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Final report for MedCLIVAR - Exchange Grant 1928

The Marseille tide gauge: recovery and analysis of high frequency sea level data from 1885

Purpose of the visit

The tide gauge in Marseille (Figure 1) is one of the longest records in the world. Hourly sea-level values have recently been recovered and put into numerical format from the original tidal charts recorded by means of a mechanical floating gauge, which is still operational. The rescued hourly data cover the period 1885 to 1988 and still required being quality controlled before publication and distribution to the scientific community. Its length (more than 100 years) and the high frequency sampling rates make it suitable for long term analysis of both the low and the high frequency sea level changes in the North-western Mediterranean. The importance of high frequency measurements relies on the potentially hazardous impact that high waters have in coastal areas. While the knowledge of mean sea level variability is crucial for coastal planning and for the design of mitigation strategies at long term, the most hazardous events are usually related to extreme high waters. This has been a motivation of the proposed work. The choice of IMEDEA as host laboratory has been motivated by the competence and knowledge of this physical oceanography group, whose experience in sea level research is supported by more than 30 publications. This work has been the opportunity to enhance my skills in oceanography as a training to contribute significantly to my PhD thesis.

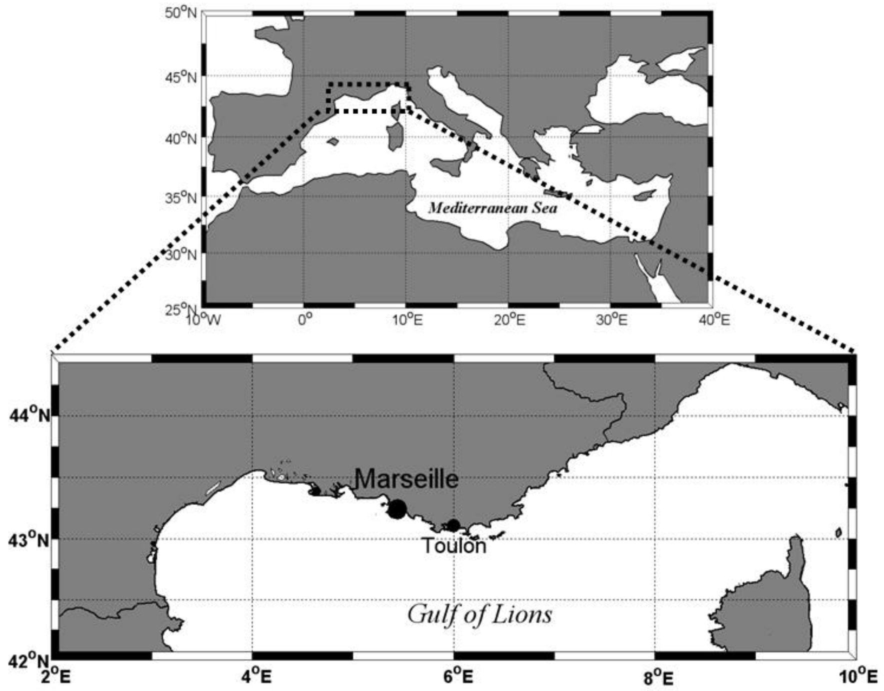
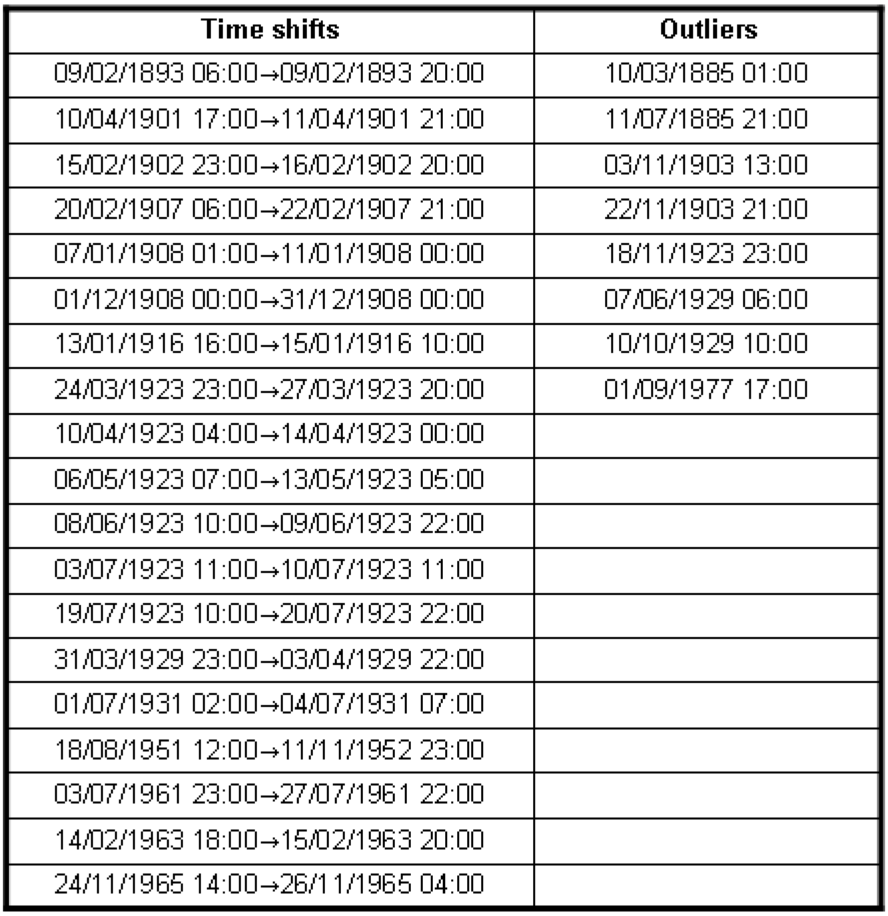


