Mediterranean Sea Level Changes over the Period 1961-2000

Boris SHIRMAN and Yossi MELZER, Israel

Key words: Sea level monitoring, Tide gauge operation, Tide gauge Bench Marks.

ABSTRACT

The mean value of the Mediterranean Sea level defines the vertical datum of the geodetic network in Israel. The Survey of Israel (SOI) has been performing tide measurements along the Mediterranean Sea coast since the twenties. Since 1996 SOI has conducted the measurements by digital instruments with a resolution of 1 cm and data recording every 5 minutes. Identical instruments were installed at the Tel-Aviv, Ashdod and Ashqelon stations.

The aims of the work are to distinguish tide long time periods and to compare average tide level with the Israeli vertical datum. The data from Ashdod, Yafo, Tel-Aviv and Ashqelon for the period 1958 – 2001 were used.

The following results were obtained:

a) Tide level changes caused by influences from the Moon and the Sun are in the same phase and amplitude along the coast between Tel-Aviv and Ashqelon. This justifies linking together data from different stations into a continuous time series of 39 years.
b) Spectral analysis of the tide level data indicates periods of about 20 years, one year and about half year.
c) The average tide level of all period investigated is 6 cm relative to the vertical Israeli datum.
d) Between 1973-2000 there is an indication of sea level rise of about 15 cm.

CONTACT

Boris Shirman and Yossi Melzer
Survey of Israel
1, Lincoln
Tel-Aviv
ISRAEL
Tel. + 972 3 623 1919
Fax + 972 3 623 1806
Email: boris@soi.gov.il and melzer@netvision.net.il

Mediterranean Sea Level Changes over the Period 1961-2000

Boris SHIRMAN and Yossi MELZER, Israel

INTRODUCTION

Sea level has been monitored along the East Mediterranean coast since the twenties of the 20 century. In a parallel with Survey of Israel (SOI), other organizations such as the Israeli Port and Railways Authority (PRA), Meteorological Service, Israel Oceanographic and Limnological Research (Rosen and Kit, 1981).
Main aims of monitoring in SOI are to derive at the mean sea level (MSL) value and to investigate its variations. The MSL is taken as zero of a geodetic heights level and as a base of the geoid construction. A new goal of such monitoring was derived during the last decades. Sea level changes are a subject of many interdisciplinary investigations such as a greenhouse effect and the global temperature changes. A rise in sea level will generate a need for a coastline protection and possible intrusion of seawater into freshwater areas in a future (Woodworth, 1987). All these suggest the necessity of a careful study of mean sea level changes.
Sea level is measured in a datum of each tide gauge station that was derived from a local geodetic system leveling. The height system was adjusted over all the period of sea level measurements as well sea level.
In this work we analyze all available data during 1958 – 2001 covered two 19 years periods. Presented sea level data gathered from different sources has certainly a different quality. We tried to estimate the reliability of such historic data.
The aims of the work are:

- to compare MSL with a current datum;
- to describe a main tide features observed at our stations;
- to distinguish tide long time periods.

1. TIDE GAUGE BENCHMARKS AND SEA LEVEL MEASUREMENTS

1.1 Benchmarcs

Sea level measurements at each gauge station are performed in a reference to a nearby benchmark called a tide gauge benchmark (TGBM). Usually, this is special headed bolt in a substantial structure which height is derived from a local geodetic leveling. The local leveling is connected to the national leveling network. Below is a short summary of the national benchmarks connected to TGBM at Yafo and Ashdod stations in different periods.

<u>Yafo station</u>
The benchmark 223/BN of height 2.350 m was fixed in the December 1954. The float operated tide gauge was installed again in about 75 m apart from the BM 223/BN and in 70 m from it previous location in June 1962. The repeat leveling between 223/BN and TGBM

carried out in August 1965 and in January 1971 and revealed heights 3.172 m and 3.175 m respectively.
On June 1985 the new benchmark 55/F was fixed at the height 2.945 m in a reference to the benchmark 223/BN. The distance between BM 55/F was about 75 m from the 223/BN. Yafo tide gauge operated without being removed until 1989.

