Scientific Research and Essays Vol. 5(10), pp. 1100-1110, 18 May, 2010
Available online at http://www.academicjournals.org/SRE
ISSN 1992-2248 © 2010 Academic Journals

Full Length Research Paper

The investigation of long-term sea level variations at Antalya-I (1935-1977) and Antalya-II (1985-2005) Tide Gauge Stations (Turkey)

Erdinç Sezen[1] and Tamer Baybura[2]*

[1]Department of Geodesy, General Command of Mapping, 06100 Dikimevi, Ankara, Turkey.
[2]Department of Survey Engineering, Faculty of Engineering, Afyon Kocatepe University, 03200 Afyonkarahisar, Turkey.

Accepted 4 March, 2010

In this study, quality control of Antalya-I and Antalya-II Tide Gauge Stations was realized by scientific methods. Seasonal and long-term sea level variations were investigated by using hourly sea level information. Seasonal (for a year and for half a year) variations, average sea level and sea level velocity were calculated according to the least squares method, with an equation having a harmonic function mathematical model. Separate and joint information of Antalya-I and Antalya-II Tide Gauge Stations were analyzed. As a result, the average sea level velocity of Antalya-I (1935 - 1977) Tide Gauge Station was determined as 1.00 ± 0.3 mm/year and the average sea level speed of Antalya–II (1985-2005) Tide Gauge Station was determined as 4.4 ± 0.7 mm/year. According to calculations using joint information, an average sea level velocity for the 1935 - 2005 period was determined as 0.2 ± 0.1 mm/year.

Key words: Tide gauge station, sea level variations, tide, trend, harmonic analysis.

INTRODUCTION

Sea level variations are the results of events occurring in a major part of the time scale which has a range changing from years to seconds. The average sea level at the coast, an appropriate time period for which can be defined as one month or one year to eliminate the effects which result from tides and waves, can be defined as the average sea level height which was measured according to a fixed reference point on the land (IPCC, 2001). These average values are known as relative sea level variations since they are mobile according to the continent on which the station is built. These measurements also include the tectonic movements of the continent. Sudden displacements as a result of earthquakes and heavy tectonic land movements caused by sedimentation and precipitation have a significant influence on the sea level (IPCC, 2001). These effects are separated from sea level measurements and the absolute sea level is obtained by means of the geodetically measurements realized in these stations.

As a result of industrialization, the amount of greenhouse gases in the atmosphere has increased and this has resulted in an increase in the world's temperature, which is known as global warming. Due to this warming, big ice layers in the Polar Regions dissolve and the amount of water joining the oceans increases. By means of the dissolving of the ice layers, the average global sea level increased by more than 100 meters above that of the last maximum ice age, which was 20,000 years ago (IPCC, 2001). A big mass transfer from the ice layers to the oceans caused a sea level rise and movements in the earth are covering (IPCC, 2001). The temperature increase resulting from global warming leads to more warming of the ocean surfaces and causes expansion. The determination of long-period trends in sea levels can be possible by using long-period sea level records. Especially in the Mediterranean region, at least 30 years' information is necessary for the determination of a linear period having a standard variation less than 0.5 mm/year (Zerbini et al., 1996). The average sea levels which were obtained from long-period sea level information from tide

*Corresponding author. E-mail: tbaybura@aku.edu.tr.

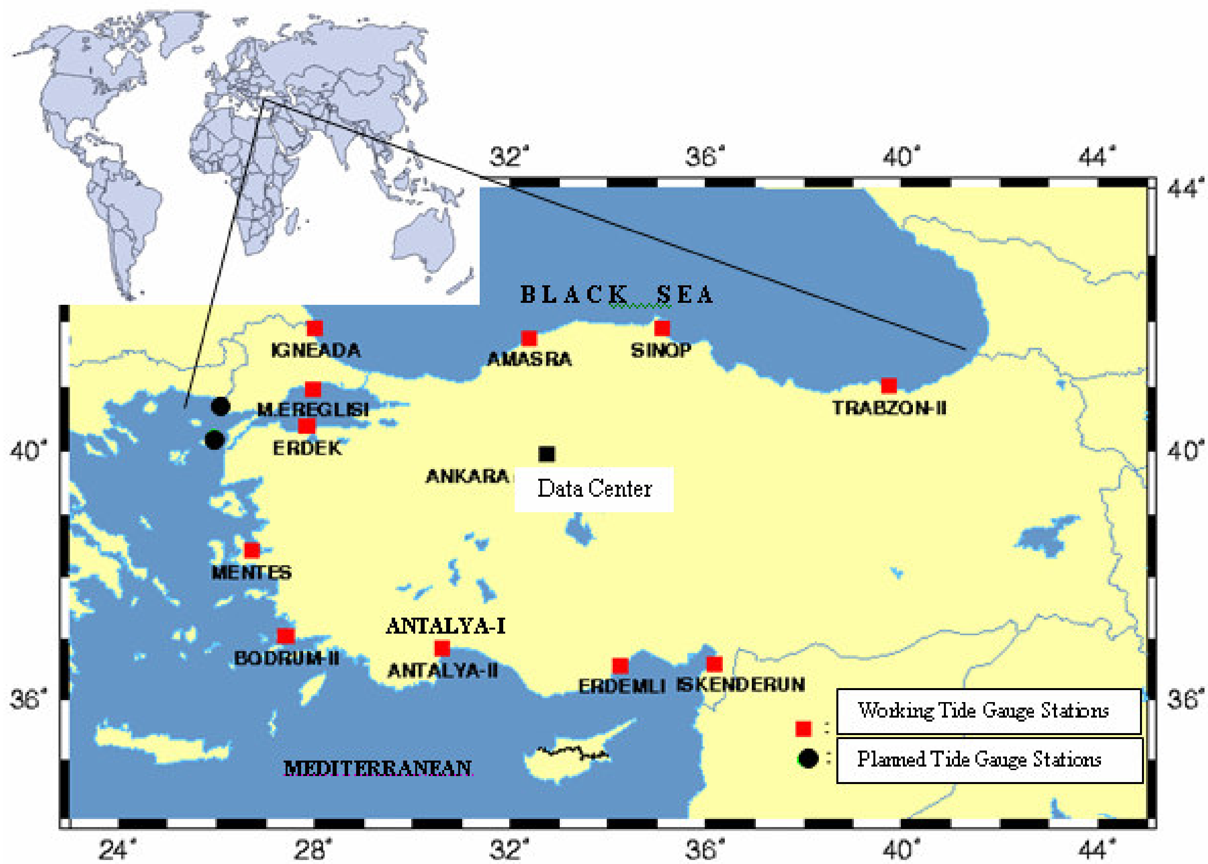

Figure 1. Tide gauge stations in Turkey. (URL 1. Accessed 7 Jan. 2008, prepared).

gauge stations are used as vertical data by assuming that they coincide with the geoids for a long time period.

