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SECULAR SEA LEVEL VARIATIONS ALONG THE TURKISH COASTS

TÜRKİYE DENİZLERİNDEKİ UZUN SÜRELİ SU SEVİYESİ DEĞİŞİMLERİ

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Abstract

The characteristics of secular sea level variations along the Turkish coasts have been investigated based upon a sequence of hourly sea level observations at Samsun, Karşıyaka (Izmir) and Antalya. Significant monthly oscillations were calculated from the power spectral estimates; which occur at 12, 6, 4 months periods at Samsun; 21.3, 12, 6, 5, 4.1 months at Karşıyaka and 12, 6, 4 months periods at Antalya. For secular changes, the decreasing trend at Samsun tide station, -6.9 mm per year, is contrary to the secular rising trend of the Black Sea probably because of its rather short monitoring period (1963-77). A rise of 3.2 mm per year in annual sea level is computed for Karşıyaka (1935-71). A linear decreasing trend (-0.4 mm per year between 1935-77) has been observed for annual sea levels at Antalya.

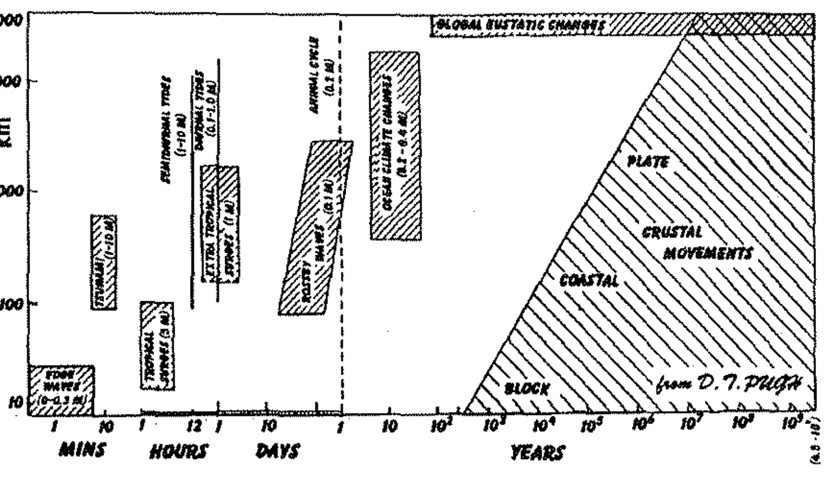
Introduction

Sea level variations provide a wealth of information on the highly variable nature of the boundary between the land and sea. Monitoring of the global sea level changes is one of the most comprehensive oceanic research today. This program provides data collected from a network of more than 200 permanent tide gauges (IOC, 1994). Standard measuring techniques, methodologies and data banks were developed so that data from different regions can be compared.

Sea level variations result from the integrated effect of a variety of physical processes spanning a broad range of spatial and temporal scales (Figure 1). High-frequency sea level variations with periods from seconds to hours are dominated by wind waves, seiches, tides, storm surges and occasional tsunamis. Slower movements of sea level with periods from days to years are mostly associated with transient synoptic scale meteorological features, ocean circulation patterns, seasonal and other short-term climatic fluctuations. The longer-term (secular) changes of global mean level, which may cause a global rise in the MSL between 1.1 and 1.8 mm per year, are associated with global scale processes. They are related to; (i) changes in ocean volume mainly arising from large-scale climate variations and ice melting; and (ii) time-varying deformation of the Earth's crust caused by the changes in glacial loading, plate tectonics, volcanism and sedimentation (NRC, 1990; Douglas, 1991).

The characteristics of the secular sea-level changes may be extracted from historical sea level records by careful analyses. The secular changes may show linear or higher degree polynomial variations reflecting the integrated effect of long-period tidal variations (longest 18.6 years), variations in ocean circulation due to climatic changes, eustatic changes and land/ocean plate deformations (Hekimoğlu, 1990).

Figure 1. Space-time relationship of sea level variations (by D.T. Pugh, cited in IOC, 1990).



