Spatial and temporal trends of sea surface temperature in the northwest African region

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Abstract – The timing and structure of sea surface temperature (SST) changes were investigated using data from the continental shelf of the northwest African region and from coastal stations in Mauritania. Empirical Orthogonal Function analysis of the data revealed differences between northern regions with permanent upwelling, and southern regions where the upwelling is seasonal. It is then hypothesized that shifts in the onset and duration of upwelling may be occurring. Furthermore, the Mauritanian shelf area, a transition zone between the northern and southern regions, appears to go through a series of cooling and warming trends, which seem to be part of a long-term process affecting the northwest African coast. In this regard, it is shown that there is a strong relationship between SST at 18–20° N latitude and the Coastal Upwelling Index computed at a coastal station. This approach may allow for adequate predictions of oceanographic processes over the Mauritanian shelf, and probably the northwest African region, from coastal stations, as has been proven in other upwelling systems such as the California system. © Elsevier, Paris / Ifremer / Cnrs / Ird

sea surface temperature / upwelling / trends / Mauritania / northwest Africa

Résumé – Tendances spatiales et temporelles de la température superficielle de l'océan au nord-ouest de l'Afrique.
La dynamique spatio-temporelle de la température de surface de la mer est étudiée à partir de données collectées sur le plateau continental de l'Afrique occidentale (10–30° N). L'analyse par la technique des fonctions orthogonales révèle des différences entre les régions situées au nord du cap Blanc, où l'*upwelling* est permanent, et celles du sud où l'*upwelling* est saisonnier. Nous émettons l'hypothèse d'un changement du commencement et de la durée de l'*upwelling*. De plus, la région mauritanienne, transition entre les deux zones, subit une série de refroidissements et de réchauffements qui paraissent s'intégrer dans un phénomène hydrométéorologique de plus grande ampleur affectant toute la côte nord-ouest africaine. Nous montrons que la température de l'eau à la latitude 18–20° N est fortement corrélée à l'indice d'*upwelling* côtier, calculé à partir d'une station côtière. Cette approche pourrait permettre de prédire des phénomènes océanographiques sur le plateau continental mauritanien et, probablement, sur toute la zone nord-ouest africaine comme elle l'a fait dans d'autres régions d'*upwelling* telles que la Californie. © Elsevier, Paris / Ifremer / Cnrs / Ird

température superficielle / *upwelling* / tendance / Mauritanie / Afrique du Nord-Ouest

1. INTRODUCTION

The northwest African ecosystem, like many other eastern boundary current systems (Peru, California, South Africa) is known to be among the most productive systems in the world due to a number of oceanographic processes, in particular upwelling [5, 10, 15, 20, 23, 26, 34, 44]. Off Mauritania, this productivity seems to be additionally enhanced by such factors as topography (e.g. wider shelf area off Cap Blanc, numerous capes and

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canyons) and the characteristics of water masses around this area (e.g. North and South Atlantic Central Waters: NACW and SACW). Description of the northwest African ecosystem variability has been, in general, inferred from atmospheric pressure and wind field data [15, 24, 38]. Rarely are studies based on in situ measurements. Recently some attempts to describe the system using satellite imagery produced interesting results [9, 16, 27, 40]. Yet, most of these studies remain rather limited in space and time.

The objective of this paper is to explore the structure and timing of the seasonal cycle of sea surface temperature (SST) along the northwest African coast using measurements on the shelf (1946–1988) as well as from coastal stations (1960–1988). The main focus is to characterize spatial and/or temporal trends in SST. Particular emphasis is given to the Mauritanian shelf which, because of its transitional nature, carries signals (such as changes in the upwelling regime) that could reflect conditions over the whole northwest African continental shelf. In the last section, we will focus our attention on possible links between coastal stations in Mauritania and oceanographic processes at larger scales.

2. MATERIAL AND METHODS

Long-term trends as well as large scale features in SST were investigated using the Comprehensive Ocean Atmosphere Data Set (COADS, [45]). These data consist of monthly SST measurements made around the shipping lanes in the Atlantic that are averaged in $2° \times 2°$ squares (figure 1). More than one million observations were collected over a 43 year period (1946–1988) in the study area which extends from $10°$ N to $30°$ N. Empirical Orthogonal Function (EOF) analysis of the data set was conducted using PRINCOMP [35]. EOF is a multivariate technique useful for data and trend reduction which enables highly correlated variables to be reduced to a small number of orthogonal functions [18, 33]. This reduction technique is frequently applied to oceanographic and meteorological data [7, 19, 36, 39, 41, 42].
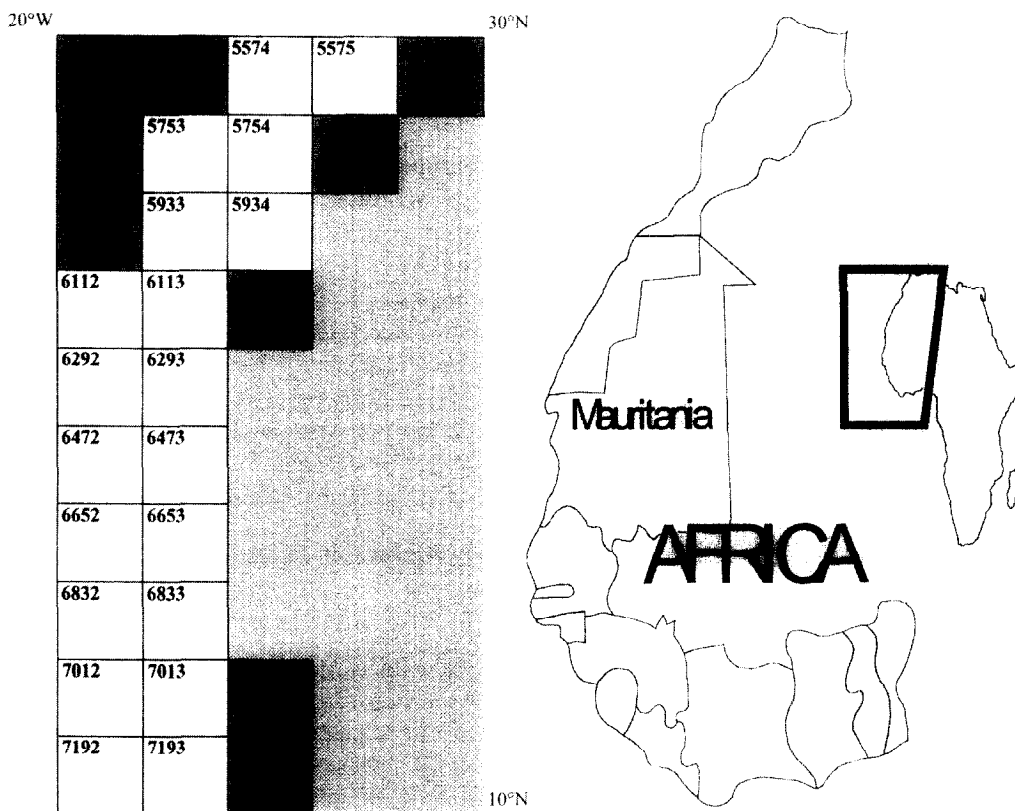

Figure 1. The study area with the $2° \times 2°$ Marsden squares (map from Harvard Graphics).

At smaller spatial scales (20' × 20' squares), the data used were mainly extracted from the database of the National Center for Fisheries and Oceanography (*Centre National de Recherches Océanographiques et des Pêches* or CNROP), Nouadhibou, Mauritania (*figure 2*). This database consists of measurements made during scientific expeditions as well as from scientific observations on board the fishing fleet off the Mauritanian coast [12].

