The relationship between sea surface temperatures and winds off Northwest Africa and Portugal

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ABSTRACT

The influence of local winds on sea surface temperatures off Northwest Africa and Portugal/Spain is described with the aid of Empirical Orthogonal Functions (EOF). For the period 1972 through 1980 the coastparallel components of synoptic measured winds and differences of sea surface temperatures (calculated by subtracting mid-ocean temperatures from coastal averages ΔSST), are investigated. It is possible to divide the coastal areas off NW-Africa and Portugal into four different upwelling regions: between 20° N and 25° N upwelling occurs during the whole year, south of 20° N upwelling is present during winter and early spring, north of 25° N upwelling prevails during summer and fall, and along the coast of Portugal, north of 35° N up to 43° N, upwelling occurs during summer and fall with peaks at nearly 37° N. North of 40° N and south of 12° N the upwelling period decreases. On account of numerous data gaps in the ΔSST-time series between 25° N and 35° N two different analyses with EOF will be made: between 36° N and 43° N off Portugal/Spain, and between 10° N and 24° N off Northwest Africa. In contrast with earlier studies which considered the influence of the large scale weather situation upon coastal upwelling, the present study indicates that off Portugal local winds account better for upwelling than synoptic scale winds. Off Northwest Africa the correlation between the coastparallel wind component and differences of sea surface temperatures is described better by the synoptic scale windregime than by locally measured winds.

KEY WORDS : Winds — Temperature — Upwelling — Coasts — Numerical analysis — North — East Atlantic.

RÉSUMÉ

RELATION ENTRE TEMPÉRATURES DE SURFACE ET VENTS AU LARGE DE L'AFRIQUE DU NORD ET DU PORTUGAL

L'influence des vents locaux sur les températures de surface de l'Océan Atlantique au large des côtes d'Afrique du nord, d'Espagne et du Portugal, est décrite au moyen de fonctions orthogonales empiriques (EOF). Les composantes parallèles aux côtes des vents synoptiques, et les différences des températures de surface entre le milieu de l'Océan et les eaux côtières (ΔSST) ont été analysées sur la période 1972-1980. Suivant les phénomènes d'upwelling qui s'y produisent, on peut diviser la zone côtière qui s'étend de l'Afrique du nord-ouest jusqu'au Portugal en quatre régions :

— *de 20° N à 25° N, l'upwelling dure toute l'année,*
— *au sud de 20° N, l'upwelling est présent pendant l'hiver et le début du printemps,*
— *au nord de 25° N, l'upwelling domine pendant l'été et l'automne,*
— *et le long des côtes du Portugal, au nord de 35° N et jusqu'à 43° N, l'upwelling survient en été et en automne, avec des valeurs maximales aux environs de 37° N.*

Au nord de 40° N et au sud de 12° N, la durée de l'upwelling diminue.

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De nombreuses données manquant dans les séries ΔSST-temps entre 25° N et 35° N, les analyses par EOF ont été menées séparément dans les deux zones suivantes : la zone comprise entre 36° N et 43° N, au large de l'Espagne et du Portugal, et la zone comprise entre 10° N et 24° N, au large de l'Afrique du nord-ouest. En contradiction avec les études antérieures, qui avaient considéré l'influence de la situation météorologique d'ensemble sur l'upwelling côtier, la présente analyse montre qu'au large du Portugal l'upwelling est mieux expliqué par les vents locaux que par les vents synoptiques. Au large de l'Afrique du nord-ouest, le régime général des vents rend compte mieux que les vents locaux de la corrélation entre la composante parallèle à la côte du vent et les différences des températures de surface.

Mots-clés : Vent — Température — Upwelling — Côte — Analyse mathématique — Atlantique nord-est.

1. INTRODUCTION

Vertical motions are essential parts of the oceanic circulation. Of particular importance are ascending motions, by which subsurface waters are brought into surface layers and induce horizontal anomalies in the distribution of physical and chemical properties. This process is called upwelling and is strong at nearly all eastern boundaries of subtropical oceans. In these areas prevailing trade winds carry away the surface waters from the coast. The result is a horizontal divergence in surface layers with ascending motion. In the last two decades considerable interest has been shown towards an understanding of the mechanisms which occur in the coastal upwelling areas. The reason is twofold: the effect on climate is well known to exist as is the importance of upwelling on the marine ecology. A review of upwelling was given by Smith (1968).

The present paper deals with the upwelling areas off Northwest Africa and Portugal. Anomalies of sea surface temperatures are used as an indicator of upwelling. In previous papers (Speth, Detlefsen and Sierts, 1978; Speth and Detlefsen, 1979; Detlefsen and Speth, 1980) ,the influence of the atmospheric circulation on seasurface temperatures was investigated. As a measure for the coastparallel wind component, differences of sea level pressure normal to the coast (taken from grid points of objective analyses) were used. Synoptic scale winds are represented by these pressure differences. An analysis by empirical orthogonal functions suggested, that off Portugal local winds mainly induce upwelling, while off Northwest Africa synopticscale winds cause upwelling. It is the main purpose of this paper to reveal whether such a relationship exists by using direct wind measurements instead of pressure differences.

2. DATA

Sea surface temperatures (SST) were obtained from the Meteorological Office, Bracknell, as five day nonoverlapping mean values with a geographical resolution by degree square for the North Atlantic. Time covers the period from August 1972 through July 1980. The mean values were deduced at the Meteorological Office mainly from synoptic observations of merchant ships. Time series of SST were established for 41 squares between 5° N and 44° N (Fig. 1). After an inspection of time series by eye we decided to omit all those time series, for which

