IVa -SEA LEVEL MONITORING ACTIVITIES IN TURKEY

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ABSTRACT

Turkish National Sea Level Monitoring Network presently consists of one data center in Ankara and four tide gauges located along the Mediterranean, Aegean and Marmara Sea coasts and is planned to be expanded to also cover the Black Sea and the East Mediterranean. The existing four tide gauges, operated by General Command of Mapping since 1985 with an analogous system, were upgraded to high standards enabling automatic data collection and real time data transfer. Monthly sea level values are obtained from hourly data between 1985-1999 after pre-analysis and mean sea levels and their changes are estimated by applying harmonic analysis. GPS measurements carried out at those tide gauges between 1992 to 1999 are also processed and evaluated. Sea level data, GPS and precise leveling observation connecting tide gauges are combined to estimate relations between mean sea levels as well as vertical crustal movements at Turkish coasts.

1. INTRODUCTION

Sea level monitoring activities in Turkey dates back to the 1930s. The General Command of Mapping (GCM), having responsibility of the basic geodetic control networks in Turkey, established the first tide gauge at the Antalya harbor in 1936 in order to define zero level surface for heights. Right after the establishment of the second one at Karşıyaka/İZMİR in 1937, they were transferred to General Directorate of Meteorological Affairs. By this institution, nine more tide gauges had been set up subsequently and operated at different coasts of the country at different time intervals. Time series from those gauges varies from five to 40 years. At all tide gauges sea level variations were recorded to daily or weekly charts with an analogous system by means of a float on a cable in a stilling well. In the late 1970s, it was not possible to operate those gauge properly and to obtain correct values due to increase in pollution and plunging of the wells caused by urbanizations surrounding the gauges (HGK, 1991; Gürdal, 1997; 1998).

During the 1980s, taking into consideration the importance of the absolute sea level variations and its outcomes, GCM, with the intention of removing deficiencies in sea level activities, took over the responsibility of operating permanent tide gauges countrywide. Afterwards, all tide gauges were scrutinized and discontinued. Instead, four new tide gauges namely Antalya II, Bodrum II, Menteş and Erdek were established and activated with the available analogous system in late 1985. At these stations sea level variations had been recorded to the weekly charts and ancillary data such as atmospheric pressure, air temperature, humidity, sea temperature had also been measured once a day. Graphical records together with the ancillary data were sent to the data center, and monthly periods and hourly values were digitized manually and issued annually to the related national and international institutions.

Due to the difficulties encountered in obtaining spare parts and in order to eliminate errors subjected to the analogous system, it was decided to modernize the existing tide gauges and to establish a state of the art sea level monitoring network and expand it with new tide gauges where necessary. Furthermore, it was also decided to re-digitize the historical sea level records with a computer-aided system to obtain more accurate time series. Due to this much effort has been made since 1995 and first step towards establishing modern sea level network in Turkey was accomplished by upgrading the existing tide gauges to GLOSS standards in 1999 (IOC, 1997).

Presently, all stations consist of a data collection unit with a self-calibrating acoustic ranging sensor and meteorological sensors such as atmospheric pressure, air temperature, air humidity, wind velocity and wind direction. Sampling rate is 10 seconds for the sea level data and 1 minute for the ancillary data. Measurement of sea level is based on a 10-minute average whereas meteorological parameters are based on one-hour average. The data are downloaded to the data center every three days using telephone lines and quality controlled regularly.

To check the tide gauge datum and to monitor the local vertical movements at or near tide gauges, local leveling network consisting of about three to five points have been measured at one and two year intervals. Within the framework of different projects, periodic GPS measurements have also been carried out since 1991. We have three-four year periodic GPS data, which are of most value in terms of tide gauge fixing (Carter et al., 1989). First epoch of absolute gravity measurements were also fulfilled at tide gauge sites in 1997.