In this study, the monthly sea level information is obtained from hourly sea level data gathered from Antalya-I and Antalya-II tide gauge stations. Analog (navigation-guided) record values of Antalya-I tide gauge station, which was active between 1935 - 1977, analog record values of Antalya-II between 1985 - 1998 and acoustic (numeric) values between 1999 - 2005 were considered as numerical inputs in the study shown on the map (Figure 1). (http://www.hgk.mil.tr/urunler/jeodezik/-resimler/image004.jpg, prepared).

Determination of tide gauge stations' local data

The carrying over of tide components which are measured at a tide gauge station to different far away geographic regions by means of leveling relationship nets is not thought to be suitable. In this study, however, two distinct stations which are 30 km apart from each other are joined by using data relationship and TUDKA-99 (Turkish National Vertical Control Network) measurement values by assuming that they are in the same region and have similar tide characteristics.

Sea level measurements in tide gauge stations are realized according to the tide gauge station's local data. For this reason, these data have to be carried over the same local data for use in sea level analysis. Local datum values did not stand constant for the Antalya-I tide gauge station, which is the first tide gauge station; local data had been changed continuously during general maintenance performed periodically after malfunctions and while devices were uninstalled. These changing values had not been kept regularly. For this reason, it was found that the necessary local data for providing continuity of local datum values of the station in itself have different values in different sources. In spite of all the research, there is no certain result for local datum values. In Figure 2, the average monthly sea level values, which are the sea level measurements obtained between 1935 - 1977 at different local datum values can be seen (the arrows signify important changes as show in Figure 2).

Local datum values determined by detailed investigations over different sources are balanced with the least squares method and subjected to significance tests of data integrity which were obtained from local datum values which are considered significant and provide the most appropriate data continuity; these are controlled according to the

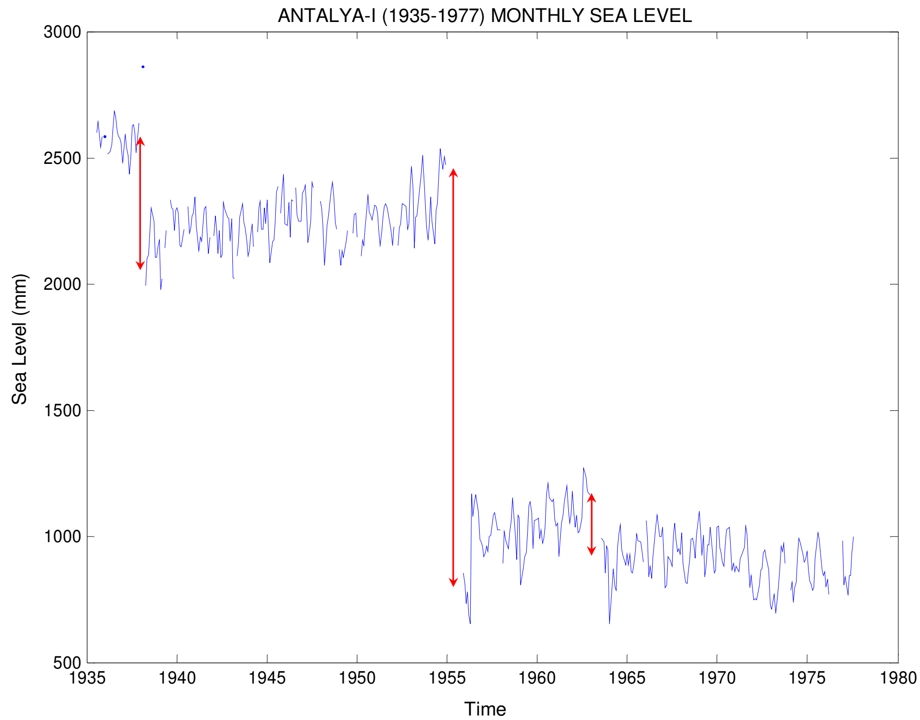

Figure 2. Monthly sea level variations of Antalya-I tide gauge station (1935-1977) according to changing local datum values.

Table 1. The local datum values at Antalya-I tide gauge station.

No.	Time interval	Local datum (mm)
1	08.06.1935 ($11^{\underline{00}}$) – 04.01.1938 ($02^{\underline{00}}$)	4730
2	10.01.1938 ($09^{\underline{00}}$) – 19.03.1938 ($07^{\underline{00}}$)	5000
3	26.03.1938 ($09^{\underline{00}}$) – 03.01.1955 ($10^{\underline{00}}$)	4391
4	13.10.1955 ($08^{\underline{00}}$) – 03.05.1956 ($07^{\underline{00}}$)	2900
5	03.05.1956 ($08^{\underline{00}}$) – 23.03.1957 ($08^{\underline{00}}$)	3190
6	24.03.1957 ($08^{\underline{00}}$) – 01.01.1963 ($07^{\underline{00}}$)	3200
7	01.07.1963 ($08^{\underline{00}}$) – 01.08.1977 ($07^{\underline{00}}$)	3030

estimated data for the same period.

If sea level time series are assumed to be coordinate time series, a mathematical model of a throw whose time is known can be written as (Williams and Teferle 2003; Williams 2003):

$$h_i = Z_0 + at_i + o_i \chi_{off} + \varepsilon_x(t_i) \qquad (1)$$

Where

$$o_i = \begin{Bmatrix} 1 & t_i \geq t_{off} \\ 0 & t_i < t_{off} \end{Bmatrix}$$

Z_0: Average sea level,

a: Trend,

χ_{off}: Throw quantity (offset),

$\varepsilon_x(t_i)$: Error.

