Lecture O9: Observed sea level variability in the Mediterranean Sea

1. Why is sea level variability important?

Sea level changes have significant and some times catastrophic impacts on the coastal zone. The coastal environment is very vulnerable to changes in mean sea level, as well as changes in sea level extremes. Changes in wave heights and wave directions also play a very important role, as well as changes in temperature and salinity.

The impacts of sea level rise on the coastal zone include erosion, coastal inundation, habitat loss and ecosystem damage. Flooding of coastal areas may lead to degradation of coastal lands and contamination of underground water. The importance of these impacts will depend on the character of the coastal environment. For example hard rock coasts are generally resilient, soft rock coasts are generally more vulnerable as sandy beaches and gravel beaches.

Deltas and estuaries are particularly vulnerable because of the complexity of the processes involved in their maintenance.

Of course, such processes have been happening in the past and society was adapting by just moving away from the advancing or retreating, depending on the extension or retreat of the sea-line.

However, today significant infrastructure has been built near the sea and millions of people chose to live near the coast for financial reasons or simply because it is a more pleasant environment. By developing such infrastructure the coastal environment has been altered significantly and our ability to adapt has been reduced. We have invested so much effort and money in developing ports, cities, touristic resources etc. near the coast, that we have also developed a need to protect them from the advancing sea rather than abandon them as our predecessors would have done.

While mean sea level reflects on changes in the slower processes like coastal erosion, potential changes in storminess and extreme sea levels are potentially more dangerous and can threaten loss of human life and destruction of coastal installations. Of course, living with increasing sea levels is not a recent problem; there are countries like the Netherlands which have developed a societal system that can cope with their reality.

In the Mediterranean Sea, the Nile delta is the area most vulnerable to changes in sea level. The combination of large density of population with the problems present in deltas, where sediment compaction can cause significant subsistence, and the damming of the Nile, which has deprived the delta from further sediment, makes this a particularly risky situation. Venice (for cultural reasons) is also a very vulnerable position in the Mediterranean Sea, although the number of people subject to the risk is much less there.

There is a second reason why sea level changes are important: They represent an indirect measurement of the melting ice-sheets and water expansion. We believe the atmosphere is warming and we have indications that sea level is rising faster than before. However, measuring ice-sheet melting and the oceans' temperature are very complicated tasks which we can only partly do successfully. By contrast, measuring sea level is relatively easy and inexpensive and has been taking place for almost two hundreds years, thus giving us a background against which we can assess the present situation. Thus, sea level rise is an important as a parameter for monitoring the advancement of warming.

2. How is sea level measured?

There are presently two major ways of measuring sea level. The first is by instruments fixed to the coast. These were originally poles having scales on them where a person would regularly read and record the sea level height. These were first installed for the monitoring of tides and ensuring safe access to ports, and thus they were termed as tide-poles and then tide-gauges. Self-recording instruments have replaced the original configurations. Tide-gauge data provide high frequency observations although, historically, hourly values are reported. The accuracy of the measurements is around 1 cm. Archived data or even near-real time sea level values can presently be found on the internet. Note that the observations from tide-gauges are only useful for long-term monitoring of sea level if they are referenced to a point on land. This means that the relative change of sea level with respect to land is always by reference to the same datum. However, this means that tide-gauge observations are not pure sea level measurements but consist of sea level changes and land movements.

The second way by which we observe sea level is by use of radars flown on satellites. Satellite altimetry, as it is called, has become operation in 1993 and since then provides almost global estimates of sea level. In order to determine the sea level height from an instrument which moves over the earth, we need to determine two things: first, we need to know the distance of the satellite from a reference surface and, second, we need to know the distance of the satellite above the sea level. By subtracting these two, we can obtain the sea level height above the reference surface.

The position of the satellite is measured by tracking the satellite from a globally-distributed network of lasers and doppler stations and by use of orbit dynamic calculations.

The surface used as a reference is the equipotential surface approximated by an ellipsoid with polar diameter 43,000 m smaller than that at the equator. However, the sea surface topography deviates significantly, for our purpose, from a smooth ellipsoid and shows deviations of up to 100 m. Such deviations are due to the inhomogeneous distribution of mass on earth and the corresponding changes in the gravitational attraction this causes.

The height of the satellite above the sea is measured with microwave radar operating in a pulse-limited mode on a carrier frequency of 13 GHz. The radar illuminates a rather large spot on the ocean surface (a few tens of km in diameter). A smaller, few km in diameter, effective footprint is sent and its two-way travel time is recorded. The return time is the basis of the determination of sea level height. However, the time of travel depends to an extent to the interaction of the signal with the atmosphere, thus various corrections for ionospheric and atmospheric delays have to be applied.

The most accurate altimeters (TOPEX/JASON/JASON 2) have a claimed accuracy of about 3-5 cm. However, they do not work properly north and south of about 60^{o} and, more importantly, at distances closer to 30-40 km from the shore.

