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# Analysis of the Water Level Variations in the Eastern Black Sea

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**ABSTRACT**

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A sequence of two-hourly water level observations at Samsun and Trabzon located on the eastern Black Sea coast have been analyzed in order to investigate the general nature of the sea level variations. Long (several days) oscillations of non-tidal origin have been identified. Water level fluctuations are dominated by energy inputs from low frequency sea level variations. The tidal oscillations are very small in amplitude with a spring range of 0.74 and 1.9 cm in Samsun and Trabzon, respectively. Tidal oscillations are dominated by semi-diurnal constituents. Short periods of oscillation (7.1, 4.3, 3.0, 2.3 hr) have been identified in the sea level spectrum.

ADDITIONAL INDEX WORDS: *Sea level, tidal variations, oscillations, Black Sea, seiches.*

## INTRODUCTION

The Black Sea is one of the world's largest landlocked marginal seas. It is an elliptical basin with an area of 423,000 km$^2$, a volume of 534,000 km$^3$, and a maximum depth of 2,206 m. The basin has four main physiographic provinces with the following percentages: shelf (29.9 %), basin slope (27.3 %), basin apron (30.6 %), and abyssal plain (12.2 %) (Figure 1) (Ross *et al.*, 1974). Maximum development of the shelf is west of the Crimean Peninsula where it is more than 190 km wide. Along the mountainous coasts of Turkey and the Crimean, the shelf is narrow and barely exceeds 20 km in width. The slope can be two types: either a steep slope that is highly dissected by submarine canyons or a relatively smooth slope. The latter is limited to the broad shelves west of the Crimean and southwest of the Sea of Azov (Ross *et al.*, 1978).

Amplitudes of the Black Sea tides are very small: in the centre of the west and east coast they are about 9 cm, and in the centre of the north coast (Crimea) they are about 2–3 cm (Defant, 1961). Principal harmonic components listed in Table 1 are based upon IHO Tidal Constituent Bank data, which kindly was provided by the Canadian Department of Fisheries and Oceans.

According to these data, the tides are semidiurnal at Odessa, while they are mixed, mainly semidiurnal, at other stations. The greatest range is observed at Odessa and the lowest ranges are observed at Poti and Sevastopol (Figure 1).

According to Defant (1961), the Black Sea can be considered as a completely enclosed water mass and any influence from the Strait of İstanbul-SOI (Bosphorus) is hardly to be expected. Tidal ranges are lower than theoretical due to the fact that the Black Sea cannot co-oscillate with the tide-producing forces. Because of the great damping of unrestricted oscillations, only pure forced oscillations become evident (Endros, 1932). A detailed account of tidal and seiche characteristics of the Black Sea can be found in Endros (1932) and Defant (1961). The Black Sea was considered a completely closed basin with regard to its seiche movements, since its connection with the Mediterranean is so narrow in relation to its great area. Endros (1932) found periods of 7.4, 6.4 and 5.54 hr after elimination of the small tides. The first period was considered essentially an oscillation of the north-western shallow section of the Bay of Odessa. The second and third were believed by Endros to be of the entire water mass of the Black Sea along the main deep basin towards the south west (Burgas, 5.5 hr) and towards the middle of the western shore (Costanza, 6.4 hr). Defant (1918) and Sterneck (1922) (cited by Endros, 1932; and Defant, 1961) found the theoretical period of these longitudinal oscillations to be 4.98 hr and 5.12 hr, respectively, utilizing two different methods and omitting the Bay

