International Hydrographic Review, Monaco, LXVII(1), January 1990

LONG-TERM VARIATIONS OF MONTHLY MEAN SEA LEVEL AND ITS RELATION TO ATMOSPHERIC PRESSURE IN THE MEDITERRANEAN SEA

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Abstract

The monthly mean sea level at 19 stations and the monthly mean atmospheric pressure at 15 stations in the Mediterranean Sea are analysed to find the trend of the sea level and to identify the significant oscillations from the power spectral estimates.

The results show that from the present data at Marseille, Trieste and Genova it is expected that the sea level tends to increase by 13 cm/100 years, which will affect the water budget of the area.

The spectral analysis of the pressure could explain most of the oscillations in the sea level time series at 12, 6 and 4 months' periods, except in the Adriatic Sea where the steric effect is expected to have an important contribution.

INTRODUCTION

In the past few years, more international attention has been given to the climatic fluctuations and their long term impact on human activities. These climatic changes are expected to raise the global mean air temperature in the next few decades. Consequently, a rise in sea level of from 20 to 140 centimetres or more is expected by the middle of the next century, which will affect the coastal areas activities [see Ref. 1] . In addition to the influence of the trend of the climatic changes, the annual pressure cycles and the steric effect will affect the monthly mean sea level in some areas.

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The study aims to investigate the long-term trend of sea level, and to identify the different oscillations affecting the level record in the Mediterranean Sea. These fluctuations will be compared with the monthly mean pressure data.

DATA AND METHODS OF ANALYSIS

Two types of data are used in the present work:

a) The monthly mean sea level, and

b) The monthly mean atmospheric pressure.

The sea level data, provided by Moscow International Data Center, were available at 19 stations in the Mediterranean, of which 10 stations are in the Eastern Mediterranean, east of 15°E, and 9 stations are west of 15°E. The positions of these stations, the periods and the number of data points considered in the analyses are shown in table 1. On the other hand, the atmospheric pressure time series were taken at 12 stations and 3 stations east and west of 15°E respectively. The positions, periods and lengths of the pressure time series are shown in table 2. Both the sea level and meteorological stations are shown in Figure 1.

Table 1

Mediterranean stations where monthly mean sea level was taken and spectral characteristics of records

Region	Station	Position Lat.N	Long.E	Period	No. of points	No. of deg.of freedom	Sign. peaks (months)
Eastern Mediterranean	1—Alexandria	31°12	29°53	1958-1972	180	10	12,6
	2—Antalya	36 53	30 42	1939-1958	240	13	12,6
Aegean Sea	3—Izmir	38 24	27 10	1937-1961	300	10	2.35
Adriatic Sea	4—Venice	45 46	12 20	1953-1967	180	10	12
	5—Trieste	45 39	13 45	1927-1956	360	20	12,6
	6—Rovinj	45 05	13 38	1956-1970	180	10	12,6
	7—Bakar	45 18	14 32	1950-1969	240	13	None
	8—Split	43 30	16 26	1955-1969	180	10	12
	9—Dubrovnik	43 40	18 04	1956-1970	180	10	None
Ionian Sea	10—Catania	37 30	15 08	1960-1971	144	08	12
Tyrrhenian Sea	11—Civita-vecchia	42 03	11 49	1899-1918	240	13	None
	12—Napoli	40 52	14 16	1897-1916	240	13	None.
	13—Palermo	38 08	13 20	1901-1920	240	13	12
	14—Cagliari	39 12	09 10	1897-1916	240	13	12
	15—La Madda-lena	41 14	09 22	1900-1911	144	08	12
Western Mediterranean	16—Genova	44 24	08 54	1884-1899	180	10	12
	17—Marseille	43 18	05 21	1886-1935	600	20	12,6
				1938-1957	240	13	12
	18—Alicante	38 20	00 29	1960-1974	180	10	12,3.1

Table 2

The Mediterranean meteorological stations where the pressure time series are considered and their spectral characteristics

Region	Station	Position Lat	Position Long	Period	No. of points	No. of deg.of freedom	Period of sign. peaks
Eastern Mediterranean	1—Alexandria	31°12	29°53	1962-1973	180	10	12,6
	2—Bengorion	32 00	34 54	1955-1976	240	13	12,6,4.1
	3—Lattakia	35 20	35 47	1956-1975	240	13	12,6
	4—Nicosia	35 09	33 17	1955-1966	180	10	12,6,4
	5—Antalya	36 42	30 44	1955-1974	240	13	12,6,4
Aegean Sea	6—Canakkale	40 08	26 24	1955-1974	240	13	12
	7—Crete	35 20	25 11	1955-1974	240	13	12
Adriatic Sea	8—Trieste	45 39	13 45	1955-1966	180	10	None
	9—Brindisi	40 40	17 57	1955-1966	180	10	None
Central Mediterranean	10—Benina	32 05	20 16	1962-1973	144	8	12,6,3.4
	11—Mesorata	32 25	15 06	1962-1973	144	8	12,6,5.4
	12—Luqa	35 51	14 29	1955-1974	240	13	12
Western Mediterranean	13—Tunis	36 50	10 14	1955-1974	240	13	None
	14—Marseille	43 27	05 13	1955-1974	240	13	None
	15—Gibraltar	36 09	05 21	1955-1974	240	13	12

