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Storm surge distribution along the Mediterranean coast: Characteristics and evolution

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Abstract

This study describes the evolution sea level extremes along the Mediterranean coasts that results from a 4-member model ensemble of model simulations covering the period 1951-2050 under the A1B emission scenario. The results are obtained by forcing a hydro-dynamical shallow water model (HYPSE) with 6-hourly meteorological fields produced by state-of-the-art global and regional climate models that have been used in the CIRCE fp6 project. The climate change signal is computed as the difference between severe storm surge statistics in the 1971-2000 and 2021-2050 periods. All sea level time series are filtered in order to cancel sea level rise and steric effects and consider only the contribution due to marine storminess. Results show that large sea level extremes occur only in the North Adriatic and in the Gulf of Gabes and this situation does not change in future climate scenarios. Further extreme values are not expected to significantly change during the next decades because of changes in storminess. However, changes in mean sea level and land subsidence (which are not considered in this study) might change significantly the frequency of coastal floods in spite of the low sensitivity of storminess to climate change.

Keywords: storm surge, climate change, Mediterranean coast, marine storminess, sea level

1. Introduction

Floods produced by storm surges are an important issues for many Mediterranean coastal areas as documented by case studies (e.g. Nichols and Hoozemans, 1996) on cities (Venice and Alexandria), deltas (Nile, Po, Rhone and Ebro), and islands (Cyprus, Crete). The severity of future floods depends on sea level rise, vertical land motion and

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marine storminess. This study describes the effect of this last factor in the present and future climate conditions, attempting to consider this issue at basin scale. This analysis integrates previous studies, which have recently addressed specific stretches of the Mediterranean coastline (e.g. Ullmann et al., 2007 and 2008; Sánchez-Arcilla et al., 2008; Mosso et al., 2009, Snoussi et al., 2008 among others) with a sequence of studies focusing on the Adriatic Sea (Lionello, 2005; Lionello et al., 2003; 2012a; 2012b).

This study uses an ensemble of recent climate simulations for forcing a barotropic tide surge model and studying the present distribution and the future evolution of storm surge extremes. Barotropic circulation models are a consolidated tool for investigating the effect of wind and atmospheric pressure variations on sea level at various time scales (e.g. Gomis et al., 2008), who investigated the role of pressure and wind on Sea level low frequency variability. In summary, we use a set of climate scenarios, which describe the evolution of mean sea level pressure (MSLP) and surface wind fields, for computing the corresponding evolution of sea level extremes.

Our analysis considers both maxima and minima (that is positive and negative surges). Positive surges are produced by pressure minima and wind blowing towards the shore in shallow waters. Negative surges are produced by pressure maxima and offshore winds (we consider both positive and negative extremes). Astronomical tide is not included, but it can be separately computed and added to storm surge levels for obtaining the actual sea level fluctuations. However, it has been shown that the effect of climate change on astronomical tide is small in the Adriatic basin (Lionello et al., 2005) and consequently negligible in the rest of the basin where its level is small. This study contributes new information to the existing literature on this subject (e.g. Marcos et al. 2011), because it is based on a new set of climate simulations, which include a high resolution interactive Mediterranean sea as a climate mode component a representation of the air-sea interaction that is more accurate than in previous studies.

