Water level variations in the Northern Levantine Sea

Sea levels oscillations
Tidal variations
Power spectra
Levantine
Mediterranean

Niveau de la mer
Cycles de marée
Spectre de fréquences
Mer Levantine
Méditerranée

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ABSTRACT

Characteristics of water level variations in the northern Levantine Sea have been investigated by reference to a sequence of hourly water level observations at Antalya and Iskenderun.

Long and short period oscillations of non-tidal origin have been identified. Long-period oscillations (several days) correspond to variations in barometric pressure; the short-period oscillations (2.8 to 4.6 hours) can be attributed to seiche-like motions.

The tidal oscillations are small in amplitude, with a spring range of 21 and 41 cm in Antalya and Iskenderun respectively. Tidal oscillations are dominated by semi-diurnal constituents.

The seasonal fluctuations of monthly mean sea level show two maxima and two minima; the major minimum occurs in March and is followed by a major maximum in August. The maximum range between extremes is 17.3 cm for the average monthly mean sea level.

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RÉSUMÉ

Variations du niveau d'eau dans le nord de la Mer Levantine

Les oscillations de surface de la Mer Levantine septentrionale sont étudiées à partir d'observations horaires du niveau de l'eau dans les golfes d'Antalya et d'Iskenderun.

On identifie des oscillations de longue et de courte périodes, qui ne sont pas liées à la marée. Les oscillations de longue période (quelques jours) correspondent à des variations de la pression barométrique, tandis que les oscillations de courte période (2,8 à 4,6 heures) sont attribuées à des mouvements de type « seiche ».

Les oscillations liées à la marée ont une amplitude faible : respectivement 21 et 41 cm en marée de vives-eaux moyennes, dans les golfes d'Iskenderun et d'Antalya. Ces oscillations sont dominées par les composantes semi-diurnes.

Les variations saisonnières du niveau moyen mensuel révèlent deux maxima et deux minima. Le minimum principal a lieu en mars ; il est suivi du plus grand maximum en août. L'écart maximal entre ces valeurs extrêmes du niveau moyen est de 17,3 cm.

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INTRODUCTION

The Levantine Sea, which is one of the four major basins of the Eastern Mediterrenean, is connected to the Ionian and Aegean Seas by means of the Crete-Africa passage and two straits to the east of Crete (Fig. 1).

Tides of the Levantine Sea are characterized by the semi-diurnal (M_2) tide (Defant, 1961). Tidal harmonic constituents for the northern Levantine Sea (Girne, Magosa) and southeastern Aegean Sea [Simi, Rodi, Lindo, Castelrossia (Fig. 1)] listed in Table 1, are based upon the IHO Tidal Constituent Bank data, which was kindly provided by the Canadian Department of Fisheries and Oceans. The phase and amplitude values of the four main constituents are presented in Table 1; these are the semi-diurnal lunar (M_2) and solar (S_2) constituents, the soli-lunar diurnal (K_1) and the main lunar diurnal (O_1) constituents.

Mean neap $2(M_2-S_2)$ and spring $2(M_2+S_2)$ tidal ranges and also form number $[F=(K_1+O_1)/(M_2+S_2)]$ (Defant, 1961) are included in Table 1.

According to these data, the tides are semi-diurnal at Magosa, while they are mixed but mainly semi-diurnal at other stations. The greatest mean spring range (36.6 cm) is observed at Magosa in the northeastern part, and the lowest mean spring range (15.0 cm) is observed at Simi in the northwestern part (Fig. 1).

Semi-diurnal tidal patterns with a maximum spring range of 52 cm were reported by Striem (1974) on the basis of a set of six-year data. Striem and Rosenan (1972) studied seasonal fluctuations of monthly mean sea level on Israel's Mediterranean coast. A major minimum in April, a major maximum in July/August, a minor minimum in October and a minor maximum in December with a range of 21 cm between extremes were reported by Striem and Rosenan (1972) on the basis of ten year averages of monthly mean sea levels for Ashod and Haifa (Fig. 1). Striem (1974) studied storm surges and unusual sea level changes on Israel's coasts.

The sea level and its variability in the Northern Levantine Sea have not previously been studied. This paper describes the characteristics of the water-level variations in the area, based on data obtained from two stationary tide gauges located at Iskenderun and Antalya (Fig. 1).