The chronological graph of the mean annual sea levels along the Black Sea coast (Figure 2) points out the long-range mean sea level variations (Figure 3). A continual rising trend can be seen in all observational points. The quantitative analysis of these trends indicated the rise of the Black Sea mean level varies from one point to another along the coast. For instance, in Varna, Constanza, Sulina, Odessa and Sevastopol the rise is of 3.3, 2.7, 3.7, 7.1 and 3 mm/year, respectively. The greatest rise in the Black Sea mean level is recorded in Poti (8.2 mm/year) and the lowest in Kerci (1.3 mm/year) (Bondar, 1989). These secular changes (rise) are due to the joint action of eustatic movements and land subsidence. The mean subsidence speeds of the Black Sea coasts are about 5.2, 1.1 and 6.5 mm/year at Odessa, Ialta (Sevastopol) and Poti, respectively (Lisitzin, 1974; Bonder, 1989) and eaustatism is assessed at about 1.1 mm/year. On the other hand, the rise of the Mediterranean Sea mean level is of about 5.3 mm/year (Lisitzin, 1974).

The quantitative analyses of the trends for the Aegean and Eastern Mediterranean indicate mean sea level rises in Thessaloniki (2.1 mm/year), Karşıyaka (0.2 mm/year), Leros (3.7 mm/year), Antalya (0.1 mm/year), Beyrouth (0.1 mm/year) and Port Said (6.6 mm/year). The greatest rise in mean sea level is recorded in Kios (7.3 mm/year) between 1969-76. Decreasing slopes were reported in Aleksandroupolis (-0.2 mm/year), Kavalla (-3.6 mm/year), Rodhos (-1.0 mm/year) and Jaffa Port (-0.8 mm/year) (Mosetti and Purga, 1991). They give the average eustatic sea level rise for the Mediterranean Sea to be 1.1-1.6 mm per year.

From paleogeographical evidence, Kayan (1988), Emery and Aubney (1991) have found a subsidence of 4.6 mm per year along western Anatolian coasts for the Late Holocene that might be because of the compression of marine sediments. Flemmimg et al (1973) reported an about 2 m relative sea level rise at the southwestern Turkey during last 4000 years but they did not state if it was because of eustatic or tectonic movements.

Materials

Sea level measurements are used in vertical datum determination for national mapping (Hekimoğlu and Şanlı, 1993). The surveys of the network of vertical control points were started by the establishment of the permanent tide gauges at Antalya (1935), Karşıyaka (1936) and Samsun (1961) (Table 1). These gauges were destroyed in 1970's and replaced by new ones at Antalya, Bodrum, Menteş (İzmir) and Erdek (Figure 2) in 1985 by the General Command of Mapping.

Figure 2. Chart of the Turkish Seas showing sea level and meteorological station locations mentioned in this text.