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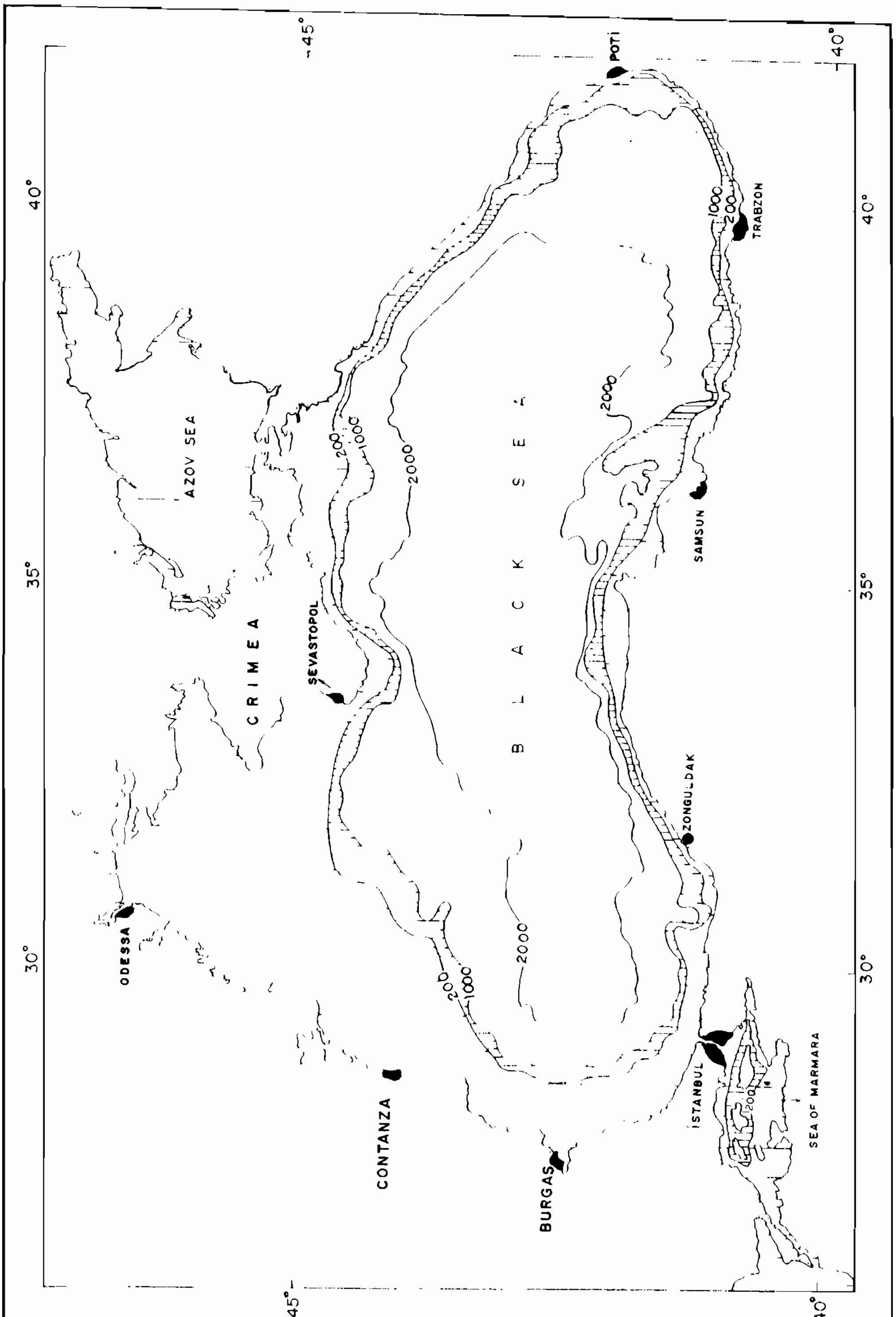


Figure 1. Bathymetry and location chart (after IOC-UNESCO, 1981).

Table 1. *Harmonic constants for the Black Sea (amplitudes in cm).*

| Place | $M_2$ | $S_2$ | $K_1$ | $O_1$ | Mean Spring Range | Mean Neap Range | Form Number |
|---|---|---|---|---|---|---|---|
| Odessa | 3.5 | 1.9 | 0.9 | 0.4 | 10.8 | 3.2 | 0.24 |
| Sevastopol | 0.4 | 0.3 | 0.3 | 0.1 | 1.4 | 0.2 | 0.57 |
| Poti | 2.9 | 1.2 | 1.5 | 0.9 | 8.2 | 3.4 | 0.58 |

of Odessa in their computations. In addition to the three seiches, ENDROS (1932) found 4.3, 3.7, 3.2, 2.7, 2.2 hr periods of oscillations.