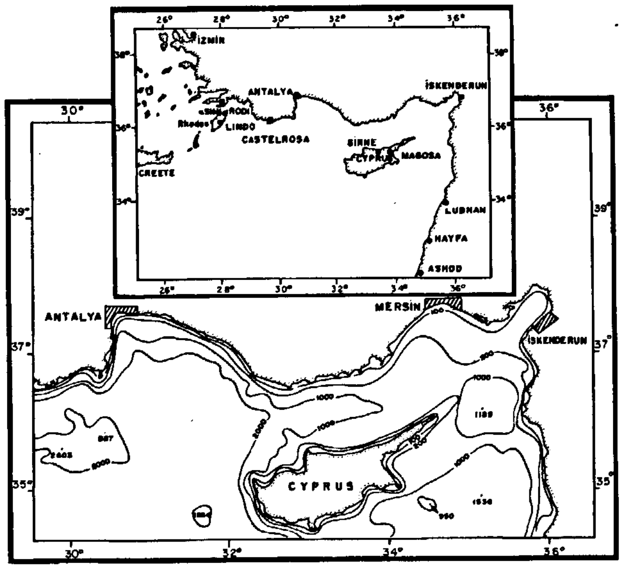

Figure 1

Gulfs of Iskenderun and Antalya showing the recording stations and main isobaths. Inset shows the location of the study area.

MATERIALS AND METHODS

Since the records have been found to be dependable in quality and without any gaps, the basic data sets used in this study are the historical analog sea-level records from Antalya for a period of 366 days from 0100 EET on 1 January 1964 to 2400 EET on 31 December 1964; and from Iskenderun (a two-month data set from 0100 EET on 1 October 1964 to 2400 EET on 30 November 1964). Simultaneous one-year sea-level data from Izmir Bay located in the Eastern Aegean Sea (Fig. 1) were also utilized for comparison.

Table 1

Previously derived tidal harmonic constituents for the northern Levantine Sea and southeastern Aegean Sea. Amplitude values (H) in centimetres; phase lags (G) in degrees, relative to the eastern European time (30 °E).

Station	M_2 H	M_2 G	S_2 H	S_2 G	K_1 H	K_1 G	O_1 H	O_1 G	Mean Spring Range	Mean Neap Range	Form Number
Simi	4.4	327	3.1	345	1.1	353	1.3	299	15.0	2.6	0.320
Rodi	5.4	308	3.2	321	2.2	330	1.4	332	17.2	4.4	0.419
Lindo	5.9	307	3.9	329	2.9	342	1.6	301	19.6	4.0	0.460
Castelrossia	6.9	303	4.0	313	1.9	332	1.6	289	21.8	5.8	0.321
Girne	10.1	293	6.4	316	2.4	308	1.8	288	33.0	7.4	0.254
Magosa	11.0	294	7.3	318	2.1	308	1.8	286	36.6	7.4	0.213

In order to examine short-period oscillations in greater detail, two-month records from Iskenderun and Antalya, taken over a period when these oscillations are easily identified, were analyzed, using a sampling interval of 30 minutes.

Data on water-level variations were collected by means of mechanical, float-type tide gauges. The tide gauge datums remained stable throughout observations. Lack of supplementary information about local reference levels prevented the references to a common level. Hourly and half-hourly water levels were abstracted from these analog time series records.

From these data sets, consecutive 50 % overlapping segments, of 1 024 points each, were taken. Trend and mean were removed from each segment and a Hamming window was also applied to each segment. The tapered segments were then subjected to Fast Fourier Transform (FFT) analysis to calculate the power spectra, utilizing the Seaspect Software developed by Lascaratos *et al.* (1990). The power spectra were plotted against frequency [cycles day^{-1} (cpd)]. The resulting numbers of degrees of freedom are given in figure captions. The data were also analyzed for tidal constituents using a harmonic analysis software package developed by Caldwell (1991). The long-period oscillations were examined using mean sea level (MSL), which was calculated by applying the $A_{24}{}^2A_{25}/(24^2*25)$ tide-killing filter (Godin, 1972). Comparative meteorological data (barometric pressure) were obtained from Antalya (1964) and Iskenderun (1964, October and November) and subjected to the spectral analyses.