<u>Tel-Aviv station</u>
In 1996, a new digital tide gauge was installed at Tel Aviv Marina (5 km norther to Yafo sight). The TGBM height was derived from the height transfer of the 55/F BM. The local TGBM was fixed at the height 2.003 m.

<u>Ashdod station</u>
Benchmark 17/F was fixed in August 1958. It height 3.538 m was derived on a base of TGBM in Haifa. BM 17/F was destroyed during the port development in December 1967. A new BM 17/F was fixed at the height 3.000 m. Ashdod benchmark was removed together with tide gauge twice: for the first time in January 1968 and second - within the port from the inner part to the entrance sector of the port (Goldshmidt and Gilboa, 1985).
A new benchmark 718/A inside the port was fixed with a height 2.518 m in 1983 and still exists nowdays. BM stability has been checked each year since 1990.

1.2. Sea level measurements

Before 1996 sea level measurements at Yafo and Ashdod stations were performed by means of analog tide gauges of OTT HYDROMETRIE company (Germany). Since 1996 the analog tide gauges were substituted float type digital instruments of the same company.

The location of tide gauge stations at the modern period is shown on the map (Fig.1). SOI tide gauges array includes the next stations: Ashqelon, Ashdod, Tel-Aviv and Haifa. Two other stations at Hadera and Haifa belong to the Israel Oceanographic and Limnological Research.

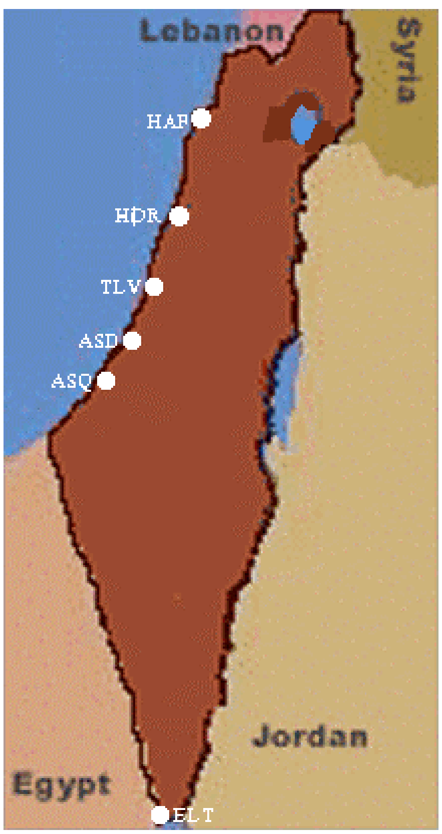

Fig. 1: Tide gauges locations along the Israeli Mediterranean sea coast.

An identical tide gauges were installed at the Tel-Aviv and Ashqelon Marinas and at the port of Ashdod. Fig 2a shows the THALES float type tide gauge at the Ashqelon Marina. Sea level record changes have been monitoring in digital form with 5-min sampling and 1 cm resolution. Sea level has been checking relativly to the nearbye Bench Marks at each station once a week.

Fig.2a Float type tide gauge at the Ashqelon Marina

Fig. 2b Radar tide gauge at the Haifa port

A new microwaves radar tide gauge was installed at Haifa station in 2001 (Fig. 2b). The KALESTO OTT radar sensor use microwaves of 24,125 GHz frequency and 5 mW power with a minimum measuring interval 5 sec.

The characteristic of data used in the sea level analysis is given in the Tab.1.

Tab.1

Years	Station	Category of data	Sampling	Responsible
1958-1960	Ashdod	Tables	Monthly mean	PRA
1961-1984	Ashdod	Tables	Hourly mean	PRA
1962-1989	Yafo	Analog records	Digitized (max – min)	SOI
1990-1995	Ashdod	Analog records	Digitized (max – min)	SOI
1996 –2001	Tel –Aviv	Digital records	15 or 5 min sampling	SOI

2. TIDE WAVES APPEARING ALONG IASRAELI COAST

In order to clarify what is a difference between tide appearance along coast shore, records from difference stations were compared.