According to ENDROS (1932), the Black Sea represents a poorly balanced oscillatory basin. At both ends (Odessa and Poti) where the seiche movements should be greatest, the weak but regular tidal movements of 6 to 12 cm range conceal the characteristic oscillations almost completely. Regular wave-like disturbances occur only at the intermediary points where the tidal movements are much smaller (ENDROS, 1932).

Water level data obtained from the two tide gauges located at Samsun and Trabzon analyzed herein describe the characteristics of the water level variations in the eastern Black Sea.

## DATA SOURCE AND ANALYTICAL TECHNIQUES

Data on water level variations were collected by means of the damped well tide gauges at Samsun and Trabzon (Figure 1). Lack of supplementary information about tide gauge installation and local reference levels precluded the references to a common level, stability of the datums, and damping ratio. Water levels at two-hour intervals were abstracted from the resulting analog time series data. These data were then subjected to FFT analysis to calculate the spectra of the fluctuations in water level. In addition, data were analysed for tidal constituents using a harmonic analysis program in which tidal constituents have been extracted from the disturbing effect of each other using a method given by SCHUREMAN (1948).

Comparative meteorological data (wind speed and direction, barometric pressure) were obtained from a station located at Samsun (Figure 1). Computations of mean sea level was conducted by application of a $X_0$ filter, which is a low-pass filter to remove the tidal energy at diurnal and higher frequencies from sea level elevations. Details of the $X_0$ filter are given in IOC-UNESCO (1985).

## RESULTS AND DISCUSSION

Figure 2a presents data for Samsun which has a relatively lower tidal amplitude. The data have a pronounced long period fluctuation superimposed by small amplitude semidiurnal tidal patterns. Short periods of oscillations due to basin oscillations are not clearly observed in the Samsun data. The long period oscillations seen in the records due to both long period tidal constituents and meteorological influences can be identified by examining variation in mean sea level (MSL). Figure 2 is an example of MSL variations and represents 15 days of data from Samsun and Trabzon. The fluctuation has a period of several days. Such long period oscillations are probably meteorologically induced and their frequency related to large scale cyclic atmospheric patterns in the region.

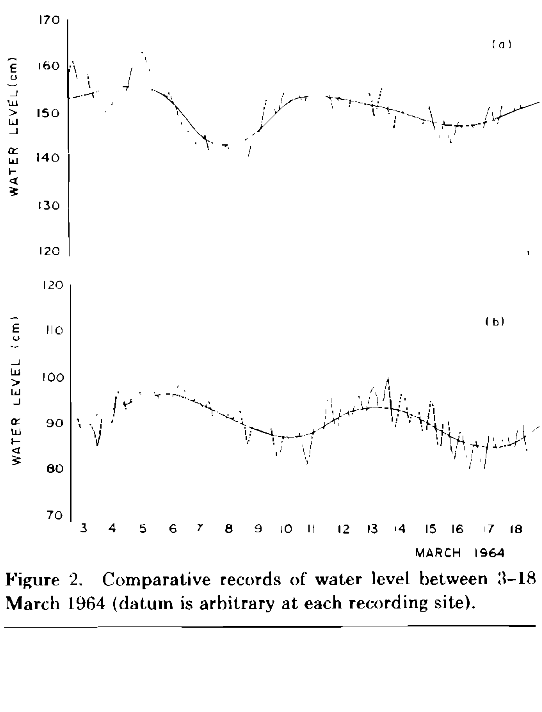


Figure 2. Comparative records of water level between 3–18 March 1964 (datum is arbitrary at each recording site).