Additional data were obtained from the National Oceanographic Data Center (NODC), Washington, D.C., USA and the U.S. National Oceanic and Atmospheric Administration (NOAA).

These finer-scale data were analysed to characterize the short, seasonal SST cycle in the Mauritanian EEZ (1983–1993). The shelf was then partitioned into two areas,
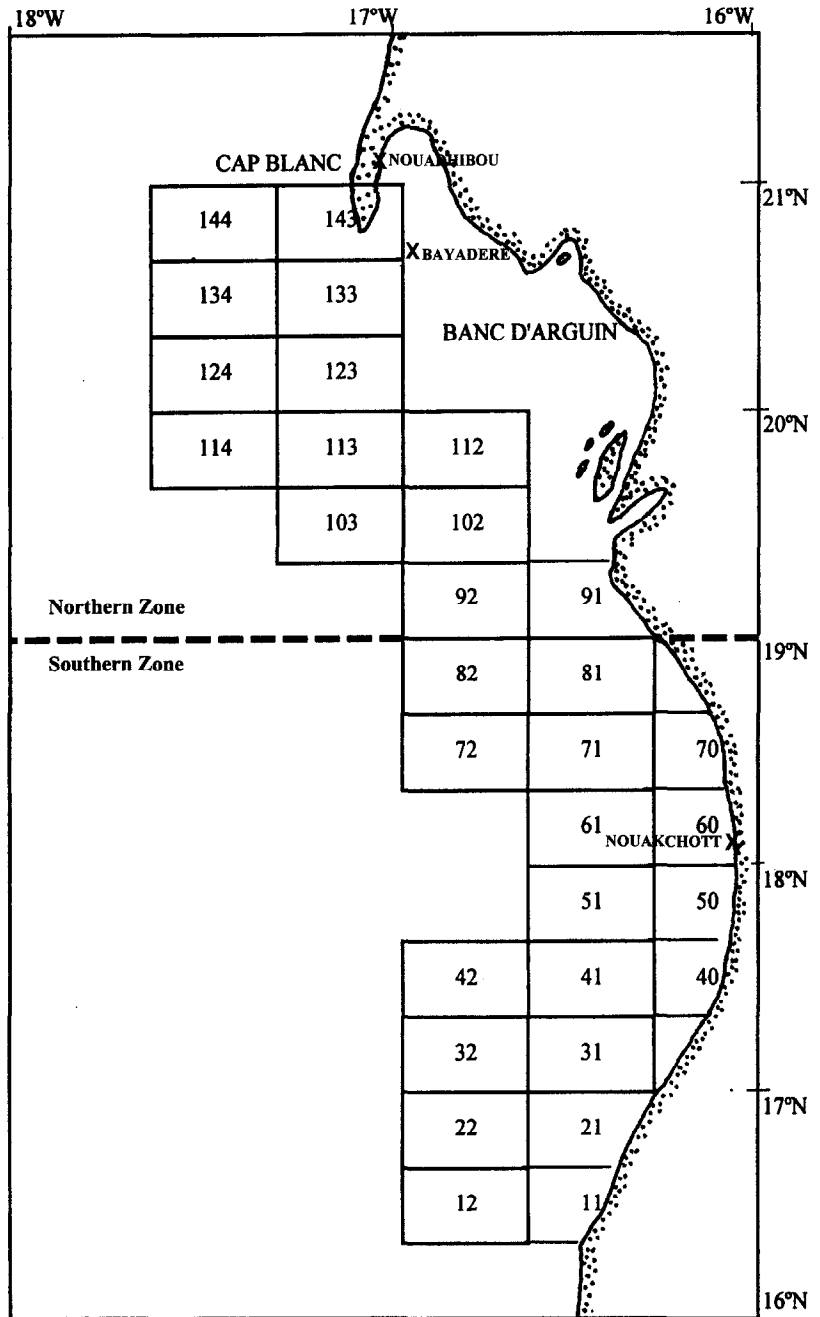
Figure 2. Geographic location of the 20'x 20' squares. Also noted are the nothern and southern zones of the Economic Exclusive Zone on either side of the 19°N latitude.

north and south of the 19° N latitude. This division is based on results from previous studies which indicated that these two zones appear to have distinct hydrographic characteristics [11, 29]. Likewise, the year was divided into four hydrographic seasons: a cold season (January–May), a warm season (August–October) and two transitional seasons (June–July and November–December). Bottom water temperature data from the coastal station of Bayadère (20° 40' N–17° 04' W; [13]) are analyzed and the Coastal Upwelling Index (CUI) is estimated [1, 2, 46] using wind data from a coastal meteorological station at Nouadhibou from 1960 to 1993 (figure 2). The CUI is expressed as the volume of water in cubic meters transported off-shore per second per 100 m of coastline as a result of the meridional wind stress component (Ekman transport).

Trend analysis was conducted on monthly CUI and bottom water temperature values using the Seasonal Kendall Test (SKT) for trend, a nonparametric procedure believed to be robust against outliers, collinearity and seasonality [17]. Whether the phenomena observed at local coastal stations were reflected at larger scales (the 2° × 2° squares and larger) was investigated using the Kendall Rank correlation coefficient [6] as well as regression techniques [25].

3. RESULTS AND DISCUSSION

3.1. Spatial and temporal trends of sea surface temperature

Annual mean SST is about 20.2 °C at the northern limit (30° N latitude) and 25.8 °C at the southern limit (10° N) of the study area. Between 20 and 26° N the average temperature is cooler and more uniform with a mean of about 19.7 °C, which reflects the persistent influence of upwelling. Mean SST is slightly warmer north of this region and significantly warmer to the south. The Mauritanian shelf, which lies between 16 and 21° N, includes the SST transition zone between the northern and southern regions (table I, figure 3). Particular attention will be given to this region in the following sections.

The eigenvalues of the EOF analysis, performed on monthly SST deviations of the nearshore boxes (figure 1), indicate that two components account for 95 % of the total variability. Subsequent components account for less than 3 % each (table I). Furthermore, since the third eigenvector and subsequent components make relatively

Table I. Eigenvalues and eigenvectors of the empirical orthogonal function analysis of sea surface temperature (°C) along the northwest African coast. PRIN1, PRIN2, denote the first two orthogonal functions.

Latitude	EOF modes		Temperature	
	PRIN1	PRIN2	Mean	STD
28-30N	0.33	–0.05	20.24	1.66
26-30N	0.33	–0.06	20.27	1.49
24-26N	0.30	–0.23	19.66	1.41
22-24N	0.31	–0.32	19.64	1.28
20-22N	0.30	–0.43	19.64	1.82
18-20N	0.32	–0.18	21.79	2.93
16-18N	0.33	0.01	23.13	3.25
14-16N	0.33	0.23	23.93	3.40
12-14N	0.32	0.43	24.72	3.25
10-12N	0.29	0.63	25.86	2.34
% variance explained	88.50	6.10		
Cumulative %	88.50	94.60		

small contributions to the total SST variance, they will not be discussed further [7, 8, 31, 42].

The first component (PRIN1) reflects the seasonal signal. This first eigenvector has approximately equal loadings at all latitudes (table I, figure 4). The signal indicates in phase cooling and warming for both the northern and southern regions. The time coefficients always have positive values (i.e. maximum temperatures) in the warm water season (August–October) and negative values during the cold water season (January–May). The largest positive value appears in September, while the largest negative value occurs in March. PRIN1 accounts for 88.5 % of the total variability, a percentage which indicates the dominance of the seasonal SST signal in the Atlantic. Similar studies in the Atlantic, but on larger scales, have reported values for the first eigenvector between 80 and 84 % of the total variance [32, 36, 42]. A recent study of SST variability off northwest Africa using satellite imagery from a relatively shorter period (1981–1989) but a much larger area than we studied found that the first EOF component contained about 75 % of the total SST variance [16].

