Journal of Coastal Research	7	3	665–676	Fort Lauderdale, Florida	Summer 1991

Characteristics of Waves off the Mediterranean Coast of Egypt

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ABSTRACT

NAFAA, M. G., FANOS, A. M., and ELGANAINY, M. A. 1990. Characteristics of Waves off the Mediterranean Coast of Egypt. *Journal of Coastal Research*, 7(3), 665–676. Fort Lauderdale (Florida). ISSN 0749-0208.

Analyses of all available wave records at Abu Quir, Egypt, collected between 1971 and 1987, are presented. Data for a 17 month period were recorded by the Offshore Pressure Operated Suspended wave recorder (OSPOS), and about 20 months of data were collected with the Cassette Acquisition System directional wave recorder (CAS). Severe wave conditions which might occur over a long period of time are given. It was found from this study, that the maximum wave height reaches about 4.00 m in winter, 3.50 m in spring, and 2.50 m in summer. The corresponding wave periods in these seasons are 14 sec. for winter, and 13 sec. for the other two seasons. The prevailing wave direction is from the WNW-NW sector, while a small amount of waves arrive from the NNE-NE sector. The average significant wave height is 0.50–1.00 m, and the average wave period is 7–8 sec. Percentage of occurrence of waves coming from different directions is also presented, which will be useful in the estimation of the net sediment transport at Abu Quir.

ADDITIONAL INDEX WORDS: *Beach erosion, delta coast, sediment transport, storms, wave climate, wave conditions, waves.*

INTRODUCTION

Waves are the principal driving force for the transport of sediments on most coasts, and hence the chief agent in beach erosion. Research has shown that reasonable estimates of the longshore and cross-shore transport rates of sand can be obtained from a knowledge of the wave characteristics, the wave height, period, and directions of approach relative to the shoreline (BIJKER, 1968; KOMAR and INMAN, 1970; and CERC, 1984).

Extreme erosion has been taking place along the Nile River delta, and accelerated significantly after completions of the Aswan High Dam in 1964 (ORLOVA and ZENKOWITCH, 1974; SHARAF EL DIN, 1974; SMITH and ABDEL-KADER, 1988; and FRIHY, 1988). Construction of the Aswan High Dam has reduced the load from more than 120 million tons per year to a negligible volume at present. With the loss of river sediment, beach erosion has been greatest adjacent to the river mouths, the promontories of the Rosetta and Damietta branches of the Nile.

Critical to an understanding of the erosion patterns along the Nile Delta shores, and for the design of engineering defense structures, is a knowledge of the wave climate in the eastern Mediterranean Sea. However, only limited wave data have been collected for this region prior to the present study. MANOHAR et al. (1974, 1976) collected some wave measurements during 1972-73 for the Burullus area, mid-way along the delta, and CARMEL et al. (1985) reported on waves measured on the coast of Israel generated by specific storms.

To obtain a better understanding of the wave climate along the coast of the Nile Delta, a wave-measurement program was initiated in 1971 and has continued to the present. The present paper reports on this data acquisition program, and specifically on the wave climate measured between 1971 and 1987 at Abu Quir Bay (Figure 1). During this period, 37 months of wave records have been obtained. The data are used to examine the waves generated by

90002 received 3 July; accepted in revision 26 November 1990.

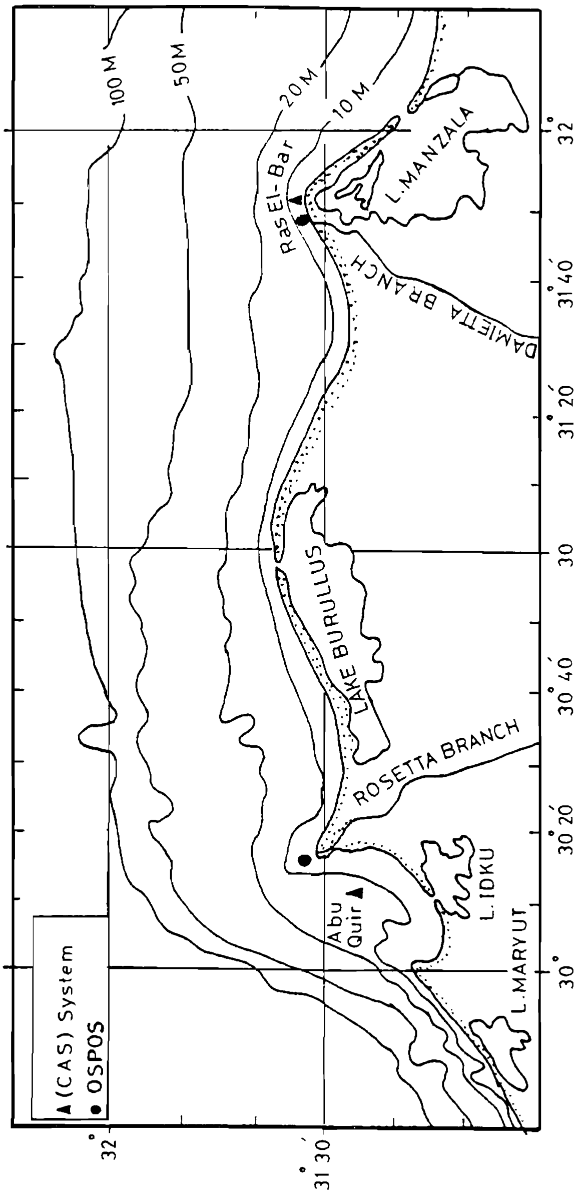

Figure 1. Location of OSPOS and CAS systems at Abu-Quir and Ras El-Bar.

individual storms, and to define long-term wave statistics for the delta coast.

