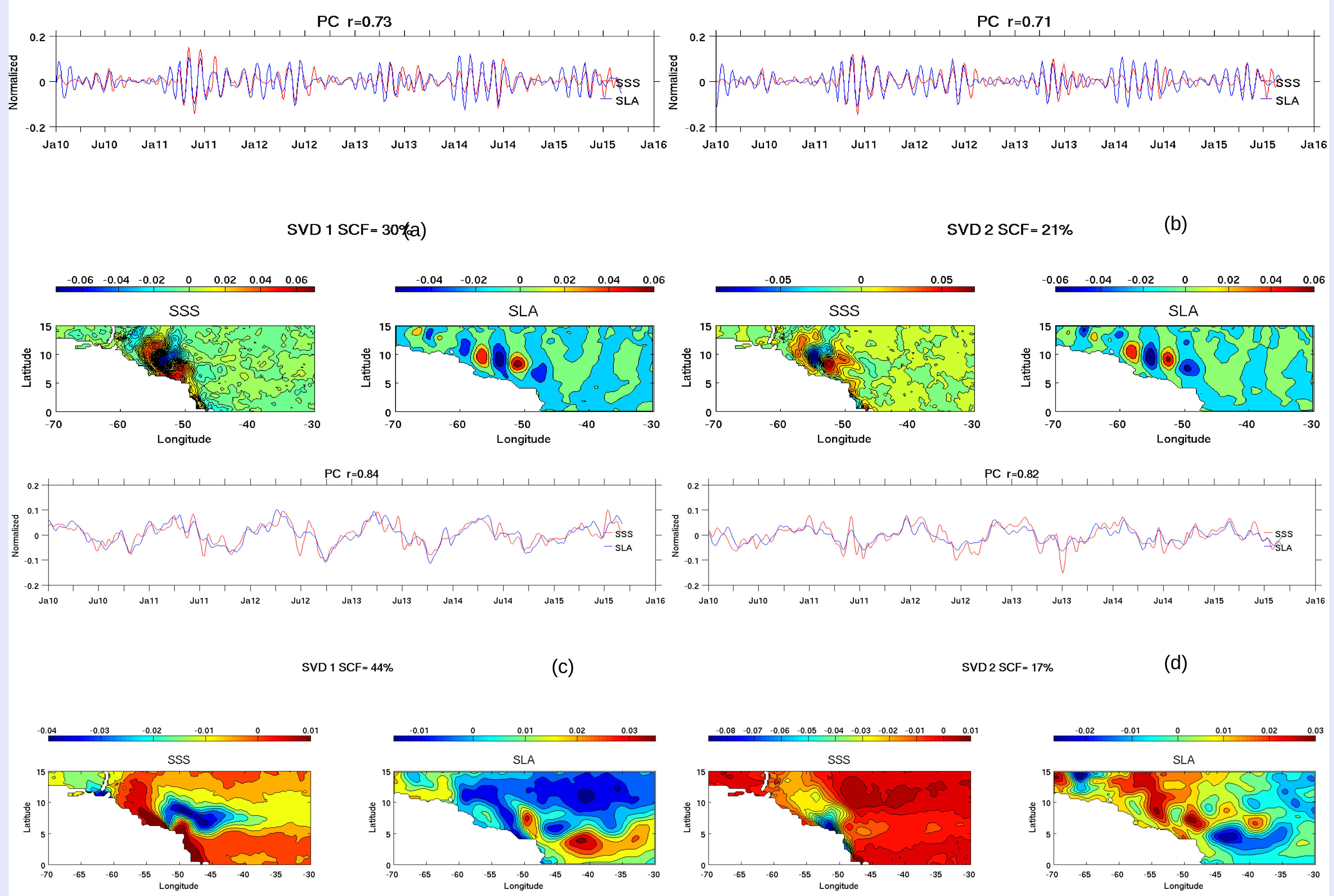

Fig. 6 : (a) and (b) : First and second SVDs between the SLA and SSS HF series. (c) and (d) : First and second SVDs between the SLA and SSS LF series.

Conclusion

The EMD method we have developed to identify propagating features in the tropical Atlantic Ocean gives very promising results when applied to altimetry data. The advantage of this EMD method is first to identify each of these mechanisms separately. Then to provide some information on frequency modulations, wavelengths and other characteristics which are unreachable from other techniques.

3 different processes are identified : NBC rings along the Brazilian coast, NECC/NBC meanders eastward and Instability Waves southward. Each of them shows a clear seasonal signal but with different phasing that could explain for instance the difference in NBC eddy number per year enounced in previous studies.

The north western processes evidenced by the EMD on the SLA datas can also be observed using the SMOS SSS datas when the same HF and LF separation is applied. The eddy structure is clearly depicted by an SVD analysis between SLA and SSS HF signals, while the retroflection and Instability Wave characteristics are shown by an SVD on the LF signal. This emphasizes the quality now reached concerning the satellite salinity data sets.

Next step will be to continue this study combining satellite information and mathematical techniques to get a new picture of the circulation and oceanic processes encountered in that region.

List of Acronyms :

CWT = Continuous Wavelet Transform
NBC = North Brazil Current
SMOS = Surface Moisture and Ocean Salinity
EMD = Empirical Mode Decomposition
NECC = North Equatorial CounterCurrent
SSS = Sea Surface Salinity
C-EOF = Complex Empirical Orthogonal Function
PC = Principal Component
STD = Standard Deviation
HF/LF = High/Low Frequency
SLA = Sea Level Anomaly
SVD = Singular Value Decomposition

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