Figure 1. Location of Marseille and the nearby Toulon tide gauge stations.

Description of the work carried out during the visit

The work has been organised following three sections.

- The first part was dedicated to a Sea level quality control and tidal analysis. For the entire time series, the tidal components have been estimated from hourly data by classical harmonic analysis using the standard Matlab program t_tide (Pawlowicz et al, 2002). An additional quality control based on the comparison between tidal time series and observations has been carried out. Observations, tides and tidal residuals have been visually checked month by month. Time shifts and outliers have been detected and removed from the time series. The periods when these problems were found have been listed in Table 1 and are available for the scientific community.



Time shifts	Outliers
09/02/1893 06:00→09/02/1893 20:00	10/03/1885 01:00
10/04/1901 17:00→11/04/1901 21:00	11/07/1885 21:00
15/02/1902 23:00→16/02/1902 20:00	03/11/1903 13:00
20/02/1907 06:00→22/02/1907 21:00	22/11/1903 21:00
07/01/1908 01:00→11/01/1908 00:00	18/11/1923 23:00
01/12/1908 00:00→31/12/1908 00:00	07/06/1929 06:00
13/01/1916 16:00→15/01/1916 10:00	10/10/1929 10:00
24/03/1923 23:00→27/03/1923 20:00	01/09/1977 17:00
10/04/1923 04:00→14/04/1923 00:00	
06/05/1923 07:00→13/05/1923 05:00	
08/06/1923 10:00→09/06/1923 22:00	
03/07/1923 11:00→10/07/1923 11:00	
19/07/1923 10:00→20/07/1923 22:00	
31/03/1929 23:00→03/04/1929 22:00	
01/07/1931 02:00→04/07/1931 07:00	
18/08/1951 12:00→11/11/1952 23:00	
03/07/1961 23:00→27/07/1961 22:00	
14/02/1963 18:00→15/02/1963 20:00	
24/11/1965 14:00→26/11/1965 04:00	

Table 1: Time shifts and outliers detected from quality control on Marseille hourly observations.

