Long Term Monitoring of the Mediterranean and Red Sea Levels in Israel

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Key words: tide-gauge station, mean sea level, geoid, meteorological factors.

SUMMARY

The Survey of Israel (SOI) has been monitoring the Mediterranean and Red sea levels for more than fifty years. Tide gauge measurements along the Eastern Mediterranean coast originated in the 1920s under the British. At present SOI is monitoring four stations along the Israeli Mediterranean sea coast. The main aim of monitoring at SOI is to derive the mean sea level (MSL) as the zero height of geodetic orthometric datum in Israel. The time series of yearly mean values show quasi-periodic changes with 15-20 period years with an amplitude of about 10-15 cm. The third period since 1958, indicates a gradual rise of sea level of about 10mm/year during approximately 10 years. This rise ended in the year 2000. In recent years, we have observed stability or even decrease in sea level during the past eight years.

Sea level changes at the Red Sea (Gulf of Eilat) differ from the Eastern Mediterranean variations. The dfference is evident not only in short tide periods but also in the MSL changes. Tide gauge measurements since 1965 show that MSL gradually rises about 1.5 mm/year. The process of the rising sea level ended in the mid 1990's. Sea level measurements are taken relative to a benchmark linked to the Mediterranean zero level. Repeat ground leveling from the Mediterranean to the Gulf of Eilat shows that the current MSL of the Red Sea is higher than the Eastern Mediterranean MSL by 17 cm.

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1. INTRODUCTION

Originally, the main aim of monitoring at SOI was to derive the mean sea level (MSL) as the zero height of geodetic orthometric datum in Israel. " It is some times supposed that the mean sea level determined by averaging the effects of tides and surges over the year or even several years, is the local level of the geoid" (Pugh, 1987). In recent years data is used for marine mapping and for mapping present shore line for engineering purpose (Zviely, 2008). We realized that long term monitoring sea level change is another important goal which contributes to the investigation of the global sea level changes (Pugh and Maul, 1999, Woodworth, 1987).
The aim of this work is to follow the long term changes of sea levels and to discuss the reasons responsible for such changes.

2. BENCHMARKS AND TIDE GAUGES FOR THE SEA LEVEL MEASUREMENTS

2.1 Mediterranean Sea.

Sea level measurements at each gauge station are performed with a reference to a nearby benchmark called a tide gauge benchmark (TGBM). Usually, TGBM height is derived from a local geodetic leveling. The local leveling is connected to the national leveling network (Intergovernmental Oceanographic Comission, 1985). The first TGBM (in the modern period) was installed at Jafo port in 1954 and at Ashdod port in 1958. Today all benchmarks are connected to the adjusted national network. BM stability has been checked each year (or even more frequently) since 1990. A short summary of the national benchmarks connected to TGBM at Yafo and Ashdod stations at different periods is described in Goldshmidt and Gilboa, 1985, Shirman, 2004.

Sea level measurements at the Yafo and Ashdod stations before 1996 were performed by means of analog tide gauges of the OTT HYDROMETRIE company (Germany). Since 1996 the analog tide gauges were replaced by float type digital instruments of the same company. Identical float type tide gauges were installed at the Tel-Aviv and Ashqelon Marinas. A new microwave radar tide gauge was installed at Haifa station in 2001 and later at Ashdod port. The KALESTO OTT radar sensor uses microwaves of 24,125 GHz frequency and 5 mW power with a minimum measuring interval of 5 sec. Sea level changes have been monitored in digital form with 5-min sampling and 1 cm resolution.

The location of tide gauge stations in the modern period is shown on the map (Fig.1). The SOI Mediterranean tide gauge network tuday includes: Ashqelon, Ashdod, Tel-Aviv and Akko.

2.2 The Gulf of Eilat.

The Eilat region is included in the national leveling network. TGBM height was extended to the Eilat port by means of repeated leveling. The float type tide gauge was installed in 1965 and in 1998 the analog output was added by digital instrumentation.

3. SOURCES OF THE SEA LEVEL CHANGES

3.1 Astronomical factors

The astronomical tidal cycle, (called semidiurnal) takes an average of 12 hours 25 minutes. The semidiurnal tide changes cyclically in amplitude over a fourteen-day period and its maximum and minimum depends on moon phases. The moon and the sun together generate in their movement more than 30 significant constituents (Pugh D., 1987). All periods repeat every 18.61 years, this is called nodal cycle. Shape and range of tide at any station depend on geographical and hydrological factors. Fig.2a and Fig.2b present monthly records from three stations. Comparison between records at Tel-Aviv and Ashqelon stations show their similarity. The differences between records can be seen to approximate a 'high frequency' noise. The mean value and standard deviations of the differences are estimated at about 1 cm. These comparisons justify arranging the data (free from irregular disturbances) from all considered stations into one composite record.