Our second eigenvector (PRIN2), which contributes 6.1 % of the total variance, has negative loadings at northern latitudes and positive loadings at southern latitudes. The northern and southern regions are out of phase with respect to the second component. This can be interpreted as a measure of the spatial variation of upwelling intensity. The latitudes between 18° N and 26° N have the
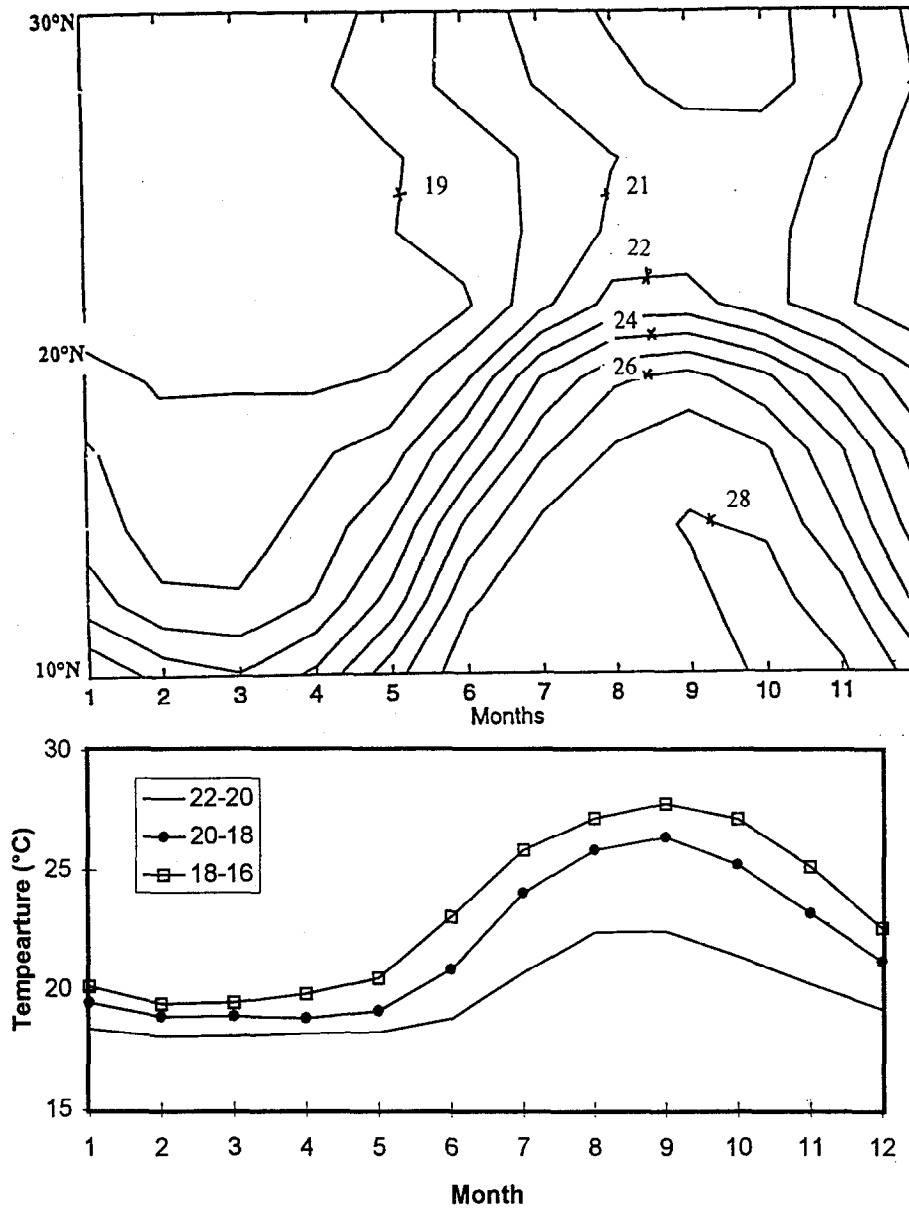
Figure 3. Contours of monthly mean sea surface temperature (top) and its evolution for selected latitudes (16–22° N) along the northwest African coast (bottom).

highest negative loadings. These are known to be regions of permanent upwelling [38, 39, 46] while north of 26° N and south of 18° N the upwelling seems to be seasonal. The temporal pattern for PRIN2 indicates a semi-annual cycle with two minima in March (cold water season) and August–September (warm water season) and two maxima in June and November–December. Plots of PRIN2 vs. PRIN1 clearly indicate the separation between the