Comparison between Ashqelon, Ashdod and Tel-Aviv records shows that tide waves appear at the same phase and almost the same amplitude in all stations. At the Fig.3 tide records with 5-min sampling from Tel-Aviv and Ashdod station over the period of September- November 1999 are presented. The differences between records are defined as a high frequency noise. A mean value and standard deviations of differences are estimated as about 1 cm. Those comparisons justify arranging the data from all considered stations in one array.

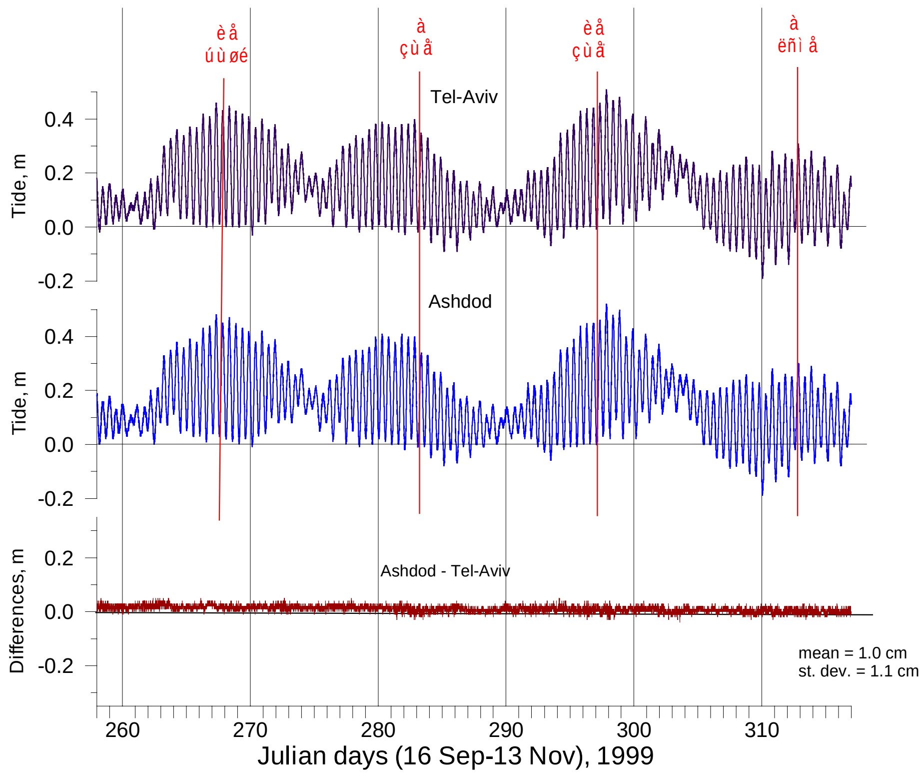

Fig.3 Comparison between Tel-Aviv and Ashdod records.

An example of 1996 yearly record at Tel-Aviv station is given on Fig. 4. The spectrum of that record is shown on the bottom part of Fig.4. The groups of the semidiurnal, diurnal and low frequencies constituents are revealed.