The available monthly mean sea level values obtained from the newly digitized data were analyzed and corrected for errors as much as possible, and mean sea level (MSL) and its changes at four tide gauges was computed. These values were incorporated with the national levelling data for the analysis of latitudinal changes of the mean sea level. In addition to this, long-term changes of the MSLs and periodic GPS measurements were also combined to study vertical crustal movements.

2. ANALYSIS OF MONTHLY MEAN SEA LEVEL DATA

The water level measured at a tide gauge is affected by a number of oceanographic and meteorological phenomena. In addition vertical crustal movements are of particular importance in determining the secular mean sea level changes. Accurate prediction of secular sea level changes (rise or fall) requires long-term data and is only possible if those effects are modelled properly. Therefore, historical sea level data provides valuable data for the studies of both crustal motion and eustatic sea level trends.

The GCM spent much effort to re-process the historical sea level data using suitable methods as well as upgrading and expanding the existing sea level network. The data obtained by analogous system is subject to many errors coming from both the instrumental drift and the method of digitization (IOC, 1985; 1994). In order to eliminate the errors as much as possible we started to re-digitize historical graphical records with a computer-aided digitizer in 1995 and this work is still on going.

Hourly sea level values are predicted from digitized values by linear interpolation and evaluated with the software of TOGA Sea Level Center (Caldwell, 1991) in order to eliminate time and datum errors. Daily and monthly mean sea levels are then obtained by simple arithmetic mean. Table-1 summarizes the re-processed data so far.

Table-1: Re- digitized and processed sea level data

Tide-gauge	Available data	Re-digitized	Processed	Remarks
Antalya I	1936-1977	1936-1977		Not operational
Antalya II	1985-1999	1985-1999	1985-1999	
Bodrum II	1985-1999	1985-1999	1985-1999	
Menteş	1985-1999	1985-1999	1995-1999	
Erdek	1985-1999	1985-1999	1995-1999	

We determined the mean sea levels and its changes by analyzing the monthly mean sea level data from four tide gauges listed in Table-1 using the well-known equation (Bath, 1974; Pugh, 1987),

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

Where, t_i is the number of months from reference epoch t_o, Z_o mean sea level, a secular trend (cm/month), A_j, ω_j and θ_i, amplitude, angular velocity and phase of the i^{th} harmonic constituent respectively. Meteorological parameters are not included in the model since they are not yet completely arranged before the analysis. In Figure-1, the measurements and model values are depicted. It can be seen from the figure that the data has many gaps due to frequent failures in the analogous system. From this analysis, mean sea level changes are found to be 7.3 ± 1.1 mm/y for Antalya, 2.1 ± 2.1 mm/y for Bodrum, 15.5 ± 6.0 mm/y for Menteş and 22.5± 4.8 for Erdek tide gauge. The computed values of the mean sea level changes at Bodrum and Erdek tide gauge are suspicious due to that their time series have many gaps. But at Antalya tide gauge having 14-year data, rising in the mean sea level is clearly identified and is compatible with the results given by Hekimoğlu et al. (1996). Although the length of data at Erdek tide gauge is 5 years, which can be considered as too small for such an analysis, it gave us clear evidence for the mean sea level rise.