To analyse the above time series, the following procedure was used:

1 — For the long period time series, where an obvious linear trend was observed, at Marseille, Genova and Trieste, a linear equation relating the sea level and the time was fitted using the least-square method. This equation represents the long-term trend; the residuals were used in the second step of the analysis.

2 — For the time series which do not show an obvious trend and for the stationary data obtained in the first step, a spectral analysis was performed.

Since the number of data points was different at the different stations, it was necessary to put a criteria for the choice of the number of data points and the number of lags to get comparable results at the different stations. This was achieved by taking the same number of lags so that the frequency resolution became the same for all cases. It was also expected that the annual cycle of pressure (with a period of 12 months) would have an important effect on the mean sea level, and that the spectral analysis might show the power at that cycle. The number of lags was therefore chosen to be 36:

$$\Delta f = 0.5/36 = 0.013888 \text{ c/month}$$

and the frequency of 0.0833 (i.e. annual cycle) was at the frequency number 6. To exploit most of the data available, different (M/N) (N = number of points, and M = number of lags) were used according to table 3. The choice in the last two columns of table 3 gives a different resolution, but it allows the use of larger number of data points, and finding the energy density at 12 months period at frequency numbers 10 and 8 for 600 and 480 points respectively.

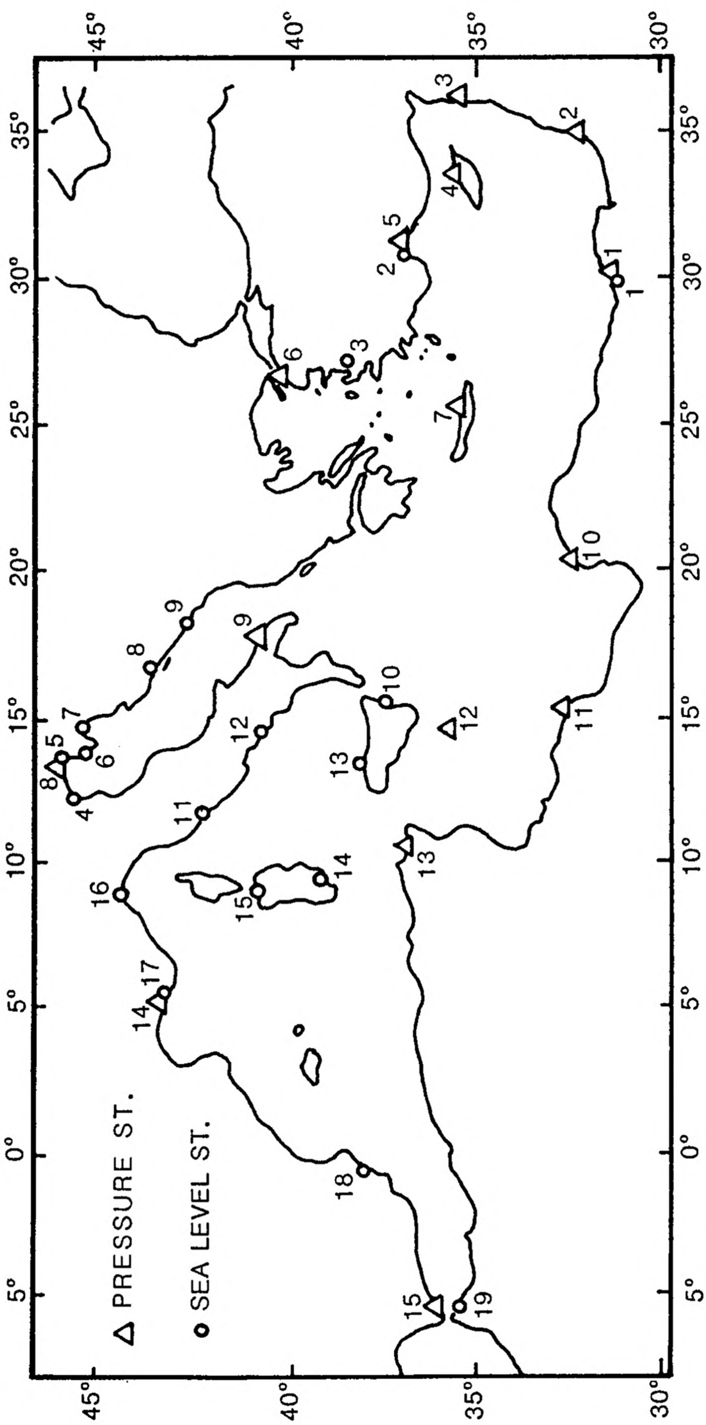

FIG. 1.— Positions of sea level and atmospheric pressure stations in the Mediterranean (see tables 1 and 2).