DATA COLLECTION AND ANALYSES

Wave data from 1971 to 1977 were collected by the Offshore Pressure Operated Suspended (OSPOS) wave recorder (Figure 2a). A detailed description of the instrument is given by RAHAL (1977). It consists of a pressure meter, which when placed at a certain depth under the water surface, measures and records the variations in pressure caused by the waves. These pressure variations are converted into an almost

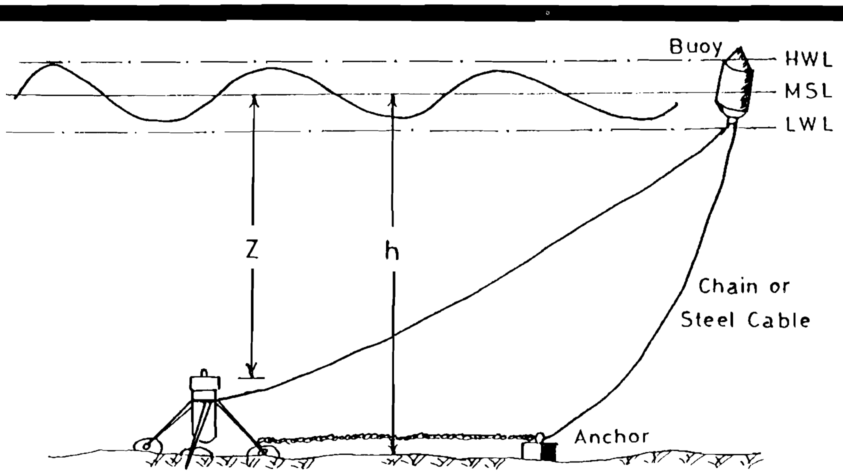

Figure 2a. Arrangement of OSPOS Wave Recorder system.

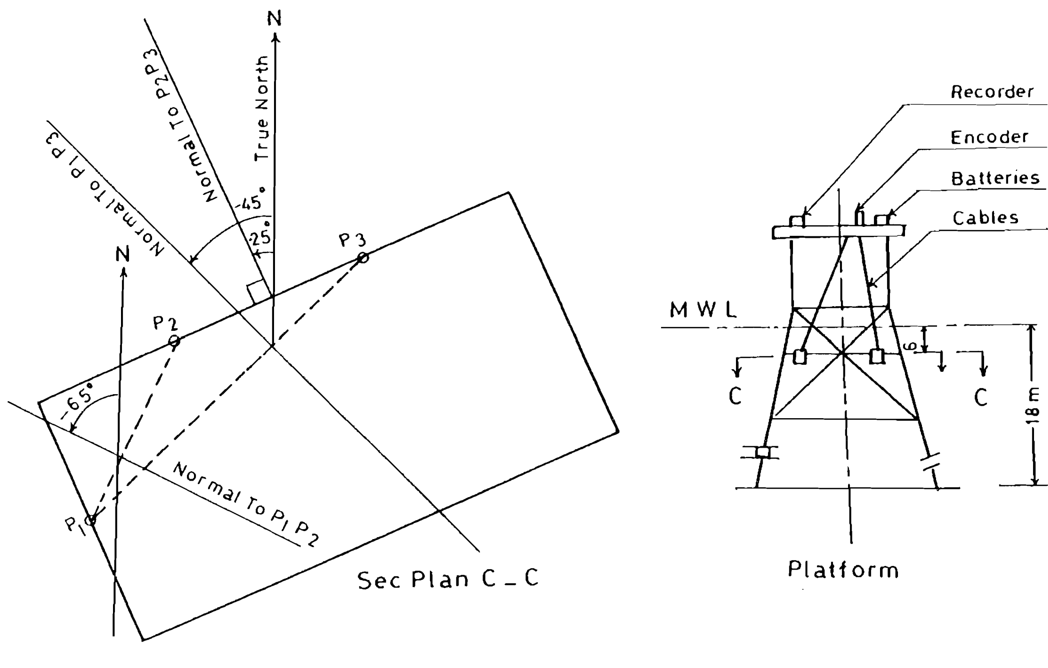

Figure 2b. Arrangement of CAS Wave Directional system.

straight horizontal displacement of the recording pen. A continuous wave record was obtained for 20 minutes each 6 hours.