cold season (January–May) and the warm season (August–October), the latter having positive PRIN1 loadings. The transitions between these two water seasons tend to have positive PRIN2 loadings. In their study, Hernandez-Guerra and Nykjaer [16] also point out the "out of phase behavior" between northern and southern regions alluded to earlier. Direct comparison of the time series of projection coefficients found in the two studies
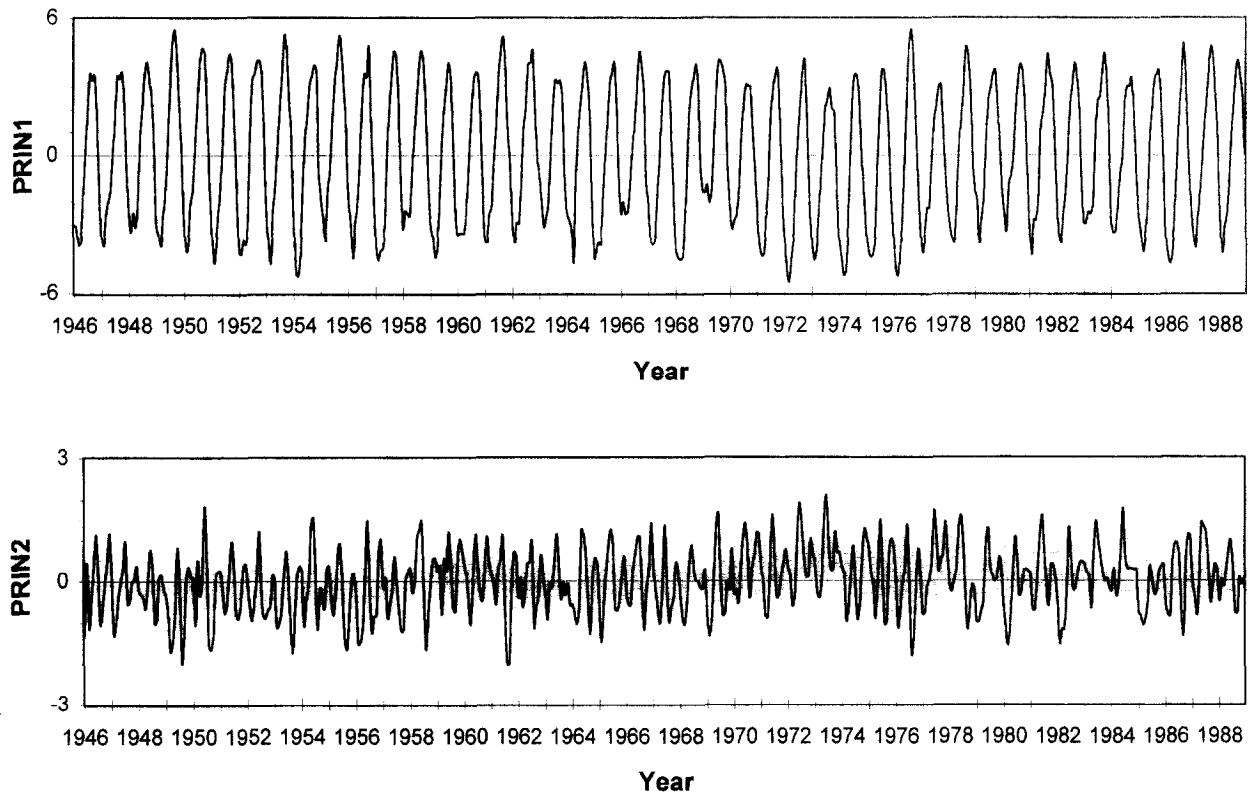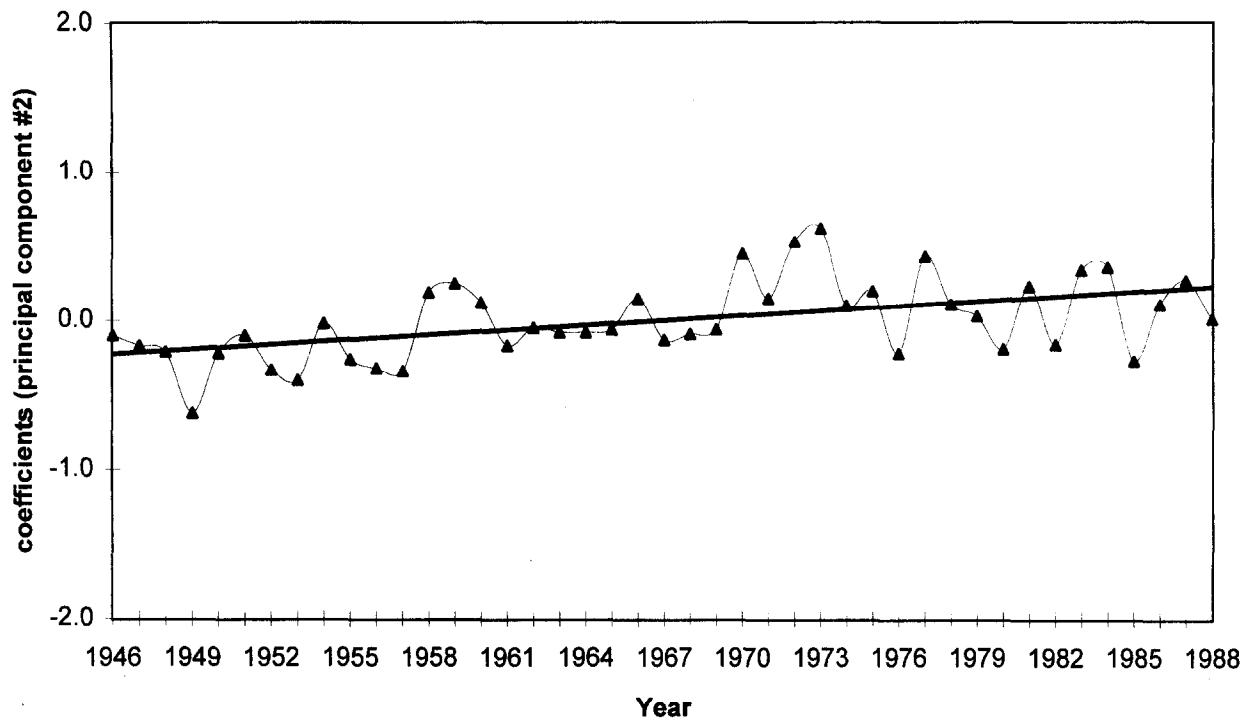
Figure 4. Plots of time coefficients for the first two orthogonal functions (i.e. PRIN1 and PRIN2) for sea surface temperature along the northwest African coast (10–30° N).

is difficult though because of significant differences in study scales – ours is limited in space and extensive in time, while theirs is the opposite.

Time series plots of PRIN2 indicate an increase in the amplitude of the separation between regions of permanent upwelling and regions of seasonal upwelling (slope of regression: 0.01 °C yr^{-1}, P < 0.001; *figure 5*). A closer look reveals a long-term cooling trend for the regions between 20 and 26° N over the study period. The reverse is observed for the southern regions, where considerable heating occurred. What then is happening in the transitional waters between these two regions? This question was addressed by plotting SST anomalies. The SST anomaly was computed as being equal to the mean monthly SST in a given year minus the long-term average. Interestingly, when plotting SST anomalies for the warmest months (August–October) at the above latitudes, a downward (cooling) trend can be easily identified (slope of regression: –0.026 °C/yr^{-1}, P < 0.001; *figure 6*), while south of 14° N and north of 22° N no such trend is observed. It is hypothesized that a shift in the time and/or strength of upwelling is occurring. This may be seen by

correlating the second principal component, which was interpreted as being a measure of the strength of the spatial (latitudinal) separation of northern and southern regions, with upwelling intensity. The correlation is strongest during the warm water season (August–September; Kendall Tau= –0.73, P = 0.0001). Also, the correlation was significantly higher between PRIN2 coefficients and upwelling during the transitional warm-to-cold-water season (November–December; Kendall Tau= –0.43). This might be a reflection of an earlier-than-usual invasion of the shelf by southward-flowing cold water masses from the Sahara Current, i.e. around November–December, warm waters are pushed quickly off the shelf earlier than in the beginning of the study's time series.

Complex EOF analyses performed on wind vectors from the same nearshore Marsden squares as the SST data, after removal of the means revealed that the first principal component accounted for 57 % of the total variance, while the second EOF mode contributed about 27 %. The first EOF represents a pattern which is strongest in the south and rotates approximately 145° clockwise from north to south,

Figure 5. Plot showing linear trend (thick line) for annual means of the second principal component time coefficients for sea surface temperature along the northwest African coast, 10–30° N (slope = 0.01 °C yr^{-1}).

suggesting a convergence near the middle of the pattern. The second EOF pattern rotates approximately 45° counterclockwise from north to south. It weakens initially moving from north to south and then strengthens slightly in the southernmost boxes. The time variability of the first EOF is primarily seasonal in nature. This signal is best resolved for the north–south component in the five northern latitude boxes and for the east–west component in the five southern latitude boxes. The other component, while still containing a dominant annual signal, is more variable in nature. The time variability of the second EOF is also dominated by a seasonal variability, but significant energy is found at a half-year period. The annual variability is, again, best resolved in the north–south winds in the northernmost squares and the east–west winds in the southern squares. The latter contribute strong pulses towards the east. We have been unable to uniquely associate the dominant wind EOFs with those of the SST. In fact, the first SST EOF has correlation coefficients of 0.32 and 0.38 with the first and second wind EOFs, respectively. The second SST EOF has a correlation coefficient of 0.20 with the second wind EOF, presumably because of the presence of a strong semi-annual signal in each projection coefficient time series. A closer look in time and space

reveals a significantly high correlation between the meridional wind contribution from the first EOF and SST contributions from each EOF in each latitude box (*table II*). For instance, between June and December, it appears that the meridional wind from the first EOF correlates well with SST contributions from each of the first and second SST EOF modes. These correlations generally indicate the out-of-phase relationship between northern and southern zones. The northernmost regions are negatively correlated with the first EOF and positively correlated with the second EOF. The reverse is observed for the southernmost boxes (*table II*).