At the same time, an essential difference is seen between level changes at Eilat (Fig.2b) and at the Mediterranean stations. The range of the Mediterranean tide measures about 50 cm while at the Gulf of Eilat it is more then 1m. Also, the ratio between semidiurnal, diurnal and monthly amplitudes of spectrum is different (Fig.3a and 3b). The contribution of the diurnal and monthly constituencies are small in the Eilat spectrum compared to the Mediterranean one.

3.2 Meteorological factors

Air pressure and wind have the most effect on sea level changes (Pugh, 1987). The 'inverse barometer' air pressure effect is expressed by the following relation (Pugh, 1987):

$$\Delta h=-0.993\ \Delta Pa$$

where Δh is sea level change in cm and ΔPa is atmospheric pressure change at the coast station relative to the Standard Atmosphere of 1013 mb.
The relation between wind parameters and sea level changes is more complicated .
It involves a spatial gradient of atmospheric pressure. Good correlation was shown between wind velocity and sea level changes on the Scotian shelf (Sandstrom, 1980), for example.
Influence of long-term wind on Mediterranean sea level changes was considered in Shirman, 2004, Tsimplis et. al., 2005. Comparisons between the meteorilogical part of sea level and wind strength were made on the basis of three hours of wind velocity measurements at the Sde Dov coastal station. The meteorological part was taken as the difference between measured sea level at the Tel-Aviv station and the astronomical tide published in Rosen, 2000.

As an example, we have examined in combination, Tel-Aviv sea level data and wind data from the Sde Dov station during the period between 25 November – 06 December 2000. Wind intensification in the North-West wind during 5 days added about 40 cm to the sea level. The graph of sea level changes has a similar form as the North component with about two days delay between them (Shirman, 2004).

4. LONG TERM SEA LEVEL CHANGES

4.1 Accuracy estimation of sea level records

For the accuracy estimation of the early analog records, sea levels at Yafo and Ashdod were compared. Comparisons between one-hour data at Ashdod with records at Yafo usually show a good coincidence over a monthly period. This means that semidiurnal, diurnal and low frequency constituents appeared with the same phases and amplitudes at both stations. A systematic error was noticed in the differences in the results from different benchmark height determinations. Two periods of systematic errors are evident during 1962 – 1984. During the first period 1962-1967 the TGBM heights were determined more accurately and the average difference between the monthly means in Ashdod and Yafo was -0.2 cm. During the second period 1968 – 1983 the average difference value was –4.8 cm. The main reason for random errors is probably due to mistakes in the sea level adjustment at the time of changing the recording paper.

Accuracy of the present digital records is considerably above the analog ones. Taking into consideration checking and adjustment over sea level, masured every week and as mentioned previously checking and adjustment over TGBM, we estimate an absolute accuracy as not more than 1 cm.

4.2 Eastern Mediterranean Sea level changes over the period 1958-2008.

The yearly mean changes over the entire period between 1958 – 2008 are presented in Fig**.** 4a. The series was compiled from the different sources including digital as well as analog records. Three repetitive sequences of MSL changes with 15-20 year period since 1958 is evident. Since the 1990's control over sea level and bencharks was handled by by the network of the Mediterranean stations. This brings out clearly that sharp changes of about 2 cm from year to year is realistic. After 10mm/year graduel rise of MSL since 1990 comes stability in 2000 and even a decrease in level during the past years. The smooth curve represents splined polynom approximation (Fig.4a).

4.3 Gulf of Eilat Sea level changes over the period 1965-2008.

Control over the Eilat tide gauge was carried out usualy once a month. Hence, we estimate accuracy of monthly mean sea level after adjustment as 1-2 cm. Fig.4b shows MSL changes since 1965. In comparison, we can see at this point a gradual rise in the Eilat MSL. The trend during the 30 following years since 1965 is estimated at about 3 mm/year. Thereafter the long-term rising process stopped. It seems quite possible that during the years which followed after 1995 a long period of the MSL decrease will come.

