

LONG-TERM EVALUATIONS OF GLOBAL EXTREME SEA LEVELS USING UNSTRUCTURED GRID MODELS

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INTRODUCTION

The effect of climate change on sea levels has received much attention these days. The global mean sea level (GMSL) is expected to rise by 0.63 to 1.01 m by 2100 under the very high greenhouse gas emission scenario (IPCC, 2021). In addition to the GMSL rise, increased events of storm surges and high waves are expected. Positive trends of annual maximum storm surge and significant wave height are projected at multiple locations worldwide under the high-emissions scenario (Shimura et al., 2022). Exceptionally high local sea surface heights induced by short-term phenomena such as storm surges and waves combined with high tides are called Extreme Sea Levels (ESLs). Changes in ESLs will result in more extraordinary flood disasters. Voudoukas (2018) shows an unprecedented rise in global flood risk by the end of this century based on his global projections of ESLs. However, existing coastal protection measures are not designed to consider a future change of disaster. Hence, this study aims to obtain the ESLs in historical and future climate scenarios and estimate the loss/damage.

ESL analysis is mainly conducted on a regional scale, and global-scale studies are still behind. On the other hand, there is a demand from the social community to clarify the regional differences in climate change impacts and fill the gap in knowledge on coastal disaster studies with global estimation. Not only projections but hindcasts of ESL were scarcely conducted. Therefore, we obtained historical global ESLs with unstructured grid models. This study is applicable to the future ESL projection study.

METHODS

ESLs were calculated as a deviation from GMSL. We obtained each component of the ESL separately and combined them afterward. We assumed that the two components of ESL, astronomical tide and storm surge, are independent. ESL does not include the effect of waves in this study. As input for the storm surge, Japan Meteorological Agency (JMA) reanalysis and JMA best track data were used complementary. The maximum target period for simulation is 62 years, from 1958 to 2019.

The reanalysis dataset JRA-55 by JMA was used as meteorological conditions for storm surges. JRA dataset has a high accuracy in representing tropical/extratropical cyclones, and better estimations can be expected compared to other long-term reanalysis such as ERA given by the European Centre for Medium-Range Weather Forecasts (ECMWF). The spatial resolution for JRA-55 is around 60 km.

Since the spatial resolution of reanalysis data is not fine enough to capture the structure of tropical cyclones, the parametric wind model is used additionally

with reanalysis climate inputs. Central pressure and position of tropical cyclones from JMA best track data were used to finely reproduce the wind and pressure fields close to the eye. Holland model and Fujii-Mitsuta's formula (Fujii and Mitsuta, 1984) were adopted for typhoon winds and pressures. Parameters are decided based on Wind/pressure fields and are blended into a reanalysis wind/pressure gradually using the pressure anomaly. Spatial resolution is 20 km, and temporal resolution is one hour.

We used astronomical tides from the tidal atlas FES2014. Storm surges were simulated with the numerical ocean model ADCIRC. We used an unstructured global mesh with minimum resolutions of 200 m around Japanese coastlines and 2.2 km worldwide. The model solves the long-wave equations on the spherical coordinates.

Hourly sea levels were calculated by the summation of astronomical tides and storm surges, which were obtained separately. Hereby, the interactions of each component were ignored. Combinations of each component were compared with global tide gauge observations. Finally, extreme values are calculated by fitting monthly/annual maximum simulated values into the extreme value distributions.

RESULTS

We confirmed that sea levels obtained with JRA-55 had high correlations and low errors from observed levels. Hourly total sea levels using JRA-55 have a solid global mean correlation coefficient (R) of 0.87, RMSE of 0.23 m, and Normalized RMSE of 0.36 from the observation. Figure 1 shows the spatial distribution of the correlation coefficients obtained from comparing hourly sea levels and observed levels over 62 years. Secondly, we compared the maximum values from simulated and observed sea levels to see the accuracy of simulated peak values. Maximum values were underestimated for the cases when only reanalysis data was used for simulation (Figure 2). Finally, ESLs are obtained globally from hourly water levels with original JRA-55. We observed that small historical ESLs minor than 1 m with a return period of 10 years are distributed along the Mediterranean Sea and the Sea of Japan, and high ESLs up to 3.5 m at the coasts of western and central Europe, China along the East China Sea, northwestern Australia, southern Alaska, and northeastern America (Figure 3 and 4 for the case with JRA-55).