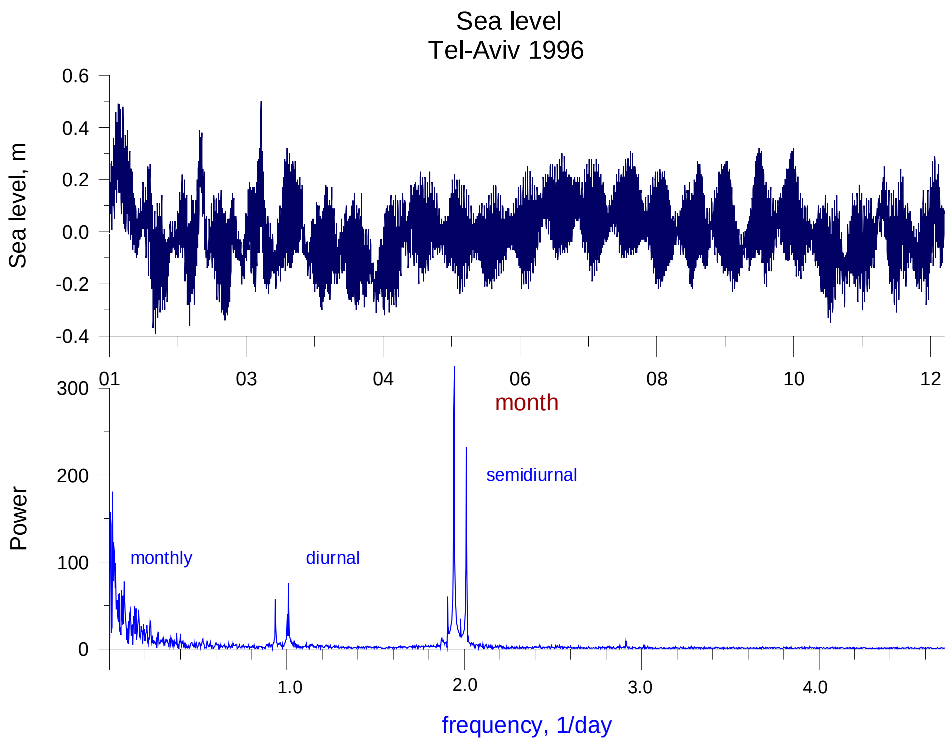

Fig..4 Yearly record at Tel-Aviv station and spectrum.

The comparison between calculated astronomical tides and measured sea level at Tel-Aviv station are given on Fig.5a and Fig.5b. It is evident that calculated diurnal and semidiurnal spectral groups are similar to the measured ones, but in a case of low frequencies distinctions are seen. Such differences in monthly periods can be explained through meteorological factor influence mainly in the winter period.