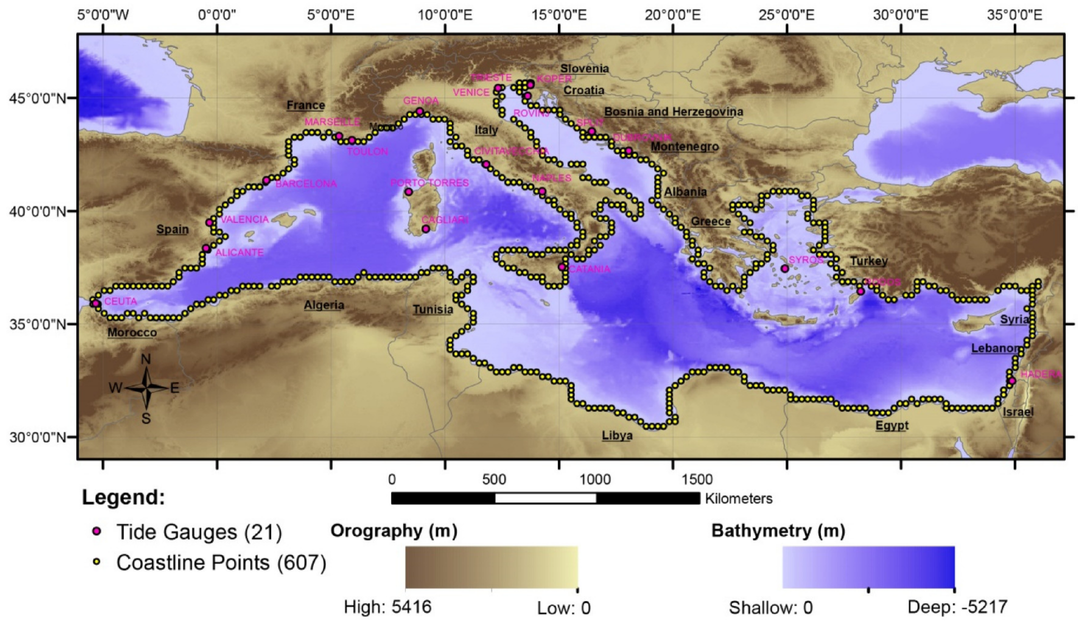

Fig. 1. Bathymetry of the Mediterranean sea. Yellow dots denote the coastal grid points used in the following figure2 for climate change analysis.

2. Data and methods

This study analyses future changes of storm surge extremes under the A1B climate scenario, which gives an intermediate level of warming among the 6 IPCC scenario groups described in Nakićenović et al. (2000). The four climate scenario datasets have been produced in the CIRCE project (Gualdi et al., 2012) and contain a sequence of 6-hourly meteorological fields covering the period 1951- 2050:

- The CMCC-LR (Euro Mediterranean Centre for Climate Change Low Resolution) datasets produced using the global climate model CMCC-Med with a horizontal resolution of about 0.75 x 0.75 degrees;
- The CMCC-HR (Euro Mediterranean Centre for Climate Change High Resolution) datasets produced using the CMCC-CLM Regional Climate model, which is the climate version of the regional COSMO model with an horizontal grid resolution of 0.12 x 0.12 degrees
- The MPI (Max Plank Institute-Germany) dataset, which is produced using REMO (REgional Model) coupled to the Max-Planck-Institute for Meteorology ocean model (MPI-OM) on a rotated latitude-longitude coordinate system with a spatial resolution of 0.22 x 0.22 degrees.
- The ENEA (Italian National agency for new technologies, Energy and sustainable economic development) dataset with a mean lat/lon resolutions of 0.27 x 0.35 degrees;

The MPI, ENEA and CMCC-LR simulations included a two-way coupling with a high resolution circulation model of the Mediterranean Sea, MPI and CMCC-LR are two different downscaling of CMCC-HR.

The sea level simulations carried out in this study are based on the Hydrostatic Padua Surface Elevation (HYPSE) model, which is a two-dimensional model based on depth averaged currents (Lionello 2005). In all simulations sea level values have been saved with hourly resolution and HYPSE has been implemented on a 168 x 82 lon-lat grid, which covers the whole Mediterranean sea with a 0.2 degrees steps in latitude and longitude. There is our HYPSE one for each climate model dataset.

Our analysis considers only the short time scale "storminess" contribution to sea level variability and how it will change at the coast. Results shown in this contribution consider the subset coastal grid points of the model grid (yellow circles in figure 1. In the representation of the results (figure 2) the coastal grid points have been ordered along a clockwise loop around the whole Mediterranean Basin, eastwards along its European northern coast and westwards along its African southern coast. Further, time series have been preprocessed using a High-Pass Filter with a cutoff frequency of 1/30 days, in order to cancel long term oscillation of sea level.

