Nonstationary joint probability analysis of extreme marine variables to assess design water levels at the shoreline in a changing climate

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ABSTRACT

The general inception of a changing climate with extreme marine events of higher intensity and frequency combined with the projected mean sea level rise (MSLR) increases the vulnerability and exposure of coastal areas to flooding and erosion hazards. In the present work extreme total water levels near the coast are assessed based on a nonstationary joint probability analysis of the marine variables to approximate coastal flooding hazard under climate change conditions. A novel methodology is developed and implemented at selected Greek coastal areas of the Aegean and Ionian Seas, prone to short- and long-term coastal flooding and inundation, respectively. The nonstationary Generalized Extreme Value (GEV) distribution is utilized to model the marginal distribution functions of deepwater significant wave height annual maxima with directions affecting the coast, as well as associated nearshore wave-induced set-up extremes. Excessive wave heights are usually defined as the primary cause of the coastal flooding hazard in Greece, and thus appropriate nonstationary distributions functions (i.e. GEV, Gamma, Log-Normal) are also fitted to deepwater wave period and nearshore storm-induced sea level height (SLH) data corresponding to the respective wave height extremes. All the time-dependent distributions are fitted using a 40-year moving time window, while all parameters of the fitted models are tested for statistically significant trends over time. Different bivariate copula functions are then fitted to model the dependence structure of wave height and period, as well as wave set-up and SLH data. The nonstationarity of the dependence structure of the studied variables is also investigated. The dependence functions used include the one- and two-parametric Archimedean, as well as elliptical copulas. The most appropriate copula structure is selected for all moving time windows using suitable goodness of fit tests. Time-dependent most likely design events of the marine variables are sorted from the fitted bivariate models and wave-induced run-up at the coast for these events is estimated using empirical formulas. Design total water levels at the selected coastal areas are then defined as a conditional sum of wave run-up/set-up, astronomical tide, SLH and MSLR at the nearshore areas. The necessary wave and SLH data cover a period of 150 years (1951-2100) and are derived from 3-hourly simulation results for the Greek Seas, produced by SWAN wave model and a high-resolution two-dimensional barotropic model of hydrodynamic ocean circulation. Forcing of wind and pressure fields are derived from dynamically downscaled simulations with Regional Climate Model (RCM), RegCM3 and future climate projections are based on the A1B emissions scenario of IPCC.

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