According to this, the design matrix (A) and unknown vector (×) are as follows. For each throw a new column will be added to matrix A and will take place in the X vector as unknown:

$$A = \begin{bmatrix} 1 & t_1 & o_1 \\ 1 & t_2 & o_2 \\ . & . & . \\ . & . & . \\ . & . & . \\ 1 & t_{N-1} & o_{N-1} \\ 1 & t_N & o_N \end{bmatrix} , \quad x = (Z_0, a, \chi_{off})^T$$

In Table 1, local datum values determined at Antalya-I tide gauge station for different time intervals are given. The data relationship defined between the two stations and Antalya-I tide gauge station's hourly sea level values are combined by transforming Antalya-I tide gauge station's into Antalya-II tide gauge station's local data and by using local datum values determined for Antalya-I tide gauge station. In Figure 3, the monthly sea level data for Antalya-I tide gauge station (1935 - 1977) and joint

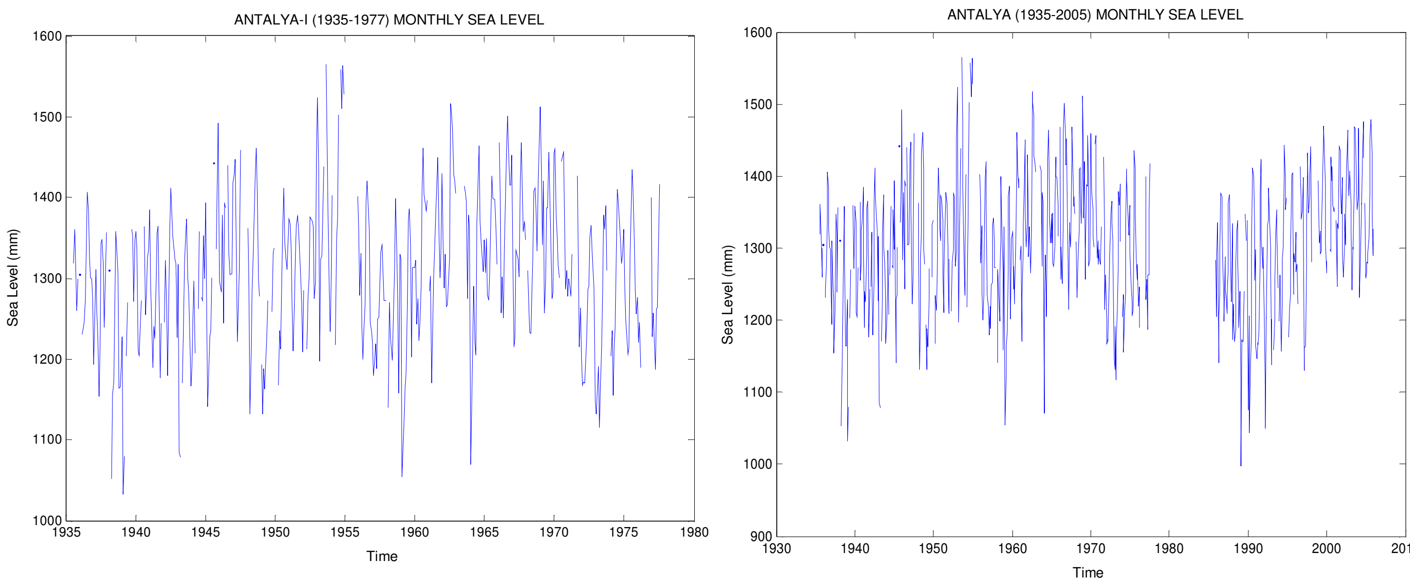

Figure 3. Antalya-I tide gauge station's (1935-1977) monthly sea level information, which was defined according to the Antalya-II local data.

Antalya-I tide gauge station (1935 - 2005) monthly sea level information can be seen (Sezen 2006).

Elimination of data and time shifts

In the years 2002 - 2003, the measurements of Antalya-II tide gauge station (acoustic tide gauge station) were recorded in a digital system. By means of SLPR2 software, harmonic analysis was performed by using space less hourly sea level values for the elimination of data and time shifts. Retrospective hourly sea level estimation (tide estimation) was performed for the years 1935 - 1977 by means of SLPR2 software (Sea Level Processing Software), by using the coefficient obtained from the harmonic analysis.

After this stage, according to the classical tide analysis procedure (tide analysis and estimation, quality control and filtering) which was defined in SLPR2 software, it will be necessary to obtain residual registries which consist of measurement estimation values for each year and eliminate time and datum shifts by using these residual registries (IOC 1994; Caldwell 1998). However, there is a necessity to make corrections since the records of Antalya-I tide gauge station between the years 1935 - 1955 are weekly graphical diagrams and the records between the years 1955 - 1977 are daily graphical diagrams.

So, it is necessary to correct errors (data and time shifts) for daily and weekly values. There is a difficulty in correcting these applications in SLPR software since it runs on a yearly basis. For this reason, new software was realized for these routine corrections by using MATLAB. As a result, the measurements were debugged from time and data shifts and reliable hourly information was obtained. Finally, monthly averages were obtained by averaging daily averages and daily averages were obtained by using a 119 point low frequency filter from hourly values by using SLPR2 software.

Sea level measurements analysis

Relative linear variations of the average sea level consist of a combination of local (local land regression) or regional earth shell movements, linear variations of meteorological parameters (atmospheric pressure, temperature and wind effects), oceanic flows, and linear variations of sea water densities and global sea level rising trends (Woodworth 1987).

Monthly sea level measurements consist of tide, meteorological, oceanographic and hydrological seasonal (for a year and for six months) and longer periodical variations. The mentioned periodical effects should be modeled appropriately to define the linear variations of the sea level with high accuracy. The following mathematical model was used in the harmonic analysis measurements of the average monthly sea level which qualify the quality control and in relative linear variation calculations (Teferle, 2003):

$$h_i = Z_o + at_i + \sum_{j=1}^{M} A_j \cos(\omega_j t_i - \theta_j)$$

In this model,

h_i: t_i average sea values for t_i th month

t_i: months from beginning epoch (i=1, 2,..., N),

a: linear trend,

Z_o: average sea level at beginning epoch

M: total number of significant tide components which

were used in this model
N: total number of monthly average values,
A_j, ω_j, θ_j: Amplitude, angular velocity and phase angle for j th tide component
If Formula (3) is extended;

$$A_j \cos(\omega_j t_i - \theta_j) = A_j \left[\cos(\omega_j t_i)\cos(\theta_j) + \sin(\omega_j t_i)\sin(\theta_j)\right] \quad (4)$$

$$A_j \cos(\omega_j t_i - \theta_j) = A_j \cos(\omega_j t_i)\cos(\theta_j) + A\sin(\omega_j t_i)\sin(\theta_j) \quad (5)$$

Here by assuming:

$$A_j \cos(\theta_j) = B_j \quad (6)$$

$$A_j \sin(\theta_j) = C_j \quad (7)$$

$$\omega_j = 2\pi f_j \quad (8)$$

And replacing 3, the equality will be,

$$h_i = Z_o + a(t_i - t_0) + \sum_{j=1}^{M} B_j \cos(2\pi f_j (t_i - t_0)) + C_j \sin(2\pi f_j (t_i - t_0)) \quad (9)$$