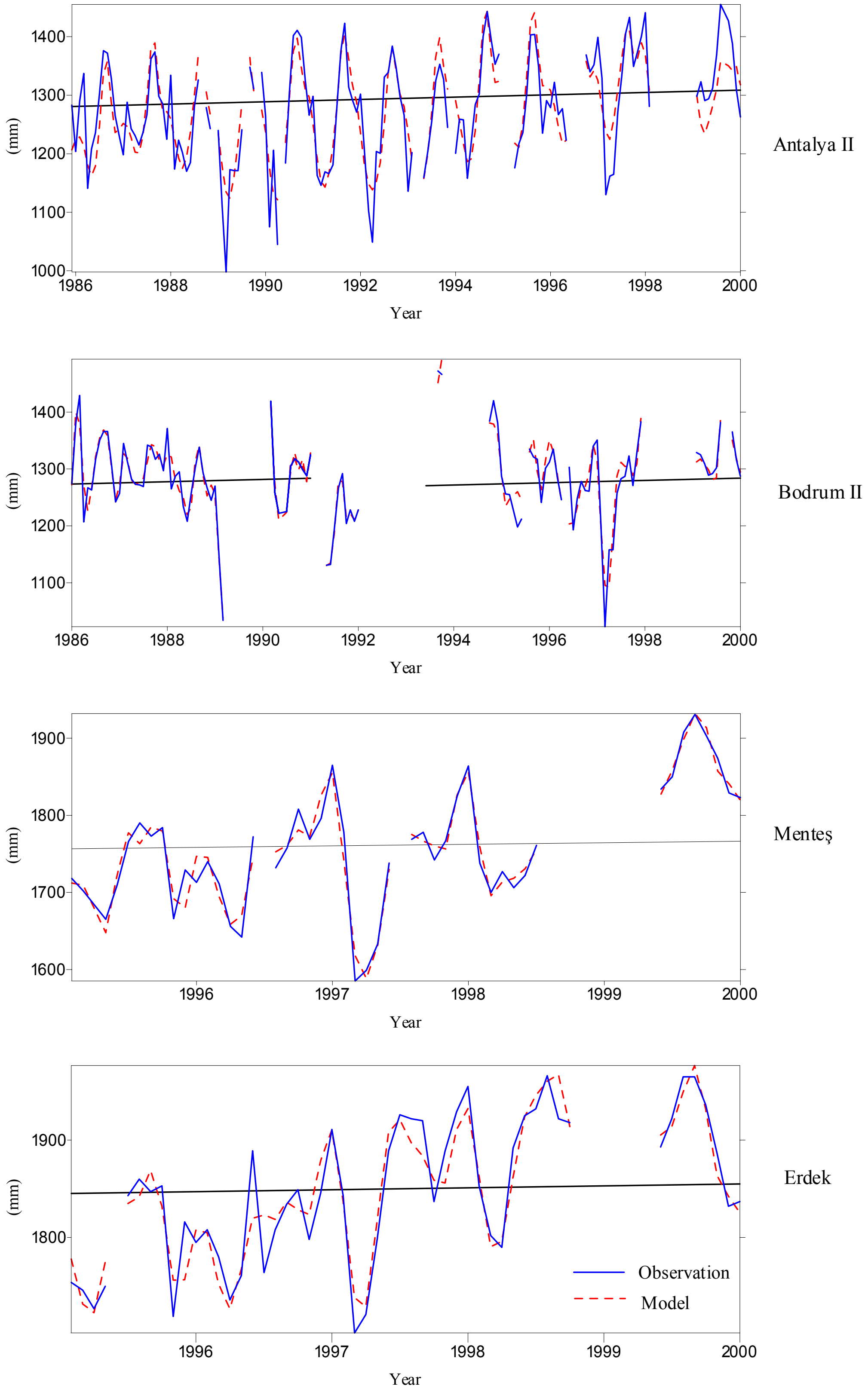

Figure-1: Observed and predicted monthly mean sea levels and mean sea level trends.

Moreover, mean sea levels were incorporated with the first or second order leveling observations between tide gauges and the latitudinal slope of mean sea level is computed as 8.9 ± 0.2 cm per degree of latitude (Fig.-2.). Mean sea level at Samsun tide gauge is based on old sea level measurements. It can be seen from the figure that the mean sea level difference between the Black Sea and the Mediterranean Sea due to sea surface topography is about to be 40 cm.