Table 3

Number of data points, number of lags, number of degrees of freedom and the confidence limits chosen in the analysis of the time series of sea level and atmospheric pressure in the Mediterranean

M/N	0.10	0.15	0.20	0.25	0.10	0.10
N	360	240	180	144	600	480
M	36				60	48
Number of degrees of freedom	20	13	10	8	20	
Confidence limit [see Ref. 2]	0.59-2.1	0.52-2.6	0.49-3.1	0.46-3.8	0.59-2.1	

RESULTS

(a) Long-term trend of sea level variations

A trend was detected at the three records taken at Marseille, Trieste and Genova (Fig. 2).

At Marseille, the regression equation relating the monthly mean sea level and the time can be expressed by:

$$H = (0.011 + 0.003)\, t + 684.464 \text{ (cm)} \tag{1}$$

where H = level height in the absence of the monthly deviation due to regular harmonic oscillations (mainly the annual cycle);

t = time (or number) of the month referred to January 1886, and given by:

$$t = (((12 \times Y + i)/12) - 1886) \times 12$$

where Y = the year for which H is calculated, and i = 1, 2, 3, ..., 12 for January, February, March,..., December.

The slope of this line is significantly different from zero at 0.1 level. This relation was based on 50 years sea level record.

At Trieste, the equation obtained using 48 years of record can be expressed by:

$$H = (0.011 + 0.004)\, t + 696.042 \text{ cm} \tag{2}$$

where $t = (((12 \times Y + i)/12) - 1927) \times 12.$

At Genova, the equation of the trend can be shown by:

$$H = (0.014 + 0.0045) \times t + 693.206 \text{ (cm)} \tag{3}$$

where $t = (((12 \times Y + i)/12) - 1931) \times 12$

where the years 1886, 1927 and 1931 are the first years in the time series used in the calculations of the trend at Marseille, Trieste and Genova respectively.