- The second part focuses on Long term sea level changes. Sea level trends have been computed from the monthly time series by performing a robust linear regression.

The decadal variability has also been examined by computing decadal trends for the monthly sea level records as the linear trends of 10-year periods overlapped year to year and corrected for the inverted barometer effect using the HadSLP2 air pressure data set (Allan and Ansel 2006). Correlations of yearly sea level time series with winter NAO index have also been computed. The seasonal cycle has been estimated for Marseille sea level observations as the mean value for each calendar month. Only complete years are used for the computation in order to avoid biases

Inter-annual variations in the Marseille record have been explored by means of spectral analysis .

- The third part studies the sea level extremes in the Marseille time series using a simple model to analyze the distribution of the extreme events and to quantify the return periods consists in fitting the distribution of the excesses over a high threshold to the Generalized Pareto Distribution (GPD). Given a time series ($x_1,\ldots,x_N$) let ($y_1,\ldots y_K$) be the exceedances over a high threshold U (y=x-U) of independent events, with K<<N. These excesses follow a GPD whose cumulative distribution function is defined as (Pickands, 1975): $G(y;\xi,\sigma)=1-\left(1+\xi\frac{y}{\sigma}\right)^{-1/\xi}$

Where ζ is the shape parameter being a real number and σ is the scale parameter with σ >0. Then parameters have been modelled as a function of time (Davison and Ramesh, 2000; Hall and Tajvidi, 2000; Coles, 2001; Méndez et al., 2006). We will follow here the approach on local regression models by Butler et al., (2007). This method is based on the estimation of the model parameters (ζ(t), σ(t)) by maximization of a weighted sum of log-likelihood functions for all times.

The N-year return levels are then estimated from the parameters (ζ_j, σ_j, $\delta\sigma_j$).

We followed the bootstrap scheme by Davison and Ramesh (2000) to estimate the uncertainty of the computed return levels. The method has already been applied successfully to sea level extremes in Butler et al. (2007).

The first part of extremes analysis explored the inter-annual and decadal variability of extreme values on the basis of yearly percentiles. The effect of mean sea level changes over the higher percentiles has been removed by subtracting the 50th. The time series of percentiles have been correlated with winter NAO Index (http://www.cru.uea.ac.uk/cru/data/nao.htm , Jones et al., 1997). Mean value has been removed from the observations for the sake of comparison with

In the second part of analysis, the local time dependent GPD model has been applied to the hourly tide gauge record in Marseille to obtain return levels. The exceedances over the 99.5th percentile have been selected as the extreme values, with events separated by at least 72 hours.

An important parameter of the time dependent GPD model is the bandwidth *h* of the Gaussian function K(Δt,*h*). Large values of the bandwidth will result in smoother variations of the return levels. The purpose is to filter out inter-annual variability not related to climate variations, but to keep inter-decadal variations which can be the consequence of changes in storminess in the region or a shift in the storm patterns. The chosen value has been *h* = 10. This value corresponds to a window of approximately 30 years around the year of interest. The choice of this value is based upon a priori knowledge of inter-decadal mean sea level trends in the area. Since it has been shown that long-term extreme changes are partly driven by mean sea level changes we consider that the scale is suitable. Other values have been tested as well (*h*=5, 15) (not shown) finding that the long-term characteristics remain unaffected.