Thus, on one hand we have several hundreds fixed instruments around the globe providing local information – we will talk about the Mediterranean later – and, on the other hand, we have an instrument flying on a satellite. Interpreting either of these measurements is far from trivial.

Comparison between satellites and tide-gauges has been made repeatedly (Mitchum, 1994). In practice tide-gauges are used to monitor the stability of satellites; thus the two datasets are not independent (Mitchum, 1998).

3. Sea level changes in the Mediterranean Sea

Because sea level measurements from satellites have only become available in 1993 onwards, it is tide-gauges we mainly rely upon to assess sea level rise. And these, as we have said, are subject to local land motions. Therefore, we need to synthesize sea level measurements from various locations, each of which is subject to different vertical land movements. This is far from an easy task.

There are only four long sea level time series available in the Mediterranean Sea, namely, Marseille (France), Genoa, Trieste and Venice (Italy). Two are located at the north part of the Adriatic Sea and two at the north-east part of the western Mediterranean Basin. Three stations indicate sea level rise of around 1.2 mm/yr or 12 cm per century. The fourth, Venice, has been experiencing faster sea level rise for the first part of the 20^{th} century due to underground water extraction, which caused land subsidence. The rates there account for the double rate compared to the three other Mediterranean stations. However, for the period after 1960, when the water extraction stopped, the rate of sea level rise is in agreement with the other three stations.

Figure 1 shows the location of tide-gauges used in the most recent estimation of sea level trends in the Mediterranean Sea (Marcos and Tsimplis 2008). Black dots correspond to the longest time series (>35 years), while red squares are the shorter records.

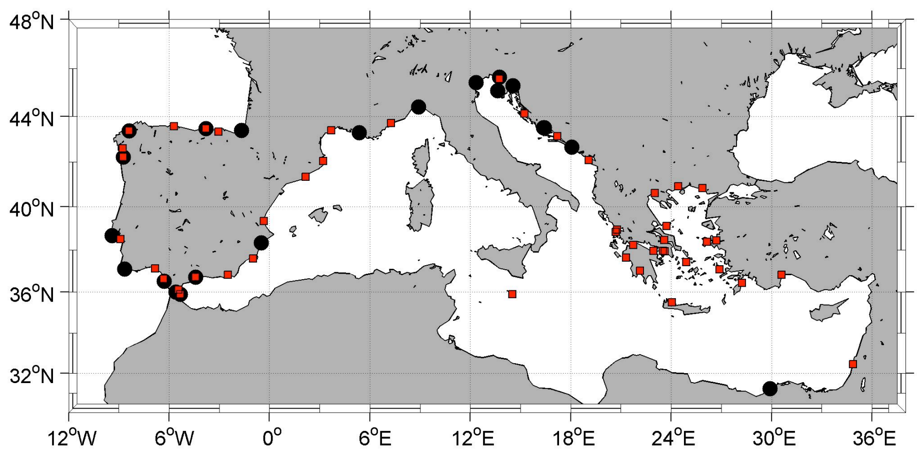

Figure 1 (Marcos and Tsimplis). Location of tide-gauges

In Figure 2 (Marcos and Tsimplis 2008), the time series of the various stations are shown. Note the differences between the various regions. Note also the differences between Venice and Trieste which are remarkable close.

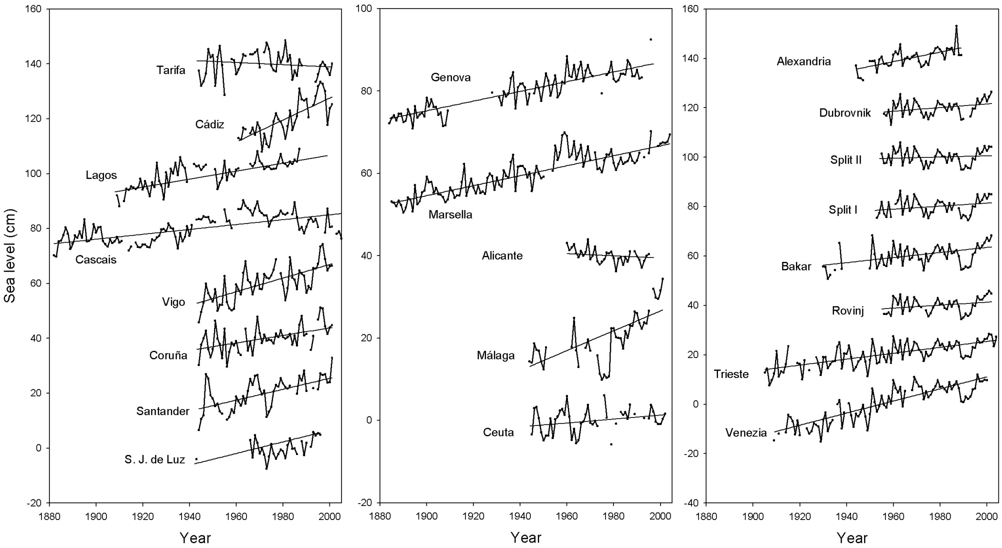

Figure 2. Time series and trends for the longest tide-gauges in the Mediterranean and Atlantic coasts (Marcos and Tsimplis, 2008)

The shorter tide-gauges show considerable scattering of trends (Figure 3). It is clear that estimating sea level change on short records can be misleading.