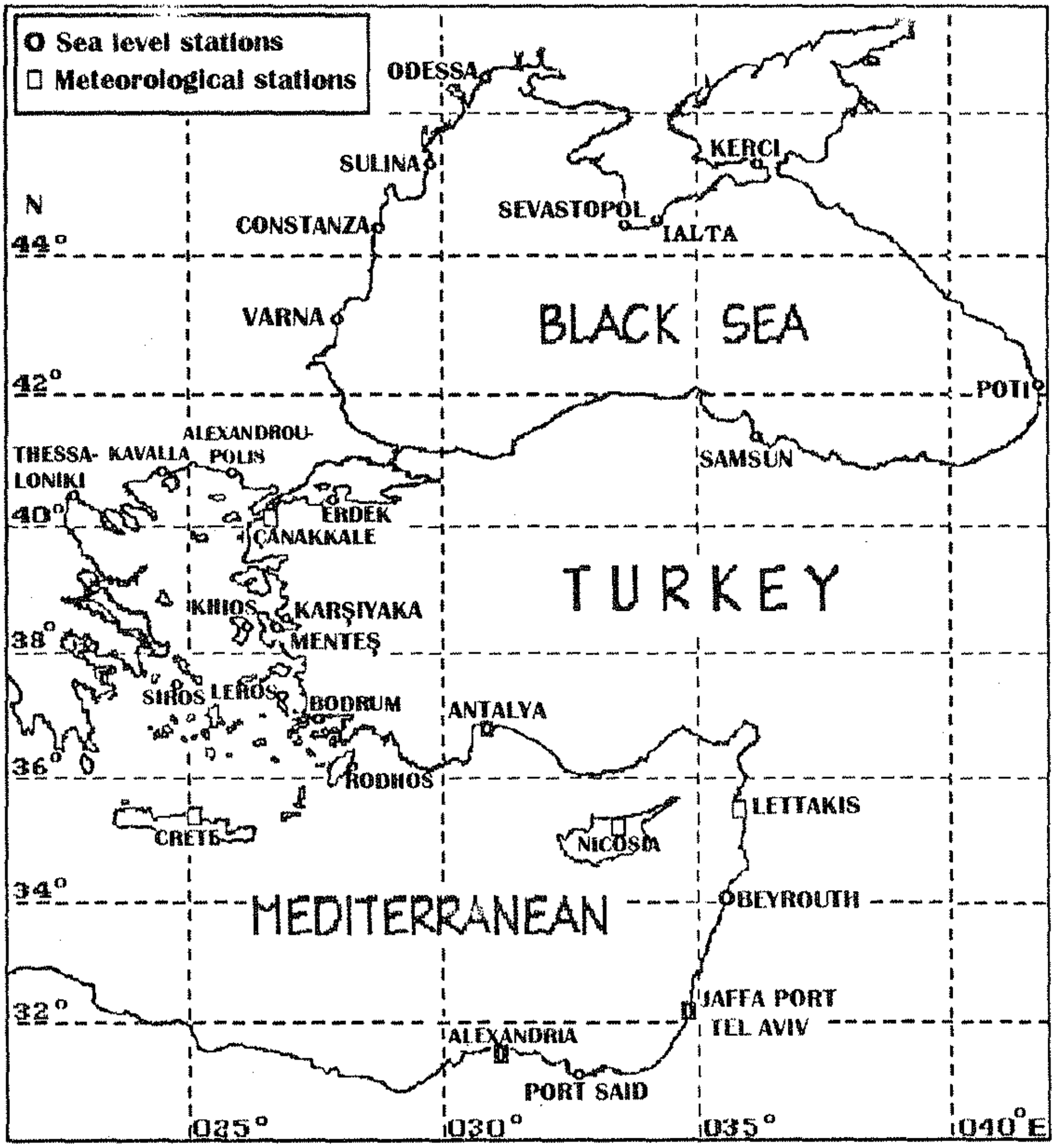


Table 1. Permanent tidal gauges used in this study

	Obs.Period	North	East
Samsun	1961 - 83	41 18 44	036 20 18
Karşıyaka	1936 - 77	38 27 23	027 07 12
Antalya	1935 - 77	36 53 13	030 42 09

Each site has its own independent bench marks and local datum, the tide staff zero. These parameters were used for the national network of vertical control points, but given up soon because some important differences aroused at distant common points (Özgen and Algül, 1977). Therefore national network of vertical control points, except for the Eastern Mediterranean, based on the MSL which were calculated by taking simple arithmetic average (22-year) from Antalya tide station. This matter is still under consideration by the General Command of Mapping. In this study, secular characteristics of sea level variations were calculated using hourly sampled tidal data at Samsun, Karşıyaka and Antalya compiled by the General Command of Mapping (1991). The historical data were collected by means of mechanical float type tide gauges. The case stories of the historical permanent tide gauges will be given below.

a. Samsun Tide Station

It is established at the end of a concrete pier where the commercial vessels port on June 8, 1961. It has two wells. But its outer connecting pipe is not sufficiently deep. Tidal records are daily from the beginning to May 31, 1971, and weekly later on. A new bench mark (MAR-1) is established in the house at June 22, 1978 instead of destroyed old bench mark (R- 61). The new bench mark was found to be only 5 mm different vertically during a visit made 10 years later in 1988 (General Command of Mapping, 1991).

The elevation of the new bench mark derived from tide gauge is 1207.3 mm and the mean height of the same bench mark calculated from 1978-83 records is 305 mm. The zero of the tide staff was given as 2350 mm from its establishment to May 1962; 2650 mm in June 1962; 2719 mm on September 25, 1962; 2638 mm in September 1966; 2445 mm on August 3, 1970 and 2225 mm from October 1974. The new bench mark is given above the zero of the tide staff as 853 mm between 1961 and April 1964 and 880 mm between May 1964 and June 1978 (General Command of Mapping, 1991).

b. Karsiyaka Tide Station

Since it was established at inner port near the pier in July 1936, affected by pollution and water movements generated by the ships. It has two wells without connection pipes but with an irregular channel. Low sea levels were not monitored due to insufficient depth of water for extreme low tides.