According to these equations, at the beginning of the epoch, the design matrices (A) and the unknown's vector (x) will be as follows. Two new columns will be added to the A matrices for each periodical effect and it will take place in the vector as unknown (Teferle, 2003):

$$A = \begin{bmatrix} 1 & t_1 - t_0 & \sin(2\pi f_1(t_1 - t_0)) & \cos(2\pi f_1(t_1 - t_0)) \\ 1 & t_2 - t_0 & \sin(2\pi f_1(t_2 - t_0)) & \cos(2\pi f_1(t_2 - t_0)) \\ . & . & . & . \\ . & . & . & . \\ . & . & . & . \\ 1 & t_{N-1} - t_0 & \sin(2\pi f_1(t_{N-1} - t_0)) & \cos(2\pi f_1(t_{N-1} - t_0)) \\ 1 & t_N - t_0 & \sin(2\pi f_1(t_N - t_0)) & \cos(2\pi f_1(t_N - t_0)) \end{bmatrix},$$

$$\chi = \begin{bmatrix} Z_0 \\ a \\ B_1 \\ C_1 \end{bmatrix}$$

After balancing by means of the least squares method, coefficients (B), (C), amplitude and phase angle for each periodical component will be found by:

$$A_j = \sqrt{B_j^2 + C_j^2} \qquad \text{and} \qquad \theta_j = \arctan\frac{C}{B}$$

Statistically; measurements are assumed to be normally distributed, thus, independent from each other and equally weighted. So, variance and co-variance matrices for the measurements are as follows.

$$C = \begin{bmatrix} \sigma_1^2 & 0 & 0 & . & . & . & 0 \\ 0 & \sigma_2^2 & 0 & . & . & . & 0 \\ 0 & 0 & \sigma_3^2 & . & . & . & 0 \\ . & . & . & . & & & . \\ . & . & . & & . & & . \\ . & . & . & & & . & . \\ 0 & 0 & 0 & . & . & & \sigma_N^2 \end{bmatrix}$$

Determination of seasonal effects

To investigate yearly and six-monthly effects, these effects were determined by means of sampling by using monthly sea level information for a year which has the complete twelve months' information instead of complete information using monthly averages.

Here,
h: monthly sea level measurement,
i: month number (1,2,…12),
j: the number of years which has 12 month information (1,2,….N),
M: yearly averages,
Y: monthly anomalies,
MA: average monthly anomalies,
The symbols, so the yearly average of monthly sea level measurements is

$$M_j = \frac{1}{12}\sum_{i=1}^{12} h_{ij}$$

Monthly anomalies within the year i

$$Y_{ij} = h_{ij} - M_j$$

From here, average monthly anomalies can be found by the following equalities.

$$MA_i = \frac{1}{N}\sum_{j=1}^{N} Y_{ij} \quad (10)$$

Yearly and six-monthly seasonal effects' amplitudes A_{Sa} and A_{Ssa} and phases P_{Sa} and P_{Ssa} can be determined from the found average monthly anomalies by means of least square balancing and the harmonic model.

$$MA_i = A_{Sa}\cos\left(\frac{2\pi}{12}t - P_{Sa}\right) + A_{Ssa}\cos\left(\frac{2\pi}{6}t - P_{Ssa}\right) \quad (11)$$

In the mathematical model above, t = i-.5 is considered

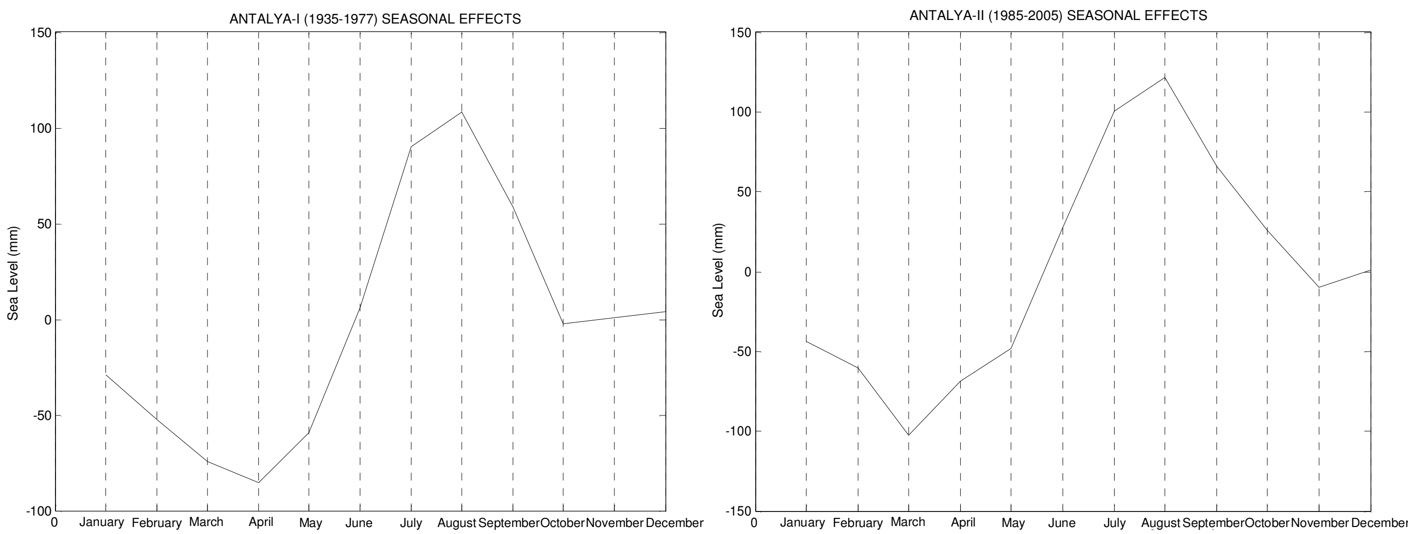

Figure 4. Seasonal effects in Antalya-I and Antalya-II tide gauge stations.

Table 2. Amplitudes in Antalya-I and Antalya-II tide gauge stations for months.

Antalya	Complete year	Jan.	Feb.	March	April	May	June	July	August	Sept.	Oct.	Nov.	Dec.
I (mm)	14	–29	–53	–74	–85	–59	6	90	108	59	–2	1	4
II (mm)	11	–44	–61	–102	–69	–48	27	100	121	66	26	–10	1

for the Mai average monthly anomaly which comes in the middle of the month, which is equal to the i th month. The phases of yearly and six-monthly seasonal effects (P_{Sa} and P_{Ssa}) become two year and two half-year signals and will be equal to maximums of the months, respectively,[-6, 6] and [-3, 3] months.