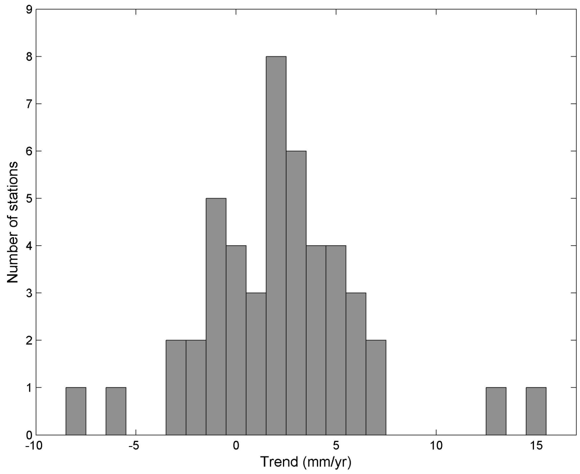

Figure 3. The distribution of the trends of the shorter tide-gauges in the Mediterranean region (Marcos and Tsimplis, 2008)

How long should a record be in order to enable a "reliable" estimation of sea level change? For the Mediterranean Sea, Tsimplis and Spencer (1997) have shown that it takes 40 years or more to get trends stable within 0.5 mm/yr. Thus, most of the Mediterranean tide-gauges are not usable for long-term trends studying, unless the forcing which causes the shorter term variability (and apparent trends) is well understood and removed from the records.

Trends can also be estimated from altimetry. A completely different picture emerges:

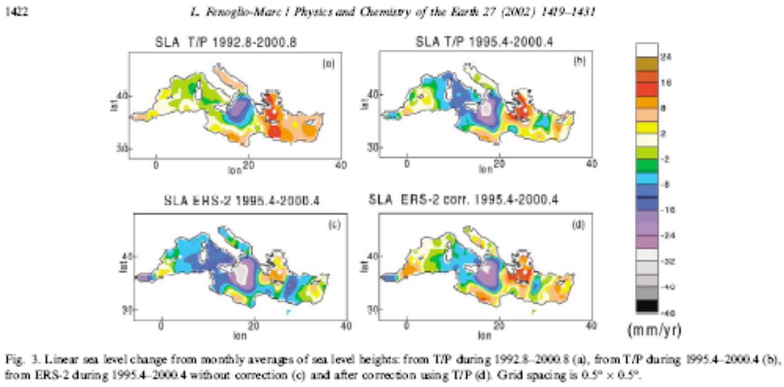

Figure 4. Sea level change from monthly averages of mean sea level heights from T/P during 1992.8-2000.8 (a), from T/P during 1995.4-200.4 (b) and correspondingly for ERS-2. From Fenoglio-Marc(2002).

The sea level signal is richer than the tide-gauge values suggest. Regions within the Mediterranean Sea show differing behaviour. The question of what is the meaning of sea level rise within the basin is thus important. Probably, in respect of sea level rise as a measure of thermal expansion, the basin average may have a meaning. However, from the point of view of coastal protection, it is clear that local measurements are needed.

5. Reconstruction of sea levels from tide-gauges and altimetry

One way to solve the problem of having long-term coastal measurements and a relatively short period of spatially complete measurements is by attempting to join them together. This can be achieved by taking the spatial patterns as observed from altimetry (or, at least the lowest EOFs of them) and link them with the observed changes from tide-gauges (see, for example, Church and White, 2006). Notably, such reconstruction would be reliable only to the extent that the observed spatial patter has been temporarily stable. For the Mediterranean, there is one such reconstruction published (Tsimplis et al., 2008).

6. Temporal variability of sea level trends

From Tsimplis and Baker (2000), who showed that sea level in the Mediterranean Sea was retreating or was stable between 1960-1993, to Cazenave et al. (2002), who claimed values of 7 mm/yr for the period 1993-1998, there is a great range of values for the Mediterranean Sea. One should be very careful not to ignore the fact that estimates over short periods of time are not representative of the long-term trends. Moreover, what matters is understanding the forcing rather than the statistic of linear change.

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http://medgloss.ocean.org.il/

http://www.eseas.org/products/?page=real_time_data

http://www.psmsl.pol.ac.uk/