3.2. The Mauritanian shelf as a transitional region

We now consider smaller scales (20' × 20') of the Mauritanian Economic Exclusive Zone (EEZ: *figure 2*). Over the Mauritanian shelf, average monthly SST exhibits a strong seasonal pattern in both the northern and southern zones, separated by the 19° N latitude (*figure 7, table III*). From January to May cold waters are observed over the whole continental shelf. Later in the year, SST increases to a maximum around August–September (warm season) and then drops quickly toward the end of the year. On

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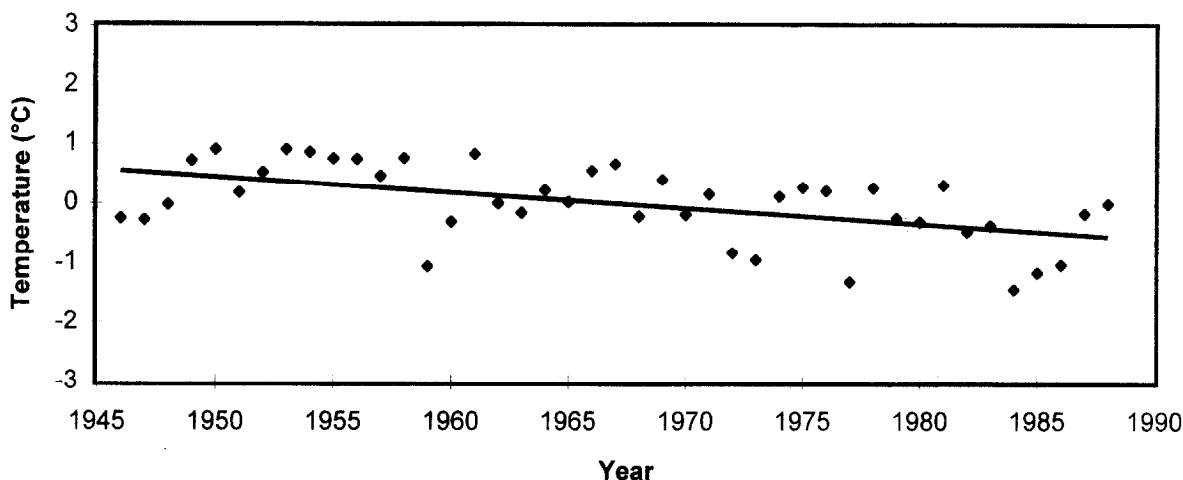
Figure 6. Plot of annual means of sea surface temperature anomalies (°C) showing a linear cooling trend during the warm water season (August–October) for a selected 2°x 2° square (16–18° N) along the northwest African coast (slope = $-$ 0.026 °C yr^{-1}).

Table II. Correlation matrix for the contribution from the meridional wind of the first EOF wind mode and the first two modes of sea surface temperature (Mode1 and Mode2) by hydrographic season along the northwest African coast.

	First EOF MODE							
	January-May		June-July		August-October		November-December	
	Mode1	Mode2	Mode1	Mode2	Mode1	Mode2	Mode1	Mode2
Latitude								
28-30N	–	0.35	–0.30	0.37	–0.43	–	–	0.38
26-30N	–	0.35	–0.35	0.41	–0.44	–	–	0.39
24-26N	–	0.35	–0.25	0.33	–0.41	–	–	0.37
22-24N	–	0.35	–0.19	0.27	–0.39	–	0.24	0.35
20-22N	–	0.31	–	–	–0.30	–	0.37	0.26
18-20N	0.28	–	0.46	–0.44	–	–0.38	0.43	–
16-18N	0.21	–0.20	0.47	–0.48	0.27	–0.44	0.31	–0.23
14-16N	–	–0.27	0.45	–0.48	0.36	–0.41	–	–0.30
12-14N	–	–0.30	0.44	–0.47	0.40	–0.37	–	–0.33
10-12N	–	–0.31	0.44	–0.47	0.41	–0.35	–	–0.34

–, denotes that the correlation is not statistically significant at α = 0.05.

average, the northern zone has much colder SST than the south (*figure 7*). The seasonal warming–cooling cycle and north–south (meridional) gradient are consistent with the physical processes active in the area (*figure 3*). At the beginning of the year, upwelling is very intense and the southward-flowing, cold Sahara Current invades the shelf. This period is generally characterized by relatively weak SST variability [12, 21]. Average SST is 18.4 °C for the whole shelf (standard deviation ± 0.97 °C; *table III*). Beginning in June, SST rises due to increased solar radiation and a change in the upwelling intensity, especially in the southern part of the EEZ where the

strongest thermal gradients are observed [11, 21, 22, 29]. During the warm season (August–October), the trade winds favorable to the development of upwelling weaken, and the inner and outer shelves are occupied by a warm, northward-flowing current, the Mauritania Current. Average SST is 24.6 °C for the whole shelf (standard deviation ± 2.59 °C, *table III*). From November to December, there is a cooling of shelf SST and a rather quick return to the initial conditions, where isotherms are distributed parallel to the isobaths [12]. Comparison of *figures 3* and *7* indicates a strong visual correlation. Clearly, the fine-scale, inner-shelf thermal patterns vary in phase with the
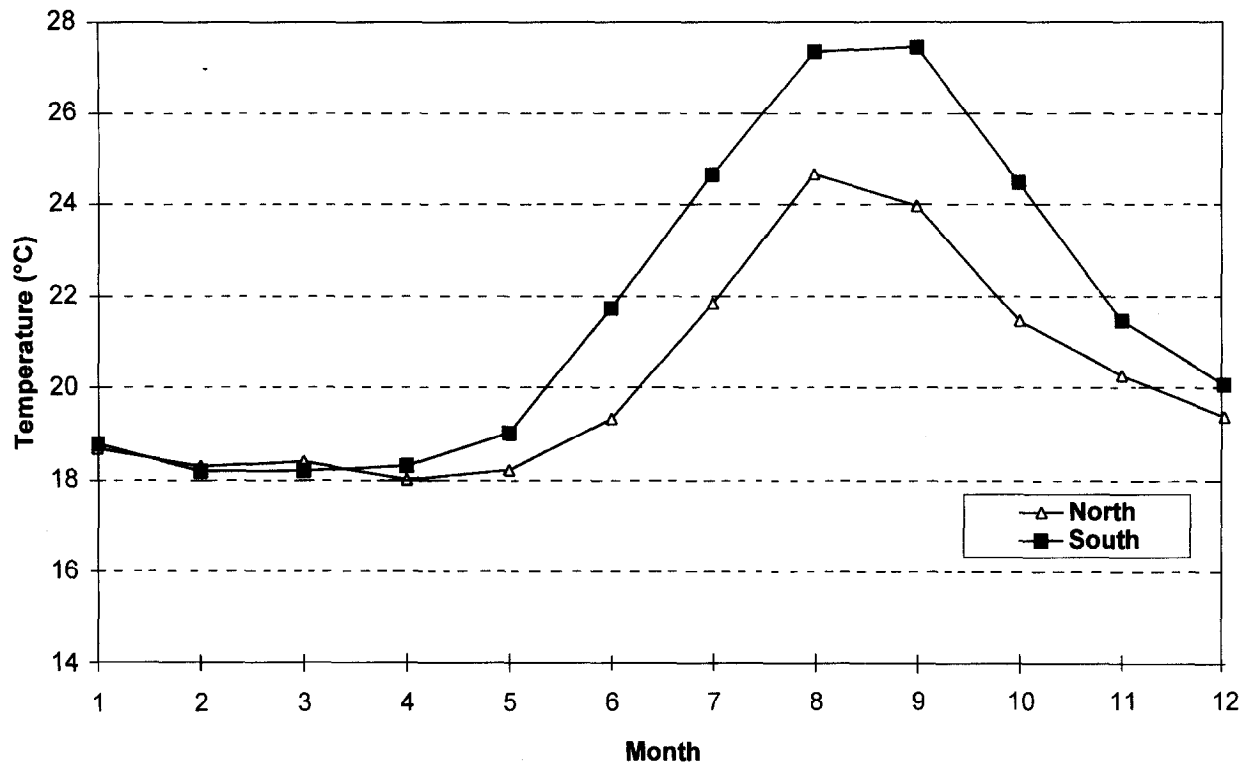
Figure 7. Long-term average monthly sea surface temperature (°C) for the northern and southern zones of the Mauritanian shelf.

