Analysis of coastal upwelling index along the Moroccan Atlantic coast using wavelets from 1967 to 2016

Bessa Ismail[1,2] , Makaoui Ahmed [2], Hilmi Karim[2], Idrissi Mohammed[2], Agouzouk Aziz[2], Afifi Mohamed[1]

Abstract-An application of wavelet analysis is done with the monthly variability of the coastal upwelling index along the Moroccan Atlantic coast from 1967 to 2016, this study will be important to oceanographic science in order to analyze the upwelling variability observed in such area. We studied each latitude separately from 21°N to 36°N using the wavelet transform. The time series analyzed by the global wavelet spectrum revealed that the variability of the upwelling is composed mainly by an annual cycle along the studied region. We suggest that there is four regions characterized by the same variability and magnitude of the upwelling, this regions are as follows from 21°N to 25°N, from 26°N to 28°N, from 30°N to 32°N and from 34°N to 36°N. This study can be considered as an important tool to understand the trend of the upwelling activity in the region.

Index Terms- Moroccan Atlantic coast, Upwelling phenomena, wavelet transform, Ekman upwelling index.

1 INTRODUCTION

Wavelet analysis or wavelet transform is an advanced method for analysis time series. The first use of this method was in 1980s for processing seismic data by [1]. The method has started to draw attention in oceanography and meteorology, where it has been practical used for time series analysis of turbulence [2] , surface waves [3], low-level cold fronts (Gamage and Blumen, 1993) and sea surface temperature [4] [5].

Wavelet analysis is a popular method for time-frequency decomposition of a signal that has a superior time-frequency resolution. It has many advantages over Fourier analysis that make it particularity used to evaluate the amplitude and phase of the spectral component in the data set. The wavelet analysis have advantage in analyzing of nonstationary data series in which the amplitudes and phases may be changing quickly in time or space. One of the advantage of the wavelet analysis over classical spectral analysis is studying different scales of temporal variability and it does not need a stationary series. Thus, it is appropriate to analyze unregulated distribution events and time series that contain nonstationary power at many different frequencies. Then, it is becoming a common tool for analyzing localized variations of power within a time series. Essentially wavelet transform can be used to analyze time series that contain

nonstationary power at many different frequencies [6], because a complex wavelet function will return information about amplitude and phase and it is better adapted for detecting oscillation comportment. In the other hand, a real wavelet function returns a signal component and it can be used for detect peaks or discontinuities of a signal (Torrence and Compo, 1998) [7] [8].

The Moroccan Atlantic coast is one of the major coastal upwelling regions of the world [8] [9]. The upwelled water is characteristically denser, cooler and richer in nutrients than surface waters and has important effects on coastal climates and marine biology [10]. Therefore, the activity of the upwelling is a significant socioeconomic, oceanographic and climatologically in the region. The upwelling ecosystems cover approximately 1% of the total ocean surface but account for over 20% of the global fish catch (Pauly and Christensen, 1995.). Consequently, monitoring changes on the variability of the upwelling have a great importance, especially as fisheries response to global climate change has recently been documented [11] [12].

1: Laboratory of Engineering and Materials, Faculty of Sciences Ben M'Sik, University Hassan II Casablanca, Morocco
2: Department of Oceanography, National Institute of Fisheries Research, Casablanca, Morocco

Author e-mail: bessaismail@gmail.com

ISSN 2229-5518

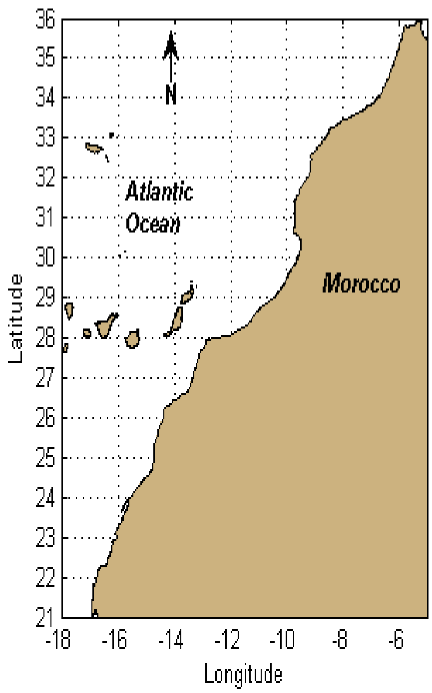

Figure 1: Location of the studied latitudes in the Moroccan Atlantic coast

In this paper, we used the wavelet transform as described by (Torrence and Compo, 1998) to study the time series of the upwelling index along the Moroccan Atlantic coast. The aim of this paper is to identify the trend of the upwelling Activity in this region using datasets with longer time series to have more robust understanding of the upwelling variability. For that, we studied 16 latitudes from 21°N to 36°N along the Moroccan Atlantic coast region Fig. 1. , this region was selected in the zones of the intense upwelling activity described by [9].