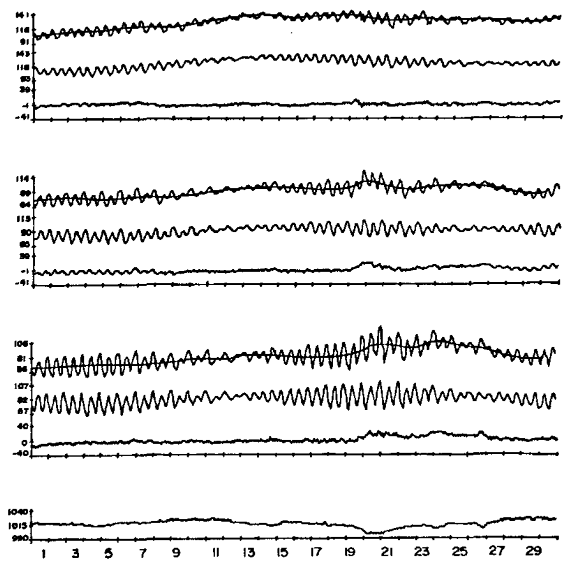

Figure 2

Records of observed, predicted and residual (observed minus predicted) water level fluctuations from Izmir, Antalya and Iskenderun for the same period of time (November, 1964) and corresponding barometric pressure from the Iskenderun meteorological station. The smooth curves with observed data is MSL which are tide killing filter. Vertical datum is arbitrary at each of the recording sites.

RESULTS AND DISCUSSION

Figure 2 presents short-term representatives of observed, sum of periodic variations (astronomical tides) and nonperiodic residual data from Izmir, Antalya and Iskenderun tide gauges with associated barometric pressure from Iskenderun. Observed data are consistent between each of the monitoring stations and demonstrate that the area is one of low tidal amplitude. They also show pronounced semi-diurnal fluctuations, with a minor diurnal inequality. There are some short-and long-period oscillations superimposed on the general semi-diurnal tidal pattern. The long-period oscillations that are exemplified by the variations in MSL can be identified more clearly than the short period ones (Fig. 2).

Short-period oscillations appearing more frequently at the peaks of high and low water may be related to the disturbing meteorological influences (wind speed or direction). On the other hand, the periodicities of the meteorologically-induced long-period oscillations may be related to large scale cyclic atmospheric patterns. Long-period oscillations in the pressure data seems to be inversely related to the long-period variations in the water level. The oscillations which are represented by MSL are due to the long-period tidal constituents and meteorological influences.

The spectral results of hourly sea levels as normalized power against frequency (cpd) are plotted on a linear (Fig. 3 *a*) and logarithmic scale (Fig. 3 *b*). Figure 3 *a* shows that the water-level fluctuations are dominated by energy inputs of semi-diurnal frequency, with secondary contributions from the long-period and diurnal fluctuations. In the tidal period range, fluctuations are dominated by energy inputs of semi-diurnal frequency with secondary contributions from diurnal fluctuations.The logarithmic plot (Fig. 3 *b*) expands the presentation into the higher frequencies, by enhancing the representation of the smaller energy inputs.The characteristics of the linear plot (Fig. 3 *a*) are again apparent here, but shorter period (*e.g.* 1/4 and 1/6 diurnal) contributions are also shown.

Numerical analysis of the energy distribution was carried out and the contributions of the energy at different frequency bands are expressed as percentages of the total energy in the records (Tab. 2). Long-period energy inputs are seen to become dominant further west toward the Aegean Sea.

These percentages confirm quantitatively the dominance of tidal energy inputs (70 %) in the Gulf of Iskenderun and the significance of its semi-diurnal part (approximately 66 %). Low-frequency inputs, presumably of large-scale meteorological origin, contribute 28.5 % of the total energy. High-frequency (> 4 cpd) inputs, due to seiche-like motions, contribute only 1.5 % of the total energy in the Gulf of Iskenderun. On the other hand, in the Gulf of Antalya, low-frequency energy input (56.1 %) is dominant. In the Aegean Sea at Izmir, the water-level variations are mainly governed by the energy inputs (71.3 %) in the low-frequency band as well. This cannot be generalized for the Aegean Sea, and attests to the isolation of the Izmir Bay from the rest of the Aegean Sea.

