# **CHAPTER 17**

## Mediterranean Sea Level Changes From Tidal Records

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# Abstract

Of the more than 90 tide gage records in the Mediterranean, 10 representative gages were analyzed for indications of sea level rise (SLR). No definitive trend of regional sea level rise has been discerned for this area. The lack of SLR may be partially attributed to local effects on sea level such as seasonal water temperature and wind differences, and to local tectonics. The extent of these seasonal changes is in the order of tens of cms/year, and varies greatly from year to year, probably masking the trends of long-term SLR of mm/yr.

## Introduction

Recent studies indicating a sea level rise on some coasts (Aubrey and Emery, 1983), together with analyses of the "greenhouse effect", have led to predictions of a future global sea level rise of 60 cm in the next 40 years (summarized in Barth and Titus, 1984). As a result, subsequent efforts have concentrated on rezoning the coasts and re-defining criteria for all coastal constructions, for the expected SLR.

In this study attention is directed at documenting and explaining seasonal sea level changes discerned in Mediterranean tide gages. These analyses are then used to help define SLR.

Tide Data

Tide records for Israel have been obtained from Israel government agencies for the following locations: Haifa 1956-60, 1965-76 Jaffa 1955-59, 1962-73, 1975-82 Ashdod 1958-83 Eilat 1965-70, 1975-83 The first three are on the Mediterranean coast, and Eilat is on the Red Sea.

Tide records for the following locations were obtained from the Permanent Service for Mean Sea Level (PSMSL) in Liverpool, U.K.: (Fig.1): Gibralter 1961-83 Alicante Spain (Mediterranean coast) 1960-78 Trieste Yugoslavia 1934-74 Bakar Yugoslavia 1934-74

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Dubrovnik Yugoslavia 1956-74 Piraieus Greece 1969-82

Comparisons of concomitant tidal data at the three Israeli Mediterranean locations indicate that they have very similar tidal curves and amplitudes (30-60 cm). The similarities in these tidal curves provided a check on the efficacy of the data and on the common sea level datum (Goldsmith and Gilboa, 1985).

# Seasonal Sea Level Changes

With the exception of Trieste, no clear long term sea level trends were discerned from statis tical analyses of the averages of annual sea levels. Further analyses were conducted by computing the monthly mean sea levels. From these results, strong seasonal changes of 15-20 cm were noted, with the seasonality varying around the Mediterranean. Further, the seasonality varied significantly (>5cm) from year to year.

Plots were made of the averages of all the monthly means for each of the 12 months (Fig. 2).

#### Temperature Effects

Along the Israeli coast there is a strong tidal seasonality with a range of 20 cm. This is approximately equal to the neap tide range, and 1/3 of the spring tide range. Highest sea levels occur at the end of summer and lowest sea levels occur at the end of winter. Heat flow data obtained over many years by the R/V Shikmona in the southeast Mediterranean continental shelf show a similar seasonality (Fig. 3). Moreover, computations of theoretical sea level changes from the measured heat flow data indicate that sea level changes based on the seasonal water temperature changes alone accounts for 2/3 of the seasonal sea level changes measured by the tide gages. This is due to changes in the water volume (i.e., cold water is denser, hence lower sea levels in winter). There appears to be a certain lag effect, with the coldest and warmest temperatures occuring at the ends of winter and summer, respectively.

A similar pattern is found in the western Mediterranean; e.g., Alicante Spain and Gibralter have a seasonality of 15 cm with highest levels in September to November, and lowest levels in February/March (Fig. 4). Here the seasonality is not so regular nor so sharp as in the eastern Mediterranean.

