TIME-VARYING EMULATOR FOR SHORT- AND LONG-TERM ANALYSIS OF COASTAL FLOODING (TESLA-FLOOD)

Dylan Anderson, Oregon State University, anderdyl@oregonstate.edu,
Peter Ruggiero, Oregon State University, pruggier@oregonstate.edu,
Fernando J. Mendez, University of Cantabria, fernando.mendez@unican.es
Ana Rueda, University of Cantabria, anacristina.rueda@unican.es
Jose A. A. Antolinez, University of Cantabria, jose.alvarezantolinez@unican.es
Laura Cagigal, University of Cantabria, laura.cagigal@unican.es
Curt Storlazzi, US Geological Survey, cstorlazzi@usgs.gov
Patrick Barnard, US Geological Survey, pbarnard@usgs.gov
John Marra, National Oceanic and Atmospheric Administration john.marra@noaa.gov

SIGNIFICANCE AND MOTIVATION

The ability to predict coastal flooding events and associated impacts has emerged as a primary societal need within the context of projected sea level rise (SLR) and climate change. The duration and extent of flooding is the result of nonlinear interactions between multiple environmental forcings (oceanographic, meteorological, hydrological) acting at varying spatial (local to global) and temporal scales (hours to centuries). Individual components contributing to total water levels (TWLs) include astronomical tides, monthly sea level anomalies, storm surges, and wave setup. Common practices often use the observational record of extreme water levels to estimate return levels of future extremes. However, such projections often do not account for the individual contribution of processes resulting in compound TWL events, nor do they account for time-dependent probabilities due to seasonal, interannual, and long-term oscillations within the climate system. More robust estimates of coastal flooding risk require the computation of joint probabilities and the simulation of hypothetical TWLs to better constrain the projection of extremes (Serafin [2014]).

This study proposes and applies a time-varying emulator for short- and long-term analysis of coastal flooding (TESLA-flood). The methodology is a hybrid statistical and process-based downscaling approach, capable of simulating thousands of years of a representative climate to produce potential combinations of contributing TWL variables not necessarily seen in the historical record. Data mining techniques are then used to identify representative combinations of forcing conditions to serve as design points for input into process-based hydrodynamic models. The emulator is applied to United States Department of Defense sites across the equatorial Pacific Ocean that are particularly susceptible to projected climate changes and also exhibit varying dependencies on such climate phenomenon as El Niños, SLR, and extratropical/tropical cyclones.

METHODS

Each process contributing to TWLs is a consequence of different climatic processes, which are simulated in the emulator through an auto-logistic regression accounting for interannual variability of the El Niño Southern Oscillation (ENSO), seasonality, intra-seasonal propagation of the Madden-Julien Oscillation (MJO), and daily variability of local sea level pressure fields (SLP). The large-scale climate is controlled by an annual weather type (AWT) capturing the time-varying longitudinal distribution of sea surface temperature (SST) along the Pacific equator during a given year. A daily weather type (DWT) is constructed from the SLPs producing waves and storm surge impacting the study sites (Rueda [2017]). The resulting statistical emulator relates variability in ocean heat content and atmospheric phenomena (SST, MJO, and SLPs) to distributions of monthly sea level anomalies, non-tidal residuals, and ocean wave parameters.

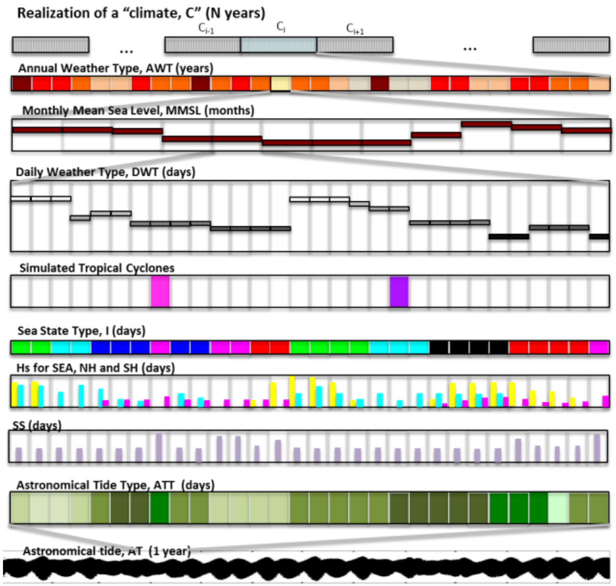

Figure 1 – Conceptual layout for downscaling climate to chronological oceanic and atmospheric conditions affecting TWLs.

Integrated Delft3D-FLOW, Delft3D-WAVE, and Xbeach model grids were used to downscale select offshore conditions to local TWLs at the coastline. Specific input conditions to dynamically simulate were chosen using a maximum dissimilarity algorithm (MDA) of all joint oceanic and atmospheric conditions derived in the statistical emulator. The MDA identified representative forcing conditions for the entire multi-dimensional parameter space such that a Gaussian process regression was able to interpolate the selected dynamic results into a continuous time series of hypothetical TWLs.

RESULTS

The dynamic portion of the emulator was demonstrated in San Diego, USA where the Coastal Storm Modeling System (CoSMoS) was utilized to simulate TWLs in the vicinity of the Coronado Naval Base (Barnard [2014]). TWL return levels are defined for the present climate with additional insight regarding conditional dependencies on the state of ENSO. Weather patterns with the greatest potential for flooding are also determined using flood thresholds relevant to the naval base's particular needs. Future changes in the probability of occurrence in any weather pattern are identified using CMIP5 global climate model SLP predictions. The methodology captures nonlinearities within both the climate and the additive processes causing coastal flooding, providing return level events with constrained confidence intervals to assist DOD managers developing policies for the future use of facilities prone to climate change.

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