The hourly sea level records between 1936 and 1962 were lost, but fortunately their monthly minimum, maximum and averages are available based on the bench mark (R-37). This bench mark is near the gate of the tide house (at least between the period of 1936-52) and 1203 mm above the instrument zero. For the measurements between 1936 and 1952 the MSL was calculated as 1334 mm below R-37 (Aykulu, 1952).

The marigrams are weekly between January 1962 and June 1963 and daily beginning from July 1963 with a negative vertical shift of 1200 mm. The records are again weekly from 1967 August. There are sudden vertical changes on the marigrams recorded after June 13, 1968 reaching up to 40 cm. They are probably caused by the temporal changes in the response function of the system due to marine growth at the orifice. The vertical shifts were obtained as; 5000 mm upward (from 1250 mm to 1750 mm) in early February 1972; 1000 mm downward (from 2100 mm to 1100 mm) on February 18, 1974; a total of 5000 mm upward caused by two events in November 1975; 750 mm downward (from 1930 mm to 1180 mm) in the beginning of 1976. There is a large gap between December 1976 and May 9, 1977 due to a failure.

The zero of the tide staff was given as 4895 mm from beginning to June 1963; 3530 mm in July 1963; 3724 mm in October 1967; 3935 mm in October 1968; 4220 mm in December 1973 and 3284 mm in February 1974. The bench mark is given above the instrument zero as 1203 mm from its establishment to June 1963; 1078 mm in July 1973; 1272 mm in October 1967 and 1115 mm after December 1973 (General Command of Mapping, 1991).

c. Antalya Tide Station

A Swiss made R.A. Neuchatel tide gauge was established in 1961 with one well. It has precise bench marks. It has worked until October 31, 1977 with short gaps. All of its data is available. The marigrams are weekly from beginning to October 13, 1955 and daily later on with a negative vertical shift of 1500 mm.

The zero of the tide staff was given as 4730 mm from its establishment to February 1940; 4391 mm between March 1940 and October 13, 1955; 2900 mm in October 14, 1955; 3.190 mm on June 11, 1956; 3200 mm on April 1, 1957 and 3030 mm from October 1973 to the end. The inner bench mark is given above the instrument zero as 742 mm between 1935 and October

1973, and 1226 mm later on. This difference was not observed on the marigrams but observed on the maximum and minimum sea levels from the bench mark (R-36). Although there is no printed documentation about this matter, it is believed to be caused by a possible bench mark move (General Command of Mapping, 1991). This bench mark, which is near the gate of the tide house between the period of 1935-52, is 742 mm above the instrument zero and the MSL was calculated as 1414 mm below the bench mark (Aykulu, 1952).

Quality Control and Data Processing

Quality control insures the scientific validity of the sea-level data. Three main aspects are emphasized: the linking of the data to a reference level, timing, and replacement of short gaps and spikes.

Since the main purpose is to produce scientifically valid sea- level data that are linked to a local datum, defined by the zero of the tide staff, quality assurance begins at the tide station. The procedures for the establishment of a tide staff and the associated network of vertical control points are described, and common reference level problems and correction techniques are discussed in IOC (1985) and will not be given in this paper.

All of the original hourly values were plotted in order to inspect the problems such as data spikes, datum shifts, timing errors and other spurious features in the data. The plotting programs are primary means used to choose the time period with the least problems. The vertical datum for each tidal station was reduced to an arbitrary constant level covering the whole period of observations by correcting the datum shifts in the records.

Timing errors are introduced into the data due to mistakes during data processing or more commonly due to inaccuracies in the time-maintaining mechanisms of sea level gauges. The errors are evident in the plot of residuals as periodic fluctuations. Timing errors in the observed data that are due to shifts of exact increments of an hour were corrected by using the software package developed by TOGA Sea-level Center (Caldwell, 1991).