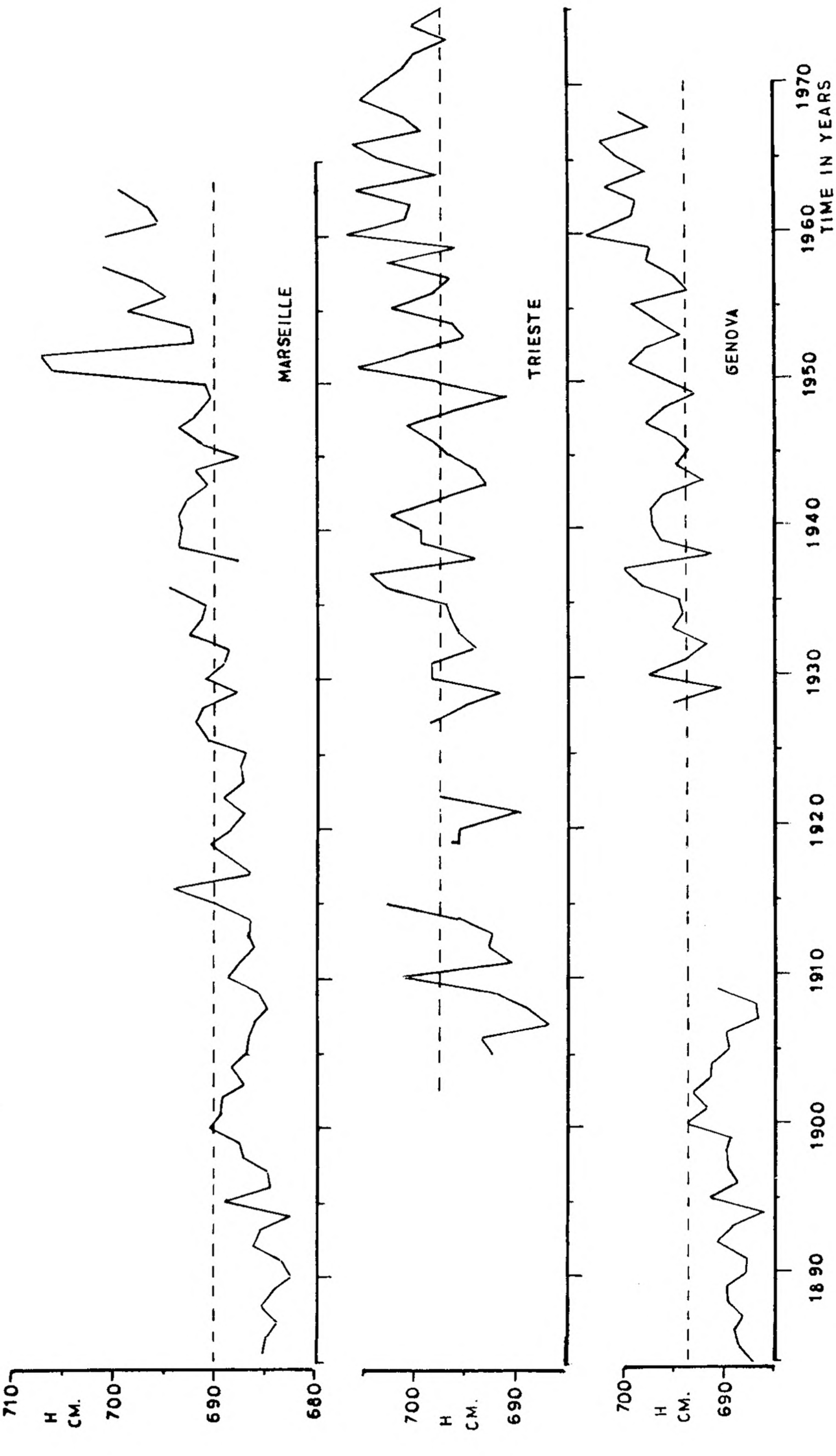

FIG. 2.— Monthly mean sea level time series at Marseille, Trieste and Genova, where long-term trend of rising is indicated.

(b) Spectral analysis of data

(1) Monthly mean sea level

The spectral analysis of the sea level data was applied with the number of data points and the number of degrees of freedom (2×N/M) given in table 3. The spectral density is represented for each of Levantine, Aegean, Adriatic, Ionian, Tyrrhenian and Western Mediterranean basins separately (Figs. 3, 4, 5 and 6). The power is expressed in cm^2/cycle. Using the confidence limits for the different degrees of freedom (table 3), the significant peaks were identified and recorded in the last column of table 1, from which the conclusions will be drawn.

East of 15 E, in the Eastern Mediterranean and Adriatic Sea, there is an oscillation with a period of 12 months nearly at all stations except at Dubrovnic and Bakar. The oscillation of 6 months period existed only at Alexandria, Antalia, Trieste and Roving, while an oscillation of 2.35 months was found at Ismir.

West of 15°E, the annual cycle was shown at seven stations, while the semi-annual cycle was found at Marseille.

Comparing the spectral results of the original sea level data and the data after elimination of the trend, the main characteristics were the same at Trieste, Genova and Marseille.

(2) Monthly mean atmospheric pressure

The spectral estimates of the atmospheric pressure in the different basins are shown in Figures 7, 8 and 9, and the summary of the results is found in the last column of table 2.

In the East of 15 E, the annual cycle was shown in the Eastern Mediterranean, Ionian Sea and the Aegean Sea, while the semi-annual cycle existed only in the Eastern Mediterranean and Ionian Sea. At some stations, higher frequency oscillations (periods between 3, 4 and 4.1 months were significant.

In the Western Mediterranean, the north front station, at Gibraltar, had an annual oscillation while at Marseille and Tunis no significant peaks were detected.

Coherence between the atmospheric pressure and the sea level was not attempted since the two-time series were not in the same time periods.

DISCUSSION AND CONCLUSIONS

From the above results, the slope of the trend line indicates an increase of sea level by about 13 cm/100 years. Assuming that the available data are accurate enough, this increase could affect the water budget of the Mediterranean.