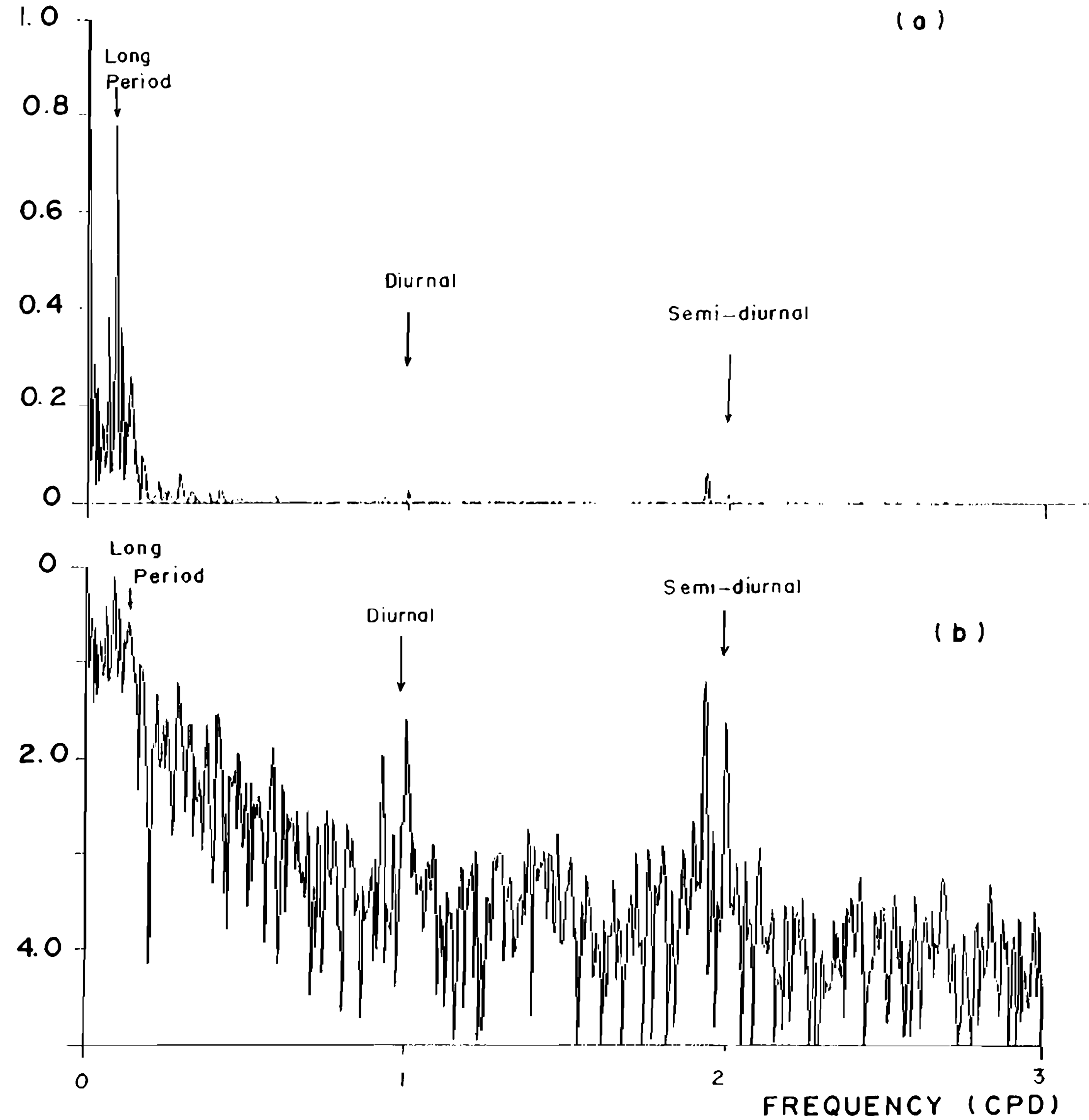


Figure 3. Power spectrum of two hour water level data between 2 January–30 June 1964 recorded at Samsun.

Short term representative data are reproduced in Figure 2 for Samsun and Trabzon. The records demonstrate low tidal amplitude at each monitoring station. Tidal amplitude is greater in Trabzon than Samsun (Figure 2). This provides evidence of smaller tidal amplitudes at intermediate points and is in accord with the previous findings of ENDROS (1932). The records indicate, as already described, that sea level fluctuations due to tidal effects are small. Ranges of greater magnitudes are observed due to meteorological phenomena. Long period fluctuations which have a period of several days are consistent throughout the records, but they do not always relate to the same period of time.

Irregularities are observed in the Samsun data. Sea level variation at Samsun shows evidence of wind set-up. This is due to the different exposure to the wind and to pressure response at each location. These in turn show that the water level movements are more often disturbed by local oscillations. At intermediate points, water movements are dominated by wind and atmospheric pressure and cyclone movements.