Short gaps are a common problem in most sea level time series records. The predicted tide method for filling gaps requires yearly files of observed and corresponding predicted data. The predicted tides are shifted in time to match the timing characteristics of the observed series for the month with the short gap. The residuals between the shifted predicted and the observed data were calculated. Then, a linear interpolation between the end points of the gap in the residual series is performed and each interpolation constant was added to the shifted predicted tides over the span of the gap.

The test for 'upside down' data were performed for all stations, if the MSL data are quoted as the distance below a bench mark height rather than above it. The most sensitive test to guard against such an error is an inspection of the seasonal cycles which, for 'upside down' data, would appear opposite to that observed in neighboring records and opposite to meteorological expectations. Only 1936-62 the data for Karşıyaka was found to be 'upside down' and inverted taking into account the remaining part of the data set. The inverted time series of Karşıyaka monthly averages were plotted together with those of Antalya and Famagusta (Figure 4) for comparison.

The daily averages were calculated using a two-step filtering operation from hourly sea-level data by the package program of the TOGA Sea-level Center (Caldwell, 1991). First, the dominant diurnal and semi-diurnal tidal components are removed from the quality controlled hourly values. Secondly, a 119-point convolution filter (Bloomfield, 1976) centered on noon is applied to remove the remaining high-frequency energy and to prevent aliasing when the data are computed to daily values. The 95, 50, and 5% amplitude points are 124.0, 60.2, and 40.2 hours, respectively. The Nyquist frequency of the daily data is at a period of 48 hours which has a response of about 5% amplitude, thus, aliasing is minimal. The primary tidal periods have a response of less than 0.1% amplitude.

The monthly values are calculated from the daily data with a simple average of all the daily values in a month. If seven or fewer values are missing, the monthly value is calculated. Finally, the annual mean sea levels were computed by taking averages of the monthly mean sea levels.

A linear fit was made to the annual time series to calculate linear trends. To get more confident results, any individual monthly mean value more than 4.5 standard deviations from the fitted line was dismissed. Then a second linear fit was made to the remaining time series to calculate linear trends.

Monthly sea-level data sets were used in calculating the power spectra. Trend and mean were removed and a Hamming window which consists of a half period of a cosine function was applied to the data sets. The tapered sets 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 frequency resolutions are 0.007812 cycles per month for seasonal and 0.023437 cycles per year for annual spectral analyses. The results were plotted as power spectrum against seasonal and annual frequencies.

Results and Discussion

The short-term representatives of the sea-level records obtained from Samsun, Karşıyaka and Antalya tide stations (Figure 5 a) demonstrate small amplitude tidal (Figure 5 b) and non-tidal (residual) (Figure 5 c) fluctuations superimposed on the long- period oscillations. The mean spring ranges are 3.5, 17.3, 22.6 cm for Samsun, Karşıyaka and Antalya, respectively (Alpar, 1993). The long-period oscillations in the records are due to long-period tidal constituents and meteorological influences and can be identified by examining the variations in MSL. These long-period oscillations with a periodicity of several days are probably meteorologically induced, and their frequency is probably related to large-scale cyclic atmospheric patterns in the regions. The filtered daily averages were superimposed on the long-period residual oscillations (Figure 5 c).

The records of the monthly mean sea level are analyzed to find out the significant monthly oscillations from the power spectral estimates. The dominant seasonal sea level fluctuations occur at 12, 6, 4 months periods at Samsun; 21.3, 12, 6, 5, 4.1 months at Karşıyaka; 12, 6, 4 months periods at Antalya (Figure 6). These results agree with those given by El-Gindy (1988) for Izmir (6, 5, 4.1 months) and for Antalya (12, 6, 2.7 months). The results of the spectral analysis of the monthly mean barometric pressures for some stations in Aegean and Mediterranean (Table 2) explain most of the seasonal sea level oscillations occurring at 12, 6 and 4 month periods in the Mediterranean Sea, but not those in the Aegean Sea where the steric effect has an important contribution.

Table 2. Spectral characteristics of the monthly mean barometric pressure (El-Gindy, 1988).