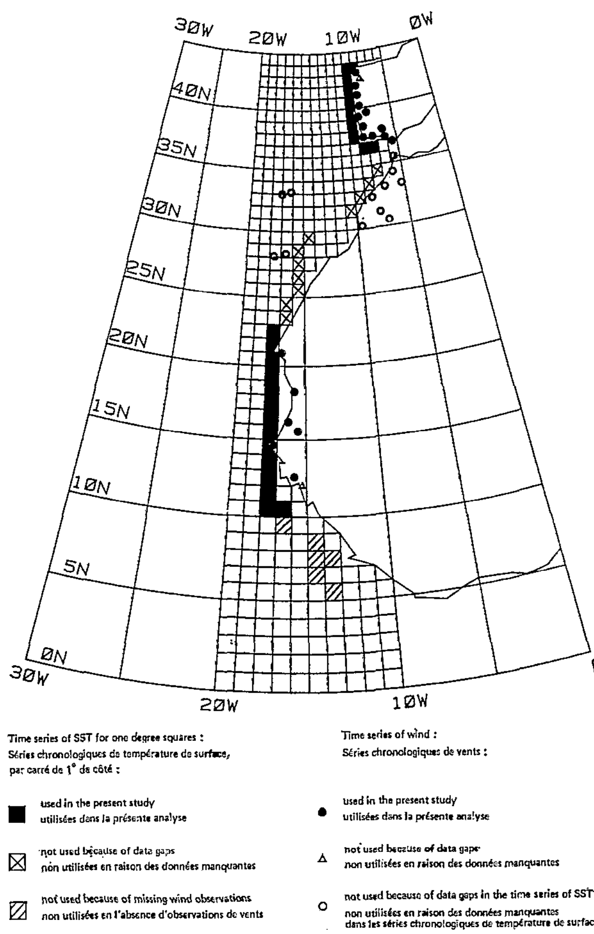

Fig. 1. — Map of study area.

Carte de la région étudiée.

TABLE I

Synoptic stations along the coast of Northwest Africa and Portugal/Spain.

Explanation:

● used in the present study.
△ not used because of data gaps.
○ not used because of data gaps in time series of SST.
— (average level of terrain in immediate vicinity of station).
+ (approximatly).

Stations synoptiques sur les côtes d'Afrique du nord-ouest, du Portugal et d'Espagne.

Symboles :

● *utilisée dans la présente analyse.*
△ *non utilisée en raison des données manquantes.*
○ *non utilisée en raison des données manquantes dans les séries temporelles de températures de surface.*
— *(altitude moyenne à proximité immédiate de la station).*
+ *(altitude approchée).*

Index	Name	Lat (N)	Lon (W)	Elevation (m)	
SPAIN					
08001	La Coruna	43°22' /	8°25'	67	●
008	Lugo / Punto Centro	43°15' /	7°29'	426	△
045	Vigo / Peinador	42°14' /	8°38'	246	●
391	Sevilla / San Pablo	37°15' /	5°54'	31	●
451	Jerez de la Frontera Aeropuerto	36°45' /	6°04'	29	●
GIBRALTAR					
08495	Gibraltar	36°09' /	5°21'	5	● read 5- lire 5-
MADEIRA					
08521	Funchal / S. Catarina	32°41' /	16°46'	49	○
524	Porto Santo	33°04' /	16°21'	82	○
PORTUGAL					
08536	Lisboa / Portela	38°47' /	9°08'	123	●
538	Sagres	36°59' /	8°57'	41	●
545	Porto / Pedras Rubras	41°14' /	8°41'	73	●
549	Coimbra	40°12' /	8°25'	140	●
554	Faro	37°01' /	7°58'	9	●
562	Beja	38°01' /	7°52'	247	●
571	Portalegre	39°17' /	7°25'	590	●
SPAIN (CANARY ISLANDS)					
60015	Tenerife / Los Rodeos	28°29' /	16°20'	618	○
030	Las Palmas de Gran Canaria / Gando	27°56' /	15°23'	25	○

TABLE I (suite)

MOROCCO				
60101	Tanger / Aerodrome	35°43' / 5°54'	15	○
135	Rabat-Sale	34°03' / 6°46'	76	○
150	Meknes	33°53' / 5°32'	549	○
155	Casablanca	33°34' / 7°40'	58	○
185	Safi	32°17' / 9°14'	45	○
230	Marrakech	31°37' / 8°02'	466	○
250	Agadir	30°23' / 9°34'	19	○
265	Ouarzazate	30°56' / 6°54'	1136	○
MAURITANIA				
61415	Nouadhibou	20°56' / 17°02'	3	●
442	Nouakchott	18°06' / 15°57'	3	●
SENEGAL				
61600	Saint-Louis	16°03' / 16°27'	4	●
627	Linguère	15°23' / 15°07'	21	●
641	Dakar / Yoff	14°44' / 17°30'	28	●
695	Ziguinchor	12°33' / 16°16'	23	●
GUINEA-BUISSAU				
61766	Bissau-Airport	11°53' / 15°39'	36+	Δ

the mean values had been formed from less than 1000 single observations (crossmarked squares in Fig. 1). From the remaining 30 time series only those north of 10° N were taken into further consideration, because south of this latitude no wind measurements were available. Time series in neighbouring squares at one latitude were combined (Fig. 1).

For the same period as for SST, wind observations from 32 synoptic stations along the coast of Northwest Africa and Portugal/Spain were made available by the Deutscher Wetterdienst, Offenbach/Main (Table I and Fig. 1). In general wind reports did exist for every day at 0, 6, 12 and 18 GMT, from which averages over five days were computed. Because of numerous data gaps two stations could not be used. They are indicated by triangles in Table I and Fig. 1. Stations which are marked by open circles had to be omitted, because time series of SST did not exist in their vicinity

Altogether the investigations, which are described in sections 3 and 4 were carried out with 24 time series of SST and 18 time series of wind.

3. TIME SERIES OF SEA SURFACE TEMPERATURES AND WINDS

In Fig. 2a time averages of SST are shown. A strong annual cycle exists with lowest temperatures in spring and highest temperatures in late summer and fall. A strong thermal gradient occurs in the south, seasonally migrating between 10° N and 20° N. It is coupled to the so-called tropical front.