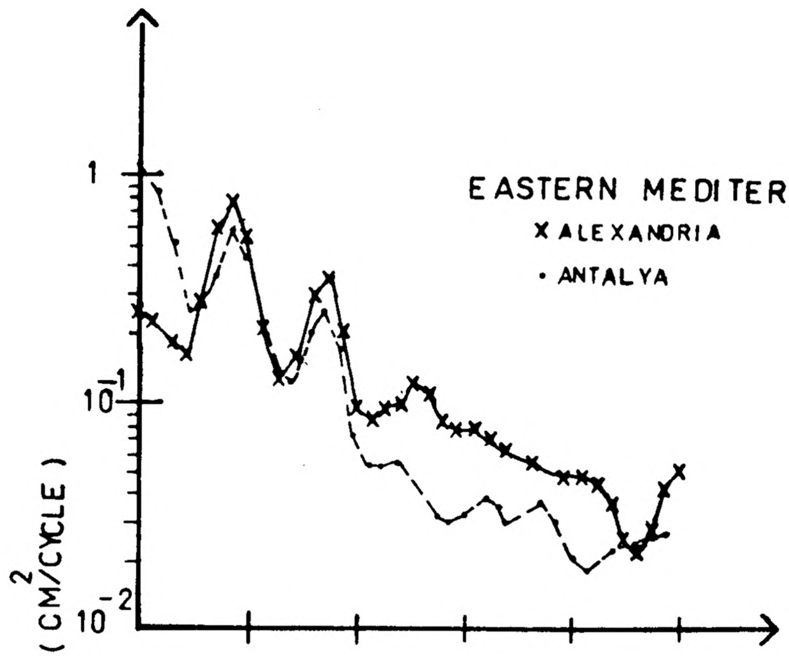

FIG. 3.— Spectra of monthly mean sea level in the Eastern Mediterranean.

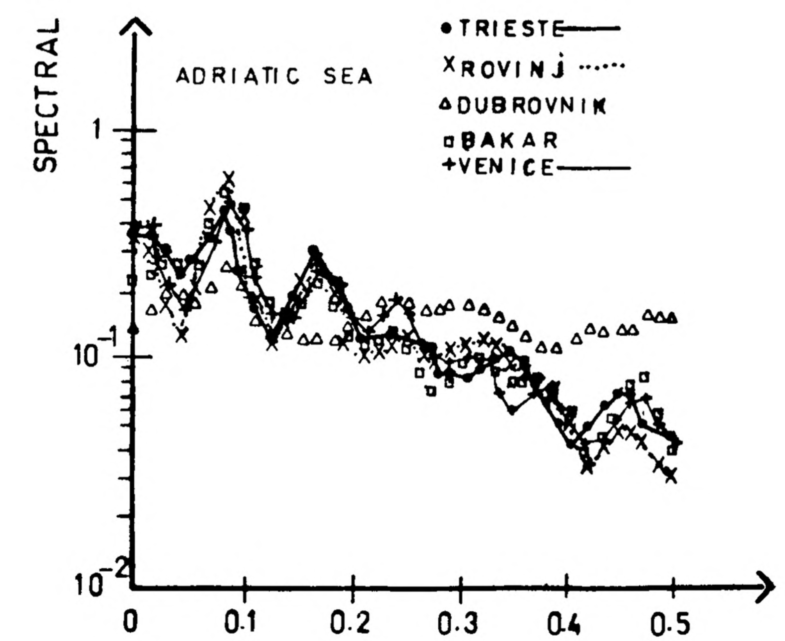

FIG. 4.— Spectra of monthly mean sea level in the Adriatic Sea.