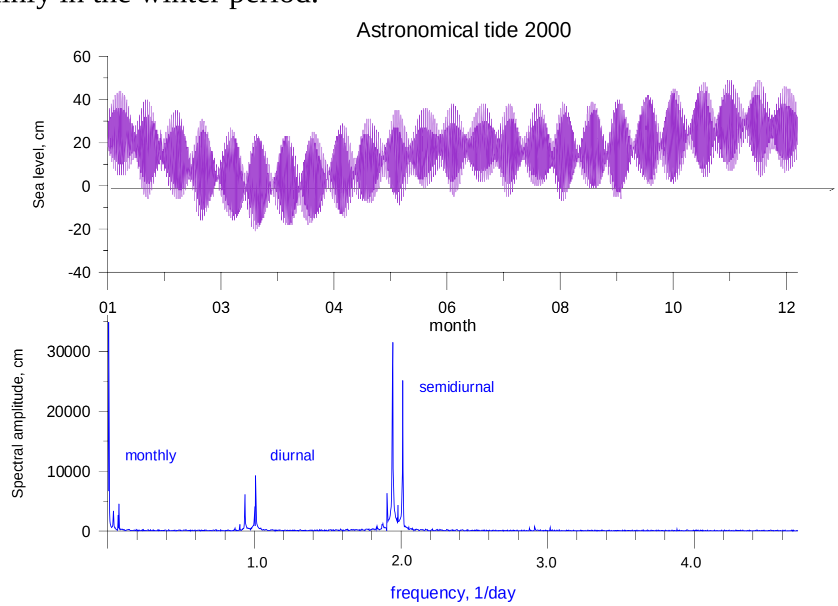

Fig.5a Calculated astronomical tide

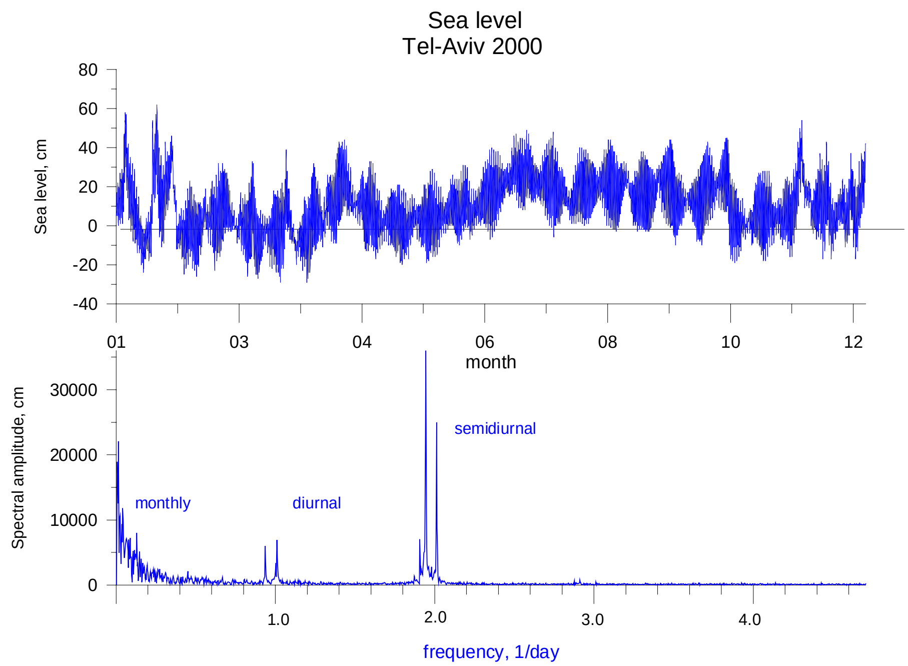

Fig.5b Yearly 2000 record at Tel-Aviv station

3. ACCURACY ESTIMATION OF ANALOG RECORDS

For the accuracy estimation of previous analog record, sea levels at Yafo and Ashdod were compared. Comparisons between one-hour data at Ashdod with records at Yafo usually show a good agreement over a monthly period. It means that semidiurnal and low frequency constituents are appeared in the same phases and amplitudes at both stations. Only full complete month records were included in a consideration. Fig.6 shows monthly mean values compiled from the records of Ashdod station and differences between Ashdod and Yafo over the period 1962 – 1984. The missing data at Ashdod station were complemented by the Yafo data. All the data reffered to the Yafo datum. A systematic mistake in noticed differences result from different benchmark height determination. Two periods of systematic errors are made evident during 1962 – 1984. During the first period 1962-1967 the TGBM heights were determined more accurate and the average of difference between month's mean in Ashdod and Yafo was -0.2 cm. During the second period 1968 – 1983 the average of difference takes value –4.8 cm. As it mentioned below, the Ashdod benchmark together with the tide gauge were removed to the other place in December 1967 and a new benchmark was fixed in 1983. Such distinction in the mean differences probably results from a mistake in a TGBM height determination at the Ashdod station in 1968 (Goldsmith and Gilboa, 1985). The main reason of random errors is probably mistakes in a sea level adjustment in a time of a recording paper changing. During the first period the standard deviation amounted to as much as 2.8 cm and during the second one it was 4.8 cm.