The indicators used for describing severe storm surge events are called positive and negative storm surge index, ssi, in this manuscript. They consider the mean of the 3-largest positive and negative, respectively, storm surges in each year. Only events separated by at least 120 hours, which represent an estimate of the maximum duration of a storm in this area, have been considered in order to ensure that statistics include only independent events. These two indicators are meant to describe the largest SL anomalies that occur regularly every year and have been computed for positive/negative storm surge values at each coastal grid point (figure 1) of the model grid and are shown in the upper panel of figure 2. In this contribution, the results of the four simulations are merged in a weighted ensemble mean (see Conte and Lionello 2013 for a detailed discussion) describing their average behavior.

3. Results

Figure 2, top panel shows the positive (red line) and negative (black line) storm surge index along the Mediterranean coast. The spatial distribution shows two main features located in the Northern Adriatic Sea and in the Gulf of Gabes, whose presence is explained by the proportionality of the wind effect to the inverse of the water depth and by the existence of relatively long wind fetch over shallow water in these two areas. Other four much lower maxima are present in figure 2. Two of them to the Gulf of Lion (France) and Tuscany coast (Italy), while the other two correspond to Aegean sea and Gulf of Alexandretta, at the Greece-Turkey boundary and near the Turkey-Syria boundary. These areas are characterized by shallow water too, even though fetch is much shorter than in the North Adriatic Sea and in the Gulf of Gabes. Note that the spatial distribution of positive and negative surges is virtually identical.

$$\Delta SSI_i = \frac{SSI_i^{(2021-2050)} - SSI_i^{(1971-2000)}}{\frac{SSI_i^{(2021-2050)} + SSI_i^{(1971-2000)}}{2}} * 100$$

Fig. 2 Bottom panel shows the climate change percent index, which is defined as where SSIi denotes the storm surge index in the i-th coastal point and the superscripts denote average in the 2021-2050 and 1971-2000 periods.

Positive (negative) values of the climate percent index show the percent increase in amplitude of the positive (negative) storm surges.