2 MATERIAL AND METHOD

2.1 THE UPWELLING INDEX

Coastal upwelling indices are calculated based on Ekman's theory of mass transport due to wind stress. Assuming homogeneity, uniform wind and stable state conditions, the mass transport of the surface water due to wind stress is 90° to the right of the wind direction in the Northern Hemisphere. Ekman mass transport is defined as the wind stress divided by the Coriolis parameter (a function of the earth's rotation and latitude). Ekman transports are resolved into components parallel and normal to the local coastline orientation. The magnitude of the offshore component is considered to be an index of the amount of water upwelled from the base of the Ekman layer. Positive values are, in general, the result of equatorward wind stress. Negative values indicate downwelling, the onshore advection of surface waters accompanied by a downward displacement of water.

The indices were computed from monthly mean pressure fields prepared by FNMOC. After providing the upwelling index with several alternate pressure field grids over time, FNMOC currently produces six-hourly fields of surface pressure on a global spherical (a 180 x 360 grid). The standard west coast six-hourly upwelling indices are a product of the pressure field interpolated from the grid. Monthly indices are derived from an interpolated from the monthly-averages of the six-hourly pressures. (Data source,NOAA: Oceanography and atmospheric products and services https://www.pfeg.noaa.gov/products/).

2.2 WAVELET TRANSFORM

Several transformations can be applied to obtain further information from signals that is not readily available in the raw signals. The most popular mathematical transformations is the Fourier transforms. However, the Fast Fourier Transform (FFT) would solve the problem of frequency localization, but would still depend on the size of the window used. The main problem with FFT is the incoherent processing of different frequencies: at low frequencies, there are so many oscillations in the window that the location of the frequency is lost, whereas at high frequencies there are so many oscillations that the localization of time is lost.

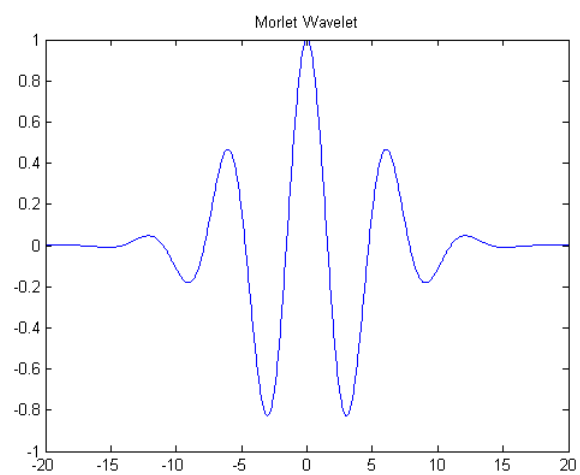

Figure 2 : Morlet wavelet base with frequency ω0 = 6

The wavelet analysis attempts to solve these problems by decomposing a one-dimensional temporal series into a two dimensional time-frequency image. It is then possible to get information about the amplitude of all periodic signals in the series and, how this amplitude varies over time.

Wavelet analysis always uses a wavelet of the same shape, only the size of scale is changing during the analyzing. In practice, the Morlet wavelet Ψ0 shown in Fig. 2 is defined as:

$$\Psi 0(\eta) = \pi^{-\frac{1}{4}} e^{iw0\eta} e^{-\frac{\eta^2}{2}} \quad (1)$$

This is the basic function of wavelets but it will now be necessary in some way to change the overall size as well as drag the whole wavelet along the signal in time. Thus, "scaled wavelets" are defined as:

$$\Psi\left[\frac{(n'-n)\delta t}{s}\right] = \left(\frac{\delta t}{s}\right)^{\frac{1}{2}} \Psi 0\left[\frac{(n'-n)\delta t}{s}\right] \quad (2)$$

Where s is the parameter "dilatation" used to change the scale, and n is the conversion parameter used to slip over time. The factor of s-1/2 is a normalization to keep constant the total energy of the scaled wavelet.