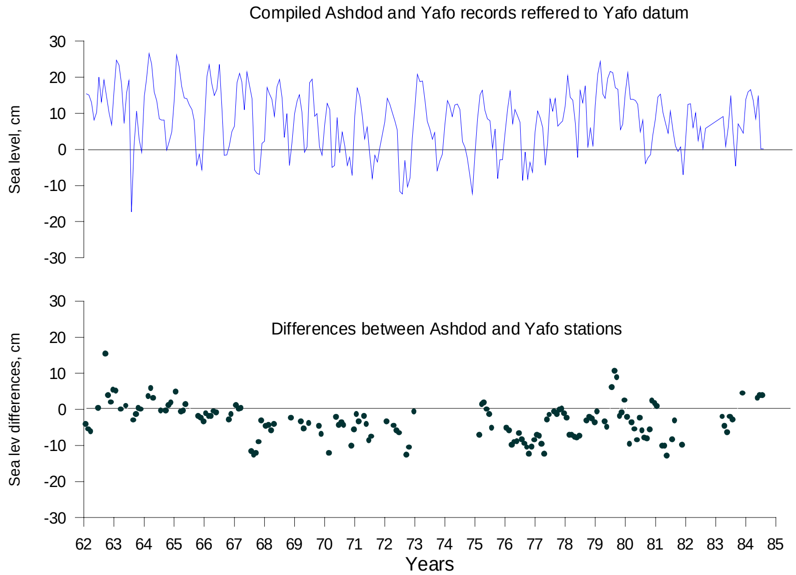

Fig 6. Comparison between the month mean sea levels of Yafo and Ashdod.

4. SEA LEVEL DATA OVER THE PERIOD 1958 – 2001

4.1 Sea level data over the period 1990 – 2001

The next part of data belongs to the latest period of sea level recordings.
It falls into two periods observations were conducted by SOI. The first was performed at the Port Ashdod during 1990 – 1995 and the second – at Marina Tel-Aviv during 1996 – 2001.
A figure of monthly mean values at Ashdod & Tel-Aviv stations during 1990 –2001 shows a gradual increase of Mediterranean sea level in the last decade (Fig.7).

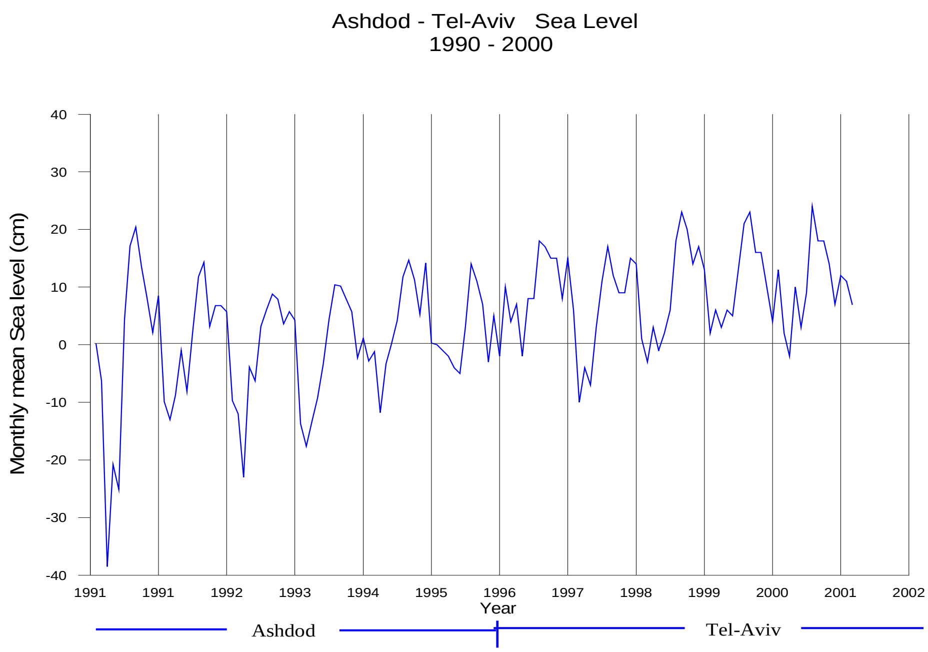

Fig.7 Monthly mean values at Ashdod and Tel-Aviv stations during 1990-2000

Sea level changes over the period 1958-2001

The monthly mean changes over all the period 1958 – 2001 are presented in Fig. 8.
In a series were included intervals when tide gauges and TGBM weren't removed.
It reduced probable errors in a sea level determining. The time series was compiled from the following sights:
Ashdod: 1958-1984. The first displacement of the tide gauge and TGBM were later, in 1968. So, the data of the period 1958-1967 can be considered reliable. The sea level during the period 1968 – 1983 was related to the Yafo datum.
Yafo: 1962-1989. The last tide gauge displacement was in 1962, before considered period. Sea level measurements were realized in reference to the benchmark 223/BN till 1985. The error in the 55/F height determining didn't exceed 2-3 mm.
Ashdod: 1990-1995. Based on new leveling and new tide gauge installation.
Tel-Aviv: 1996-2001. Yafo-Tel-Aviv high precision (about 1 cm) leveling.