The Tucker-Draper method [TUCKER (1963) and DRAPER (1966)] is used to calculate the significant wave height H_s. According to this method the value of H_s is determined from the relation:

$$H_s = 4\sqrt{m_o} \quad (1)$$

where m_0 is the zero moment or area of the energy density spectrum which can be determined from a special graph given by TUCKER (1963) as a function of N_z, H_1, and/or H_2, where:

- N_z = the number of times the record moving in an upward direction crosses the zero line;
- H_1 = A + C; H_2 = B + D;
- A = the height of the highest crest;
- B = the height of the second highest crest;
- C = the depth of the lowest trough;
- D = the depth of the second lowest trough.

The estimates of H_s based upon H_1 are generally higher than those calculated as the average of the one-third of the highest waves in the record, while those based upon H_2 are relatively good RAHAL (1977). In the present study, all values of m_o are calculated using H_2 values. The zero crossing period is calculated by dividing the time needed for the whole record (20 minutes) by N_z; *i.e.*, $T_z = 20 \times 60 / N_z$; in seconds.

Since the records represent wave pressures near the sea bed, corrections are applied to obtain surface wave heights. The normally accepted pressure response factor is that given by small amplitude theory. Therefore the calculated values of H_s from Equation (1) are multiplied by a corresponding correction factor, $K_p^{\ -1}$, where:

$$K_p = \frac{\cosh\left(2\pi \frac{h - z}{L}\right)}{\cosh\left(2\pi \frac{h}{L}\right)} \qquad (2)$$

in which:

- h = the water depth (about 7 meters);
- z = the depth measured from the mean water surface to the pressure sensor; and
- L = the wave length associated with the zero crossing period.

Due to the difficulties faced in the installation of the OSPOS, the tedious job of its record analysis, and the assumption that the wave direction is the same as the wind, it was decided in 1981 to install the Cassette Acquisition System (CAS). Two stations for the measurement of wave energy and direction were installed off the Nile Delta at Abu Quir and Rasel Bar (Figure 1). The system is a portable, self-contained remote recording system for sensing nearshore environmental parameters such as wave energy, wave direction, and currents (BOYD *et al.*, 1985). Each station consists of four basic units, plus cables for interconnections. These units are a recorder unit, an acquisition unit, a power unit, and a sensors array (see Figure 2b for the Abu Quir system). The sensor array incorporates three wave pressure sensors. The pressure sensors are situated about 18 km from the shore at 6 m below mean water level and 11.5 m above the sea bed. They are spaced 7 m apart in a triangular array. The wave data are recorded 4 times per day, every 6 hours, for 34 minutes each record. The data are recorded on cassettes and analyzed by the use of the computer, which gives the significant wave height, wave period, and wave direction.

The wave data are subjected to a pre-processing treatment designed to detect areas of invalid data, based on expected maximum and minimum recorded values for each time series, maximum excursion from the mean and expected slew rates. Once the magnitude and slew rate checks have been applied, a linear quadratic interpolation is applied across the set of spurious values detected. The processed time series resulting from the above treatment is used as input for analysis programs.

Each 34 minute pressure time-series is Fourier transformed. The Fourier coefficients of sea surface elevation are obtained by applying the frequency dependent depth correction given by linear wave theory, $K_p^{\ -1}$ (calculated from Eq. 2). The total variance $<\eta^2>$ of the sea surface displacement η is obtained for each pressure sensor by summing the variance in the frequency range 0.05 – 0.35 hz. The mean variance of the three pressure sensors is also calculated. The high frequency cut-off was established at wave frequency 0.35 hz. The agreement between the frequency spectra S(f) for the different sensors is generally very good as shown in Figure 3.

Each wave event is characterized by three parameters obtained from the wave frequency spectra and their phase difference:

(1) The significant wave height H_s is obtained from the mean of the variance of the three pressure sensors.

(2) The wave period is obtained at the frequency band containing the maximum energy density in the frequency spectrum.

(3) The mean direction, $\alpha\ (f_i)$, for frequency band i, is calculated from the phase difference