Thus, for a temporal series X, with values of xn, and the temporal index n, each value is separated in time by a constant time interval δt. Then, the wavelet transform Wn (s) is the inner product (or convolution) of the wavelet function with the original time series:

$$\text{Wn (s)} = \sum_{n'=0}^{N-1} xn,\ \Psi * \left[\frac{(n'-n)\delta t}{s}\right] \quad (3)$$

Where the asterisk (*) denotes a complex conjugate.

By sliding this wavelet along the time series, a new time series of the projection amplitude with respect to time can be constructed. Finally, the scale of the wavelet can be modified by changing its width. The technical details used in the wavelet transform can be seen in appropriate literature (eg, Torrence and Compo 1998).

3 RESULTS

Since the used data are monthly distributed, the parameters for the wavelet analysis are set as δt = 1 month and S0 = 2 months, because S0 = 2*δt. the figures below show the absolute value squared of the wavelet transform |W|² for the monthly IUC in different latitudes from 21°N to 36°N. The IUC is a record of the last 49 years. As mentioned before, the wavelet spectrum gives information on the relative power at a certain scale and a certain time. The wavelet spectrum show the oscillations of the individual wavelets, rather than just their magnitude. The black contour in the figures below show the region of the cone of influence, because we are studying a finite-length time series, errors will occur at the beginning and in the end of the wavelet power spectrum.

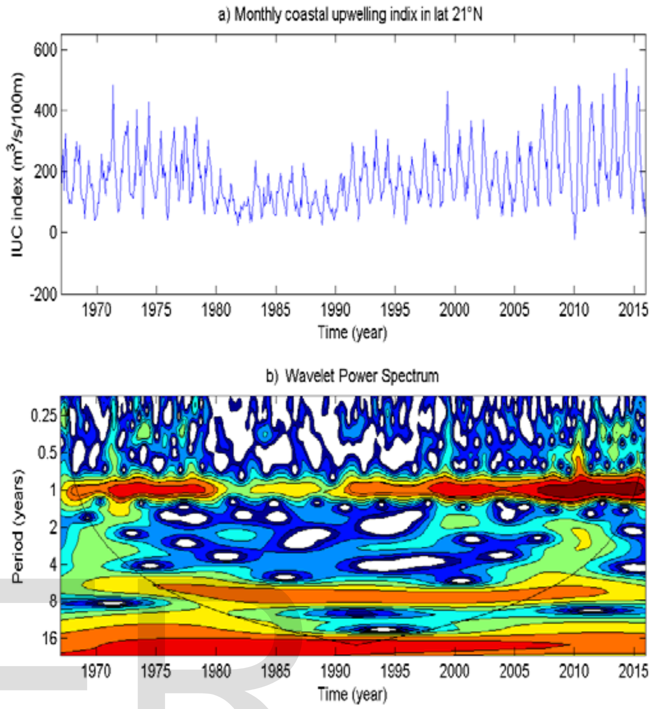

Figure 3: (a) Monthly IUC in 21°N for 1967 to 2016 period. (b) The wavelet power spectrum using Morlet mother wavelet.

Fig,3 a), shows the variation characteristics of the IUC from 1967 to 2016 in latitude 21°N. At this period, the IUC variation increase with fluctuations. We can notice a decrease in the upwelling index from 1980 to 1990 followed by an increase of the IUC from 2000 to 2016. Fig, 3 b) is the result of the wavelet transform. In this figure, in one-year time scale, the oscillating period of the wavelet is obvious, with a period of reduction of the upwelling signal. In long time scale about 7-8 years, also the oscillation is clear with less density compared with the small time scale.