Description of the main results obtained

In Marseille the trend for the entire period 1885-2007 is 1.1±0.1 mm/yr coinciding with the linear trend of the historical record. The Marseille record shows large decadal fluctuations with values between -10 and 10 mm/yr, in agreement with the variability found in Trieste variations by Holgate (2007). Marcos and Tsimplis (2008) also examined the decadal sea level fluctuations in the Mediterranean and demonstrated the presence of a periodic signal of 10-15 years observed in Marseille. Over the common period 1992-2000, the decadal changes of the sea level variations are consistent among the stations around Marseille tide gauge. The good result for correlation (-0.5) of yearly sea level time series with winter NAO index indicates that a significant part of the sea level variability is controlled by large scale atmospheric patterns. In particular it has been shown that the atmospheric effects (mainly the atmospheric pressure) are responsible of a significant part of the sea level drop observed in the Mediterranean during the period 1960-1990 (Tsimplis and Josey, 2001; Gomis et al., 2008).

The temporal variability of the occurrence of extreme events has been explored on the basis of percentiles (Figure 2). It has been shown that high order percentiles present positive trends around 1 mm/yr for the entire period 1885-2008 mostly attributed to mean sea level changes. At decadal scale however changes in extremes not always coincide with mean sea level rise. It has been observed that for some periods the velocity at which the amplitude of the extremes varies doubles the mean sea level rise, indicating a period with enhanced atmospheric activity associated to increasing intensity of the storms.

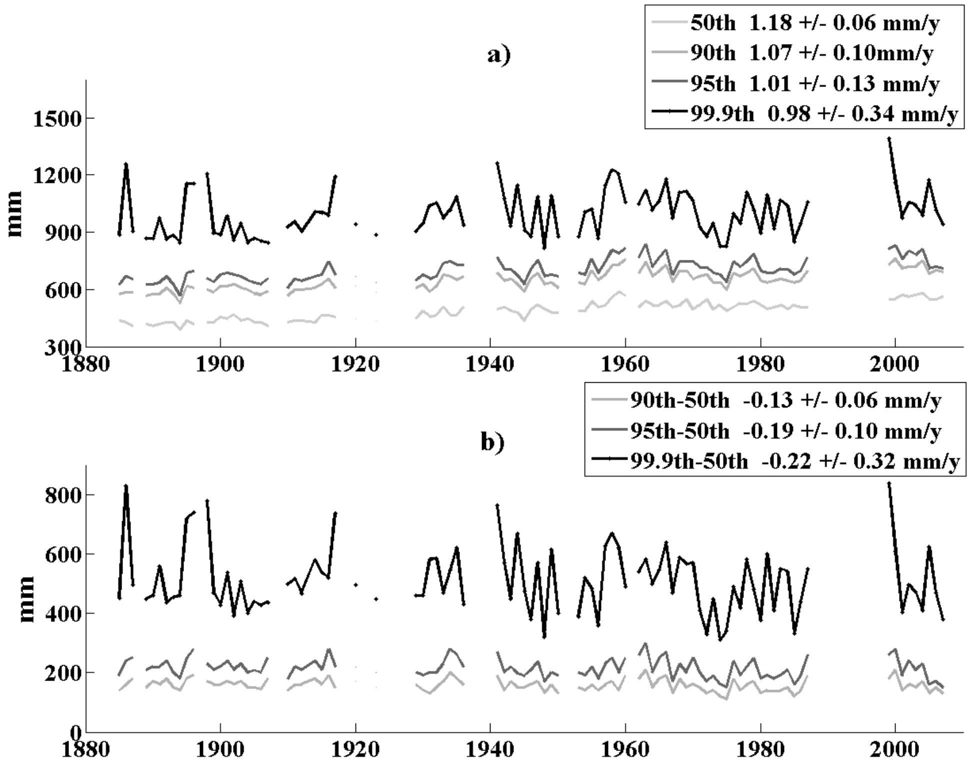
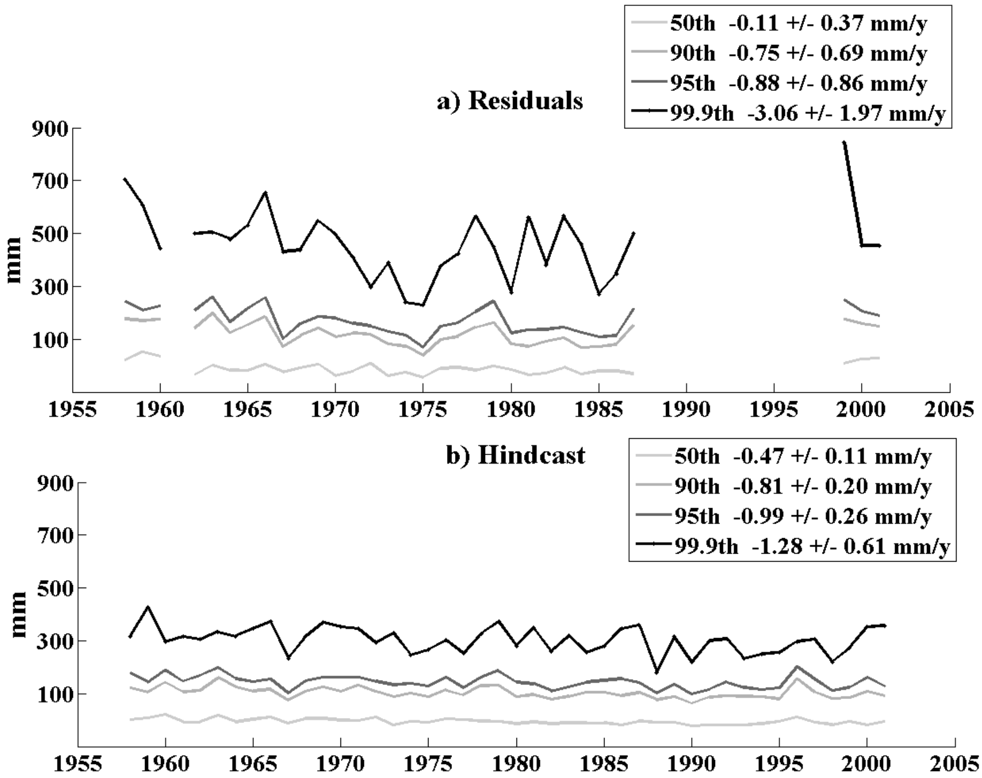


