COMPARATIVE STUDY OF EXTREME SEA LEVEL PREDICTIONS IN THE MEDITERRANEAN SEA

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INTRODUCTION

Extreme Sea Levels (ESL) pose a threat to the world's coastline, more recurrent coastal flooding can be expected on rised mean sea level, and global warming might intensify and increase the duration of storms (Kirezci et al. 2020). If no adaptation measures are implemented, coastal communities will face increased risks to infrastructure, property, and human safety. The expected changes in future climate will cause an increase in the extent of damage at low-elevation coastal zones (IPCC 2021; Kron 2013), resulting in annual damages reaching nearly 10% of the global gross domestic product by the year 2100 (Wahl et al. 2017). Therefore, assessing potential changes in coastal flood risk and developing adaptation strategies is essential. In this regard, accurate prediction of ESL plays a critical role in adapting coastal areas to climate change. Regional Extreme Sea Levels, which are composed of mean sea level, tides, storm surges and waves, are driven by basin-scale meteorological conditions (pressure and wind), and bathymetry/topography. The changing climate, with the high influence of global warming, has a significant impact on meteorological characteristics and sea level rise at several spatial and temporal scales (Hinkel et al. 2014). However, although substantial research efforts have been dedicated to quantifying future global and regional sea level rise (SLR) projections and their associated uncertainties, the same does not apply to ESL. Therefore, accurate high-resolution prediction of ESL and coastal inundation underpin the quantification of the risks on coastlines, help decision-makers pinpoint the geographical areas at higher flood risk, and facilitate mitigation strategies (Ward et al. 2015).

In recent years, the global ESL prediction models based on General Circulation Models (GCMs) have been rapidly growing with challenges associated with the global scale, such as demanding high computational cost. Hence, the global models are still too coarse, although some improvements, like the application of unstructured grids in hydrodynamic modeling, have been conducted. The performance of the global simulations of ESL also depends on the accuracy of the meteorological forcing coming from the GCMs. On the other hand, the large uncertainties, which are important limitations in climate predictions, can be attributed to several processes through the entire modeling chain from scenarios to GCMs, downscaling, and impact modeling (hydrodynamic modeling in our case), and it is difficult to quantify them (Noto et al. 2023). The relative importance of the different sources of uncertainty also varies with different time horizons and spatial scales (Hawkins&Sutton 2009; Raisanen 2001). The potential to reduce uncertainties associated with each source is still under discussion in the available literature.

Mediterranean Sea is prone to the consequences of climate change, including ESL and consequent flooding. The Mediterranean coast is highly vulnerable to climate-change driven coastal hazard due to its densely populated and highly industrialized coasts, low-lying coastal zones at particular locations and potential for high-impact damage from intensive storms and coastal flood as experienced in recent years (Little et al. 2023). However, the prediction of ESL is challenging for the Mediterranean due to insufficient representation of basin characteristics (geographical features, e.g. bathymetry and topography). For this reason, in this study, we aim to address the uncertainties associated with one of the components of climate modeling, the impact of (hydrodynamic) modeling on regional ESL in the Mediterranean Sea. For this purpose, we perform numerical modeling of water levels driven by tidal and meteorological forcing for both the present and the future climate. The analysis is based on a climate model ensemble of high-resolution GCMs (HighResMIP) (Haarsma et al. 2016) as part of the Coupled Model Intercomparison Project Phase 6 (CMIP6). We compare the computed ESL using a depth-averaged hydrodynamic model, NAMI DANCE SUITE, with both the observations, results of the Global Tide and Surge Model (GTMSv3.0) (Kernkamp et al., 2011), and downscaled ESL from this global model. This way, we also aim to address the different sources of uncertainties related to the hydrodynamic modeling of regional ESL, such as model formulation, grid structure and resolution, and spatial and temporal extent.

GENERAL FEATURES OF AVAILABLE DATA

As mentioned, for the assessment, we use the already produced ESL outputs from the Global Tide and Surge Model (GTMSv3.0) forced with meteorological fields of the multi-model HighResMIP ensemble, consisting of five ~25 km resolution GCMs at 6-hourly intervals (Muis et al. 2023). GTSM is a depth-averaged hydrodynamic model based on the Delft3D Flexible Mesh modeling suite (Kernkamp et al., 2011) and simulates total water levels resulting from tidal and meteorological forcing (Muis et al., 2020). The spatial resolution varies from 2.5 km along the coast (1.25 km in Europe) to 25 km in the ocean. The HighResMIP simulations produce meteorological fields based on a common set of future emissions of green house gasses and land use scenarios of the so-called Shared Socioeconomic Pathways (SSPs) under CMIP6 (O'Neill et al., 2016).

The other hydrodynamic model, NAMI DANCE SUITE (Dogan et al. 2023; 2021), will be run with the same atmospheric input from the HighResMIP experiments and tidal forcing as well. NAMI DANCE SUITE is a depth-averaged nonlinear shallow water model with atmospheric forcing and wind terms that allows high-resolution simulations. In this model, several different grid resolutions can be tested fast, enabled by the GPU version.

MODEL SETUP AND METHODOLOGY

NAMI DANCE SUITE will be run with the aforementioned meteorological forcing to produce the water level time-series along the European coastline for a period of 100-years (1951-2050) as employed in the Global Tide and Surge Model (GTSMv3.0). The same methodology followed in GTSMv3.0 (Muis et al. 2023; 2020) to obtain the surge levels will be employed. In this method, first, the total water levels are computed resulting from both the tidal and meteorological forcing, and then a tide-only simulation is performed. The surge levels are computed by subtracting the water levels produced by the tide-only simulation from the total water levels. The bathymetry data will be obtained from EMODnet at ~115 m resolution in Europe (EMODnet, 2018). The Mean Sea Level (MSL) changes will be dynamically included in the simulations by applying a spatially varying MSL field based on CMIP6 models. Different mesh sizes will be generated to compare, but here, the goal is to achieve a higher resolution at the sub-km scale and show the value added by this approach. The results will be produced at equidistant points, increasing the output resolution from the deep ocean toward the coast.

EXPECTED RESULTS

A dataset is produced, including the time series for a large number of output locations, and stored at a 10-min temporal resolution in NetCDF4 file format. The modeled water levels are compared with the observations from tide gauge stations in the Global Extreme Sea Level Analysis (GESLA) dataset. The study focuses on the annual maxima and return periods, but other climate change indicators can be included as well. Model performance against observations is assessed in terms of the Pearson's correlation coefficient, Root-Mean-Squared Error, mean bias, mean absolute error, and the mean absolute percentage error. Changes in different return-period water levels in response to climate change are evaluated and presented.

CONCLUSION

This study aims to contribute to the reliable prediction of surge and water levels for coastal zones in the Mediterranean basin under climate change and focuses on the evaluation of uncertainties resulting from hydrodynamic modeling of extreme sea levels from a multi-model high-resolution GCM. It will allow us to examine the different sources of uncertainties, such as model formulation and grid structure and resolution, and analyze the performance of different models, which are expected to help to increase the reliability of the current predictions. Gained experience from this analysis provides insights into understanding the capabilities and limitations of ESL predictions.

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