The seasonal effects for Antalya-I and Antalya-II tide gauge stations can be seen in Figure 4 and amplitude values can be seen in Table 2. The minimum water level in Antalya-I tide gauge station is 85 mm in April; the maximum water level with a 108 mm rise was seen in August. The minimum water level for Antalya-II tide gauge station is 102 mm in March and the maximum water level for Antalya-II is 121 mm in August (Sezen 2006).

Modeling of one year or longer periodical effects

To model one year or longer periodical effects, nodal (18.613 year period), perigee (8.847 year period), Chandlerian (1.2 year period), yearly (1 year) and half a year (0.5 year period) tide frequencies were used (Vanicek 1978). Since there is a 5º 17' angle between the moon's trajectory plane and elliptical plane, these planes intersect. Both planes' section is called the nodes line. The points which intersect the sun's visible orbit are called the lunar node. The node lines are not fixed and make a precession movement of 19.3548º for the year whose period is 18.6 years (Figure. 5). Likewise, the nearest point of the moon's orbit of the earth (this is the perigee point) has a precession movement of 8.847 years. One turn of the earth's polar axis around its average position which is equal to 1.2 years is called a Chandlerian period.

The monthly sea level measurement trends, which are balanced by the least squares method and debugged from yearly and longer period effects, were determined by the mathematical model in equation 9 in which the frequencies are placed. To determine the inappropriate measurements, during the balancing Pope test a 1–α = 0.90 statistical reliability level (Tau test) was used. Balancing was continued iteratively until there was no inappropriate measurement. Explanations with regard to the Tau test are given below (Nakipoğlu and Demir 2002):

$$-\tau_{m;1-\alpha_0/2} \le \frac{\hat{r}_i}{\sigma_{\hat{r}_i}} \le \tau_{m;1-\alpha_0/2}$$

After eliminating the inappropriate measurements, the balancing process continued and all unknowns were subjected to a significance test (t-test) at a 1–α = 0 statistical confidence level (Koch, 1987). If both components of a tide are found to be insignificant during this test, the

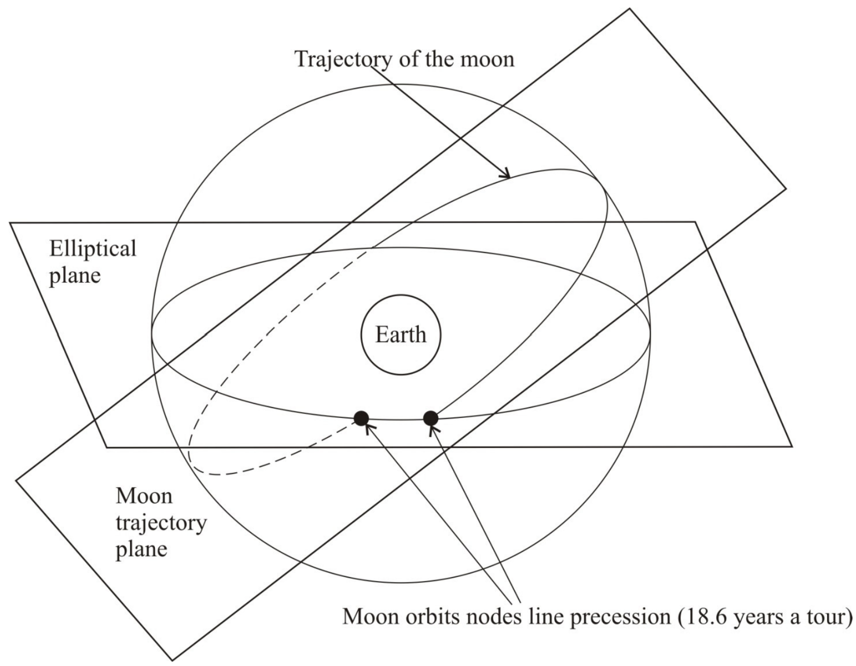

Figure 5. Moon's node points and precession.

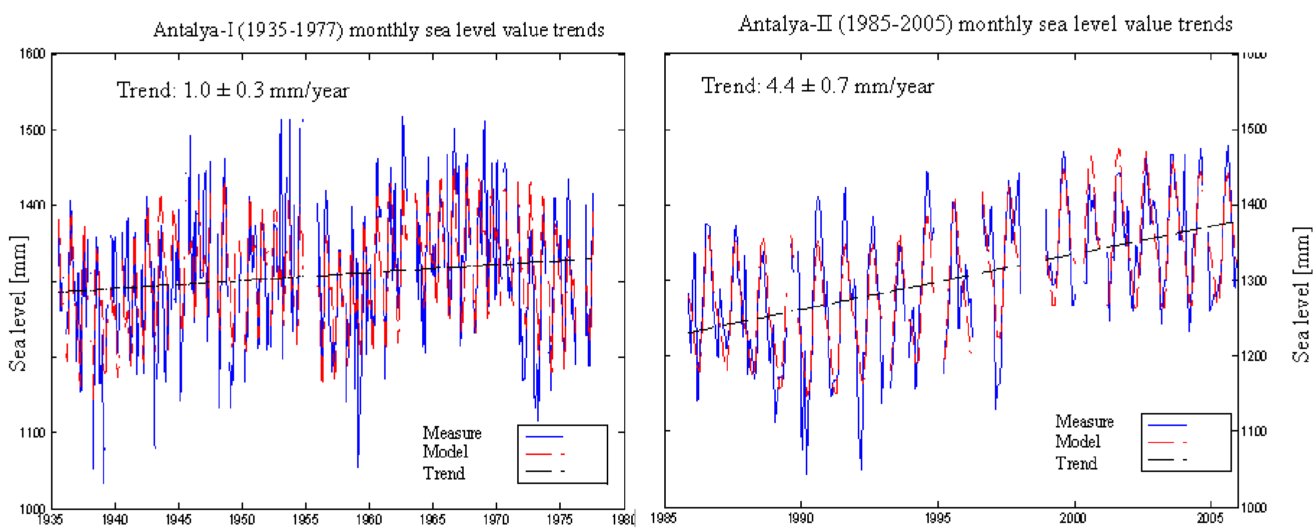

Figure 6. Monthly sea level value trends for Antalya-I and Antalya-II tide gauge stations.

related component is removed from the frequency list since it is considered insignificant for monthly sea level measurement modeling. If one coefficient of the tide is found significant and the other insignificant, that tide component is considered significant and left in the model.

In this study, first of all, each station was evaluated independently within its own operation period. Variations in sea levels were explicated within their own period by using information between 1985 - 2005 for Antalya-II Tide Gauge Station and information between 1935 - 1977 for Antalya-I tide Gauge Station (Sezen, 2006). The results obtained after balancing are given in Figure 6 and parameter values are given in Table 3.