Figure 2 a). 50th, 90th, 95th and 99.9th percentiles computed for observed sea level 2 b). 90, 95 and 99.9th minus 50th percentile. Linear trends for all time series are quoted. The uncertainties correspond to the standard errors.

For the period 1958-2001 a hindcast sea level data set forced by atmospheric pressure and wind is available (Ratsimandresy et al., 2008). The comparisons between the hindcast and the tidal residuals have shown (Figure 3) that, although the temporal variations are similar, the model underestimates the magnitude of the extremes in about 20 cm in Marseille. This can be due to different factors. On one side the atmospheric forcing is obtained by a dynamical downscaling of ERA40 (Garcia-Sotillo et al., 2005) but may not represent with enough accuracy the regional winds in the Gulf of Lions. On the other side the intensity of the sea surges can be amplified by the local topography which is not well represented by relatively the low spatial resolution of the model. For this period trends are found to be negative both for observations and hindcast due to an average increase of the atmospheric pressure over the area between 1960 and 1990. Our study evidences the limitations of numerical modes when estimating the magnitude of the extremes, which can be an issue for the model-based predictions of flooding events.



3a). 50th, 90th, 95th and 99th percentiles computed for tidal residuals 3 b). 50th, 95thand 99th percentiles computed for hindcast data. Linear trends and their uncertainties are quoted for each time series

A local regression model based on the GPD has been used to derive trends in return levels (Figure 4). The time series of the observations has been detrended before the estimation of return levels so the threshold U may be considered constant. This implies that changes observed in return levels are not associated to mean sea level changes. This is correct as far as the mean sea level rise is not linked with the mechanism that generates surges. We consider that this is true for the secular trends, not for decadal or inter-decadal trends, where the atmospheric pressure has been shown to influence the mean sea level trends.