In comparison to these features mid-ocean temperatures vary in a relatively simple fashion (Fig. 2b). The annual cycle as well as meridional gradients are decreasing toward the south. The structure of Fig. 2a suggests the occurrence of coastal upwelling, which can be identified best by computing zonal temperature differences by subtracting mid-ocean temperatures (Fig. 2b) from coastal averages (Fig. 2a) (done by WOOSTER *et al.* (1976) for monthly mean values). The results are presented in Fig. 3 as a function of geographic latitude and time. For a negative difference upwelling can be assumed. In order to exclude influences like radiation, only

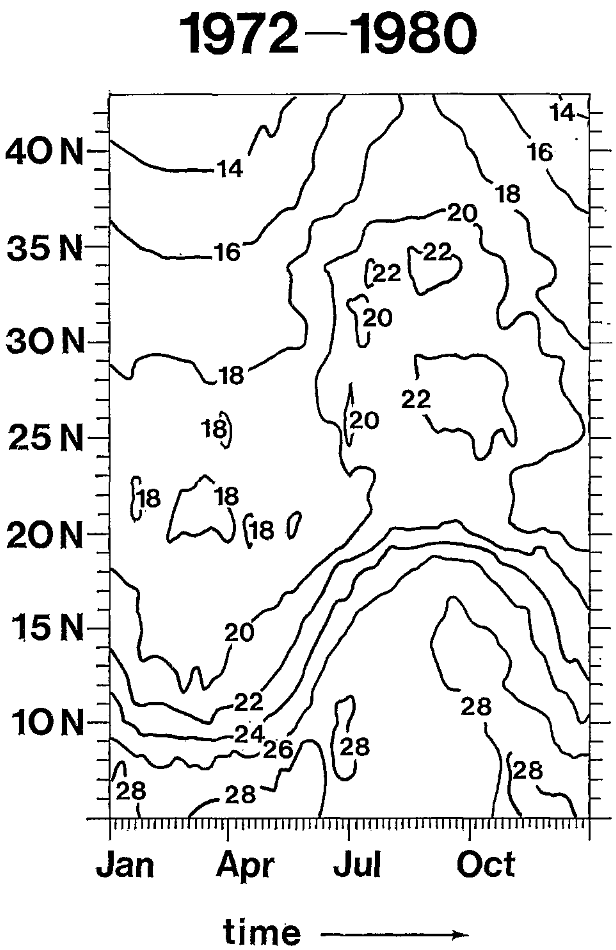

FIG. 2 a. — Sea surface temperatures, in °C, off Northwest Africa and Portugal for the period 1972 to 1980, using 41 times series. Averages over five days.

Températures de surface, en °C, au large de l'Afrique du nord-ouest et du Portugal, pour la période 1972-1980, d'après 41 séries chronologiques. Moyennes de 5 jours.

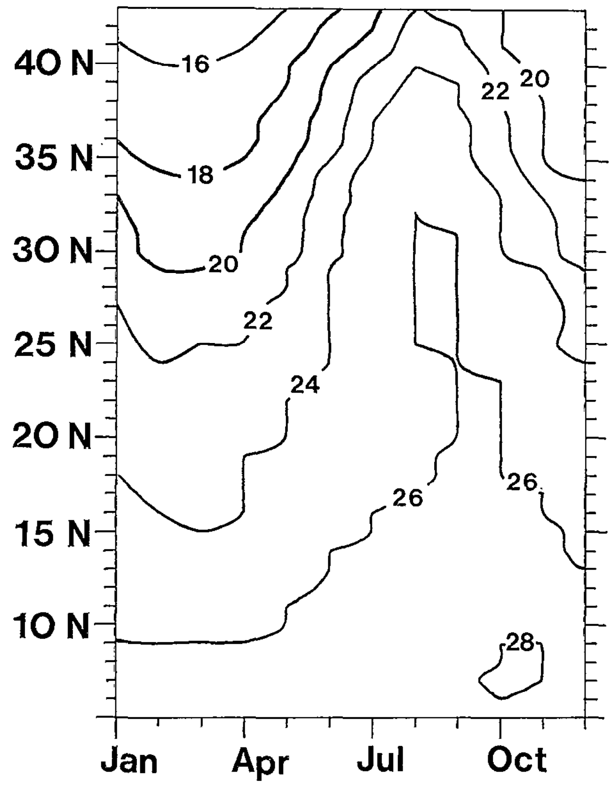

FIG. 2 b. — Monthly mean values of sea surface temperatures, in °C, of the Atlantic Ocean at about 40° W, taken from the "Monatskarten für den Nordatlantischen Ozean" (Deutsches Hydrographisches Institut, 1956).

Moyennes des températures de surface, en °C, de l'Océan Atlantique vers 40° W, extraites de "Monatskarten für den Nordatlantischen Ozean" (Deutsches Hydrographisches Institut, 1956).

temperature differences less than or equal to — 3 K were interpreted as upwelling. In accordance with WOOSTER *et al.* (1976) and with our previous papers four significantly different regions can be recognized from Fig. 3:

R 1: south of 20° N where upwelling exists during winter and spring;

R 2: between 20° N and 25° N upwelling can be found during the whole year, with strongest activity in late spring and summer and in fall;

R 3: north of 25° N upwelling prevails during summer and fall,

R 4: along the coast of Portugal north of 35° N up to 43° N, upwelling occurs during summer and fall with peaks during summer at nearly 37° N. North of 40° N the duration of upwelling decreases with increasing latitude.