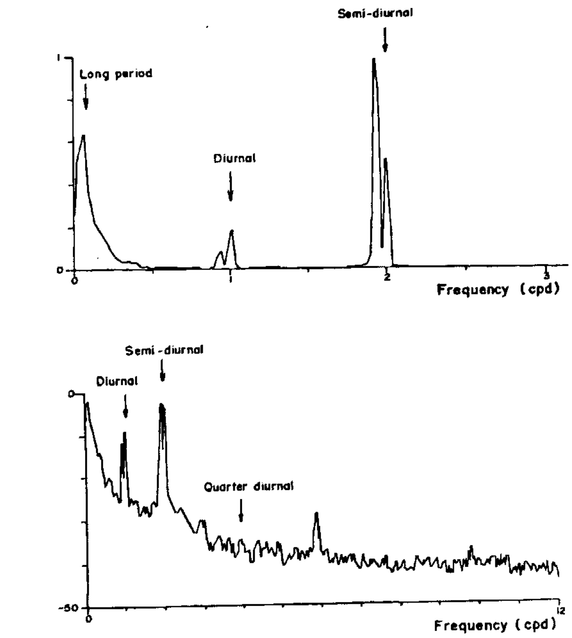

Figure 3

Power spectra (on 8192 points) of hourly water level data for Antalya on linear and logaritmic scales. The 95 % confidence factors, for 30 degrees of freedom, are (0.639, 1.787). Spectrum normalization factor is 0.5850E + 07.

Another important point which can be inferred from Table 2 is the decrease in the diurnal and semi-diurnal band energy contributions towards the Aegean Sea.

Due to the length of the sampling interval in the analyses, the shortest period of oscillation which can be resolved is two hours; consequently, shorter periods of oscillations do not appear in the analysis. In order to analyse shorter period oscillations, analog records over two months from two stations have been sampled every 30 minutes, and tidal and long-period constituents removed by using a simple 0-3 cpd band reject filter. The spectra of the tidal and long-period free data (Fig. 4) combined with Figure 3 *b* display the presence of weak higher order contributions generated by the basin itself.

The most important short period of oscillation has a periodicity of 3.6 hours in the Gulf of Iskenderun. The presence of short-period oscillations with periods of 4.6, 4.0, 3.3 and 2.8 hours are distinguishable in the Gulf of Antalya. But energy inputs at these frequencies are rather weak.

To examine natural periods for mononodal standing oscillations in the Gulfs of Iskenderun and Antalya, the formula for semi-closed (open at one end) basins was used (Thurman, 1984) : $T = 4L/(gh)^{1/2}$, where L is the characteristic length of an embayment, h is the mean depth and g is the acceleration due to gravity (9.81 m/s^2). Substituting values of 80 km for the length and 62 m for the mean depth for the Gulf of Iskenderun, gives a natural period of oscillation of 3.6 hours. For the Gulf of Antalya, on the other hand, substituting values of 260 km and 1 100 m gives a period of 2.8 hours. These figures compare favourably with the calculated standing oscillations (Fig. 3 and 4) for both of the embayments.

Table 2

Distribution of energy percentages in the records.

	Stations		
Frequency Range	Iskenderun	Antalya	Izmir
Low frequency (< 0.8 cpd)	28.51	56.14	71.30
Diurnal (0.8-1.2 cpd)	4.12	3.26	3.08
Semi- diurnal (1.8-2.2 cpd)	65.91	39.20	22.84
Quarter diurnal (3.8-4.2 cpd)	0.05	0.11	0.04
Other	1.30	1.15	2.07
Total energy in record	100.00	100.00	100.00

In order to investigate the low-frequency contributions in sea-level variations, the tide-killing filter (Godin, 1972) is used to eliminate the diurnal and semi-diurnal oscillations and its spectral result was compared with that of the barometric pressure for Antalya (Fig. 5). Spectral analysis of the MSL data reveals long-period oscillations with periods of some 21 days. On the other hand, spectral analysis of the barometric pressure data reveals a major peak at 21 days, followed by a minor one at around 8.5 days. Thus, the low-frequency part (21 days) of the sea-level variations can be attributed to long-period fluctuations in barometric pressure. The dynamical reason why the sea level does not reflect the atmospheric signal at 8.5 days merits further study.