Table III. Mean sea surface temperaturses (°C) and their standard deviations (std) for the Mauritanian shelf during the different hydrographic seasons.

Season	Southern zone	std	Northern zone	std	Whole shelf	std
Cold (January-May)	18.52	0.95	18.21	0.97	18.43	0.97
Cold-warm (June-July)	21.45	1.99	20.31	1.80	21.01	1.99
Warm (August-Oct.)	25.60	2.57	23.30	1.68	24.58	2.59
Warm-cold (Nov.-Dec.)	20.71	1.61	20.05	1.00	20.49	1.46

larger scale characteristics of the outer shelf and slope. Therefore, the Mauritanian shelf plays the role of transition zone between the northern zone of permanent upwelling and the southern zone of seasonal upwelling in the northwest African region. This zone may serve as a sensitive indicator of climatic changes in the region.

3.3. Link to coastal stations

The CUI can provide some insights into onshore and off-shore Ekman transport variability [14, 37]. The CUI computed at coastal stations is derived from and reflects the regional wind patterns. In the northern part of the Mauritanian shelf the mean wind stress has a steady component from the north favorable for the development of year-round coastal upwelling, with maximum intensity from

March to July (*figure 8*). Bottom water temperatures at the Bayadère coastal station during the cold water season (1963–1988) show modest similarities with the upwelling intensity (1960–1993). Bottom water temperatures are colder at times of high CUI values and warmer at times of lower CUI values (*figure 9*). In the southern part, CUI is much lower than in the north because of a reduction in wind speed and increased directional variability [28, 30].

Analysis of yearly CUI anomalies in Nouadhibou (1960–1988) revealed a succession of years with high upwelling intensity followed by years of low intensity. The period of the cycle was approximately ten years; the mid-1960s, 1970s and 1980s showed high CUI values (*figure 10*). Examining SST long term variability over the Mauritanian shelf, it appears that the study area went through
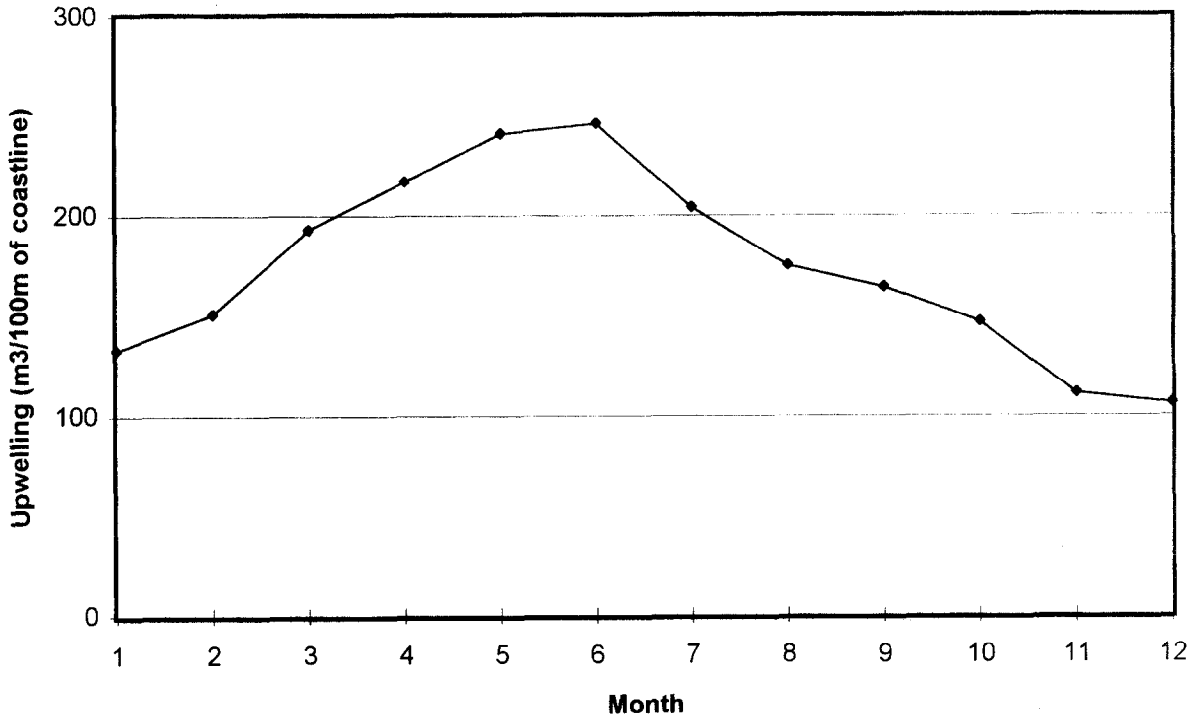
Figure 8. Temporal evolution of monthly mean upwelling intensity (m³/s per 100 m of coastline) off Mauritania estimated from the Nouadhibou coastal station data (1960–1993)
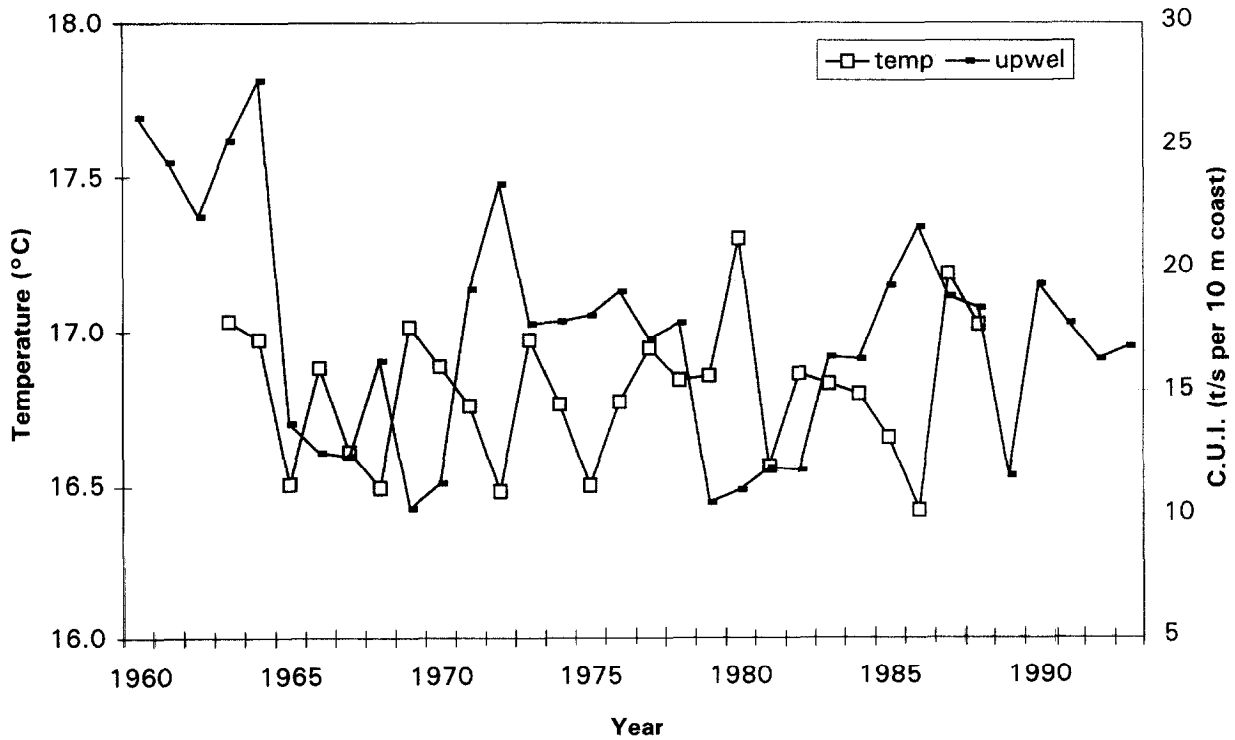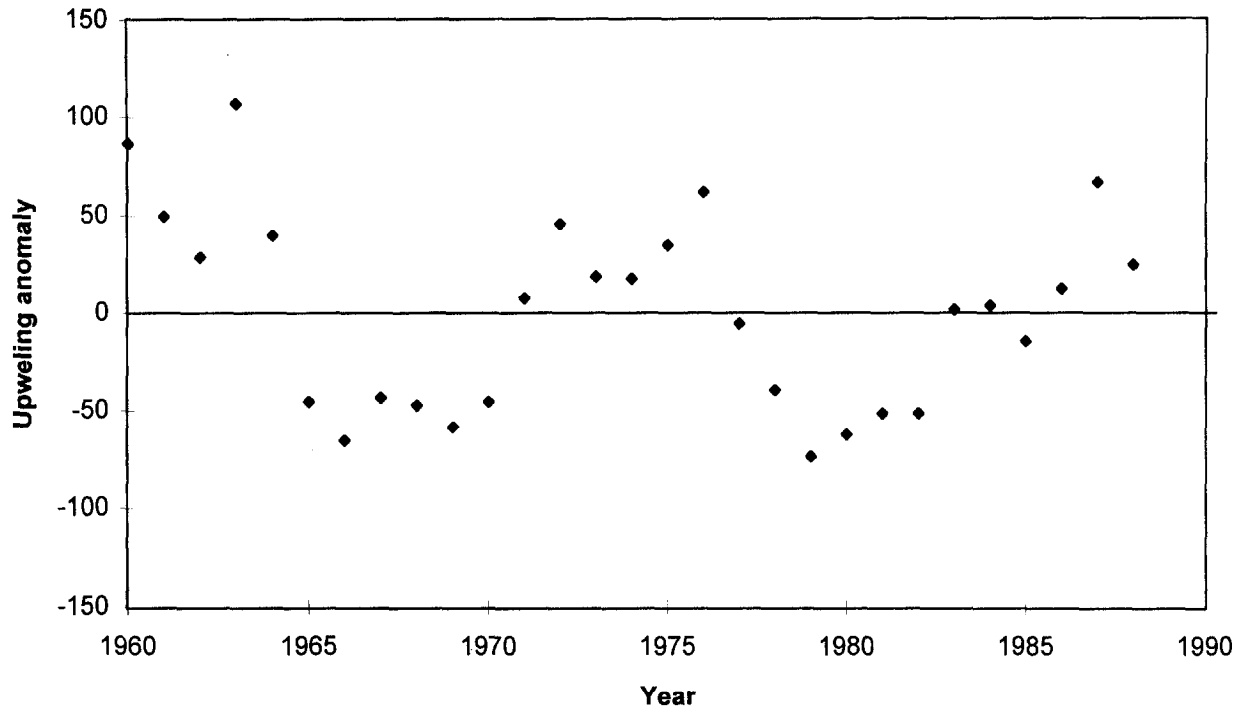