To get an impression of the relationship between sea surface temperatures and winds, a selection of time series is shown in Fig. 4, which are representative for the different upwelling regions. In these diagrams the coastparallel wind component is approximated by the meridional wind component, since the coastline is orientated more or less in a north-south direction. Winds blowing from the north have a negative sign. It is obvious that south of 20° N, strong northerly winds are associated with upwelling. The annual cycle of winds as well as of temperature differences dominates the fluctuations on a shorter time-scale. This is in contrast to the features in the northern part of the area considered, where winds are much more variable (e.g. for Beja, 38° N) and seem to be related to fluctuations of temperatures

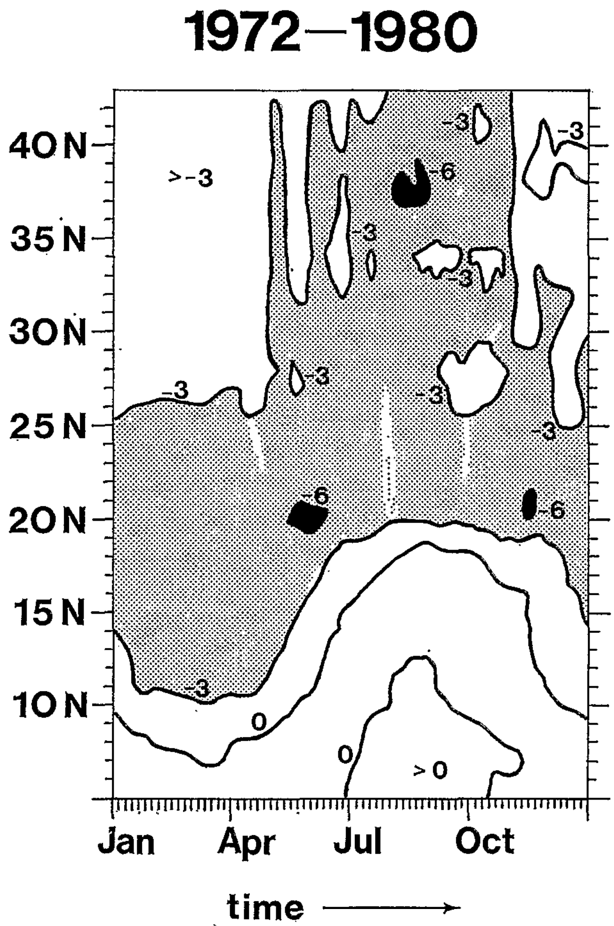

FIG. 3. — Mean sea surface temperature differences, between coastal areas and the central Atlantic Ocean in K, for the period 1972 until 1980. Values less than — 3 K are lightly hatchured and values less — 6 K are darkly hatchured.

Différences moyennes des températures de surface, en K, entre les eaux côtières et l'Océan Atlantique central, dans la période 1972 à 1980. En grisé les valeurs inférieures à — 3 K, en noir les valeurs inférieures à — 6 K.

on a shorter time scale. However between 20° N and 25° N winds blow from the north with high speeds during the whole year (e.g. for Nouadhibou, 21° N). Sea surface temperatures are on average 6 K lower than those of the mid-ocean.

Considering Fig. 4 it is suggested that a relationship between winds and upwelling exists, which is not uniform for the whole area considered. This will be investigated in the following section.

4. EMPIRICAL ORTHOGONAL FUNCTIONS OF WINDS AND SEA SURFACE TEMPERATURE

An efficient description of the relationship between winds and upwelling can be obtained by decomposing wind- and ΔSST-time series into Empirical Orthogonal Functions (EOF's) (1). Concerning these mathematical tools reference can be made to KUTZBACH (1967), DAVIS (1976), FECHNER (1978), SPETH and DETLEFSEN (1979) and DETLEFSEN and SPETH (1980); in the present work only a short review is given.

F is the M by N observation matrix whose nth column vector $\mathbf{f}_n$ contains altogether M observations of wind (v) and ΔSST ($M = M_V + M_T$; M_V: number of used wind stations, M_T: number of used observations cf SST). Looking for a vector **e** which resembles all the observation vectors **f** as well as possible one has to solve the equation:

$$\mathbf{R}\,\mathbf{e} = \mathbf{e}\,\lambda$$

where **R** is a M by M symmetric matrix, which describes all possible spatial covariance relationships within the period considered. In computing this matrix **R** variables of different physical units are linked together and so matrix elements have different and partly absurd dimensions. To overcome this, the variables are normalized, i.e. they have zero means and unit variances and the symmetric matrix **R** then becomes the correlation-matrix $\mathbf{R}^+$.

Results of solving the given equation are M eigenvectors **e**i (i = 1, ...M) with eigenvalues λi. **E** is a M by M matrix whose columns are the eigenvectors $\mathbf{e}_i$. One defines a M by N matrix **C** with $\mathbf{C} = \mathbf{E}'\,\mathbf{F}$; it is deducible that:

$$\mathbf{F} = \mathbf{E}\,\mathbf{C} \text{ or } \mathbf{f}_n = \sum_{i=1}^{M} c_{in}\,\mathbf{e}_i;$$

($\mathbf{E}'$ is the transposed matrix **E**). Usually it is assumed that the eigenvectors $\mathbf{e}_i$ and the eigenvalues λ_i are arranged such that $\mathbf{e}_1$ is associated with the largest eigenvalue λ_1, $\mathbf{e}_2$ with the next largest eigenvalue λ_2 and so forth. The eigenvectors $\mathbf{e}_i$, where i is the mode of the function, are orthogonal functions with respect to space only and describe the spatial coherence. Their coefficients c_{in} are orthogonal functions of time only and describe the temporal variation. In order to interpret the functions it should be known, that for each mode of EOF's, an opposite sign of wind and ΔSST denotes a negative correlation between the two variables, and a positive correlation is indicated by the same sign. The

(1) ΔSST stands for differences of sea surface temperatures as described in section 3.