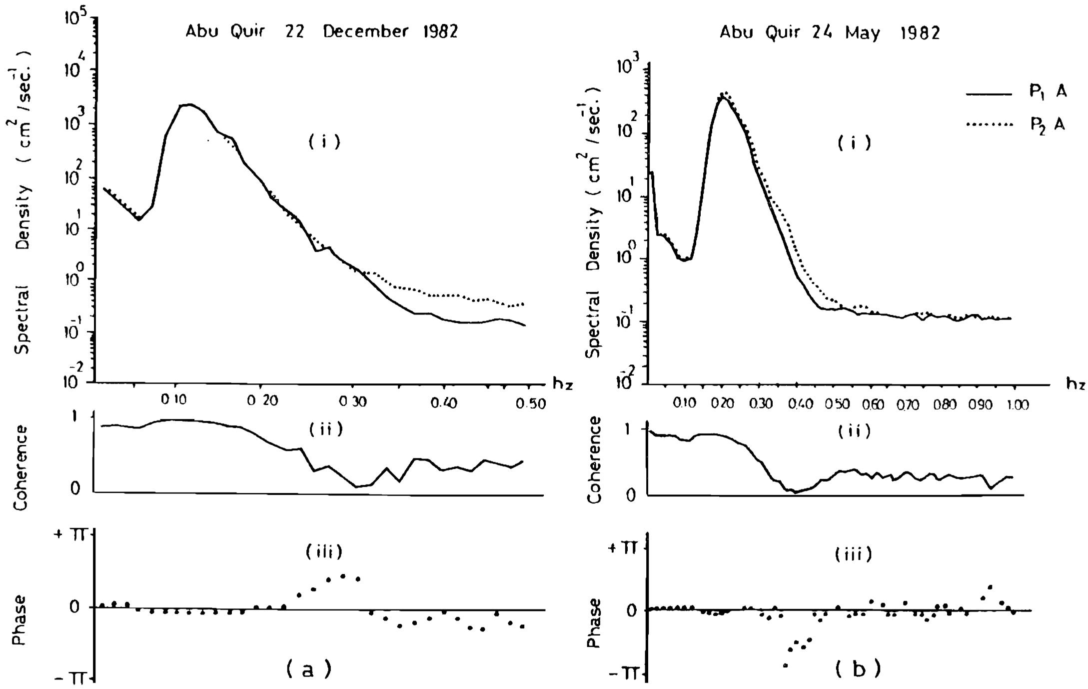

Figure 3. Frequency spectra for two pressure sensors P1A, P2A (i), Coherence (ii), and Phase Difference (iii).

Φ_i between the signals of two sensors expressed in radians by:

$$\alpha (f_i) = \sin^{-1} (\Phi_i \frac{L_i}{2\pi l}) \quad (3)$$

where $L_i = 2\pi / K_i$ is the wave length for a wave frequency f_i;
$K = (2\pi f)^2/g \tanh Kh$ is the wave number of frequency f;
g = the gravitational acceleration;
l = the distance between the sensors; and
α = the angle of the wave approach relative to the normal to a line separating the sensors.

The phase difference of the wave signals of the two sensors as a function of frequency is obtained from the cross-spectrum analysis. It is related to the real and imaginary parts of the cross spectrum by $\Phi = \tan^{-1} (\Theta_{12} / C_{12})$, in which Θ_{12} is the quadrature part and C_{12} is the co-spectrum.

The present study is concerned only with the wave data at Abu Quir. Different wave windows occurring on the Mediterranean coast of Egypt are present in Figure 4. The greatest fetch for all wave windows is approximately 1300 km.

The measured wave data are grouped according to the seasons. Three seasons with respect to atmospheric circulation patterns have been distinguished by HAMED (1983), which are winter, spring, and summer. Table 1 shows the available wave data for those three seasons.

During the winter season which occurs from November to March, the Azores anticyclone often extends over the Libyan Desert, and North Atlantic depression may enter the Eastern Mediterranean area and bring in masses of cold Arctic air. This cold air, meeting the warm and moist air of the Mediterranean area, produces vertical instability which often leads to moving atmospheric perturbations associated with meteorological fronts. The travelling depressions when associated with ridges of high pressure over the north-western Libyan Desert, generate high waves in the Eastern Mediterranean causing damage on the northern Egyptian coast. Spring season extends from April to May, causing strong winds associated with sand storms due to the desert depression. The sum-

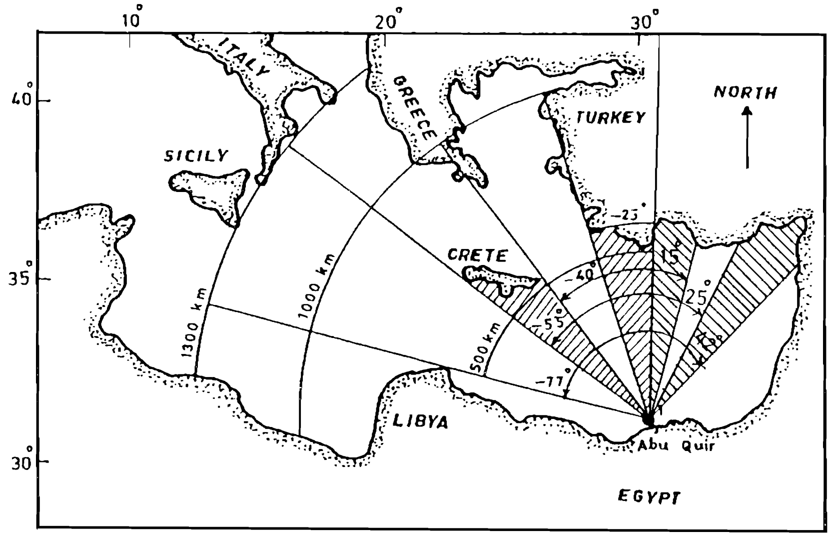

Figure 4. The various wave windows at Abu-Quir, Egypt.