When hourly sea level value information for Antalya-I and Antalya-II Tide Gauge Stations are combined, in the first investigation a trend change can be seen beginning from the early 1960s. The sea level, which expresses a positive trend until 1960, expresses a negative trend tendency until 1990. The trend for the 1935-1959 periods for Antalya tide gauge station is 2.3 ± 0.7 mm/year; after 1960 the trend had become –3.8 ± 0.5 mm/year for the 1960-1990 periods (Figure 7).

Table 3. Parameters which were determined by harmonic analysis in Antalya-I and Antalya-II tide gauge stations.

Parameter		Antalya-I (mm)	Result	Antalya-II (mm)	Result
a		1.0 ± 0.3	Significant	4.4 ± 0.7	Significant
18.6 year	B_1	–8.6 ± 4.5	Significant	21.6 ± 4.7	Significant
	C_1	–32.2 ± 4.4	Significant	-27.2 ± 5.8	Significant
8.8 year	B_2	11.8 ± 4.3	Significant	–	Insignificant
	C_2	7.5 ± 4.4	Significant	–	Insignificant
1.2 year	B_3	–4.3 ± 4.3	Insignificant	5.0 ± 4.4	Insignificant
	C_3	19.6 ± 4.3	Significant	-8.6 ± 4.4	Significant
1 year	B_4	–24.4 ± 4.3	Significant	-41.1 ± 4.4	Significant
	C_4	–61.7 ± 4.3	Significant	-73.5 ± 4.4	Significant
0.5 year	B_5	30.3 ± 4.3	Significant	21.2 ± 4.4	Significant
	C_5	29.9 ± 4.3	Significant	21.5 ± 4.4	Significant

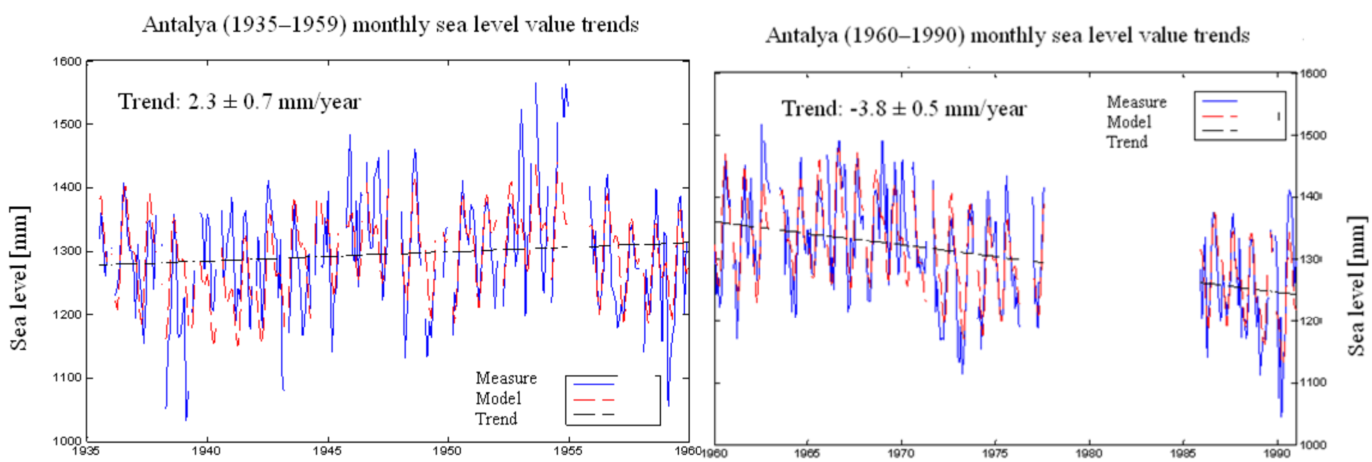

Figure 7. Monthly sea level trends related to the 1935-1959 and 1960-1990 periods for Antalya tide gauge station.

In the studies realized for Antalya-II tide gauge station, trends related to 1985 - 1998 and 1998 - 2005 were investigated. According to the investigation results, while a 5.7 ± 1.2 mm/year trend was determined for the 1985 - 1998 periods, no significant trend was determined for the 1999 - 2005 periods (Sezen, 2006). The results related to this study can be seen in Figure 8.

Finally, long-period sea level variations are investigated in the combined Antalya tide gauge stations (1935 - 2005). After this stage of the study, Antalya-I and Antalya-II tide gauge stations will be called Antalya tide gauge station. The seasonal effects for Antalya tide gauge station can be seen in Figure 9 and Table 4. The minimum sea level can be seen in March with an 89 mm decrease from the average and the maximum sea level can be seen in August with a 113 mm rise above the average (Sezen, 2006).

After this practice, seasonal (for one year and for six months) and longer period effects were eliminated for the combined Antalya tide gauge station (1935 - 2005); the monthly sea level trend was found to be 0.2 ± 0.1 mm/year for the 1935 epoch (Sezen, 2006). The results related to this investigation are given in Figure 10 and the parameter values are given in Table 5.

RESULTS AND SUGGESTIONS

After evaluation, the monthly sea level measurement trends of Antalya-I tide gauge station, which are

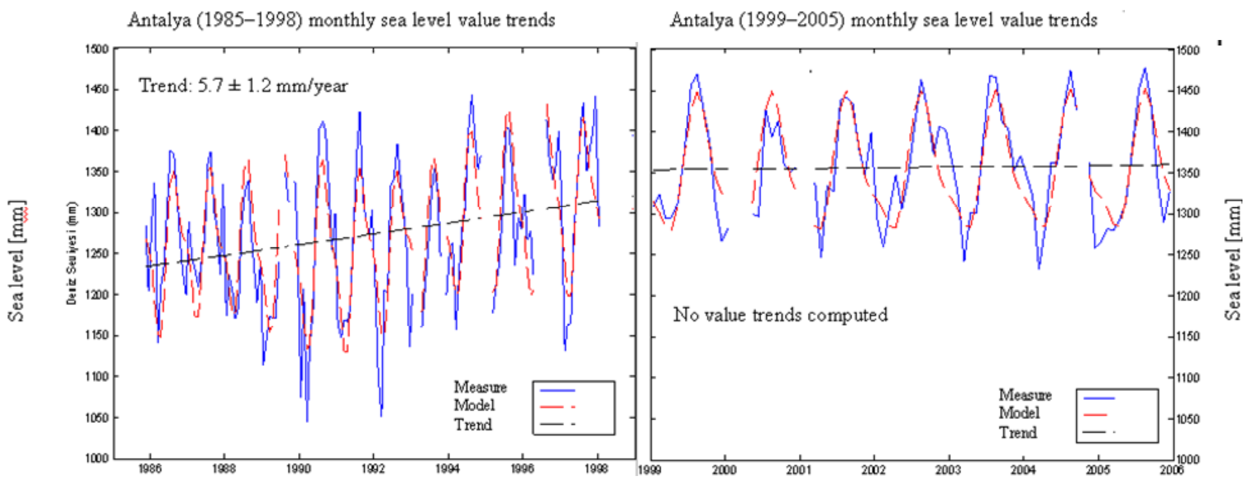

Figure 8. Monthly sea level trends related to the 1985-1998 and 1999-2005 periods for Antalya-II tide gauge station.