ISSN 2229-5518

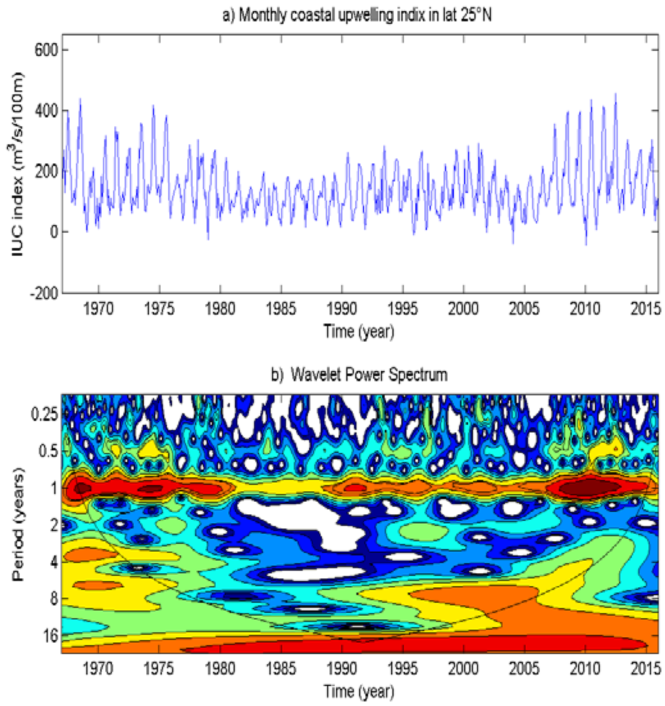

Figure 4 : (a) Monthly IUC in 25°N for 1967 to 2016 period. (b) The wavelet power spectrum using Morlet mother wavelet.

Using the same method, we take the wavelet transform on the IUC in latitude 25°N. Fig, 4 a) shows the trend of the upwelling activity. The fluctuation trend is regular, with intensity in signal from 1967 to 1975 followed by a long decrease of signal from 1980 to 2005, and from 2007 to 2016 the signal become intense again. Fig, 4 b) shows the results of the wavelet transform. The period of one year is clear with deference in intensity followed the IUC signal.

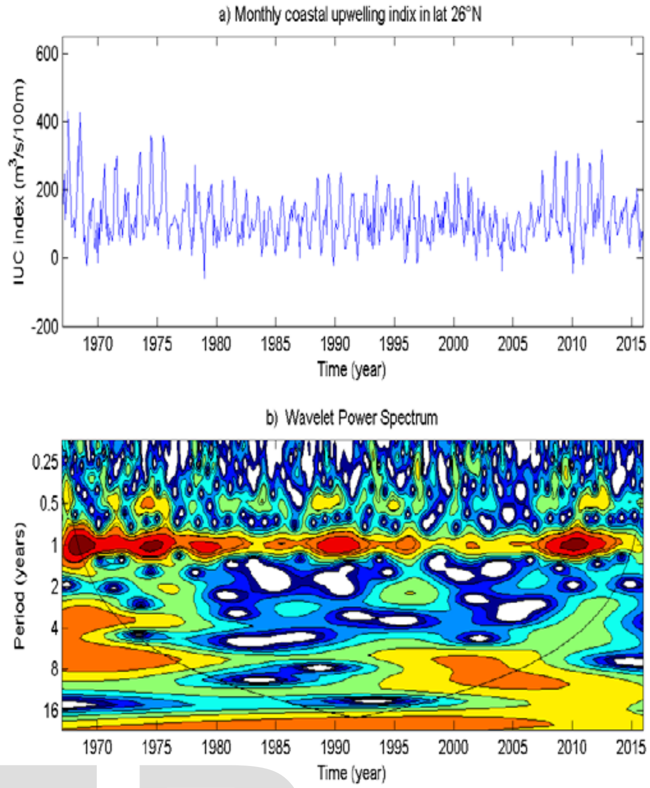

Figure 5 : (a) Monthly IUC in 26°N for 1967 to 2016 period. (b) The wavelet power spectrum using Morlet mother wavelet.

We take the wavelet transform on the IUC in latitude 26°N. Fig, 5a) shows the trend. The fluctuation trend is regular, with intensity in signal from 1967 to 1975 followed by a long decrease of signal from 1980 to 2007, and from 2008 to 2014 the signal become intense again followed by a decrease of signal from 2015 to 2016. Fig, 5 b) shows the results of the wavelet transform. The period of one year is clear with deference in intensity followed the IUC signal.