# Wind Effects

Another factor in the seasonal sea level changes involves local wind effects, especially in on/offshore winds. In the southeast Mediterranean, very low monthly mean sea levels occur occasionally in the winter months (i.e. 20 cm below MSL). This is attributed to strong offshore easterly winds which may blow continuously for many days. In the western Mediterranean unusually high monthly mean sea levels occur in the summer months. Along the Spanish coast the dominant winds are onshore from March to April with the highest frequency in July, and offshore from November to February, peaking in February (Sanjaume, 1984, and Figure 4). The measured monthly mean tide heights decrease from December to February at both Alicante and Gibralter, coincident with the dominance of offshore winds. Similarly, the monthy mean tide heights increase from March to October coincident with the dominance of onshore winds.

Thus the seasonal sea level changes appear to be related to a combination of sea temperature and wind effects in the Mediterranean.

Long-term Sea Level Changes From Yearly Averages

At Trieste the long-term trend is a rise in sea level, but between 1955-83 sea level was relatively stable. At Ashdod and Piraeus in the eastern Mediterranean, the annual average sea level was higher in the 1960's, and decreased by 5 cm in 1979-1980, then rose and fell again. At Gibralter and Alicante in the western Mediterranean, sea level was lower in the 1960's; it peaked higher in Gibralter in 1970-1980 and then decreased by 12 cm. (Fig. 1).

Linear regression analyses and r2 values were derived from the annual averages of the 10 tide gages. The computed trends and the r2 values are presented in the top portion of Figure 5. Only Trieste shows a clear SLR (1.3 mm/yr). Due to the many uncertainties in these tide data (including placement of the gages relative to a common datum, continuity of records, and annual variations in local climatological factors) there is some statistical uncertainty in choosing the proper limiting r2 value. Imaginary tide gage records were constructed using a random numbers table, and similar statistical computed sea level trends with r2>0.1 are accepted (Fig. 5). Note that at two locations, Haifa and Alicante, at opposite ends of the Mediterranean, a trend of sea level lowering is indicated.

Long-term Sea Level Changes From Monthly Averages

Because of the large seasonal range observed in the tide gage records, and the large variations from year to year in this seasonality, it appears that a better indicator of long-term changes might be discerned in the analysis of the trend for an individual month, i.e., the monthly means of all the January's for all the years of record. The results of the statistical analyses of the monthly sea level trends and concomitant r2 values are shown in the bottom half of Figure 5. Of the 120 analyses (10 gages X 12 months) only those with r2 values > 0.1 are shown.

A strong trend of rising sea level of  $1-2 \, \text{mm/yr}$  is clearly shown for Trieste (especially in the summer months) and for the neighboring station of Bakar (for June and August). A weak trend of falling sea level is shown for Ashdod (August and September) and Alicante (June).

What is clar, however, is that the best results occur in the

summer months. This appears to be due to more consistant climatological factors in the summer. In the winter the Mediterranean is in the zone of westerlies with storms passing through on an average of every 7-10 days (Goldsmith and Sofer, 1983). In the summer, the subtropical low moves north and winds in the eastern Mediterranean blow every day from the northwest.

## Conclusions

SLR trends in the Mediterranean are "masked" by the local processes including seasonal sea level changes from thermal expansion of the sea due to temperature changes, and from seasonal changes in the offshore/onshore winds. These seasonal changes in the sea level of 15-20 cm have large annual variations (> 5cm). Of the 10 gages analyzed only Trieste shows a definite trend of SLR amounting to 1-2 mm/yr. The location of Trieste, at the end of the Alps, suggests the importance of local tectonic effects.

To overcome the "noise" in the data resulting from seasonal effects, sea level trends of individual months, rather than annual averages, were delineated. In some cases the individual months are statistically more significant than the annual averages. The best results occur in the summer months when climatological conditions are more consistent.

The lack of consistent definitive trends in Mediterranean sea level records suggests the importance of local effects. The analyst looking for indications of SLR should be aware of local effects and take these into account before making definitive statements on SLR trends.

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YEARLY AVERAGES OF M.S.L IN THE MEDITERRANEAN

Figure l





Figure 2



Figure 3







Figure 4



Figure 5

# Tidal sea level changes in the Med. & significance yearly averages