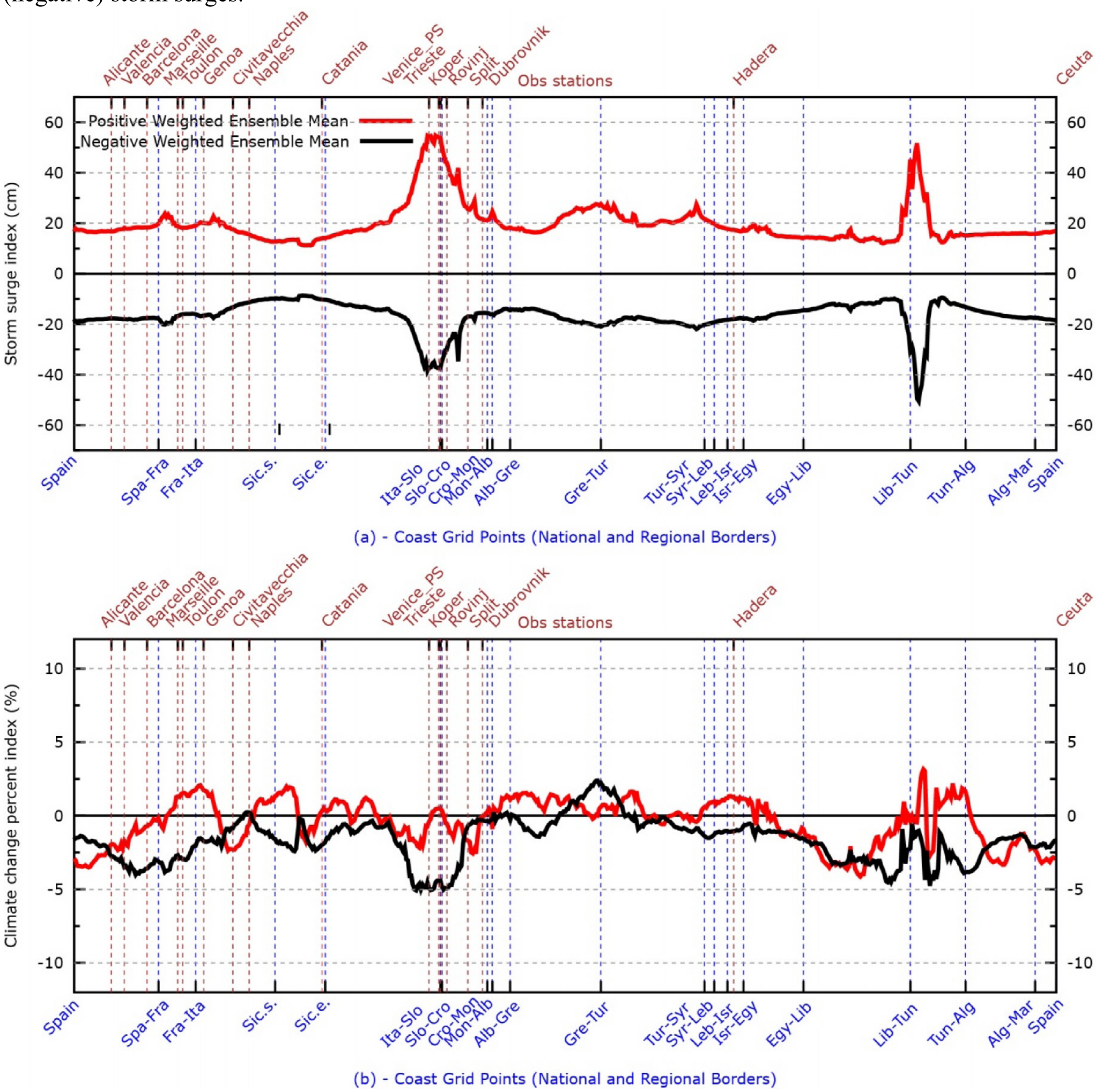

Fig. 2. Ensemble mean storm surge index (cm) for positive (red line, cm) and negative (black line, cm) surges in the present climate in model simulations (top panel). Climate change percent index (%) for positive (red line) and negative (black line) surges. Coastal points are ordered clockwise starting from Gibraltar. Country national borders and some stations used are marked to help locating the different stretches of the Mediterranean coastline.

In general changes are small (maxima are lower than 5%), very few values are statistically significant, there is little coherency in the spatial distribution and in the comparison between positive and negative surges. However, negative surges are projected to slightly increase, possibly because of the more intense high pressure systems that most simulations suggest for future climate scenarios (e.g. Lionello and Giorgi, 2008). This may explain the increased amplitude of negative surges which involves a large fraction of the eastern Mediterranean Sea, from the coast of the Adriatic Sea, all around the Balkan peninsula and to the Aegean coast of Anatolia, which has no corresponding feature in the distribution of positive surges. A weak indication of larger positive surges is limited to few points along the French Riviera and the Middle East.