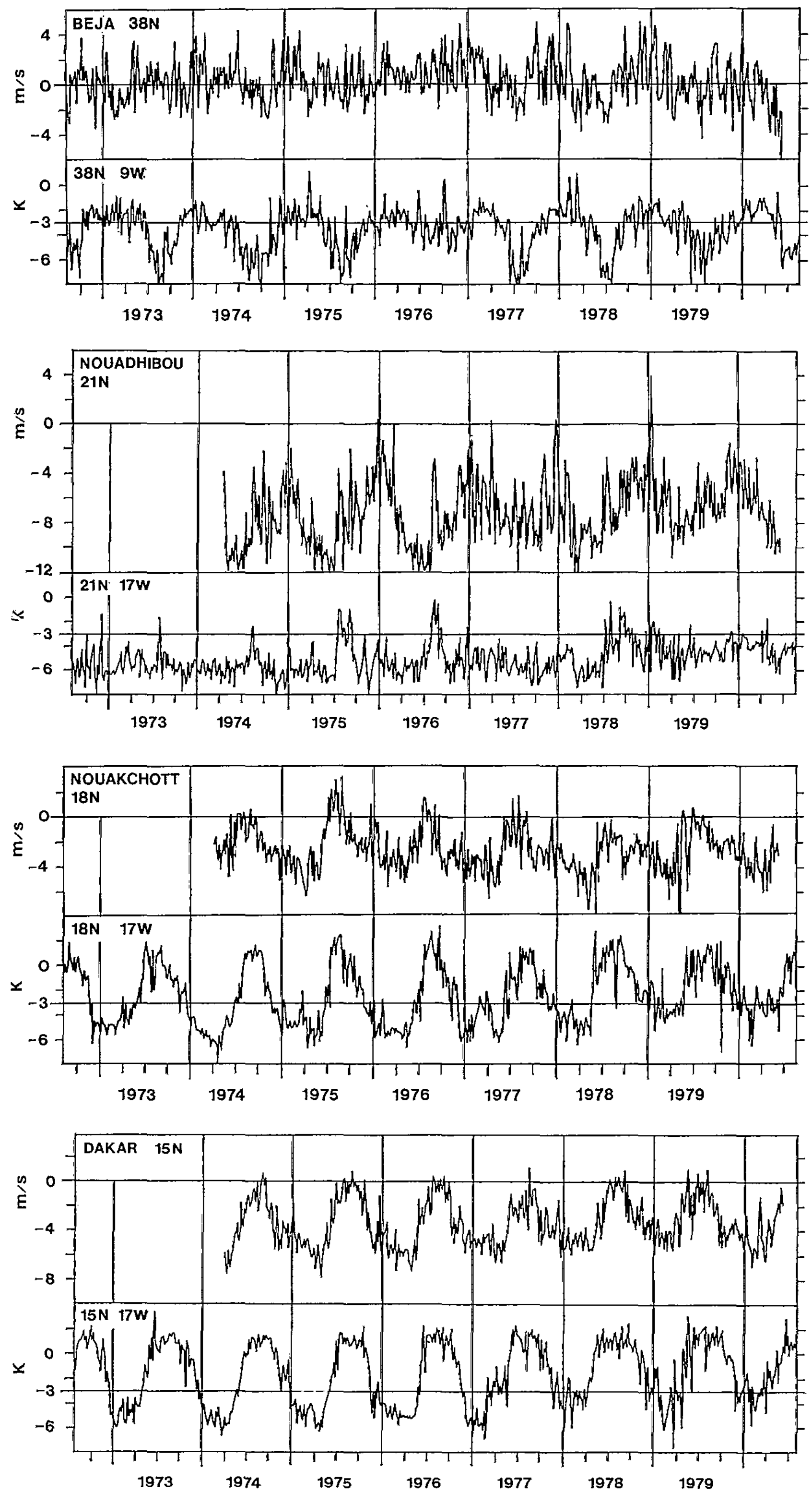

FIG. 4. — Time series of mean sea surface temperature differences and of meridional wind components. Temperature differences less than – 3 K are interpreted as upwelling. The abscissae are labeled for the months January, April, July and October.

Séries chronologiques des différences moyennes des températures de surface et des composantes méridionales des vents. Les différences de température inférieures à – 3 K sont interprétées comme des upwellings. En abcisse sont repérés les mois de janvier, avril, juillet et octobre.

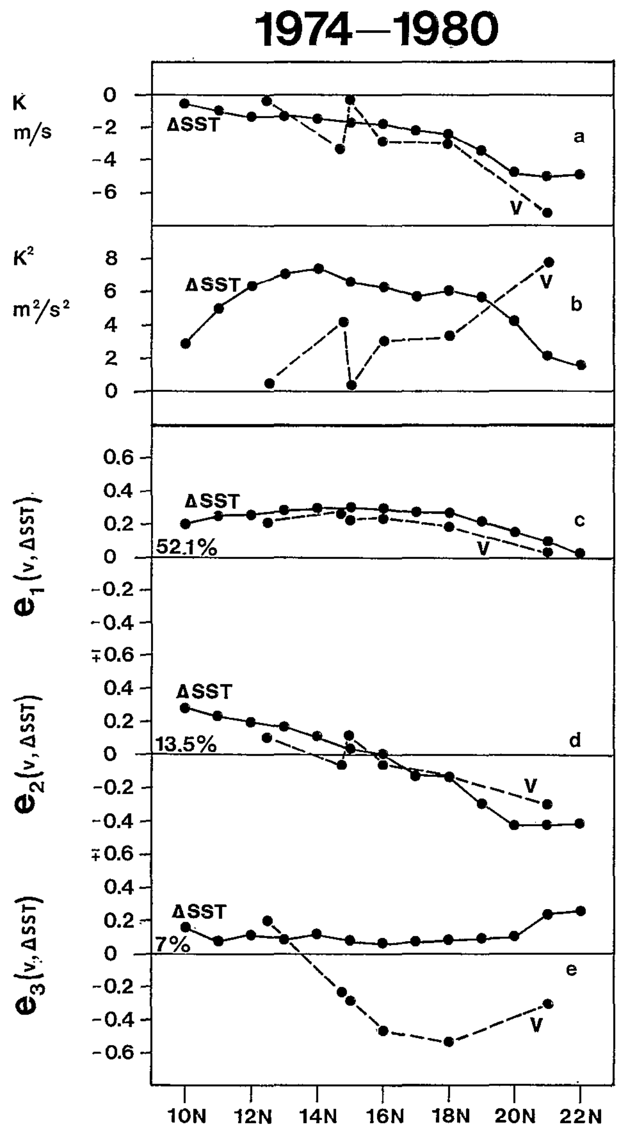

FIG. 5. — Analysis of the area between 10° N and 22° N for the period 1974 to 1980 (1). From top to bottom:
a: mean sea surface temperature differences ΔSST between coastal areas and mid-ocean in K. Mean winds v for coastal stations (Table I) in m/s. b: as top but for variances in m^2/s^2 and K^2 respectively. c: phase $\mathbf{e}_1$ of the first EOF, explaining 52 . 1 % of the total variance. d: phase $\mathbf{e}_2$ of the second EOF, explaining 13.5 % of the total variance. e: phase $\mathbf{e}_3$ of the third EOF, explaining 7 % of the total variance.