The results from spectral analysis of two-hourly sea level data are shown on a linear and logarithmic scale in Figure 3. Figure 3a shows that the water level fluctuations are dominated by energy inputs of long period range. In the tidal period range, fluctuations are dominated by energy inputs of semidiurnal frequency with secondary contributions from diurnal fluctuations.

Due to the length of the sampling interval in the analysis, the shortest period of oscillation that can be resolved is 4 hr; consequently, the shorter period oscillations do not appear in this analysis. The logarithmic plot (Figure 3b) expands the presentation into the higher frequencies by enhancing the representation of the smaller energy inputs. The characteristics of a linear plot (Figure 3a) are again apparent, but semidiurnal, diurnal and shorter period contributions are also shown. In order to examine the short period oscillations in more detail, a 30-day record from Trabzon which possesses higher amplitudes and short period oscillations was analysed using a sampling interval of 1.0 hr (Figure 4). The presence of short period oscillations with periods of 7.4, 5.6, 5.0, 4.5, 3.8, and 2.5 hr are distinguishable. Figure 4 combined with Figure 3 demonstrates the presence of weak higher order contributions generated by the basin.

In order to investigate low frequency contributions in sea level variations, a $X_0$ filter (IOC-UNESCO, 1985) is used to eliminate diurnal and semidiurnal oscillations and the results are presented in Figure 5. Time representation of the low frequency part of the tidal record presented in Figure 5 revealed almost-persistent oscillations with periods from 5 to about 20 days modulating sea level variations of longer periods. These oscillations are generally associated with the natural periods of occurance of cyclones in mid latitudes. Considering this fact, it seemed useful to make a comparison between the sea level and atmospheric pressure data at Samsun in order to test for a possible correlation between these phenomena. Accordingly, a power spectrum was worked out on the atmospheric pressure and filtered sea level data (Figures 6 and 7) for approximately the same period. The sea level fluctuations indicate significant variability in the 5–21 day periods (Figure 6). Similar spectral bands have also been observed in barometric pressure. Spectral analysis of hourly barometric pressure from Samsun station demonstrate long period variation of frequency $< 0.3$ cpd (Figure 7) which correspond to long period oscillations in water level. It is evident from these analyses that sea level and atmospheric pressure at Samsun are characterized by significant oscillations at 7.7 days. The existence of a well defined correspondence between the energy peaks in the two spectra is a doubtless consequence of a hydrostatic effect of the atmospheric pressure on the sea surface; *i.e.*, the well known "inverse baro-

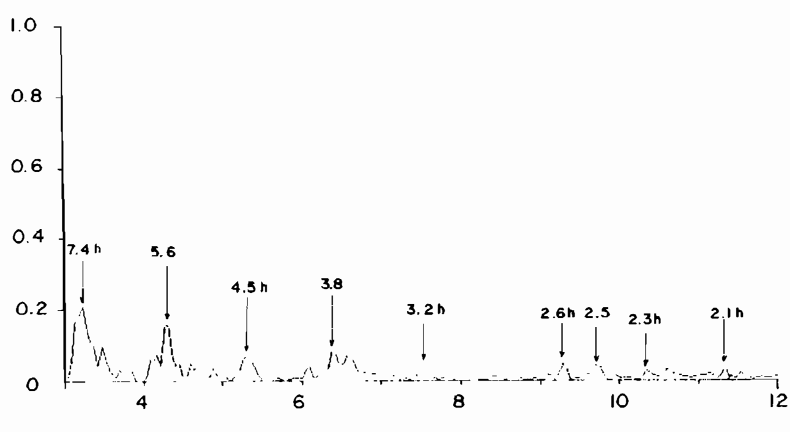


Figure 4. Spectral analysis of hourly sea level data for Trabzon.