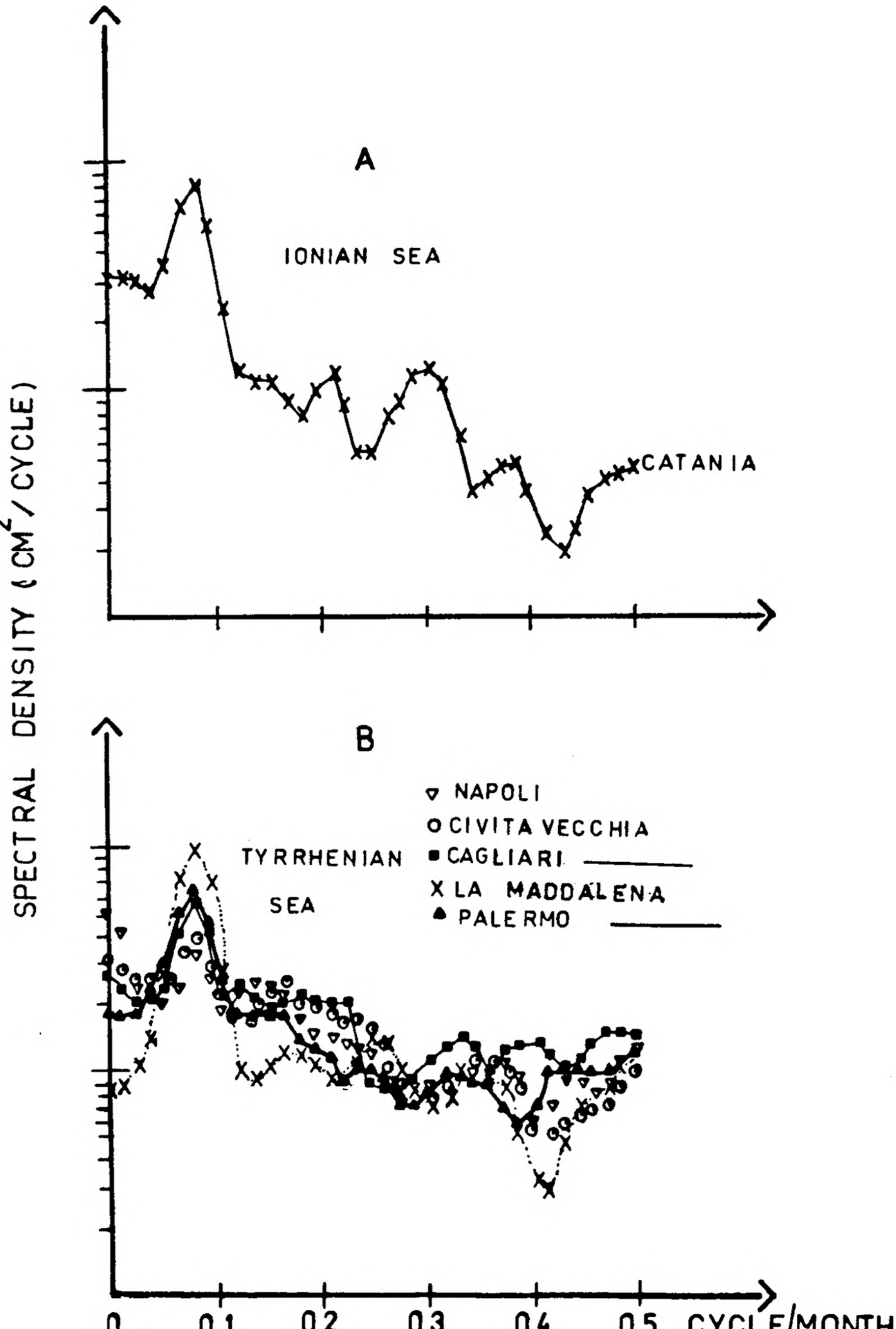

FIG. 5.— Spectra of monthly mean sea level in the Ionian (A) and Tyrrhenian (B) Seas.

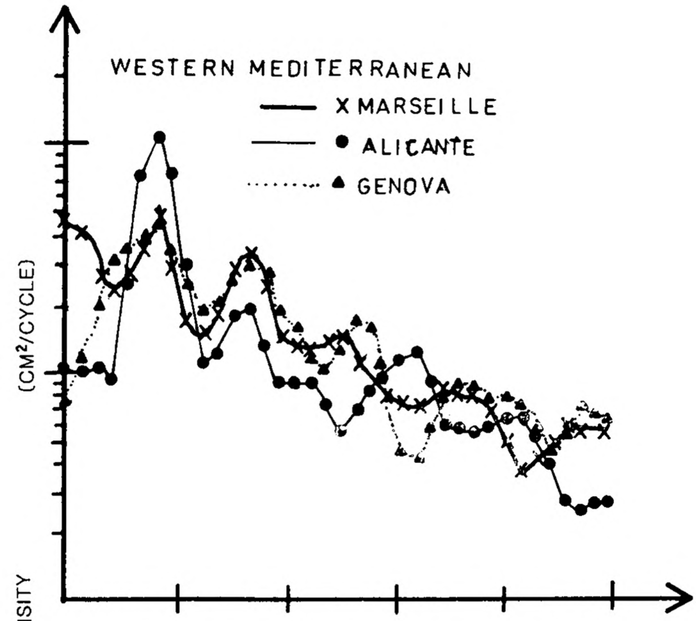

Fig. 6.— Spectra of monthly mean sea level in the Western Mediterranean.