Analyse de la région comprise entre 10° N et 22° N pour la période 1974-1980 (1). De haut en bas :
a : différences moyennes des températures de surface, ΔSST, entre les régions côtières et la région centrale de l'Atlantique, en K. Vents moyens, v, aux stations côtières, en m/s (Tableau I) ; b : variances, respectivement en K^2 et m^2/s^2 des valeurs représentées en a ; c : $\mathbf{e}_1$ de la première EOF, expliquant 52,1 % de la variance totale ; d : $\mathbf{e}_2$ de la seconde EOF, expliquant 13,5 % de la variance totale ; e : $\mathbf{e}_3$ de la troisième EOF, expliquant 7 % de la variance totale.

absolute magnitude of the function values resembles a strong or weak correlation: large values stand for strong correlation, small values for weak correlation between the variables considered.

In the present paper we performed the EOF analysis with combined wind- and ΔSST-time series. Since we are mainly interested in a spatial relationship, the spatial functions and only two time coefficients are shown.

In the discussion of Fig. 4 it was suggested that the relationship between winds and upwelling is not uniform throughout the entire area. For that reason two separate EOF-analyses have been performed: one for the region south of 22° N and one for the region north of 36° N. Because of numerous data gaps in SST time series the region between 22° N and 36° N could not be considered. The first three EOF's are shown together with mean values and variances in Fig. 5 and Fig. 7. Each EOF resembles a percentage part of the total variances (Fig. 6b, 8b). Modes greater than three are not presented, since significance test (PREISENDORFER and BARNETT, 1977) indicated, that they have no physical content.

First the region south of 22° N is discussed (Fig. 5). For mean values (Fig. 5a) SST are low (small ΔSST) and winds (v) are strong from the north (small v) in the northern part, where north of 20° N steadily blowing trades and upwelling during the whole year are found (cf. Fig. 3 and Fig. 4).

With decreasing latitude mean values of ΔSST and v are increasing. Striking features for the two synoptic stations Linguère (15°23′ N) and Ziguinchor (12°33′ N) are weak northerly winds. The variance of the wind is a reflected image of the mean wind itself (Fig. 5b). The variance of ΔSST is large in the middle of the region, where the annual cycle of SST is large (cf. Fig. 2 and 3).

Fig. 5c shows that the first EOF $\mathbf{e}_1$ explains 52,1 % of the total variance, and identifies the principal mode of seasonal variation, as can be seen from the time dependent amplitudes (Fig. 6a). Winds and ΔSST are positively correlated for the entire area, i.e. one of the two following situations exists in 52,1 % of all cases:

(1) northerly winds ($v < 0$) are connected with upwelling ($\Delta SST < 0$);

(2) when southerly winds blow ($v > 0$) no upwelling occurs ($\Delta SST > 0$).

(1) SST time series of 15° N are available since April 1974. Therefore the period considered for all time series starts in 1974 (cf. Fig. 6).

(1) *Des séries chronologiques de températures de surface à 15° C ne sont disponibles qu'à partir d'avril 1974. En conséquence toutes les séries débutent en 1974 (cf. fig. 6).*

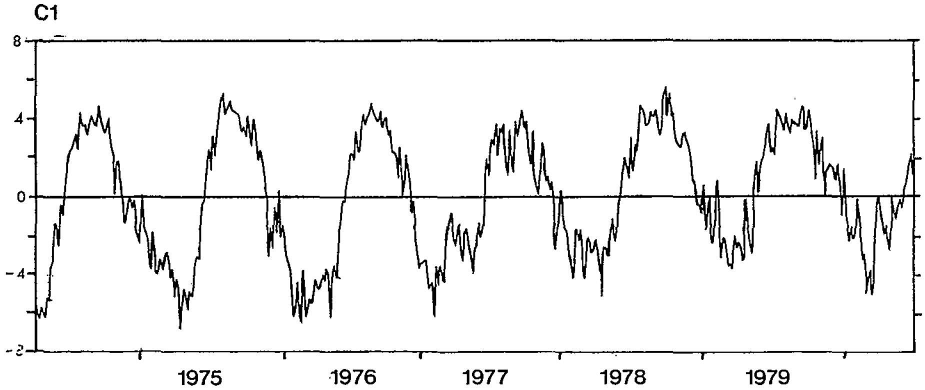

FIG. 6 a. — Time coefficient corresponding to the first EOF (cf. Fig. 5 c); the abscissa concists of 73 pentad values for each year.

Coefficient de temps correspondant à la première EOF (cf. fig. 5 c) ; en abcisse dans chaque année les 73 valeurs par 5 jours.

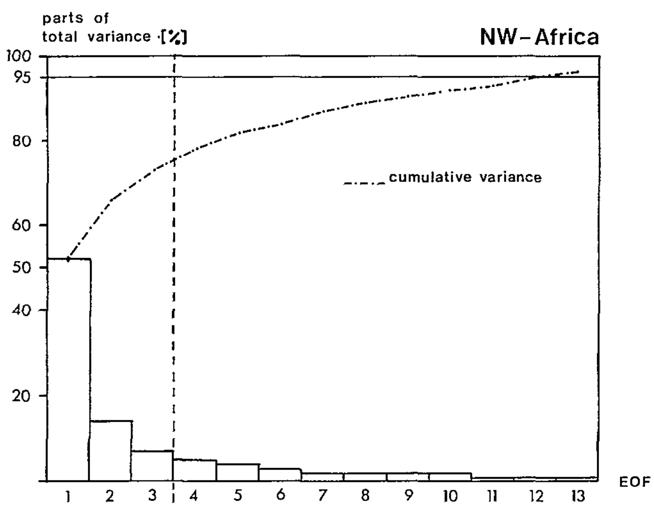

FIG. 6 b. — Histogram explaining the percentage part of each EOF to the total variance, for the analysis in the area between 10° N and 22° N. The first three EOF's (cf. Fig. 5 c-e) are significant.