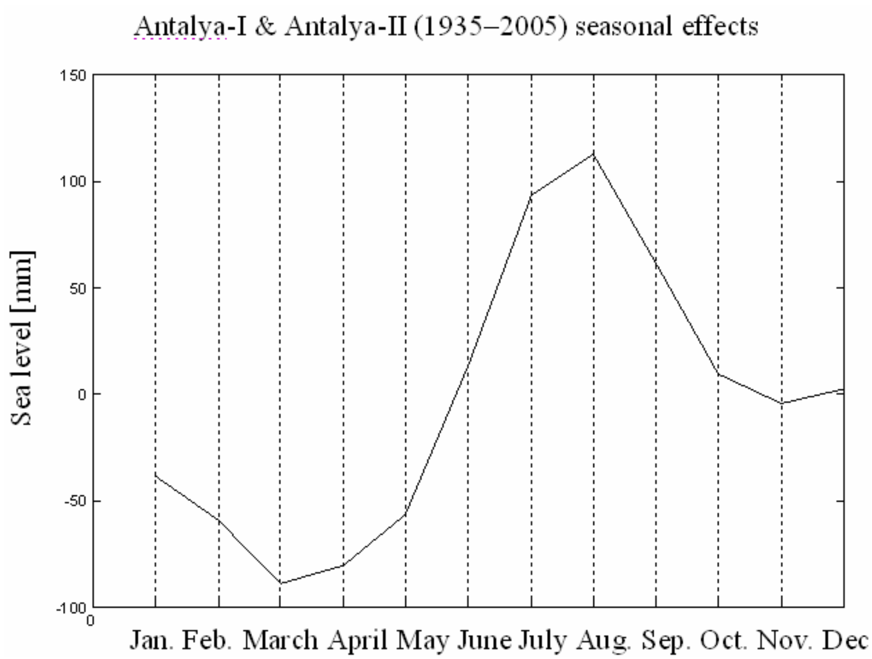

Figure 9. Seasonal effects for Antalya tide gauge station (1935-2005).

debugged from a period of nearly 43 years from 1935 – 1977 and seasonal effects, are found to be 1.0 ± 0.3 mm/year. It can be seen that this value is appropriate for ~1.3 ± 0.4 mm/year interval at the eastern Mediterranean between 1958 - 2001 (Tsimplis et al., 2005). Also, it can be seen that, this value is appropriate for a 1.0-2.0 mm/year interval, which is defined as the global average sea level rising rate for the 20th century (IPCC 2001; Zerbini et al., 1996). After the evaluation of Antalya-II tide gauge station's 1985 - 2005 data, monthly sea level measurements from a period of nearly 21 years, and after eliminating seasonal and long period effects, the sea level measurement trends are found to be 4.4 ± 0.7 mm/year. It can be seen that these values are more than the average global sea level trends.

When Antalya-I and Antalya-II tide gauge stations are integrated in the evaluation, the years 1960, 1990 and 1999 can be seen as break points for trend changes. While a positive trend of 2.3 ± 0.7 mm/year can be seen between 1935 - 1959, a negative trend of -3.8 ± 0.5 mm/year can be determined for the 1960 -1990 periods. A powerful trend of 5.7 ± 1.2 mm/year, which was seen between 1985 - 1998, had become stagnant after 1999, and between 1999 - 2005 a significant trend could not be

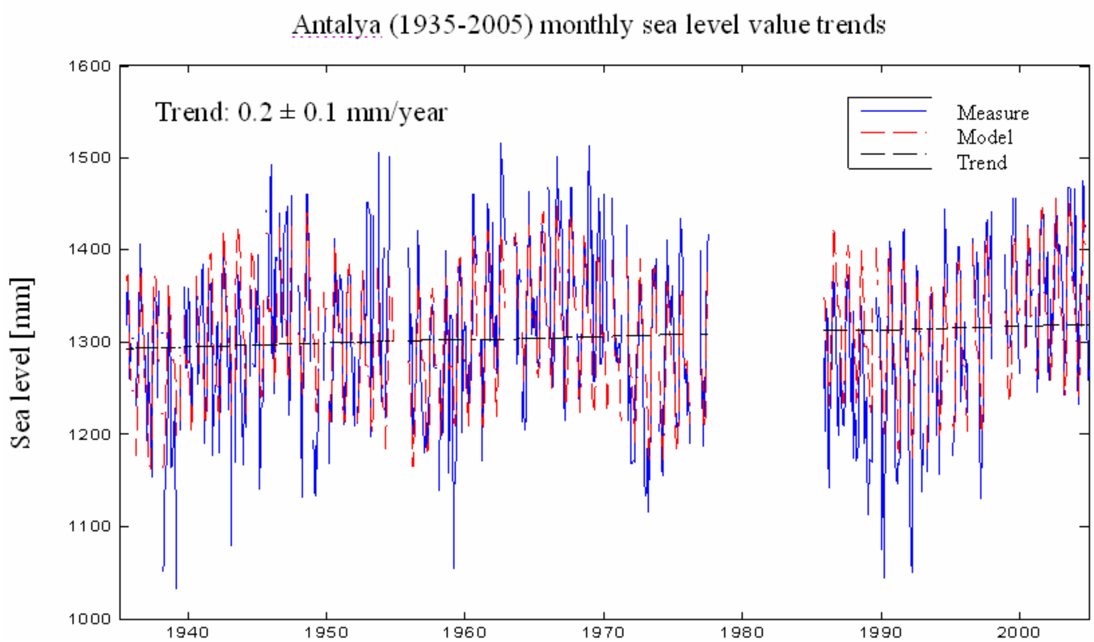

Figure 10. Monthly sea level trend determined for the 1935-2005 period at Antalya tide gauge station.

Table 4. Seasonal effects at Antalya tide gauge station (1935-2005).

Antalya	Fullyear	Jan.	Feb.	March	April	May	June	July	August	Sept.	Oct.	Nov.	Dec.
(mm)	25	-39	-59	-89	-81	-57	14	93	113	61	9	-4	3

Table 5. Parameters determined by means of harmonic analysis in Antalya tide gauge station (1935-2005).