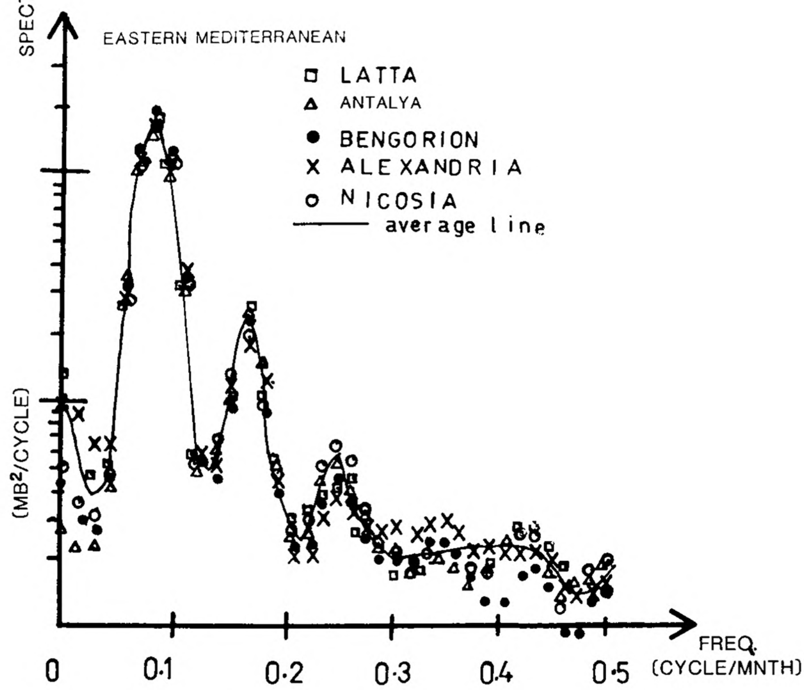

Fig. 7.— Spectra of monthly mean atmospheric pressure in the Eastern Mediterranean.

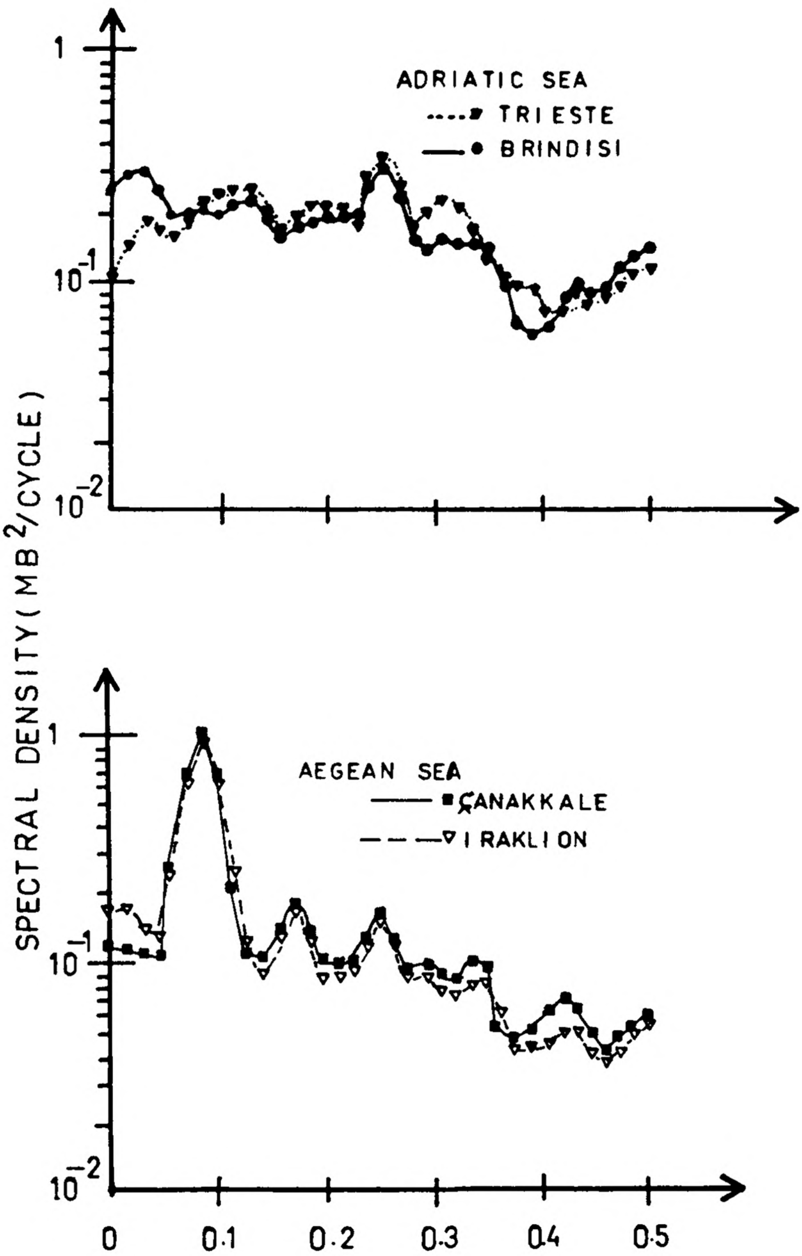

FIG. 8.— Spectra of monthly mean atmospheric pressure in the Adriatic and Aegean Seas.