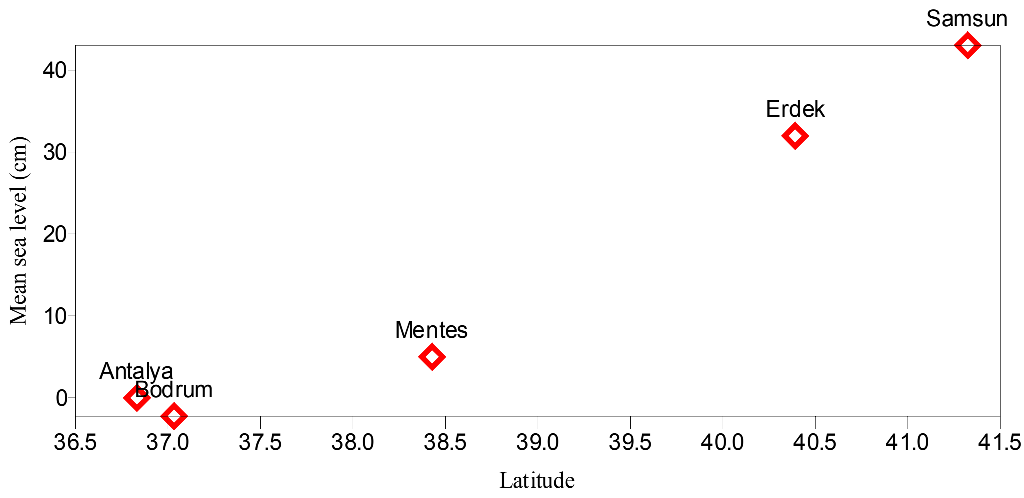

Figure-3: Latitudinal slope of the mean sea levels

3. VERTICAL CRUSTAL MOVEMENTS

Turkey is situated in a tectonically very active region where major tectonic plates interact. Although the horizontal velocity field of Turkey is more or less modeled using periodic GPS measurements conducted for ten years, we have still many questions for the vertical crustal movements. GPS measurement campaigns, carried out so far at existing four tide gauges, are given in Table-2.

Table-2: GPS measurements at tide gauges

Gauge/year	93	94	95	96	97	98
Antalya II		x	x	x	x	x
Bodrum II		x	x	x	x	x
Erdek	x	x (2)		x (2)		x
Menteş	x	x	x	x		x

(x) Observed in two different campaigns

GPS campaigns conducted between 1993-1999 at gauges in Turkey are processed with BERNESE software version 4.0 (Rothacher and Mervart, 1996) using IGS products following the strategy proposed by EUREF sub commission. Loosely constrained solutions of SINEX format are combined with the last GLOBK software (Herring, 1997) in ITRF96. In the combination, we applied 1 mm constrains for both velocity and coordinates of some selected IGS sites for reference frame fixing. These results are given with the mean sea level rises in Table-3.

Table-3: Rate for the up component and mean sea level trends at gauges.

Tide gauge	Vu (GPS) (mm/y)	MSL trend (mm/y)
Antalya II	1.4 ± 2.7	7.3 ± 1.1
Bodrum II	3.4 ± 1.3	2.1 ± 2.1
Erdek	-8.5 ± 5.6	22.5 ± 4.8
Menteş	1.2 ± 1.8	15.5 ± 6.0

Table-3 shows that velocities at Antalya and Menteş tide gauge are insignificant due that MSL rise at Menteş and Bodrum are seem to be unreliable due to many gaps. Besides, mean sea level trend and GPS measurements at Erdek tide-gauge are somehow confirming the vertical crustal movements here, although the sea level data period is fairly short. It is anticipated that more GPS surveys and long series of sea level data will yield better results for the understanding of vertical motion at tide gauges.

CONCLUSION

In this paper, the present practices of the General Command of Mapping relevant to sea level activities were explained. We intended to give a general status of the work done rather than focus on a comprehensive investigation. Modernization of the Turkish tide gauge network, efforts for re-digitization of historical sea level records and periodical GPS measurements are also emphasized. Analyses of available monthly sea level values and periodical GPS measurements gave us interesting information about sea level trend and vertical crustal movements at tide gauges and, latitudinal sea slope in Turkey. But these results should be considered preliminary, and need to be improved with GPS and additional sea level data using more complex evaluation of the data.

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