Parameter		Antalya (mm)	Result
a		0.2 ± 0.1	Significant
18.6 year	B_1	-23.2 ± 3.6	Significant
	C_1	-25.6 ± 3.5	Significant
8.8 year	B_2	–	Insignificant
	C_2	–	Insignificant
1.2 year	B_3	-5.7 ± 3.5	Significant
	C_3	12.4 ± 3.5	Significant
1 year	B_4	-31.0 ± 3.5	Significant
	C_4	-66.3 ± 3.5	Significant
0.5 year	B_5	26.4 ± 3.5	Significant
	C_5	27.4 ± 3.5	Significant

determined.

The relationship between these changes in trends and the hot water circulation situation changes and fluctuations in the sea level for a few decades is the key question. In a study realized by Roether et al. (1996) on recent dates, sudden salinity and a temperature increase was determined in the eastern Mediterranean's deep and medium-depth waters. This sudden change, which started in the early 1990s, can be based on a transition of deep sea formation from the Adriatic's single source to the Aegean Sea's new significant regime.

Hydrographic information from the eastern Mediterranean Sea shows that the deep sea source for the last century is the Adriatic Sea (Vigo et al., 2005). A new model had occurred in this century when a new source called the Temporary Eastern Mediterranean Source was found in the Aegean Sea between 1987 - 1995 (Roether et al., 1996). After a few cold winters, the Adriatic Sea again became committed to the role of being the deep sea source in the 1997-1999 periods. Related to the return to the situation before the Temporary Eastern Mediterranean Source, regional powerful sea level anomalies were reported (Vigo et al., 2005). A sharp trend change which was seen in Antalya-II tide gauge station in 1999 can be explained with this formation. This change was determined by investigations made in the Black Sea and Atlantic coasts by Tsimplis (2000).

After the complete evaluation of the monthly sea level

Table 6. Average sea level velocities (ASLV) which are determined at certain periods in Antalya tide gauge station.

Station	Period	ASLV Speed (mm/year)
Antalya–I	1935 - 1977	1.0 ± 0.3
Antalya–II	1985 - 2005	4.4 ± 0.7
Antalya (combined)	1935 - 2005	0.2 ± 0.1
Antalya–I	1935 - 1959	2.3 ± 0.7
Antalya–I and Antalya–II	196 - 1990	-3.8 ± 0.5
Antalya–II	1985 - 1998	5.7 ± 1.2
Antalya–II	1999 - 2005	(There is no significant velocity)

information for Antalya tide gauge station in the 1935 - 2005 periods, the monthly sea level trend, which was debugged from long-term and seasonal effects, in the 1935 epoch, was found as 0.2 ± 0.1 mm/year. This can be seen as less than the global sea level rising values. The Mediterranean Sea can be thought of as an inland sea, and the Mediterranean Sea's general circulation model has significant changes between years and, especially after 1990, the changes in the deep sea source regimes have an influence. Also, since there is no information for the years 1977-1985, during which the station was inactive, there is a lack of information integrity so the model was affected negatively. Besides, the substitution of meteorological information in the mathematical model which is absent and the determination of the absolute sea level changes by means of investigating earth shell movements by GPS are evaluated to provide more significant results. The results which were obtained from this study are given in Table 6.

REFERENCES

Caldwell P (1998). Sea Level Data Processing On IBM-PC Compatible Computers Version 3.0 (Year 2000 Compliant), National Oceanographic Data Center and University of Hawaii Sea Level Center, Honolulu, Hawaii.

IOC (Intergovernmental Oceanographic Commission) (1994). Manual On Sea Level Measurement and Interpretatıon, Volume II - Emerging Technologies, UNESCO.

IPCC (Intergovernmental Panel on Climate Change) (2001). Climate Change 2001: The Scientific Basis, Published By The Press Syndicate of The University of Cambridge, United Kingdom, Chapter 11 (Changes in Sea Levels) Executive Summary, Technical Summary.

Koch KR (1987). Parameter Estimation and Hypothesis Testing in Linear Models, Springer- Verlag, New york.

Nakipoğlu M, Demir C (2002). Adjustment I, Harita Genel Komutanlığı, Harita Yüksek Teknik Okulu Komutanlığı, Ankara.

Roether W, Manca B, Klein B, Bregant D, Georgopoulos D, Beitzel V, Kovacevic V, Luchetta A (1996). Recent Change in Eastern Mediterranean Deep Waters, Science. 271(5247): 333-335.

Teferle FN (2003). Strategies For Long–Term Monitoring of Tide Gauges Using GPS, Thesis submitted to the University of Nottingham for the degree of Doctor of Philosophy.

Tsimplis MN (2000). Sea level drop in the Mediterranean Sea: An indicator of deep water salinity and temperature changes?, Geophys. Res. Lett., 27 (12): 1731-1734.

Tsimplis MN, Álvarez-Fanjul E, Gomis, Fenoglio-Marc L, Pérez B (2005). Mediterranean Sea level trends: Atmospheric pressure D and wind contribution, Geophysical Res. Lett., 32: 803-806.

Sezen E (2006). Investigation into sea level variations at Antalya-I (1935-1977) and Antalya-II (1985-2005) Tide Gauge Stations, Master Thesis (in Turkish), Afyon Kocatepe University, Afyonkarahisar, Turkey.

URL 1. (2008) http://www.hgk.mil.tr/urunler/jeodezik/resimler/image004.jpg, (Accessed 07 Jan), prepared

Williams SDP, Teferle FN (2003). ESEAS CGPS Coordinate Time Series Analysis Strategy, May 13, p. 11.

Williams SDP (2003). Offsets in Global Positioning System Time Series, J. Geophys. Res., 108: B62310, doi:10.1029/2002JB002156.

Woodworth PL (1987). Trends in U.K. Mean Sea Level, Marine Geodesy, 11: 57-87.

Vanicek P (1978). The problem of noise reduction in sea-level records used in vertical crustal movement detection, Physics of Earth and Planetary Interiors, 17: 265-280.

Vigo I, Garcia D, Chao BF (2005). J. Marine Res., Volume 63, Number 6, Change of Sea Level Trend in The Mediterranean and Black Seas, pp. 1085-1100.

Zerbini S, Plag HP, Baker T, Becker M, Billiris H, Bürki B, Kahle HG, Marson I, Pezzoli L, Richter B, Romagnoli C, Sztobryn M, Tomasi P, Tsimplis M, Veis G, Verrone G (1996). Global and Planetary Change, Volume 14, "Sea Level in The Mediterranean: A First Step Towards Separating Crustal Movements and Absolute Sea-Level Variations", pp. 1-48.