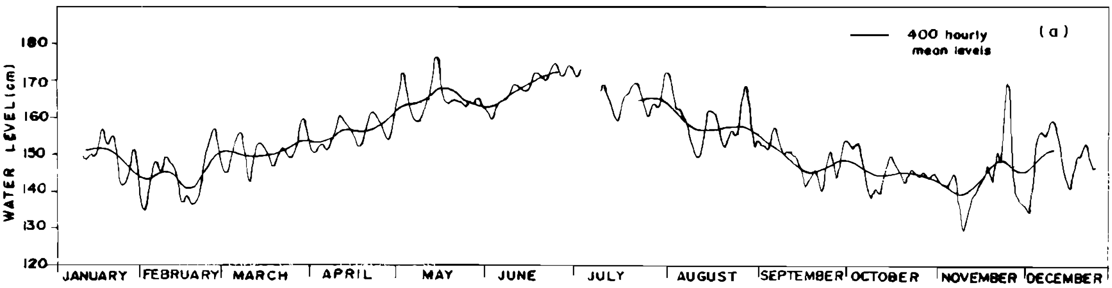


Figure 5. Daily and 400 hourly mean water level at Samsun.

metric effect". Figure 5 demonstrates the presence of fluctuations of water level throughout the year caused by meteorological forces and river runoff. Ranges of greater magnitude are produced by wind effects within a duration of 2–4 days. For the eastern Black Sea coast, the average monthly mean sea levels were calculated for Samsun using 12 years (1962–1973) of monthly mean values compiled by GENERAL COMMAND OF MAPPING (1991). The fluctuations of mean sea level are shown in Figure 8 and in Table 2. It is seen that the curve has a maximum in June and a minimum in November.

The maximum range between extremes is about 18.6 cm for the average monthly mean sea level. Annual progress of water level is in accord with annual fresh water cycle of the Black Sea. Water level increases to a maximum around June which suggests approximately a one-month lag time from the Danube where the maximum monthly runoff is found in May during the period 1928 to 1959 (DAMOC, 1971). The minimum mean monthly water level is observed around October–November.

Numerical analysis of the energy distribution was carried out. Distribution of the total energy in the records at different frequency bands are shown in Table 3. It displays the importance of long period oscillations. The contribution of higher frequency oscillations are higher than the diurnal. It indicates that the long period energy input becomes dominant in the central part of the Black

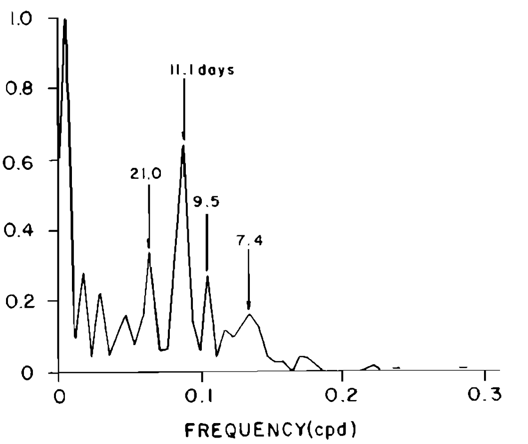


Figure 6. Spectral analysis of mean sea level data calculated by $X_0$ filter (IOC-UNESCO, 1985) for the Samsun 2 January 30 June 1964 data.

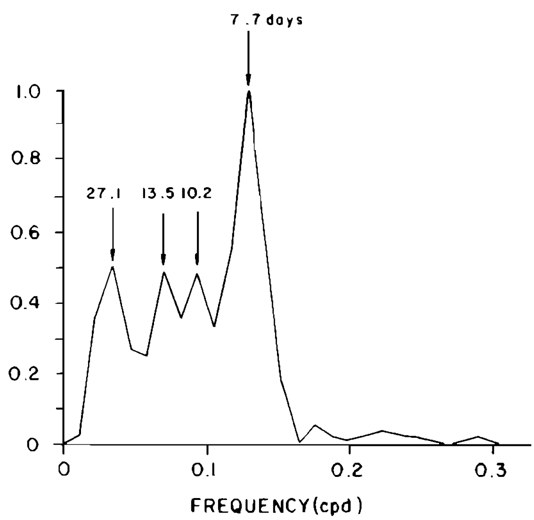


Figure 7. Spectral analysis of hourly barometric pressure for the 1 January 30 July period observed at Samsun.