Figure 9. Yearly average bottom water temperature at Bayadère (1963–1988) and Coastal Upwelling Index at Nouadhibou (1960–1993) during the cold water season, January–May (correlation coefficient = 0.3).

Figure 10. Plot of upwelling anomalies (yearly value minus long-term average value) for Coastal Upwelling Index calculated during the warm water season (August–October) at the Nouadhibou coastal station (1960–1988).
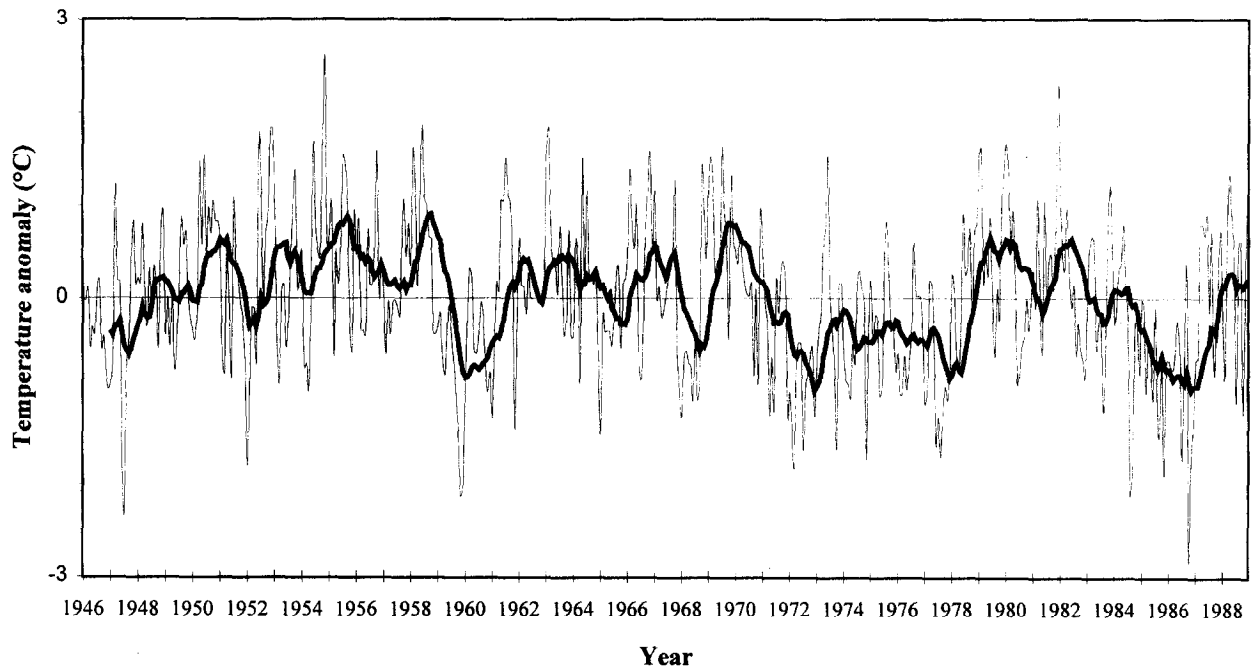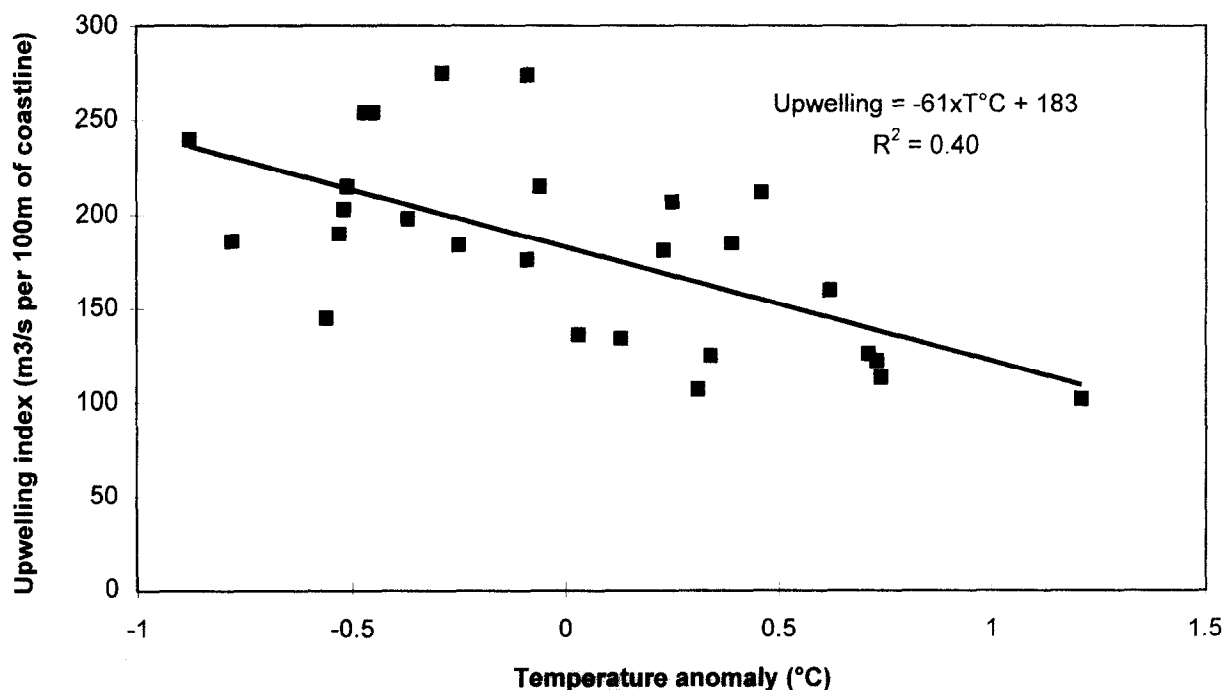