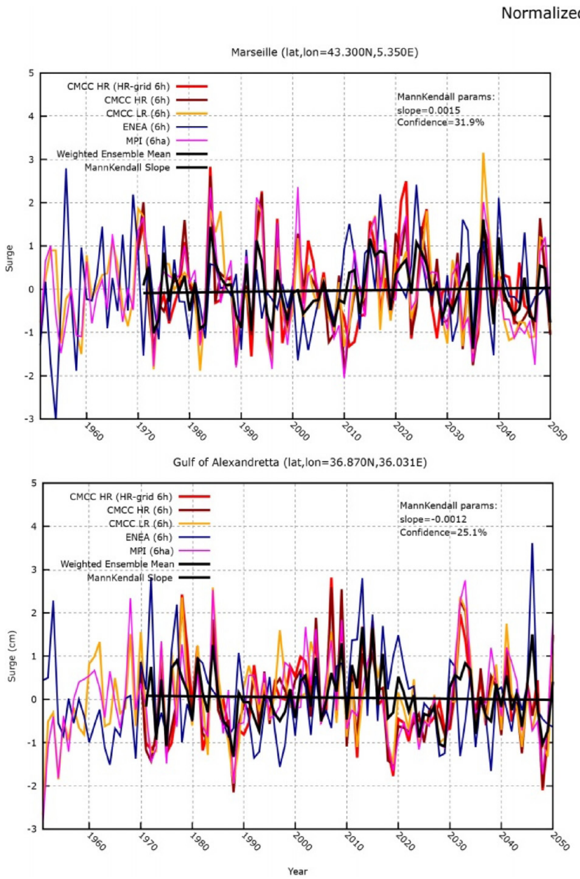

Fig. 3. Time series of the normalized annual maximum surge values at four costal stations: Marseille, Split, Alessandretta, Gabes. The colored lines refer to the individual model simulation. The weighted ensemble average is the black line. The Sen's estimate of the linear trend and the confidence level are shown in the figure as well. Annotations shows the trend and the confidence level

Figure 3 shows why in general it is very difficult to detect a trend in high storm surge levels. The panels show for 4 locations (Marseille, Split, Alessandretta, Gabes) the time series of the storm surge annual maxima for the simulations discussed in this contribution. In order to compensate for systematic differences among models, each time series has been normalized with its standard deviation. Also the ensemble mean time series is reported in this figure (thick black line). The main feature of the data is their large inter-annual variability, which is in all cases but Split masks the small trend that might be eventually present. Only in Split there is a negative trend (denoting a progressive attenuation of storm surges) that is statistically significant at the 95% confidence level.

4. Conclusions

This contribution describes the effect of climate change on extreme surges along the whole Mediterranean coast. Results have been obtained by forcing a hydro-dynamical shallow water model (HYPSE) with meteorological surface fields derived from a 4-member model ensemble covering the period 1951-2050 for the A1B emission scenario Results show that the largest surges occurs in the Northern Adriatic and in the Golf of Gabes. Other maxima are located in the gulf of Lion, in the northern Aegean and in the Gulf of Alexandretta (see also Marcos et al., 2009).

Future scenarios shows results that are not coherent spatially (climate change has different signs in different parts of the coastline) and are mostly not statistically significant. According to these results storm surge extremes are little affected by climate change with changes within the ±5% range. Results suggest an increase of negative surges along the northern coasts of the Levantine basin and in the Adriatic Sea. Very few stretches of coastline show a minor increase of positive surges. However, changes in mean sea level and subsidence (which are not considered in this study) might change significantly the hazard posed by coastal floods in spite of the low sensitivity of storminess to climate change.

References

Sánchez-Arcilla A.; J.A. Jiménez; H.I. Valdemoro; and V. Gracia (2008). Implications of Climatic Change on Spanish Mediterranean Low-Lying Coasts: The Ebro Delta Case. Journal of Coastal Research: Volume 24, Issue 2: pp. 306 – 316.

Gomis D.; S. Ruiz; M. G. Sotillo; E. Álvarez-Fanjul; J. Terradas (2008). Low frequency Mediterranean sea level variability: The contribution of atmospheric pressure and wind, Global and Planetary Change, Volume 63: 215-229, ISSN 0921-8181, 10.1016/j.gloplacha.2008.06.005.