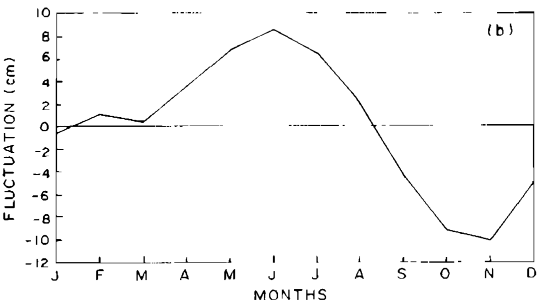


Figure 8. Fluctuations of the mean monthly water level at Samsun for the years 1962 1973.

Sea and decreases farther west. It shows quantitatively that tidal energy input is not important and that its energy input decreases toward the east.

Two-month data abstracted from Samsun and Trabzon have been analyzed for their constituents. The amplitude values of the 4 main constituents are presented in Table 4. These are the semidiurnal lunar ($M_2$) and solar ($S_2$) constituents, the soli-lunar diurnal ($K_1$) and the main lunar diurnal ($O_1$) constituents. Mean spring $2(M_2 + S_2)$ and mean neap $2(M_2 - S_2)$ tidal ranges and form numbers are included in Table 4.

The tidal amplitudes demonstrate the importance of the various constituents. In both of the stations, the most important constituent is the $M_2$. Its amplitude is small at both stations. But higher amplitude values are observed at Trabzon. Low amplitude diurnal constituents cause a minor diurnal inequality. Tides are small in amplitude with a spring range of 3.22 and 7.18 cm at Samsun and Trabzon. Since tides are small, they are masked by the long period fluctuations caused by wind and atmospheric pressure. The form numbers ($F = (K1 + O1)/(M2 + S2)$) demonstrate $S_2$ that the tides at both Samsun and Trabzon are dominantly semidiurnal in character. Lunar fortnightly tide $S_2$ have amplitudes of 0.35 and 1.2 cm at Samsun and Trabzon respectively.

Table 3. *Distribution of energy percentages in the record.*

| Frequency | Trabzon | Samsun |
|---|---|---|
| Low frequency (0 ~ 0.8) | 73.6 | 91.5 |
| Diurnal (0.8–12) | 5.5 | 1.9 |
| Semidiurnal (1.8–2.2) | 15.8 | 3.5 |
| Others | 5.1 | 3.1 |
| Total energy in record | 100.0 | 100.0 |

## CONCLUSIONS

Long period, tidal and short period oscillations have been identified in water level data from Samsun and Trabzon located in the eastern Black Sea. The long period oscillations are associated with mesoscale meteorological phenomena and river runoff. The periodical vertical rise and fall of water level in the eastern Black Sea from astronomical influences is small. Semidiurnal tidal constituents are dominant in the tidal period range. Mean spring ranges are 3.22 and 7.18 cm, respectively, at Samsun and Trabzon. Tidal ranges are small at intermediate points which are in agreement with previous findings. Short periods of oscillations, which have periodicities 7.4, 5.6, 4.5, 3.8, and 2.5 hr, are in accord with earlier results (ENDROS, 1932).

Although water level variations are small, there is, however, a regular fluctuation of water level throughout the year caused by meteorological phenomena. In the Black Sea, these fluctuations may be produced by wind and pressures, but ranges of greater magnitude may be produced by river runoff and seiches. These ranges increase rapidly in spring and early summer. Annual progress of water level is in accord with the fresh water cycle of the Black Sea.


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Table 2. *The seasonal fluctuation of the monthly mean sea level (January-December: relative to the annual mean sea level), in cm.*

| Month | J | F | M | A | M | J | J | A | S | O | N | D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Fluctuations | 0.5 | 1.1 | 0.4 | 3.4 | 6.8 | 8.5 | 6.6 | 2.2 | 4.4 | −9.2 | −10.1 | −4.9 |

Table 4. *Tidal harmonic constituents (amplitudes in cm).*

| Stations | $M_2$ | $S_2$ | $K_1$ | $O_1$ | Mean Spring Range | Mean Neap Range | Form Number |
|---|---|---|---|---|---|---|---|
| Samsun | 1.05 | 0.56 | 0.38 | 0.25 | 3.22 | 0.98 | 0.39 |
| Trabzon | 2.12 | 1.47 | 1.10 | 0.64 | 7.18 | 1.30 | 0.48 |

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