Histogramme montrant la contribution de chaque EOF à la variance totale, dans l'analyse de la région entre 10° N et 22° N. Les trois premières EOF sont significatives (cf. fig. 5 c-e).

$\mathbf{e}_2$, explaining 13,5 % of the total variance (Fig. 5d), is dominated by a large indirect relationship between latitudes south and north of 16° N: if northerly winds are strong in the south ΔSST are low (upwelling); at the same time in the north southerly winds occur with high ΔSST. The opposite holds for southerly winds in the south. $\mathbf{e}_3$, explaining only 7 % of the total variance (Fig. 5c), characterizes SST changes north of 13° N in such a way that northerly winds are connected with high ΔSST, and vice versa for southerly winds. Hence by this mode a relationship between SST and winds is described which cannot be attributed to the classical wind-induced upwelling mechanism.

The discussion of Fig. 5 leads to the results that the first three EOF's are sufficient to explain 72,6 % of the total variance. In the EOF-analysis local winds and SST have been combined. Upwelling can be described by the first two EOF's with a cumulative variance of 65,6 %. In contrast it was shown in SPETH and DETLEFSEN (1979) that synoptic scale winds are related to SST to an essentially

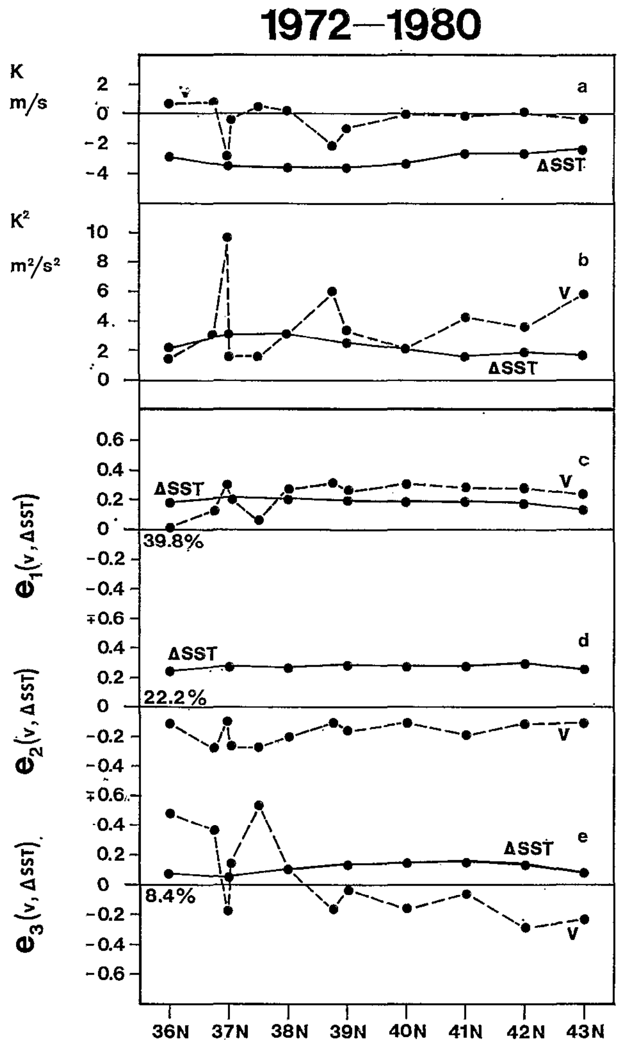

FIG. 7. — Analysis of the area between 36° N and 43° N for the period 1972 to 1980. Otherwise as Fig. 5. All time series are available since 1972 (cf. Fig. 5).

Analyse de la région comprise entre 36° N et 43° N pour la période 1972-1980. Même légende que pour la fig. 5, toutes les séries chronologiques débutent en 1972 (cf. fig. 5).

higher degree; the first three modes were able to explain 95 % and the first two modes 81 % of the total variance. On this account we conclude that for the area off Northwest Africa south of 22° N, synoptic scale winds are better able to describe upwelling than are local winds.

Fig. 7 shows the results for the region north of 36° N. Winds (v) are strongly variable in time north of 40° N, with mean values (Fig. 7a), that are nearly zero. In the southern part of this area off Portugal/Spain large differences in both space and time are to be found with especially strong northerly winds ($v < 0$) at Sagres (36°59′ N), Lisboa (38°47′ N) and Portalegre (39°17′ N). Therefore the variance of the wind (Fig 7b) shows high values along the entire coast of Portugal/Spain with maximum values at Sagres and Lisboa.

It is seen from Fig. 7c-7e that for the area off Portugal and Spain the first three EOF are sufficient to explain 70,4 % of the total variance. That is comparable to the area off Northwest Africa. In contrast however upwelling is now described only by the first EOF with 39,8 % of the variance. From the sign of the time dependent amplitude for that mode (Fig. 8a) it is inferred that in fall northerly winds ($v < 0$) are linked to upwelling ($\Delta SST < 0$), with an opposite association during spring. The principal mode of seasonal variation is described by the first EOF and its time dependent coefficient (Fig. 8a). The coefficient shows greater fluctuations in a shorter time scale, and the absolute amplitude is smaller compared with the amplitude of the time coefficient shown in Fig. 6a.

However the second EOF exhibits a relatively large part of the total variance (22 %) and describes that warm water along the entire coast occurs in connexion with northerly winds. Hence, in contrast to the relationship off Northwest Africa, the departure from the classical wind-induced upwelling mechanism is described by this mode. The same is the case for the third EOF for latitudes north of 38° N.

In DETLEFSEN and SPETH (1980) a combined EOF-analysis for the areas off Northwest Africa and Portugal was performed. Besides the ΔSST, differences of sea level pressure were used with the purpose of investigating the influence of the synoptic-scale wind. It was shown that the first three significant modes only described 57 % of the total variance, which means that only in 57 % of all considered cases a relationship between SST and synoptic-scale wind exists. The direct connexion between synoptic-scale wind and upwelling could also be identified by the first mode (28,3 %). Although in DETLEFSEN and SPETH (1980) the well correlated area off Northwest Africa was also taken into consideration in the combined analysis, it is evident that off Portugal/Spain the local wind is better suited to describe the association with SST as well as with upwelling than the synoptic-scale wind.