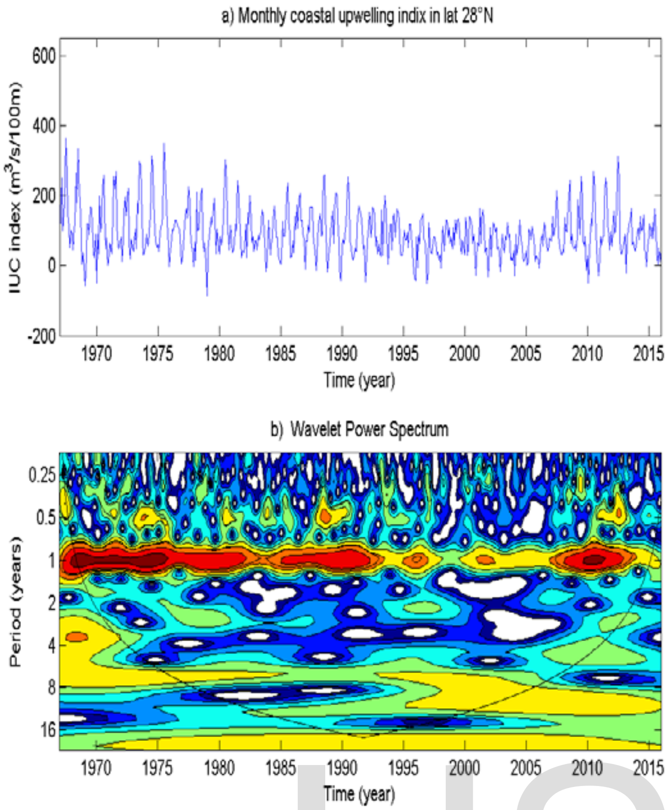

Figure 6: (a) Monthly IUC in 28°N for 1967 to 2016 period. (b) The wavelet power spectrum using Morlet mother wavelet.

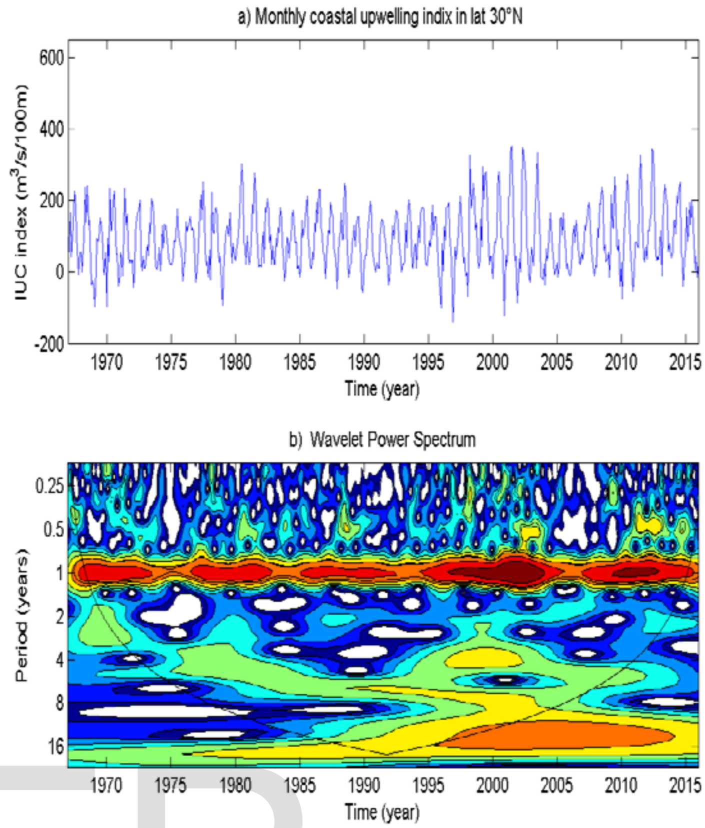

Figure 7 : (a) Monthly IUC in 30°N for 1967 to 2016 period. (b) The wavelet power spectrum using Morlet mother wavelet.

We do the wavelet transform on the IUC in latitude 28°N. Fig, 6 a) shows the variation trend. The fluctuation trend is always regular in the region, with a smaller value and variable amplitude than that in the south latitudes. IUC signal is intense from 1967 to 1975 followed by a long decrease of signal from 1975 to 2009, and from 2009 to 2010 the signal become intense again followed by a decrease of signal from 2014 to 2016. The results of the wavelet transform on the latitude 28°N Fig, 6 b), The period of one year is clear with deference in intensity followed the IUC signal.

Fig, 7 a) shows the variation trend. In this latitude, we remarked a regular fluctuation along the time series with increase of the signal from 1998 to 2003 and from 2008 to 2013.Fig, 7 b) shows the results of the wavelet transform. The period of one year also is clear.