Table 1. *Number of wave recordings available in different seasons.*

Season	Year / Month	* 1971	* 72	* 73	* 74	* 76	* 77	** 81	** 82	** 85	** 86	** 87
Winter	Nov.	19		22	29			89		118	95	
	Dec.	33		9	40					112		
	Jan.						33				90	
	Feb.						22				76	
	Mar				39						38	45
Spring	Apr		29		30						120	107
	May		15		76				56		88	
Summer	June				6	24					108	
	July					13			66		107	
	Aug.								13	71	118	
	Sept.	35								76	118	

*wave data collected by Ospos for a period of 17 months.
**wave data collected by CAS system for a period of 20 months.
***October is a transition month.

mer season covers the period from June to September. This period is free from moving depressions with high winds. Sea swells are due to north to northwest winds. October (or part of it) represents a transition month of relatively calm seas.

RESULTS AND DISCUSSIONS

The wave action along the coast is seasonal in nature. During the winter season there are generally about 15 storms which cause severe erosion to the coast. Table 2 shows the approximate time of occurrence of the conventional storms along the Egyptian coast. For the three seasons, scatter diagrams for the wave height with the associated wave period have been proposed. Histograms for wave height and period for the three seasons are presented in figures 5 and 6. It is seen that the average wave height is concentrated between 0.50–1.00 m for all seasons. The maximum wave height is 4.00 m

Table 2. *The approximate time of occurrence of the conventional storms along the Egyptian coast.*

Date		Storm name	Direction	Duration (Days)	Remarks
1	October	Saliba wind	W	3	—
21	October	Saliba wind	W	3	—
17	November	Maknasa	NW	4	heavy rain
5	December	Kasem	SW	5	stormy
20	December	Elfeda elsogra	NW	5	rainy
29	December	Christmas	W	2	heavy rain
2	January	New Year	W	4	rainy
12	January	Elfeda elkobra	SW	6	heavy rain
19	January	Elkotas	W	3	rainy
28	January	Elkaram	W	7	heavy rain
18	February	Elshams elsogra	NW	3	rainy
1	March	Elsaloum	SW	2	rainy
10	March	Elhosoum	SW	7	usually rainy
19	March	Elshams elkobra	E	2	—
24	March	Awwa	E	6	—

in winter, 3.50 m in spring, and 2.50 m during summer. The average wave period is between 7-8 sec. for all seasons, reaching 14 sec. maximum in winter and 13 sec. in spring and summer.

The cumulative distributions of wave heights and wave period for various wave height ranges are calculated. Table 3 presents the results of these calculations.

Year 1986 has been chosen to calculate the wave rose diagrams through the different seasons, as it represents the most complete directional wave measurements. Figure 7 shows the monthly and yearly changes in wave directions. Table 4 summarizes the results.

ESTIMATION OF SEA SEVERITY

Estimation of extreme waves is necessary to evaluate the structural failure which takes place when wave forces exceed the value critical for the structure's strength. The prediction of extreme wave heights has been discussed by BORGMAN (1970 and 1973), DATTATRI (1973), ST. DENIS (1975), LIU and MA (1980); and OCHI and WHALEN (1980). In the present paper sea severity is obtained from statistical data of significant wave height with the associated wave period.

The peak period of wave spectrum is used instead of the zero-crossing period. The scatter diagram of the wave height and period for all the available data is used. The number of observations is 2,382 during the whole period. The cumulative distribution function of wave height is plotted on Weibull distribution (NORDENSTROM, 1969; HOUMB and OVERVIK, 1977). Precise representation of the data is to express the cumulative distribution function as a combination of an exponential and a power of wave height;

$$F(x) = 1-e^{-[\lambda(X-a)]^c} \quad (4)$$

The parameters λ, a, and c are determined numerically by a nonlinear least squares fitting procedure. The cumulative distribution function obtained by using these values is plotted on log-normal probability paper. The extreme wave height which might occur after 50 years is then obtained as 5.5, 3.2, and 2.8 m during the winter, spring, and summer, respectively.

In order to estimate the average period associated with extreme significant wave heights, the conditional cumulative distribution of the

Table 3. *Percentage of occurrence of wave height and period.*

	Winter		Spring		Summer	
% of occurrence	Height m.	Period sec.	Height m.	Period sec.	Height m.	Period sec.
20	1.20	7.80	0.95	7.00	1.10	6.60
50	0.55	6.40	0.45	6.00	0.60	5.80
80	0.25	4.00	0.25	4.00	0.30	4.20

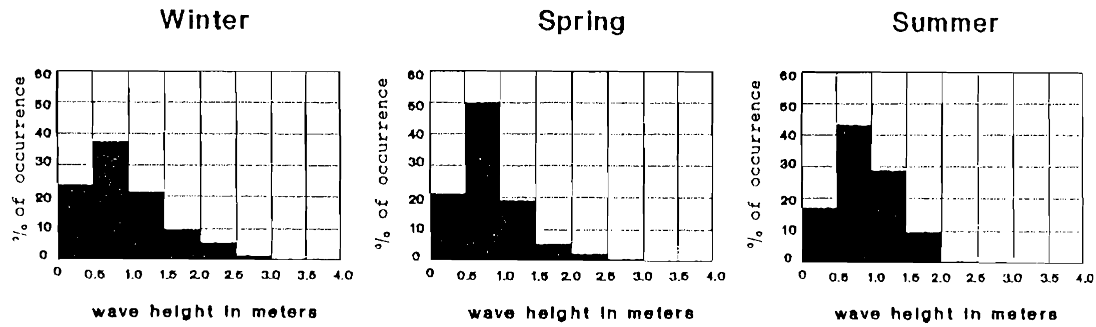

Figure 5. Histograms of wave height during the different seasons at Abu-Quir (1971–1987).