Station	Time	dof	period of significant peaks (months)
Çanakkale	1955-74	13	12, 6, 4, 3, 2.4
Crete	1955-74	13	7
Antalya	1955-74	13	12, 6, 4, (3.6 .... 3.1)
Nicosia	1955-69	10	36, 12, 6, 4, 3.6
Tel Aviv	1955-74	13	12, 6
Lettakis	1956-75	13	12, 6, 4, (3.6 .... 2.1)
Alexandria	1963-75	10	12, 6, 4.5, 4, (3.6 .... 2.1)

The quantitative analyses of the annual mean sea levels in Samsun, Karşıyaka and Antalya indicate some distinct minimum and maximum values fluctuating around their third order polynomial fits (Figure 7). A linear fit is made to the time series and the sea level rises in annual means are computed to be -6.6, 4.2 and -0.5 mm per year at Samsun, Karşıyaka and Antalya, respectively. The values for Karşıyaka and Antalya are somewhat different from ones given by Mosetti and Purga, (1991). This may be partly because the data sets used in this study are 7-13 years longer than those used by Mosetti.

After the individual monthly mean values more than 4.5 standard deviations from the fitted line was dismissed, the secular changes in annual means were computed to be -6.9, 3.2 and -0.4 mm per year at Samsun, Karşıyaka and Antalya, respectively. The annual averages from

Samsun tide station between years 1963-77 were also added in Figure 3, together with its third order polynomial fit. Its trend, as if a continuation of the secular trend given for Varna, seems to be coherent with the secular trend of Constanza. The linear decreasing trend of Samsun annual means has a conflict with that of at Sulina for the same period of time, although the fluctuations around the trends have similar characteristics. This may indicate vertical land movements in reverse directions at these two distinct places. For tide stations placed where the tectonic movements were not expected; the secular trends of the records less than 30 years are 2-5 times steeper than those of the longer data sets more than 40 years, which are about +4 mm per year (Hekimoğlu, 1990). So it would be dangerous to tell something about the long-term trends from relatively short data sets, such as at Samsun.

The power spectra of the monthly averages of the sea-level data for Karşıyaka and Antalya, which are sufficiently long time- series for such an analysis, were calculated. The spectral computations were made using one segment over the simultaneous data. There are periodicities around 42.6, 10.6, 7.1, 4.2, 2.7 and 1.7 years at Karşıyaka, while 42.6, 7.1, 3.8, 2.5 and 1.8 years variations are dominant at Antalya (Figure 8) besides annual and semiannual fluctuations given in Figure 6.

Figure 3. Variations of the Black Sea mean annual levels at Sulina, Constanza, Odessa, Sevastopol, Kerci, Ialta, Poti and Varna (Bondar, 1989). Annual averages calculated for Samsun were also added for comparison. Level units in cm.