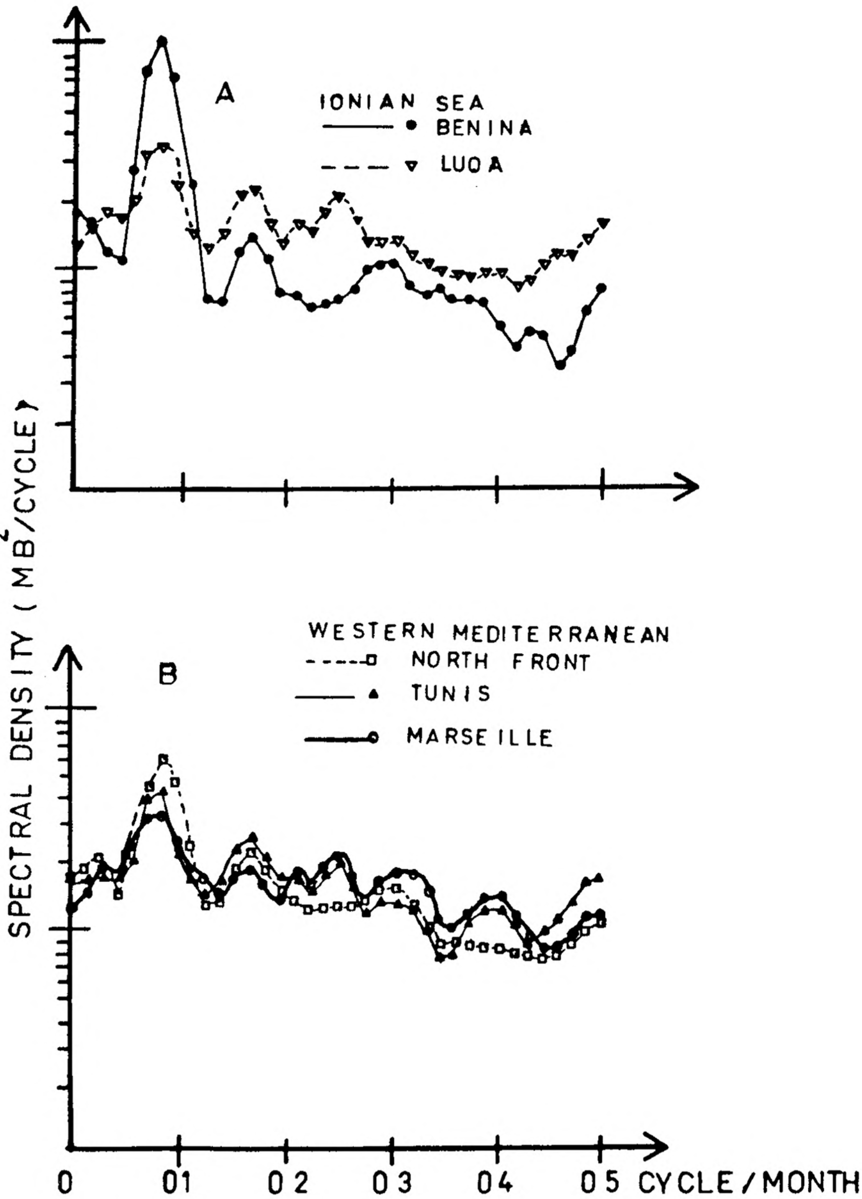

FIG. 9.— Spectra of monthly mean atmospheric pressure in the Ionian Sea (A) and Western Mediterranean (B).

The spectral analysis of the sea level and the atmospheric pressure show that, in the Eastern Mediterranean, the annual and the semi-annual oscillations of the mean sea level can be explained by the atmospheric pressure effect which manifests the same type of fluctuations. However, in the Adriatic Sea, the 12 and 6 months oscillations in sea level could be due to interaction between the pressure and the steric effect, which is expected to be important in the Adriatic Sea with significant river discharge.

In the Tyrrhenian Sea, no meteorological stations are taken. However, comparing the sea level in this area with the pressure in the Ionian Sea, the behaviour of the time series indicates good agreement.

In the Western Mediterranean, the annual cycle in the sea level is shown at the North Front meteorological station. The periods less than 4 months could be due to local factors such as steric effect associated with the circulation of the Mediterranean.

References

[1] CCD 87-04 (1987): Executive summary of the report, effects of a one metre rise in mean sea level at Saint John, New Brunswick and lower reaches of Saint John River. Prepared by Mertec Limited for Atmospheric Environment Service (Canada).

[2] MUNK, W.H., SNODGRASS, F.E. and TUKER, M.J. (1959): Spectra of low frequency ocean waves. *Bulletin of Scripps Institution of Oceanography,* California Univ., Vol. 7, No. 4, pp. 283-362.