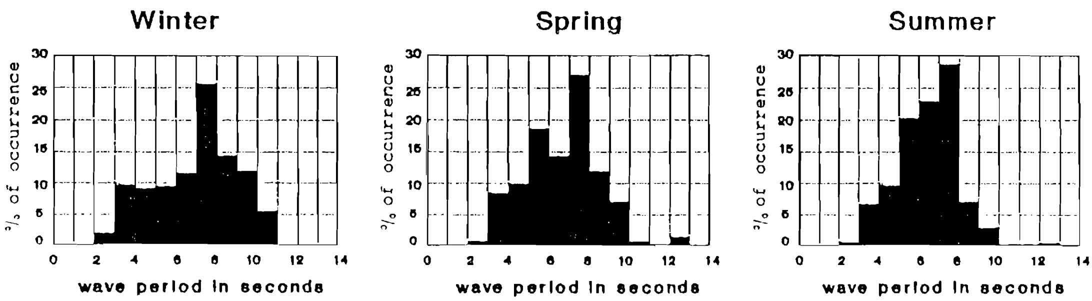

Figure 6. Histograms of wave period during the different seasons at Abu-Quir (1971–1987).

average period for a given significant wave height is calculated and plotted on log-normal probability paper. The mean values of log-normal distribution can be obtained by:

$$\text{Mean value} = \exp\left(\mu + \frac{\delta^2}{2}\right) \quad (5)$$

where μ is the mean of zero–crossing period.
δ^2 is the variance of zero–crossing period.

The two parameters of the distribution μ and δ correspond to the extreme wave height are evaluated using all available wave measurements. The wave period which might occur after a return period of 50 years is 8, 9, and 12 sec. during summer, spring, and winter respectively.

The JONSWAP spectral formulation is representative of wind-generated seas with a fetch limitation (HASSELMAN *et al.*, 1973). The JONSWAP spectral formulation is obtained for the different seasons using the previous result (Figure 8). It is shown that the most severe sea condition is during the winter season when high waves often occurred. Comparison between JONSWAP spectral formulation and the measured spectrum at Abu Quir shows good agreement.

In designing marine systems, the expected extreme wave height is required. Frequency curves were plotted between the wave height and recurrence interval, (Figure 9).

SUMMARY

The wave climate study off Abu Quir, Egypt, has provided some insight with obtaining the wave characteristics from directional spectra in shallow water. A summary of the findings from this study is presented below:

(1) The average wave height is concentrated between 0.50–1.00 m for winter, spring, and summer seasons.

(2) The wave climates of the winter and

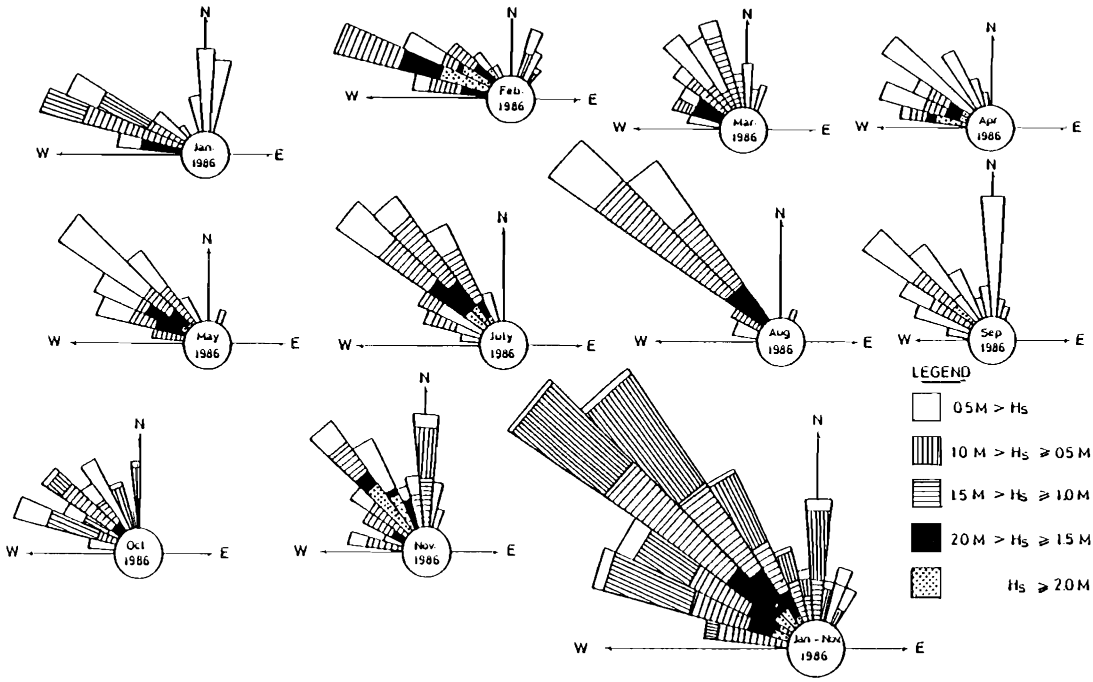

Figure 7. Monthly and yearly wave roses at Abu-Quir.