We take the wavelet transform on the IUC in latitude 32°N. Fig, 8a) shows the trend. The fluctuation trend is regular, with low intensity in signal. Fig, 8 b) shows the results of the wavelet transform. The period of one year is clear with deference in intensity followed the IUC signal.

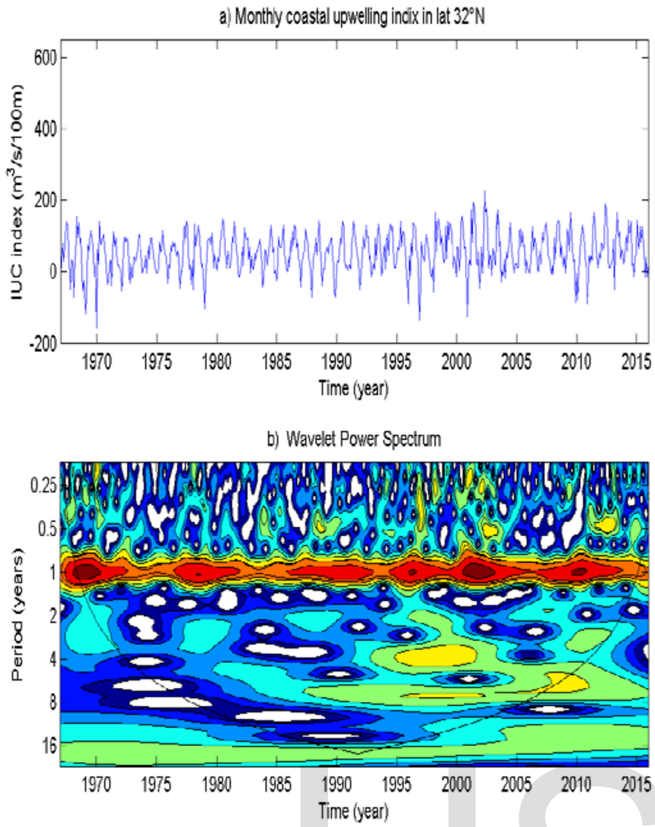

Figure 8 : (a) Monthly IUC in 32°N for 1967 to 2016 period. (b) The wavelet power spectrum using Morlet mother wavelet.

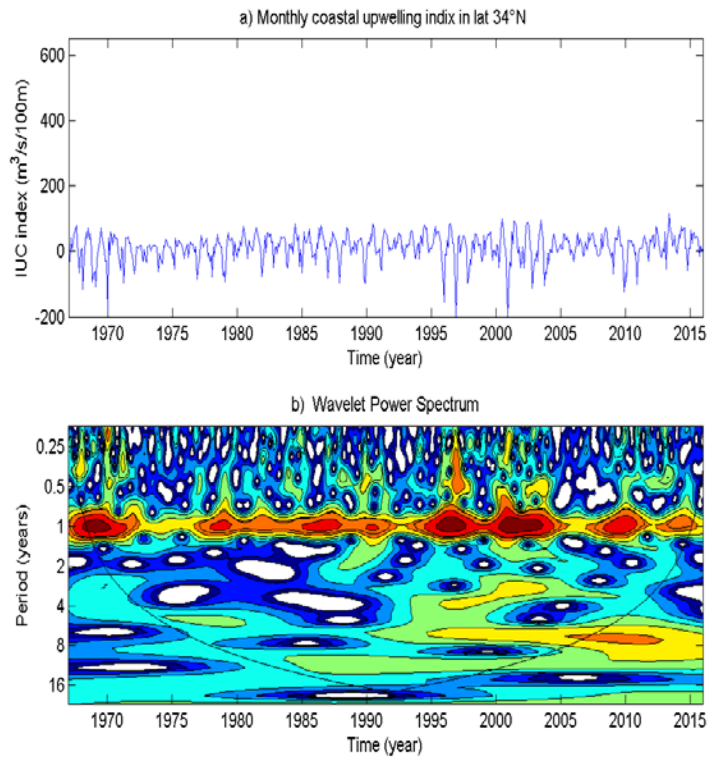

Figure 9: (a) Monthly IUC in 34°N for 1967 to 2016 period. (b) The wavelet power spectrum using Morlet mother wavelet.

We applied the wavelet transform on the IUC in latitude 34°N. Fig, 9a) shows the trend. The fluctuation trend is regular, with low intensity in signal compared with the south latitudes. In this latitude, we have negative IUC that explain the activity of the downwelling. Fig, 9 b) shows the results of the wavelet transform of the downwelling. The period of one year is also clear with deference in intensity followed the IUC signal magnitude.