Fig.8 shows sea level time series referring to Yafo datum. The average value of all periods showen above is 6.3 cm regarding the Israeli vertical datum.

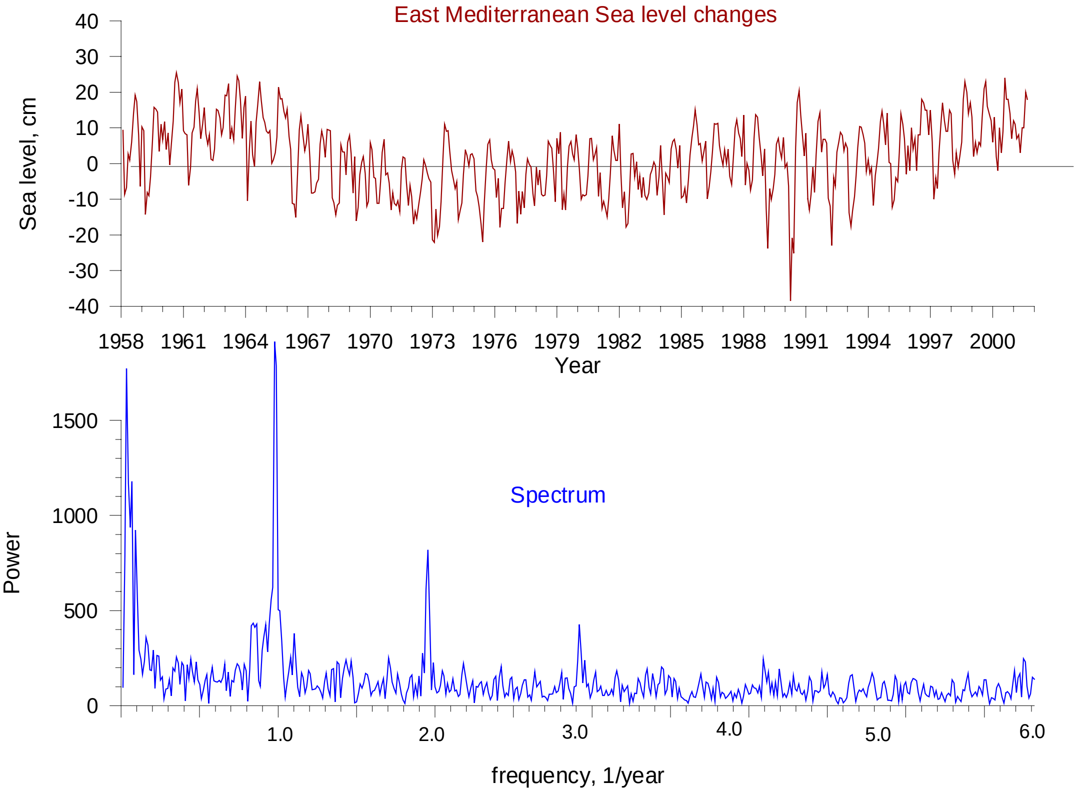

Fig.8 East Mediterranean Sea level during 1958 – 2001.
All the month mean data were reffered to the Yafo datum.

Missing data was provided by the maximum entropy method. This method is based on the signal extrapolation using spectrum characteristics in complex plan (Press et al., 1988). Two examples of this method are illustrated in the Appendix.

The spectral analysis performed by means FFT revealed periods of about 20 years, eight years, one year, half year and about a third year.

DISCUSSION

Sea level changes over forty four years constitute a series of different frequencies fluctuations. Yearly and semiyearly periods are due mainly by astronomical effect. The period of about 1/3-year is conditioned probably by meteorological factor influence. Really, comparison between calculated astronomical tide and measured sea level shows significantly difference in the winter high winds period.