Table 4. *Change in wave direction through different seasons.*

Season	Month	Average wave height m	Peak Direction
Spring	April	1.00–1.50	50 W of N
	May	1.00–1.50	50 W of N
Summer	June	—	—
	July	1.00–1.50	50 W of N
	August	1.00–1.50	50 W of N
	September	1.00–1.50	50 W of N
Winter	November	1.00–1.50	40 W of N
	December	—	—
	January	0.50–1.00	70 W of N
	February	1.00–1.50	70 W of N
	March	1.00–1.50	20 W of N

spring seasons are much more severe than the summer season.

(3) The maximum wave height is 4.00 m in winter, 3.50 m in spring, and 2.50 m during summer.

(4) The average wave period is between 7–8 sec. for all seasons reaching 14 sec. as maximum in winter and 13 sec. in spring and summer.

(5) The predominant direction of the waves is WNW-NW, while a small amount of waves are coming from the NNE-NE sector.

(6) The energy supplied by severe winter storms contributes significantly to the total energy budget for a year.

(7) The most severe wave height which might occur during 50 years is obtained as 5.5, 3.2, and 2.8 m for winter, spring, and summer, respectively.

(8) The wave periods associated with extreme 50 year wave heights are 8, 9, and 12 sec. during summer, spring, and winter, respectively.

(9) The wave statistics along the Mediterranean coast of Egypt, will be used to study the delta erosion problem. Development of wave refraction analyses, a computer model for predicting sediment transport, and the associated shoreline change are continuing.

ACKNOWLEDGMENTS

This research was supported by the Agency for International Development, as part of a joint U.S.–Egypt Co–operative study on

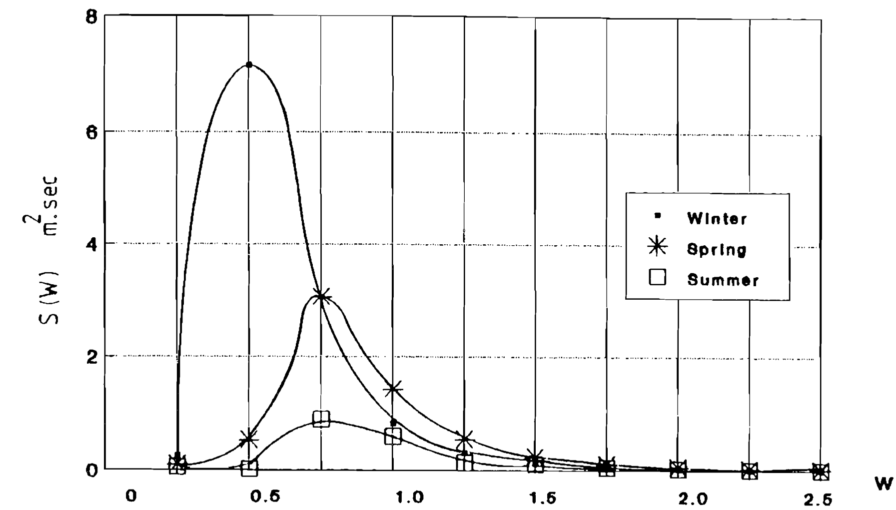

Figure 8. Wave spectrum during the different seasons at Abu-Quir.

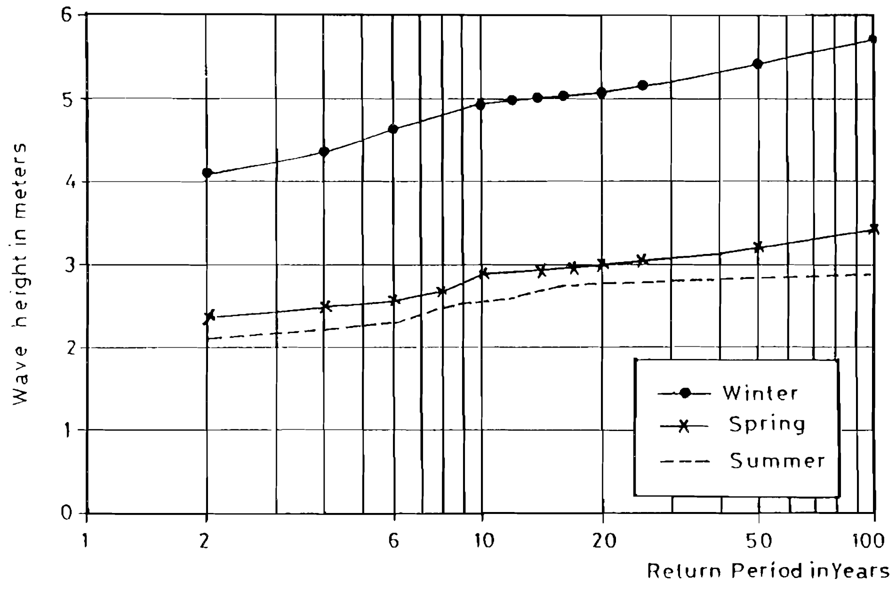

Figure 9. Return periods of storm waves computed from measured at Abu-Quir during the period from 1971 through 1986.