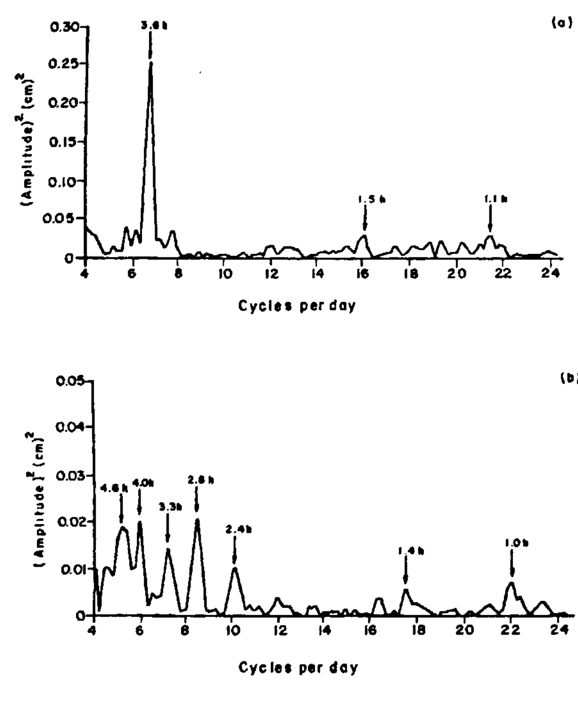

Figure 4

Power spectra (on 2048 points) of : a) Iskenderun; and b) Antalya half-hourly sea level data. The 95 % confidence factors, for 6 degrees of freedom, are (0.415, 4.849).

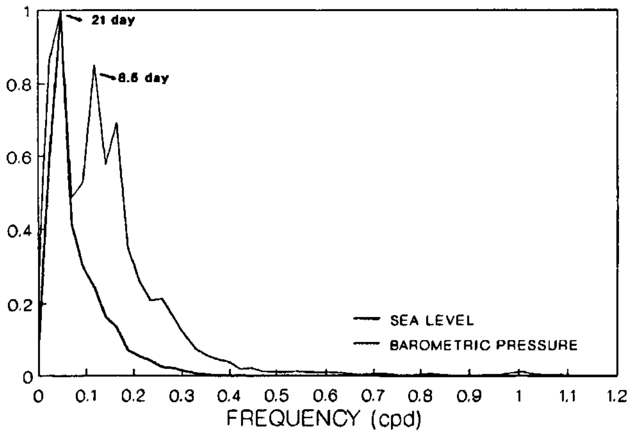

Figure 5

Power spectra (on 8192 points) of mean sea level (thick one) and atmospheric pressure for observation period 1964 in the Gulf of Antalya. The 95 % confidence factors, for 30 degrees of freedom, are (0.639, 1.787). Spectrum normalization factors for mean sea level and atmospheric pressure are 0.4770E + 07 and 0.1120E + 07 respectively.

The sea-level data from Iskenderun, Antalya and Izmir have been analysed for their tidal constituents using the software package developed by Caldwell (1991). The phase and amplitude values of the four main constituents are presented in Table 3.

The amplitudes and phases were calculated as applying the nodal corrections to the outputs from the linear least squares tidal analysis (Caldwell, 1991). Applying nodal corrections allows the fitted components to be used further from the actual time period used to fit the components.

The tidal amplitudes demonstrate the relative importance of the various constituents. In all cases, the most important constituent is M_2. The S_2 is approximately 63 % of the M_2; this constitutes a large amount of radiation tidal input from the sun, typical of the Mediterranean. The form numbers demonstrate that the tides at Iskenderun are dominantly semi-diurnal in character; at Antalya and Izmir they are mixed, predominantly semi-diurnal. Observed amplitude difference may be due to the local circulation pattern in the Gulf of Antalya and the presence of the nodal point in the west. The amplitude and phase angle of the constituents which are calculated in Table 3 can be compared with the values presented in Table 1. The amplitudes and phase angles are in good agreement with those calculated previously.