5. DISCUSSION

As indicated above, there are some reasons for long–term sea level changes. Among them: astronomical, meteorological, steric (water salinity and temperature). According to different estimations (Pugh, 1987) the amplitude of the nodal cycle can reach 4-7 mm. This means that contributing in observed changes is very low. The next possible contributers are meteorological factors.

As it was mentioned, the most important effect on sea level at the Mediterranean tide gauge stations is the North-West wind, while air pressure acts according to 'inverse barometer' law. Fig 5a and 5b present air pressure changes at the Sde Dov meteorological station and the sea level changes associated with them. Yearly means changes of air pressure do not exceed 2-2.5 mb, resulting in 2-2.5 cm sea level changes. From Fig. 5b it follows that air pressure changes should not be a main reason for observed long term sea level changes. The yearly means of wind strength from the Northern and Western directions gathered from the coastal meteorological stations Sde Dov and Nahariya during the years 1965-2001 varied within a small range of +/- 0.5 m/s, which also can't provide observed changes.

It is clear that observed differences between Mediterranean Sea and Eilat (Red sea) level changes are due to the oceans with which they are associated: the North Atlantic and the Indian oceans.

Ocean surface topography (water density and currents) contribute significantly to sea level changes. The North Atlantic Oscillation (NAO) makes an important contribution to the Mediterranean sea level (Tsimplis, 2001). The NAO is a large decadal timescale variation in atmospheric pressure between the Azores and Iceland. When the positive state of NAO (High Azores and low Icelandic pressure) reverse to the negative one storms track southerly to the Mediterranean Sea. A connection between the NAO and the sea level of the Mediterranean was reported in Tsimplis, 2001. As discussed in cited paper, the NAO can affect sea level via both salinity changes in deep water and surface pressure.

6. RESULTS

The time series of yearly mean values shows quasi-periodic changes of about 15-20 years with the amplitude of about 10-15 cm at the Israeli Mediterranean stations. The third period since 1958 indicates a gradual rise of sea level of about 10mm/year during approximately 10 years. This rise ended in 2000. Today we have observed stability or even a decrease in level during the past years. Considering long term sea level changes, it is concluded that mean sea level may be only the first approximation to the geoid. There are other oceanographic effects such as water density variations, permanent ocean circulations, atmospheric effects (air pressure and wind), which displaced the mean sea level from the geoid.

Sea level changes at the Red Sea (Gulf of Eilat) differ from the Eastern Mediterranean variations. The difference is evident not only in short tide periods but also in the yearly means changes. Tide gauge measurements since 1965 show that sea level rose compared to the current level about 7 cm. Measurements are taken relative to the benchmark linked to the Mediterranean zero level. Repeat ground leveling from the Mediterranean to the Gulf of Eilat shows that the MSL of the Red Sea is higher than the Eastern Mediterranean mean sea level by 17 cm in the present-day period.

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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.

Manual of sea level measurement and interpretation V.1, 1985. Intergovernmental Oceanographic Comission, UNESCO.

Pugh D.T., 1987. Tides, surges and mean sea-level. John Wiley & sons, Chichester, 472 p.

Pugh D.T. and Maul G.A., 1999. Coastal sea level prediction for climate change.
In: Coastal and eatuarine studies, American Geophysical Union, Washington, DC.

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.

Rosen, D., 2000. The forecast at the Israeli Mediterranean coastline for year 2000.
IOLR REPORT H01/2000.

Sandstrom, H, 1980. On the wind – induced sea level changes on the Scotian shelf.
Journal of Geophysical Research, 85, 461-468.

Shirman B., 2004. East Mediterranean sea level changes over the period 1958-2001. Israel Journal of Earth Science, 53, 1-12.

Tsimplis, M. and Josey, S., 2001. Forcing of the Mediterranean Sea by atmospheric oscillations over the North Atlantic. Geophysical Research Letters, 28, 803-806.

Tsimplis, M., Alvarez-Fanjul, Gomis, D., Fenoglio-Marc, L., Perez, B., 2005. Mediterranean Sea level trends: Atmospheric pressure and wind contribution. Geophysical Research Letters, 32, 803-806.

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

Zviely, D., Kit, E., Rosen, B., Galili, E., Klein, 2008. M. Shoreline migration and beach-nearshore sand balance over the last 200 years in Haifa Bay (SE Mediterranean). Geo-Mar. Lett., DOI 10/1007/s00367-008-0126-2.

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