"Coastal Management and Shore Processes in the Southeast Mediterranean."

The writers wish to thank Prof. Dr. P. D. KOMAR and Prof. Dr. R. G. DEAN for reviewing this paper during their visits to Egypt in October 1989 and March 1990, respectively.

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APPENDIX I. NOTATION

The following symbols are used in this paper:

a	= parameter
c	= parameter
C_{12}	= co-spectrum
F	= cumulative distribution function
f	= frequency
H	= wave height
H_s	= significant wave height
L	= wave length
l	= distance between the sensors
S(f)	= frequency spectra
α	= angle of the wave approach relative to the normal to a line separating the sensors
δ^2	= variance of zero–crossing period
η	= sea surface displacement
λ	= parameter
μ	= mean of zero-crossing period
Φ	= phase difference
Θ_{12}	= quad-spectrum

Subscript

i	= frequency band

□ RÉSUMÉ □

On présente l'analyse de tous les enregistrements de houle recueillis entre 1971 et 1987. Les données ont été enregistrées par houlographe suspendu à pression OPOS durant 17 mois et par houlographe à cassette d'acquisition directionnelle CAS pendant près de 20 mois. On donne les conditions extrêmes de houle qui peuvent intervenir durant un long laps de temps. Il découle de cette étude que la hauteur maximale de la houle atteint 4,00 m l'hiver, 3,50m au printemps, et 2,50m l'été. Les périodes correspondantes sont 14 s l'hiver, et 13 s pour les autres saisons. La direction dominante de la houle est de secteur WNW-NW, et pour une petite fraction de secteur NNE-NE. La hauteur significative moyenne est de 0,50m-1,00M, et la période moyenne de 7-8 s. On pésente aussi le pourcentage des houles provenant d'autres directions, ce qui peut aider à l'estimation du bilan sédimentaire à Abu Quir.—*Catherine Bousquet-Bressolier, Géomorphologie EPHE, Montrouge, France.*

□ RESUMEN □

En este artículo se presenta el análisis del total de información disponible del oleaje en Abu Quir, Egipto, recogida entre 1971 y 1987. Los Datos de 17 meses provienen del recogedor de datos Offshore Pressure Operated Suspended (OSPOS), otros 20 meses de datos proceden del Cassette Acquisition System (CAS), de carácter direccional. Se muestra las condiciones severas de oleaje que pueden producirse en largos períodos de tiempo. Del estudio se obtiene que la máxima altura de ola alcanza los 4.00 metros en invierno, 3.50 m en primavera y 2.50 m en verano. Lo períodos correspondientes a estas mismas estaciones son 14 seg en invierno y 13 seg en las otras estaciones. La dirección prevaleciente del oleaje es del sector WnW-NW, mientras que muy pocas olas Ilegan del NNE-NE. La altura de ola significante media oscila entre 0.50 y 1.00 m y el período medio varía entre 7 y 8 segundos. El porcentaje de ocurrencia de las direcciones de incidencia del oleaje también se presenta, que puede ser útil para la estimación del transporte neto de sedimento en Abu Quir.—*Department of Water Sciences, University of Cantabria, Santander, Spain.*

□ ZUSAMMENFASSUNG □

Die Analyse aller verfügbaren Aufzeichnungen von Wellen bei abu Quir, Ägypten, die zwischen 1971 und 1987 gemacht wurden, wird vorgestellt. Die Messungen wurden für einen Zeitraum von 17 Monaten mit dem OSPOS-Wellenschreiber (OffShore Pressure Operated Suspended wave recorder) und für etwa 20 Monate mit dem CAS-Wellenschreiber (Cassette Acquisition System directional wave recorder) durchgeführt. Außergewöhnliche Wellenbedingungen, die in einem langen Meßzeitraum auftreten können, werden beschrieben. In dieser Studie stellte sich heraus, daß die maximale Wellenhöhe im Winter etwa 4,00 m, im Frühling 3,50 m und im Sommer 2,50 m erreicht. Die zugehörigen Wellenperioden sind 14 sec im Winter und 13 sec für die beiden anderen Jahreszeiten. Die vorherrschende Wellenrichtung liegt im WNW-NW-Sektor, ein kleinerer Anteil von Wellen kommt aus dem NNE-NE-Sektor. Die durchschnittliche signifikante Wellenhöhe beträgt 0,50-1,00 m, die durchschnittliche Wellenperiode 7-8 sec. Der Prozentsatz, mit dem die Wellen aus den verschiedenen Richtungen kommen, wird ebenfalls vorgestellt. Das dürfte für die Abschätzung des Nettosedimenttransportes bei Abu Quir nützlich sein.—*Helmut Brückner, Geographisches Institut, Universität Düsseldorf, F.R.G.*