For the northwestern Levantine coast, the average monthly mean sea levels were calculated for the Gulf of Antalya using 12 years (1965-1976) monthly mean sea-level values compiled by the General Command of Mapping (1991). The fluctuations of monthly mean sea level are given in Table 4 and Figure 6. Comparison with the seasonal averages (1964-1971) of the Izmir data in Figure 6 shows that the curve has two maxima and two minima; the major minimum occurs in March and is followed by a major maximum in August. The minor minimum occurs in October/November and a minor maximum in December. The maximum range between extremes is 17.4 cm for average monthly mean sea level. These are similar to the results of Striem *et al.* (1972), with a minor difference of a slight time shift between the minimum and maximum monthly means and the range of fluctuation. The barometric pressure, thermal expansion and the piling of water onshore as a result of storm surges were considered to produce this observed fluctuation in the southeastern part of the Levantine Sea by Striem and Rosenan (1972).

The annual mean sea levels (derived from the January-December monthly mean levels) fluctuate around their long-term average.

For Antalya, a twelve-year series (1965-1976) of average annual levels was computed.Their deviations from the twelve-year average are shown in Table 5. They are above the average during the period 1965-1970.

CONCLUSIONS

Non-tidal (long- and short-period) and tidal-period oscillations have been identified in short term (one year) water-level records from the southern coasts of Turkey. These have been confirmed by the spectral analyses of the data.

The low-frequency part (21 days) of the long-period non-tidal oscillations corresponds with the variations in barometric pressure associated with mesoscale meteorological phenomena. On the other hand, short-period non-tidal

Table 3

Tidal harmonic constituents. Amplitude values (H) in centimetres; phase lags (G) in degrees, relative to eastern European time (30 °E).

Station	M_2 H	M_2 G	S_2 H	S_2 G	K_1 H	K_1 G	O_1 H	O_1 G	Mean Spring Range	Mean Neap Range	Form Number
Iskenderun	12.5	266.7	7.9	268.2	3.4	262.7	2.0	286.0	40.8	9.2	0.26
Antalya	6.2	304.3	4.2	308.1	2.4	280.7	1.5	295.9	20.8	4.0	0.37
Izmir	4.6	97.8	3.7	107.2	1.8	328.6	1.2	328.5	16.7	1.6	0.36

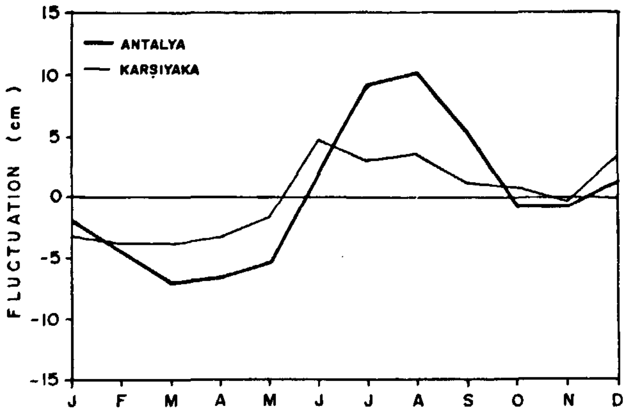

Figure 6

Seasonal fluctuations of the monthy mean sea level at Northern Levantine Sea (Antalya) and Eastern Aegean Sea (Karsìyaka, Izmir).

Table 4

Seasonal fluctuation of the monthly sea level (relative to the annual mean sea level) in centimetres.

Month	J	F	M	A	M	J	J	A	S	O	N	D
Fluctuations	-1.9	-4.6	-7.2	-6.7	-5.5	1.5	9.3	10.1	5.4	-0.8	-0.8	1.3

Table 5

The trend of the annual mean sea level (centimetres).

Year 19..											
65	66	67	68	69	70	71	72	73	74	75	76
Deviation from average											
2.8	7.2	12.1	3.3	4.6	4.	-.2	-6.3	-7.2	-2.8	-2.9	-4.9

contributions are generated by the basins themselves. Although they are rather weak in amplitude, they may be attributed to seiche-like motions.

Tidal amplitudes are low, mean spring tidal ranges are about 40.8 cm, reducing to 9.2 cm on mean Neap tides in the Gulf of Iskenderun. The amplitude of tidal constituents decreases toward the west. Tidal energy input is dominant in the Gulf of Iskenderun, while low frequency sub-tidal energy input is dominant in the Gulf of Antalya.

Finally, the fluctuations of monthly sea level are in fairly good agreement with the general fluctuation of the mean sea level along the southeastern Mediterranean as reported by Striem (1974).

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