Currently, simulated sea levels using updated wind/pressure fields with reanalysis data and best tracks were compared for the 2018 Typhoon Jebi case near the landfall area and showed significantly better correlations and errors against observed data than the case for the original reanalysis data (Table 1). Future efforts include the findings of optimal parameter settings for parametric cyclone models, the use of climate inputs blended with

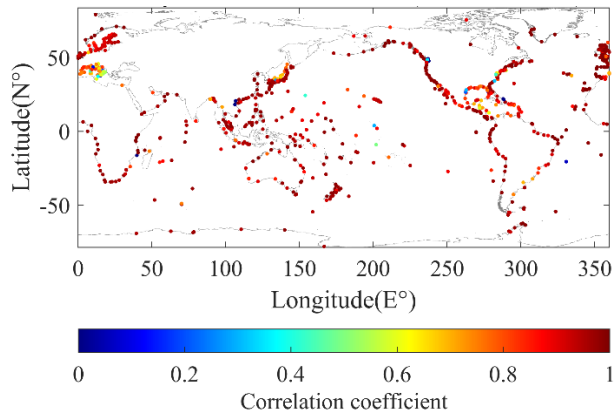


Figure 1: Correlation coefficient of simulated hourly sea levels using only JRA-55 against in-situ observations (GESLA)

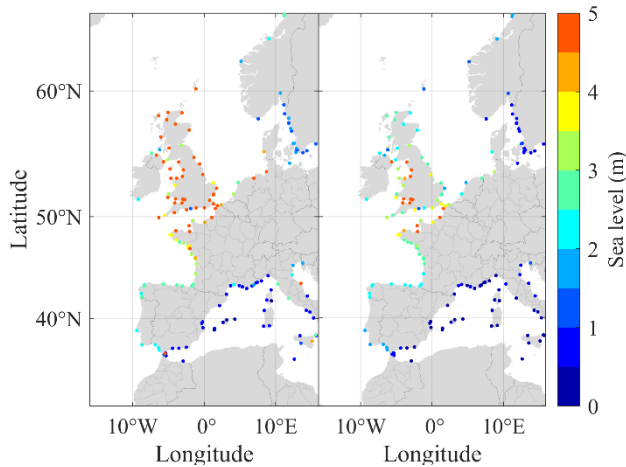


Figure 2: Comparison of max sea levels in Western Europe (Left: observed sea levels/ Right: simulated total sea levels with only JRA-55)

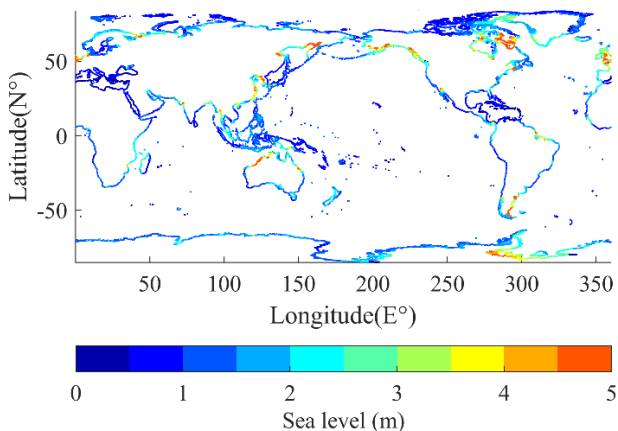


Figure 3: Historical global extreme sea levels with a return period of 10 years using only JRA-55

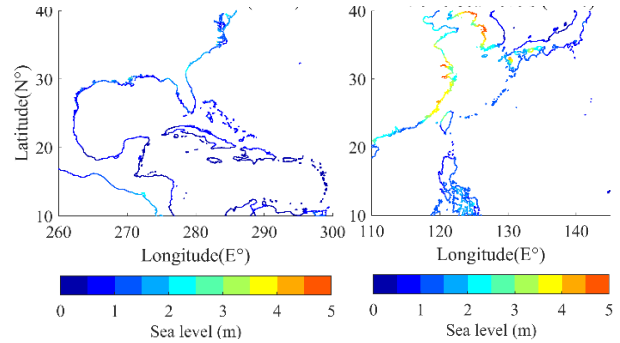


Figure 4: Historical extreme sea levels with a return period of 10 years using only JRA-55 in Tropical-cyclone-prone regions (Left: Northwest Atlantic, Right: Northwest Pacific)

Table 1: Validation of 10-min-timestep sea levels for the Jebi case (Blended: blended pressure and wind field)

Input	Error (m)	Normalized Error	RMSE (m)	R
JRA-55	-1.13	-0.87	0.24	0.64
JRA-55+ Blended TCs	-0.67	-0.53	0.20	0.70

parametric cyclone models for storm surge/wave simulation, and the consideration of wave effects on ESLs. This work can be further extended to future ESL projection and exposure analysis, such as inundation areas or monetary/personal damages along the global coastlines in the past/future climate scenarios.

CONCLUSION

Global extreme sea levels were estimated using long-period reanalysis. First, historical total sea levels were simulated using an unstructured grid storm surge model ADCIRC and validated against the tide gauge data across the global coastlines. We used a high-resolution mesh, particularly near the Japanese shorelines, to capture their features well. JRA-55 global reanalysis was used as climate input for calculating accurate storm surges. In order to represent the structure of tropical cyclones, we used the Holland parametric storm model considering super gradient wind in the reanalysis of wind and pressure field. Next, we confirmed that modeled elevations significantly agree with tide gauge levels at each gauge point. Finally, extreme value analysis evaluated extreme sea levels using monthly maxima.

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