Fig, 10 a) shows the variability of the IUC in the latitude 36°N. The fluctuation trend is not obvious, with low intensity in signal compared with the south latitudes. In this latitude, we have negative IUC, which explain the activity of the downwelling. Fig, 10 b) shows the results of the wavelet transform of the downwelling. The period of one year is also clear with deference in intensity followed the IUC signal magnitude.

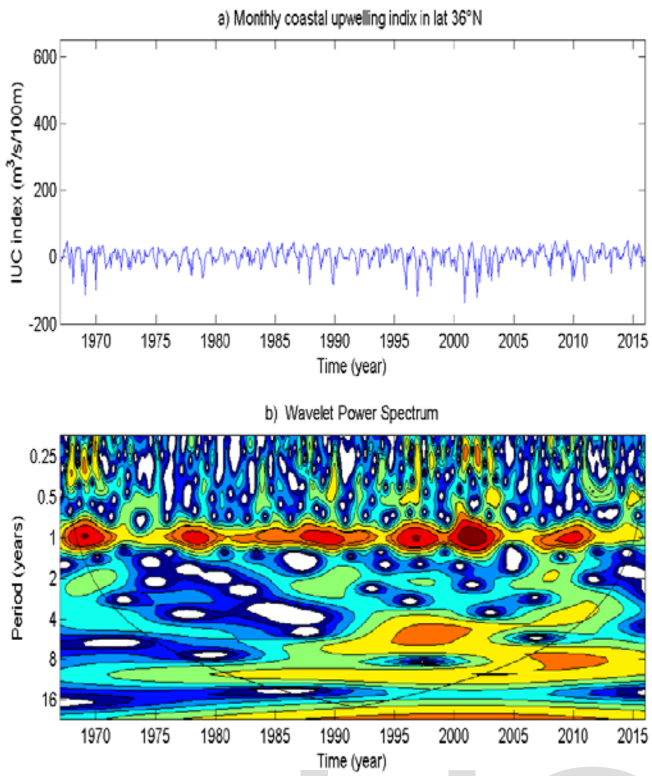

Figure 10 : (a) Monthly IUC in 36°N for 1967 to 2016 period. (b) The wavelet power spectrum using Morlet mother wavelet.

4 Discussion

In this paper, we studied each latitude separately from 21°N to 36°N using the wavelet transform. we suggest that there is four regions characterized by the same upwelling variability and magnitude, this regions are as follows from 21°N to 25°N, from 26°N to 28°N, from 29°N to 32°N and from 33°N to 36°N.

We notice that, latitudes from 21°N to 25°N had similar results Fig 3, 4. A strong upwelling activity can be identified during late 1970, until the beginning of 1980 followed by a weak activity period from 1980 until the beginning of 1990 followed by a long period of a strong upwelling. The wavelet Transform in the same latitudes shows that in short time scale, the oscillating period is obscure because of containing complex variations in short time scale. At scale of 1 year, the oscillating period of the wavelet is obvious. In long time scale, at the time scales 6 to 8years, the period is also obvious, with a period about 6 to 8 years. In Short, it present approximately 2 periods a 1 years and 7 to 8 years period.

Latitudes from 26°N to 28°N show comparable results Fig 5, 6. A strong upwelling activity can be identified along the period of study with small decries in 1985, 1995 and 2005 respectively. The wavelet Transform in the same latitudes shows an obvious period of 1 year. In long time scale, the oscillating period is obscure comparing with the South latitudes. Latitudes from 30°N to 32°N illustrate related results Fig 7, 8. A strong upwelling activity can be identified during late 1995, until the beginning of 2004, a small decries can be noticed in 1975, 1985, 1994 and 2005. The wavelet Transform in the same latitudes shows an obvious period of 1 year. In long time scale, the oscillating period is obscure comparing with the south latitudes. Finally, Latitudes from 34°N to 36°N show similar results Fig 9, 10. An extreme reduction in power can be found in this latitudes compared with the south ones along the period of study. In this region, the downwelling is more favorable.

Observing wavelet transform of all latitudes. We can notice that there is more concentration of power in the scale 1 year, which shows that this time series has a strong annual cycle. When the power decreases substantially in this band, it means a weak upwelling activity year and when the power is maximum means a strong upwelling activity year. In this study, we remark that the variation of upwelling index in the latitudes 21°N, to 24°N had the same order of magnitude, while the value of the IUC in the north latitudes was considerably smaller. The lowest value of the IUC is located at the 36°N.

