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Climate Change Impacts on the Storm Surges of Mediterranean Coastal Areas

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ABSTRACT

Intense storm surge events threaten low-elevation coastal areas with large inundation risk. In the past, storm surges have been responsible for human casualties, loss of land and property, damages to onshore infrastructure, harbor structures and coastal defenses. Global climate change is associated with impacts on the regional regime of sea level variations, i.e. influencing the intensity and frequency of occurrence of extreme storm surges.

1. Methodology

In the present work, the storm surge patterns in the coastal zone of the Mediterranean Sea are investigated for a period from 1971 to 2100 covering the observed past- and estimated future-climate. The future variation trends of the storm-induced extremes of sea level in the Mediterranean are also explored.

1.1. Storm surge and coastal flood modelling

The surge-induced sea surface height (SSH) in coastal areas is numerically simulated with MeCSS (Mediterranean Climatic Storm Surge) model. MeCSS is a 2-DH barotropic model for hydrodynamic ocean circulation based on the depth-averaged shallow water equations (Androulidakis et al., 2015; Makris et al., 2016). Simulations cover three 35-year time-windows, i.e. the Reference (1971-2005), short-term Future (2021-2055) and long-term Future (2066-2100) periods.

1.2. Climate change analysis and data

The atmospheric forcing of the MeCSS model consists of wind (velocity and direction) and atmospheric pressure fields produced by three Regional Climate Models (RCMs), namely the CMCC-CCLM, CNRM-ALADIN, GUF-CCLM-NEMO, implemented in the framework of the MED-CORDEX initiative (https://www.medcordex.eu/; Ruti et al., 2016). Historical climate data by all the RCMs for the Reference Period are validated against ECMWF reanalyses, based on assimilation system fields produced under CERA-20C (https://www.ecmwf.int/en/research/projects/cera). Estimations of future climate change projections from the RCMs are based on two climatic scenarios of the Representative Concentration Pathways, RCP4.5 and RCP8.5 (IPCC, 2014). The reproduction of the extreme barometric systems (Deep Depressions) over the Mediterranean region is also investigated together with their impacts on rough sea-states and coastal surge-induced sea levels.

2. Results and Discussion

2.1. Model validation

In situ SSH observations from tide gauges by national hydrographic services, during the last 50 years, are used to evaluate the performance skill of MeCSS model in several coastal areas of focus. Appropriate statistical measures, such as the Storm Surge Index (SSI), high-order percentiles, probabilities of exceedance, root-mean-square error, Error Index, Pearson correlation, Willmott Skill score, etc., concerning intra- and inter-annual SSH maxima reveal the agreement between historical sea-level data and simulation outputs.

Figure 1 presents analytic comparisons of 10-year averaged SSH maxima in 5 Greek stations for the GUF-forced MeCSS model implementation against in situ observations. Table 1 presents thorough quantitative validation of MeCSS model results against available field data in 5 Greek stations. Comparisons are based on

10-year mean values of SSI in 5 characteristic Greek stations, together with average error and error index (E_i and EI_i), Pearson correlation, RMSE, RMSE/SSI_{mean}, and Willmott Skill Score.

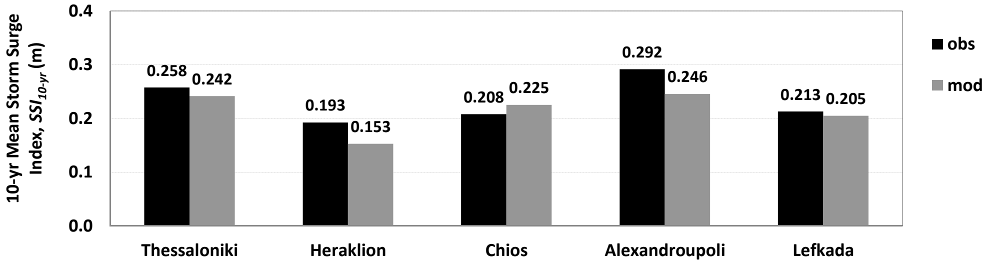

Fig. 1. Comparison of 10-yr average SSI (m) in 5 Greek stations for GUF-forced MeCSS model (mod) and field (obs) data.

Table 1. Comparison of 10-yr average SSI (m) in 5 Greek stations for model (mod) and field (obs) data; Mean error and error index E_i (%) and EI_i (m) are provided together with Pearson correlation, RMSE (m) and RMSE/SSI_{mean} (%), and Willmott Skill Score.

Coastal Site	$SSI_{obs,10yr}$ (m)	$SSI_{mod,10yr}$ (m)	MEAN E_i (%)	MEAN EI_i
Thessaloniki	0.258	0.242	-6.29%	-0.206
Heraklion	0.193	0.153	-16.82%	-0.486
Chios	0.208	0.225	8.28%	0.281
Alexandroupoli	0.292	0.246	-17.20%	-0.561
Lefkada	0.213	0.205	-4.17%	-0.133

Pearson Correlation	Willmot Skill Score
0.793	0.816
RMSE (m)	RMSE/SSI_{mean}
0.029	13.1%

2.2. *Coastal inundation by storm surges*

Figure 2 presents characteristic MeCSS simulation results for the 35-year Reference Period for the inter-annual maxima SSH_{max} throughout the entire Mediterranean coastal zone (left graph). Detailed maps of possible areas of inundation caused by extreme coastal flooding under an estimation of 35-year storm surge maxima in a characteristic Greek coastal region, *i.e.* the deltaic area of Nestos river in northern Aegean Sea (Greece) is also presented concerning the Reference Period (right graph).

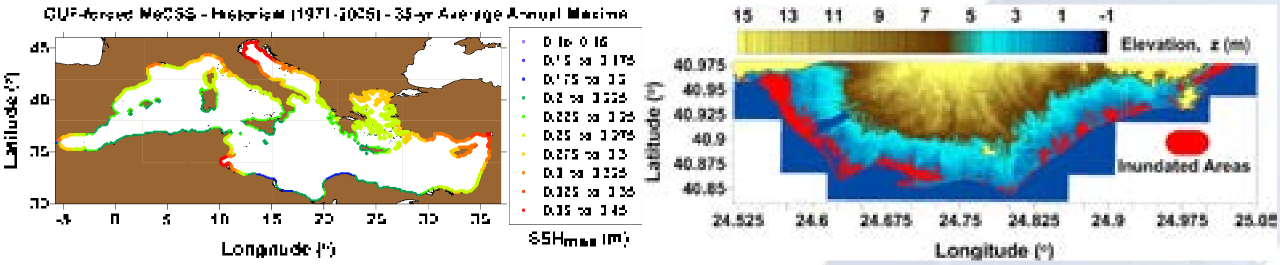

Fig. 2. Map of GUF-forced MeCSS model output of 35-yr average annual maxima SSH_{max} (m) for the Reference Period (left graph). Inundated areas by extreme coastal flooding induced by the 35-year storm surge maxima in a characteristic Greek coastal zone (right graph).

3. Conclusions

The above results confirm the ability of MeCSS model to estimate the episodic sea surface elevation response to intense climatic conditions. Our results support that there is a general decreasing trend only in the averaged patterns of storminess under the considered climate scenarios. However, the magnitudes of SSH maxima are estimated to increase locally in certain regions of the Mediterranean during the 21st century. Different topographical characteristics of the regional seas (e.g. northern Adriatic and Aegean Seas, Gulf of Gabes, etc.) in the Mediterranean basin have a significant influence on the variability of storm surge maxima.

Acknowledgements

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