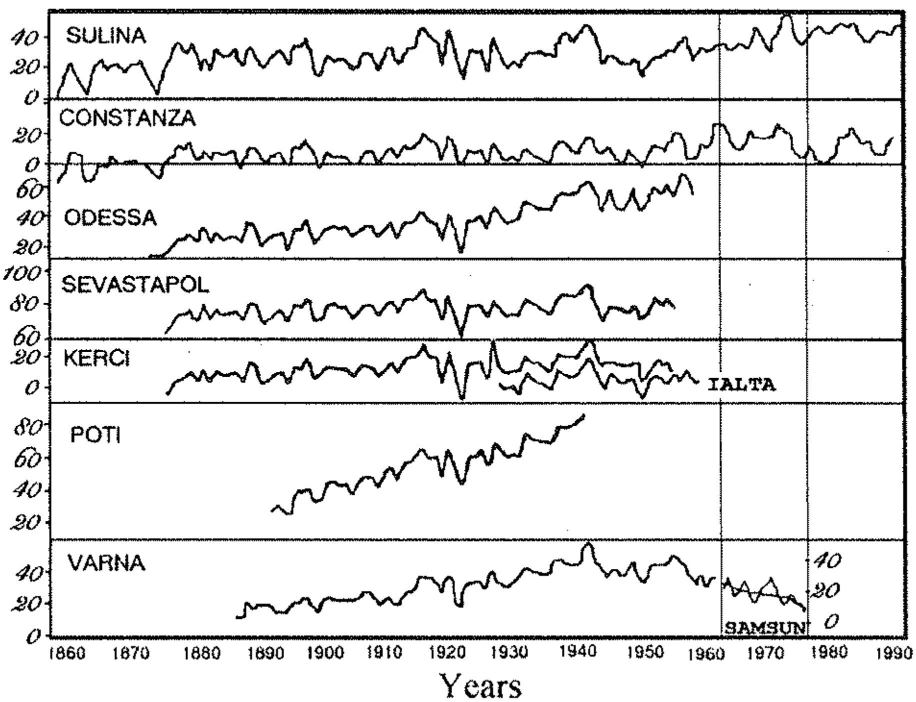


Figure 4. The comparison of the variations of the inverted Karşıyaka monthly averages, which was 'upside down' against the bench mark R-37, with those of at Famagusta (supplied by IOC, 1994) and Antalya for the period 1938-1940.

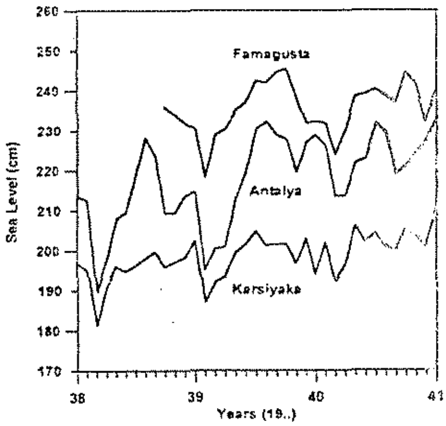


Figure 5. Sample records of (a) observed sea level, (b) predicted tides and (c) tidal free residuals from Samsun, Karşıyaka and Antalya. The open circle indicates full moon. The daily averages computed using the 119-point low-pass filter are superimposed on the residuals.

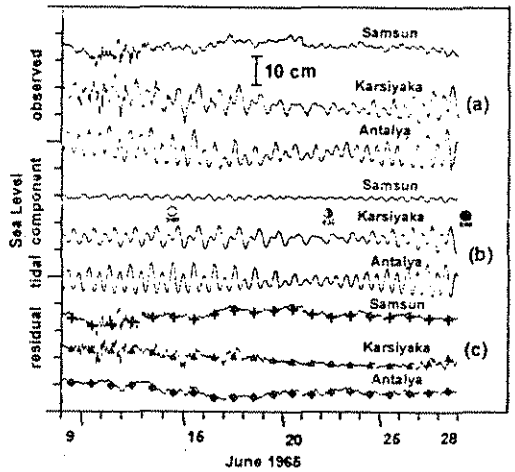


Figure 6. Power density spectra of the monthly sea level averages for seasonal periods at Samsun, Karşıyaka and Antalya. Degrees of freedoms are 6, 10 and 14, respectively.

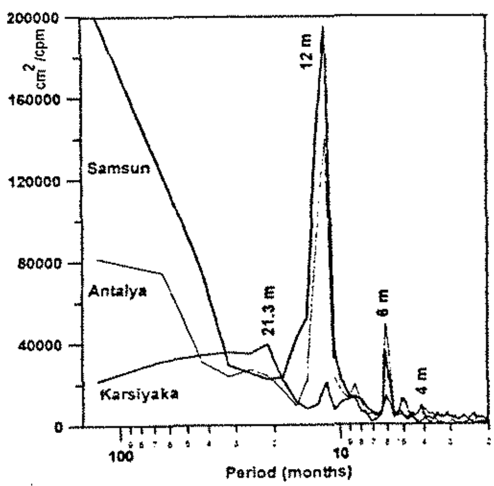


Figure 7. Variations of the mean annual levels at Samsun, Karşıyaka and Antalya. Third order polynomial fits are superimposed on data sets. The shorter data sets used in Mosetti's (1991) calculation were also added.