5 Conclusion

The wavelet transform promises to be an advantageous tool in oceanography. For example, to study the time series analysis, the continuous transform is advantageous and efficient. In order to study the variability of the monthly IUC time series in the Moroccan Atlantic coast, wavelet analysis was applied. The wavelet power spectrum show a big power concentration in the scale of 1 year, revealing an annual periodicity of such events. We studied each latitude separately from 21°N to 36°N using the wavelet transform. We suggest that there is four regions characterized by the same variability and magnitude of the upwelling, this regions are as follows from 21°N to 25°N, this region is characterized by a higher intensity of upwelling. Moreover, this region is known by the permanent activity of upwelling. From 26°N to 28°N, in this region the upwelling is weak, with a weak signal of the UIC compared with the first region. From 30°N to 32°N, in this region of Cap Ghir the upwelling become higher, with a period of one year. Finally, from 34°N to 36°N in this region we talk more about the downwelling, because IUC in this region is negative, furthermore, the period of the downwelling is one year with deference in intensity followed the IUC signal magnitude. Further study could be done with wavelet analysis especially the cross-correlation between the IUC and the wind speed or with the ocean mixed layer depth for understanding more the variability of the upwelling phenomena in the Moroccan Atlantic coast.

Acknowledge

The writers wish to thank Dr. Christopher Torrence for Advenced study at National center for Atmospheric Research, Colorado, for providing the wavelet analysis function, as well as for his comments.

References

[1] P. Goupillaud, A. Grossmann and J. Morlet, "Cycle-octave and related transforms in seismic signal analysis.," *Geoexploration,* pp. 23, 85-105., 1984.

[2] M. Farge, "Wavelet transforms and their applications to turbulence.," *Annu. Rev. Fluid Mech,* pp. 24, 395–457., 1992.

[3] Z. Shen, W. Wang and L. Mei, "Finestructure of wind waves analyzed with wavelet transform.," *J. Phys. Oceanogr. ,* pp. 24, 1085-1094., 1994.

[4] M. Mak, "Orthogonal Wavelet analysis : interannual variability in the sea surface temperature," *Bulletin of the American Metreorological society,* p. 2179, 1995.

[5] S. D. Meyers, G. B. Kelly and J. O'Brien J, "An introduction to wavelet analysis in oceanography and meteorology With application to the dispersion of Yanai waves.," *Mon. Wea.,* 1993.

[6] I. Daubechies, " The wavelet transform, time frequency localization and signal analysis," *IEEE,* 1990.

[7] G. Kaiser, A Friendly Guide to Wavelets, springer, 2011.

[8] E. Thomas, N. Cropper, E. ,. Hanna and G. ,. Bigg, "Spatial and temporal seasonal trends in coastal upwelling off Northwest Africa, 1981–2012," *Deep-Sea Research I,* p. 86 94–111, 2014.

[9] A. Makaoui, A. Orbi, K. Hilmi, S. Zizah, J. Larissi and M. Talbi, "L'upwelling de la côte atlantique du Maroc entre 1994 et 1998," *Comptes Rendus Geoscience,* Vols. Volume 337, Issue 16, p. Pages 1518–1524, 2005.

[10] P. Miranda, J. Alves and N. Serra, "Climate change and upwelling: response of Iberian upwelling to atmospheric forcing in a regional climate scenario.," *Clim. Dyn.,* pp. 40, 2813–2824 , 2012.

[11] M. Payne, "Climate change at the dinner table," *Nature ,* pp. 497, 320–321., 2013.

[12] W. Cheung, R. Watson and D. Pauly, "Signature of ocean warming in global fisheries catch," *Nature,* pp. 497, 365–368., 2013.

[13] C. Torrence and G. P. Compo, "A Practical Guide to Wavelet Analysis," American Meteorological Society, 1998 .

[14] D. Pauly and V. Christensen, "Primary production required to sustain global fisheries.," *Nature ,* pp. 374, 255–257., 1995. .

[15] N. Gamage and W. Blumen, "Comparative analysis of lowlevel cold fronts: Wavelet, Fourier, and empirical orthogonal function decompositions.," *Mon. Wea. Rev.,*, pp. 121, 2867–2878, 1993.