5. CONCLUSION

The main purpose of this paper is to describe the influence of local winds on coastal upwelling off Northwest Africa and Portugal/Spain with Empirical Orthogonal Functions. To identify upwelling regions,

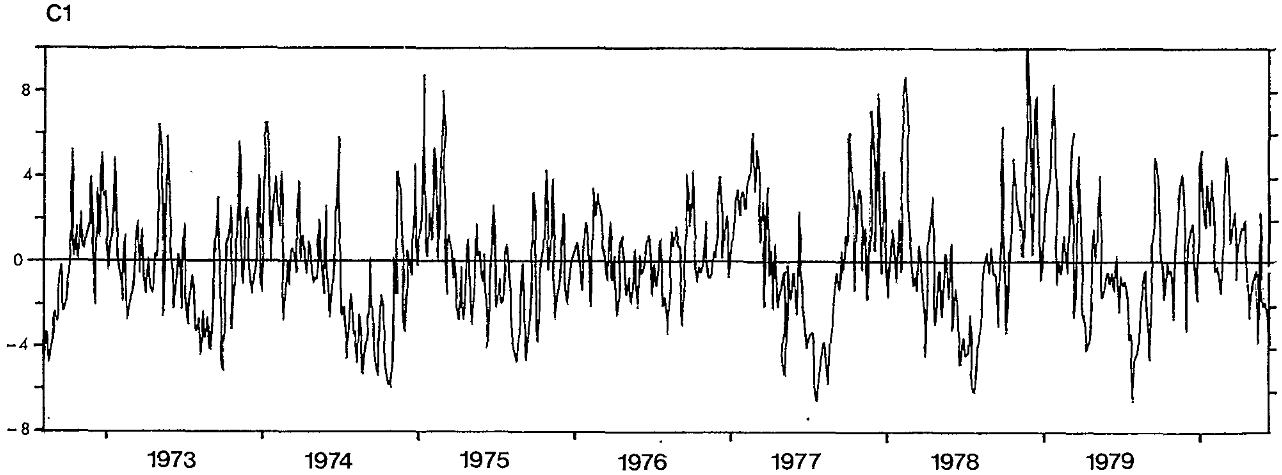

FIG. 8 a. - As Fig. 6a for the first EOF shown in Fig. 7c.
Même légende que fig. 6a pour la première EOF représentée sur la fig. 7c.

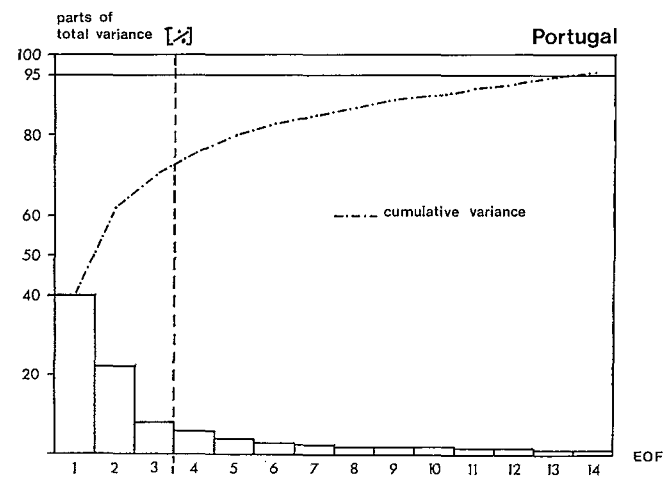

FIG. 8b. - As Fig. 6b for the analysis in the area between 36° N and 43° N.
Même légende que fig. 6b pour l'analyse de la région entre 36° N et 43° N.

differences of SST were constructed by subtracting mid-ocean temperatures from coastal averages. In good agreement with WOOSTER *et al.* (1976) and DETLEFSEN and SPETH (1980) four significantly different regions can be recognized as pointed out in section 3. Two separate EOF-analyses have been performed: one for the region south of 22° N, and one for the region north of 36° N off Portugal/Spain. For the region south of 22° N three modes are significant and describe 72,6 % of the total variance. Upwelling is described by the first two modes with a cumulative variance of 65,6 %. In contrast to SPETH and DETLEFSEN (1979) it is shown that for the area off Northwest Africa south of 22° N synoptic scale winds given by sea level pressure differences normal to the coast are able to describe upwelling to a higher percentage than local winds. For the region north of 36° N three modes are also significant and describe 70,4 % of the total variance.

The seasonal variation and the deviations from the annual cycle are described only by the first two modes with a cumulative variance of 62 %. The comparison with DETLEFSEN and SPETH (1980) verifies the suggestion that local winds off Portugal and Spain are better suited to describe the association with SST and upwelling than the large scale synoptic situation. In DETLEFSEN and SPETH (1980) it is shown that in 57 % of all cases a relationship between SST and synoptic scale wind exists. The direct connexion between wind and upwelling is identified by the first mode, which is like the annual cycle, in our analysis as in DETLEFSEN and SPETH (1980), but although the well correlated area off Northwest Africa was taken into account in the combined analysis in DETLEFSEN and SPETH (1980), it is evident that the first mode for local winds and SST yields a higher percentage than for synoptic-scale winds.

ACKNOWLEDGEMENT

The work was supported by the Deutsche Forschungsgemeinschaft within the scope of the main supporting programme "Phenomena of upwelling in the sea". We are very much indebted to P. B. GILDERSLEEVES and J. H. MINHINICK from the Meteorological Office, Bracknell/England, for arranging the sea surface data set on magnetic tapes. We further wish to express our gratitude to the Deutscher Wetterdienst, Offenbach/Main, for data of synoptic wind measurements at coastal stations of Northwest Africa and Portugal/Sapin.

Manuscrit reçu au Service des Éditions de l'O.R.S.T.O.M. le 7 décembre 1982

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