Figure 11. Plot of monthly sea surface temperature anomalies (°C) at latitudes of 16–18° N on the northwest African coast from 1946 to 1988. Also shown is the 13 period moving average (thick line).

successive cooling and warming events (*figure 11*) in agreement with the upwelling index values reported above for the same time period. In general, it can be seen that the middle years of some decades (e.g. 1972–1978; 1984–1988) show relatively negative anomalies (cooling) in the Mauritanian EEZ (*figure 11*). This cooling period was then followed by a warming trend (1989–1993, [29]). These cooling and warming patterns may be part of a long-term process affecting the northwest African coast and are the topic of on-going research.

There appears to be a strong agreement between SST on the continental shelf (18–20° N) and CUI computed at the Nouadhibou coastal station during the cold water season (January–May, *figure 12*). Regression analysis indicates the expected negative association between SST and CUI computed at the Nouadhibou station (P < 0.0001). This coastal station, therefore, provides an adequate indicator of thermal oceanographic processes in the Mauritanian shelf waters, both surface and bottom temperatures. In fact, the coastal station data are an indication of the larger-scale wind field. Regression analysis showed that the coastal meridional wind component at Nouadhibou is about 0.8 of the same offshore wind component in the 22–24° N latitude box (correlation coefficient = 0.5).

In an effort to determine the spatial scale associated with the observed temporal variability, we correlated our local time series with a large number of extensive oceanographic patterns used in climate studies (*table IV*). When examining this correlation matrix, atmospheric pressure and temperatures correlate well with large-scale parameters such as wind and temperature. The results, again, exhibit the out-of-phase behavior between the zones north and south of the Mauritanian shelf. For instance, an increase in the difference between minimum and maximum air temperature at Nouadhibou is associated with low and high values of the southward wind component in the northern and southern regions, respectively. The extent to which this merely reflects a seasonal pattern in each parameter time series or a more important indication of teleconnections is not presently known, but the possibility of using coastal measurements in this transition region as an indicator of larger-scale variations is tantalizing.

The representativeness of coastal stations for larger-scale variability is further supported when investigating associations between CUI and such global climatic indices as the East Atlantic Pattern (EA). The EA and the East Atlantic Jet (EA-jet) are two of the three most prominent

Figure 12. Temporal plot of sea surface temperature anomaly at selected latitudes (18–20° N) of the Mauritanian shelf and Coastal Upwelling Index at Nouadhivou station during the cold water season, January–May (1960–1988).

Table IV. Correlation matrix between hydrological and meteorological parameters at the coastal station of Nouadhibou and the wind meridional component along the northwest African coast.

	Coastal station indices			
Latitude	Vy	Min-Max	Pressure	Temp.
28-30N	0.40	0.37	0.51	-0.39
26-30N	0.40	0.33	0.53	-0.45
24-26N	0.39	0.27	0.48	-0.38
22-24N	0.50	0.14	0.48	-0.34
20-22N	0.57	–	0.37	-0.16
18-20N	0.45	-0.20	–	0.19
16-18N	–	-0.42	-0.45	0.71
14-16N	–	-0.39	-0.67	0.82
12-14N	-0.14	-0.37	-0.71	0.85
10-12N	-0.16	-0.40	-0.72	0.87

–, denote the correlation is not statistically significant at $\alpha = 0.05$.
Vy: meridional wind component (m s^{-1}) at Nouadhibou
Min–Max: difference between min and max air temperature (°C) at Nouadhibou
Pressure: atmospheric pressure (mbar) at Nouadhibou
Temp: bottom temperature (°C) at Bayadère

Table V. Correlation matrix for Kendall Tau correlation coefficient between coastal indices in Mauritania and various scale and global climatic indices.

	EA	EA-JET	SATL	TROP
Temp.	-0.54	0.39	-0.70	-0.45
NDB_Pressure	0.53	-0.53	0.41	0.22
NDB_MinMax	0.48	-0.39	0.36	0.24
CUI	-0.18	0.33	0.43	0.34
Vy	0.23	-0.37	-0.38	-0.32

Temp: bottom temperature (°C) at Bayadère
NDB_Pressure: atmospheric pressure (mbar) at Nouadhibou
NDB_MinMax: difference between min and max air temperature (°C) at Nouadhibou
CUI: coastal upwelling index (m^3/s per 100 m coastline) at Nouadhibou
Vy: meridional wind component (m s^{-1}) at Noudhibou
EA: East Atlantic pattern*
EA-JET: East Atlantic Jet*
SATL: South Atlantic SST (0-20S, 30W-10E)*
TROP: Tropical zone SST (10S-10N, 0-360)*
* Data source: NOAA

modes of low-frequency variability over the North Atlantic [3, 43]. Both EA and EA-jet consist of a north–south dipole of pressure anomaly centers which span the North Atlantic. The former appears in all months except May–August while the latter appears mainly between April and August. There is negative correlation between CUI and EA (Kendall Tau = −0.54) and positive correlation between CUI and EA-jet (Kendall Tau = 0.39, *table V*).

Moreover, the correlation is much stronger for the warm water season where the correlation coefficients reach values of −0.6 and 0.6 for the EA and EA-jet in September–October and August, respectively. These results are consistent with those from a previous study that found strong correlations between ship-recorded pressures and sea-level coastal stations along the tropical Atlantic coast of Africa [4]. Interestingly enough, CUI and temperature data at the Nouadhibou station seem to correlate best with temperatures from the South Atlantic (0–20° S, 30° W–10° E) and the Tropics (10° S–10° N; 0–360°); the Kendall correlation coefficient values are 0.70 and 0.45, respectively (*table V*). The most important point, though, is that time series from a single coastal station are strongly correlated with the variations of larger-scale oceanic patterns and may serve as a surrogate for these patterns.

4. CONCLUSION

Investigations of the timing and structure of SST reveal the seasonal variability of complex spatial patterns along the northwest African coast. Of interest are the differences between northern regions with permanent upwelling and southern regions where the upwelling is seasonal. Likewise, it seems likely that shifts in the extent and timing of upwelling are taking place, partly because of changes in wind direction and intensity. The Mauritanian shelf, a region of confluence between colder waters in the north and warmer waters in the south as well as upwelling waters, seems to play an important role as a transition between temperate and tropical regimes. Moreover, the likely strong relationship between SST, over parts of the shelf, and CUI computed at a coastal station may be an indication that coastal stations can give an nsadequate representation of the oceanographic processes at larger scales. The processes involved, however, warrant further investigation.

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