The low frequencies changes are clearly visible from the showed yearly mean sea level changes over all the considered period. The yearly MSL reached the maximum at the beginning of sixties. After that, it falls sharply to the minimum value in the middle seventies. Such lowering MSL (about 10 cm) in the middle seventies was observed also at UK tide gauge stations (Woodworth, 1987). Sea level gradual rise is observed since 1973.

In addition to the meteorological influence on sea level effects a water salinity and temperature, and rainfall (Woodworth, 1987).

It is very important collaboration with geodetic observations (GPS stations) in order to estimate a local land movement. So, long periods sea level variations call for further investigation.

RESULTS

Tide level changes caused by influences from the Moon and the Sun are in the same phase and amplitude along the coast between Tel-Aviv and Ashqelon.

This justifies linking together data from different stations into a continuous time series of 44 years.

Spectral analyses of the tide level changes revealed semidiurnal and diurnal periods and long periods of about 20 years, eight years, yearly and half-yearly and third of a year. The period of the third of a year is probably caused by meteorological factors.

Yearly means indicate a gradual rise of sea level about 15 cm since 1973.

APPENDIX

As written previosly, Missing data was provided by the maximum entropy method.

In order to fill short gaps in data forward and backward extrapolations across the gaps were performed. The gap in data was filled by linear combination of two extrapolations if both agree tolerably well (Fig 10).

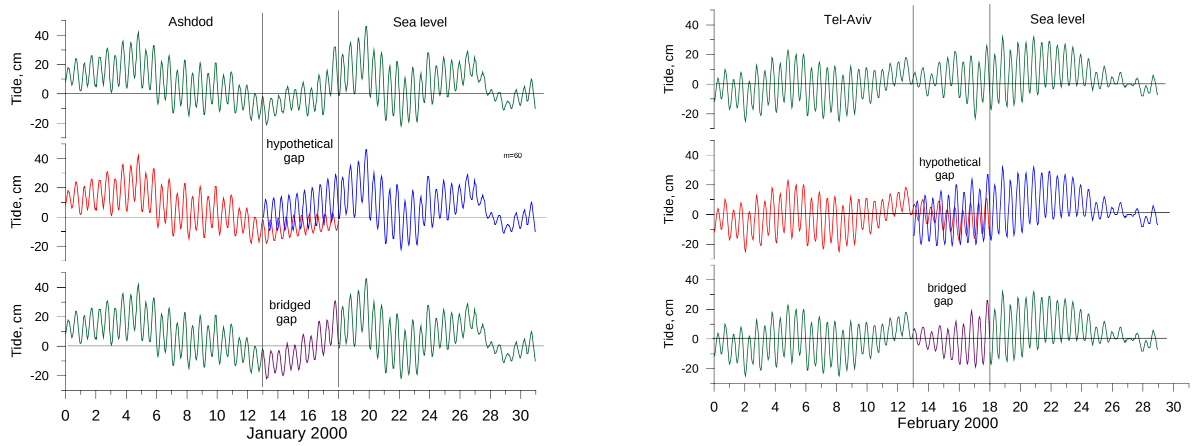

Fig.9 Examples show data processing by means of the maximum entropy method.

ACKNOWLEDGMENTS

The work was carried out at the Research Division of the Survey of Israel (SOI).
Klara Shpitalnik carried out the work of the analog data. The field work was carried out by Aaron Nahary and Iliya Perelman. We would like to thank them for their work and devotion.

REFERENCES

Goldshmidt, V. and Gilboa M. 1985. Development of an Israeli tidal atlas and comparison with other Mediterranean tidal data. IOLR rep. H8/85, Haifa, 28 pp.

Rosen, D. and Kit, E., 1981. Evalution of the wave characteristics at the Mediterranean coast of Israel. Israel Journal of Earth Science, 30, 120-134.

Press W. H., Flannery B. P., Teukolsky S. A., Vetterling W. T.,1988, Numerical recipes. Cambridge University Press, Cambridge. 818 p.

Woodworth P. L., 1987. Trends in U.K. mean sea level. Marine Geodesy,
11, 57-87.