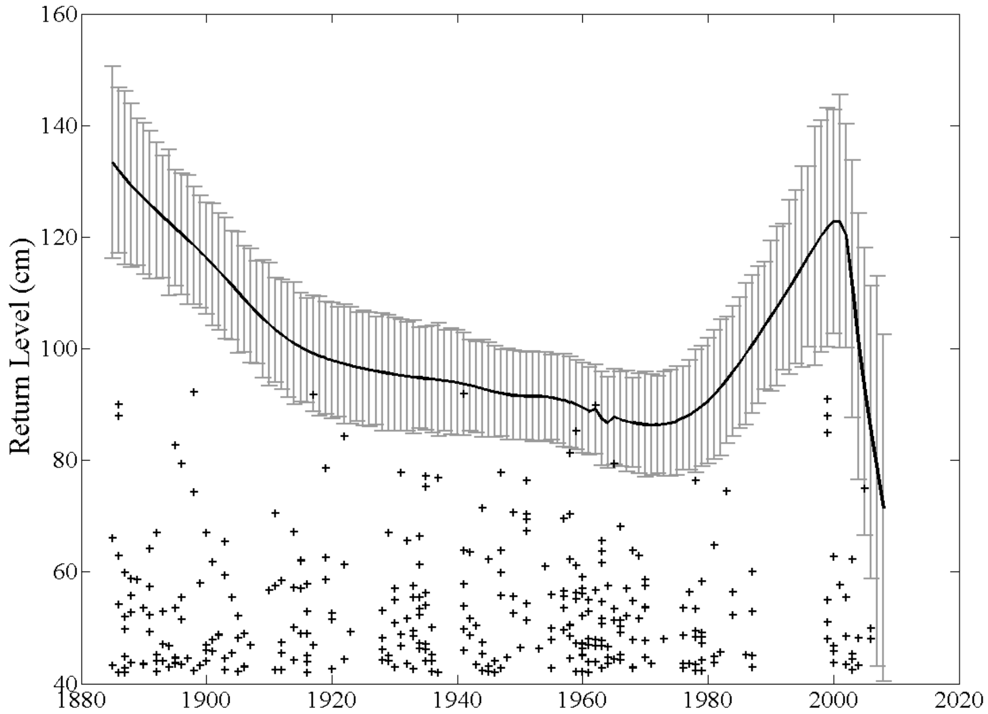


Figure 4. 50-year return levels (in cm) and their uncertainties.

The changes found in the return levels are related to complex changes in the distribution of extreme events as evidenced by the variations in the shape and scale parameters of the GPD model. Changes in return levels show a decrease from the beginning of the record until the late 1970s of about 20 cm followed by a rapid increase in their magnitude. The larger return levels obtained for the last decade are also reflected in the larger values of high percentiles around year 2000. This period is associated with a strong negative phase of North Atlantic Oscillation Index (NAO), which has been found to be correlated with the occurrence of high surges in the Gulf of Lions (Ullmann et al., 2008). This correlation has been attributed to an eastward shift of the Azores anticyclone since 1975 (Wakelin et al, 2003; Ullmann and Moron, 2008), that could have favoured stronger depressions in the Gulf of Lions and so the intensification of surges. Other factors could also play a significant role in the increasing surges since the 1970s, including coastal erosion and reduction of the beach width which could modify the responses of the coast to the propagation and intensification of the surge events over the long term (Ullmann et al., 2007a).

Publications

Letetrel, C., M. Marcos, B. Martin Miguez , G. Wöppelmann,2009. Sea level extremes in Marseille (NW Mediterranean) during 1885-2008, submitted.

Letetrel, C., M.Marcos, G.Wöppelmann, (2009): “The Marseille Tide Gauge: analysis of sea level extremes during 1885-2007 ”. EGU Vienne, Autriche, 19-24 Avril 2009, Session CL60 “Mediterranean climate variability and change”, Poster.

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