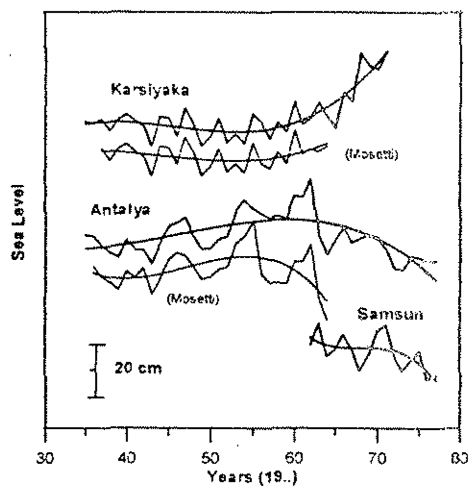
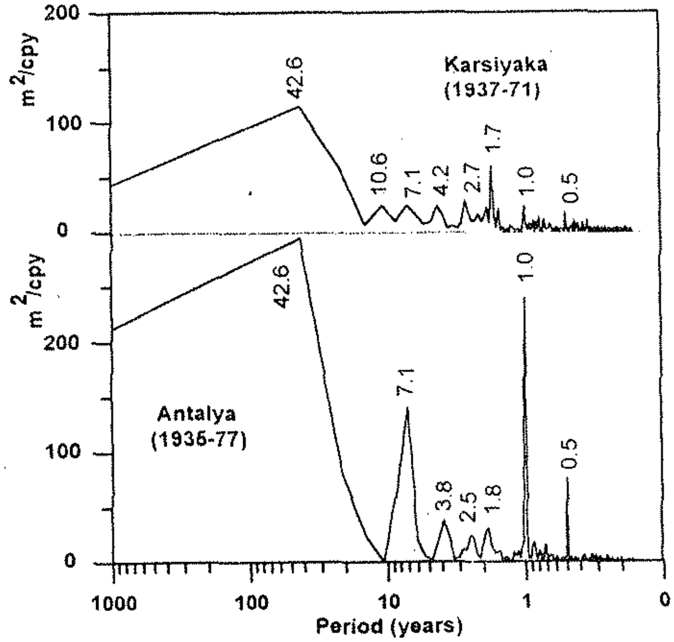


Figure 8. Logarithmic power density spectra of the monthly sea level averages for annual periods at Karşıyaka and Antalya.



Conclusions

The sea-level stations and records used in this study are found to be dependable enough although some deficiencies occurred due to the distribution of the responsibilities between different institutions, lost geodetic points, mistakes in choosing and establishment of the tide gauge stations.

Only sea level records of the tide stations which are regularly checked out for precise levelling, may give some important clues for the local land subsidence and plate tectonic movements. Therefore, the network of vertical control points on land relative to the tide staff zero should be controlled regularly. This will make possible the replacing of the tide staff at the same elevation during the progress of the observations, should it become destroyed or should its elevation be changed by accident.

The records in a stilling well are likely to be significantly different from the true signal of sea level excursions at the well site due to the inherent non-linear problems of stilling wells; currents in the vicinity of the station, exposure to surface waves and the influence of local density changes (Lennon and Mitchell, 1992). Therefore, the performance of the instrumentation needed to be examined more closely.

Studying eustatic changes needs high-quality continuous data. But the lack of sufficient information prevented us to archieving the desired results. An urgent necessity, taking account of the eustatic and tectonic movements, is the establishment of a permanent archive that contains quality- controlled data at hourly, daily, and monthly intervals written in standardized formats suitable for incorporation into international archives, where sea-level data are available to the scientific community for exchange and analysis. Existing studies need to be improved based on the results of these analyses.

Özet

Samsun, Karşıyaka (Izmir) ve Antalya'da kaydedilmiş saatlik su seviyesi verileri kullanılarak, Türkiye denizlerindeki yüzyıllık su seviyesi değişimlerinin karakteristikleri incelenmiştir. Güç yoğunluk spektrumlarından, peryotları Samsun'da 12, 6, 4; Karşıyaka'da 21.3, 12, 6, 5, 4.1; ve Antalya'da 12, 6, 4 ay olan mevsimsel salınımlar saptanmıştır. Yüzyıllık değişimlere bakıldığında, Samsun'da ortalama su seviyesi yılda -6.9 mm azalmaktadır. Bu sonucun Karadeniz'de ortalama su seviyesinin yükseldiği gerçeğine ters düşmesinin nedeni gözlem peryodunun kısa olmasıdır (1963-77). Karşıyaka için 1935-71 gözlem peryodunda yılda 3.2 mm bir yükselme ve Antalya için 1935-77 gözlem peryodunda yılda -0.4 mm bir alçalma hesaplanmıştır.

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