Giorgi F. and P.Lionello (2008). Climate Change Projections for the Mediterranean Region Global and Planetary Change 63:90-104, DOI: 10.1016/j.gloplacha.2007.09.005

Gualdi S.; S. Somot; L. Li; V. Artale; M. Adani; A. Bellucci; A. Braun; S. Calmanti; A. Carillo; A. Dell'Aquila; M. Déqué; C. Dubois; A. Elizalde; A. Harzallah; D. Jacob; B. L'Hévéder; W. May; P. Oddo; P. Ruti; A. Sanna; G. Sannino; E. Scoccimarro; F. Sevault and A. Navarra (2012). The CIRCE simulations: a new set of regional climate change projections performed with a realistic representation of the Mediterranean Sea, 10.1175/BAMS-D-11-00136

Lionello P. (2005). Extreme surges in the Gulf of Venice. Present and Future Climate in Fletcher C. and T.Spencer Eds., Venice and its lagoon, State of Knowledge Cambridge University Press, Cambridge UK, 59-65

Lionello P.; E. Elvini; A. Nizzero (2003). A procedure for estimating wind waves and storm-surge climate scenarios in a regional basin: the Adriatic Sea case Clim. Research., 23: 217-231

Lionello, P.; Mufato, R.; Tomasin, A. (2005). Sensitivity of free and forced oscillationsof the Adriatic Sea to sea level rise. Clim. Res. 29, 23–39.

Lionello, P.; Cavaleri, L.; Nissen, K.M.; Pino, C.; Raicich, F.; Ulbrich, U.(2012a) Severe marine storms in the Northern Adriatic: Characteristics and trends Phys. Chem. Earth, 40-41:93-105, DOI:10.1016/j.pce.2010.10.002

Lionello P.; M.B. Galati; E. Elvini (2012b). Extreme storm surge and wind wave climate scenario simulations at the Venetian littoral Phys. Chem. Earth 40-41, 86-92, DOI: 10.1016/j.pce.2010.04.001

Marcos, M.; M.N. Tsimplis; A. G.P. Shaw (2009). Sea level extremes in southern Europe, J. Geophys. Res.- 114, doi- 10.1029/2008JC004912

Marcos, M., G. Jordà; D. Gomis; B. Pérez, (2011). Changes in storm surges in southern Europe from a regional model under climate change scenarios, Global and Planetary Change, 77:116-128, ISSN 0921-8181, 10.1016/j.gloplacha.2011.04.002.

Mosso, C; Mestres, M; Sierra, JP; Sanchez-Arcilla, A; Goodess, C. (2009). Waves and surges in the Valencia Gulf. Variability rather than climate change. J Coast Res SI56: 243−24

Nakićenović , R.; Alcamo, N.J.; Davis, G.; de Vries, B.; Fenhann, J.; Gaffin, S.; Gregory, K.; Grübler, A.; Jung, T.Y.; Kram, T.; La Rovere, E.L.; Michaelis, L.; Mori, S.; Morita, T.; Pepper, W.; Pitcher, H.; Price, L.; Raihi, K.; Roehrl, A.; Rogner, H.H.; Sankovski, A.; Schlesinger, M.; Shukla, P.; Smith, S.; Swart, R.; van Rooijen, S.; Victor, N.; Dadi, Z. (2000). IPCC Special Report on Emissions Scenarios. Cambridge University Press, Cambridge, United Kingdom, New York, NY, USA. p. 599.

Nicholls R.J.and F. M.J. Hoozemans (1996) The Mediterranean: vulnerability to coastal implications of climate, Ocean Coast. Manage, 31: 105-132 DOI: 10.1016/S0964-5691(96)00037-3

Snoussi, M.; T. Ouchani; S. Niazi (2008). Vulnerability assessment of the impact of sea-level rise and flooding on the Moroccan coast: The case of the Mediterranean eastern zone, Estuarine, Coastal and Shelf Science, 77: 206-213, ISSN 0272-7714, 10.1016/j.ecss.2007.09.024.

Ullmann, A.; P.A., Pirazzoli; A., Tomasin (2007). Sea surges in Camargue: Trends over the 20th century, Continental Shelf Research, 27: 922-934, ISSN 0278-4343, 10.1016/j.csr.2006.12.001.

Ullmann, A.; P.A. Pirazzoli; V. Moron (2008). Sea surges around the Gulf of Lions and atmospheric conditions, Global and Planetary Change, 63:203-214, ISSN 0921-8181, 10.1016/j.gloplacha.2007.10.002.