A MODIFIED LINEAR SUPERPOSITION METHOD FOR THE INTERACTION OF TIDE AND STORM SURGE

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INTRODUCTION

Due to their size, movement, and wind fields, extra-tropical cyclones can produce elevated water levels that persist for multiple tidal cycles. Recent Federal Emergency Management Agency (FEMA) study areas have featured a relatively large tide range of approximately 6 to 8 ft, depending on location. These two factors combine to make the interaction of tides with extra-tropical cyclone surge an important aspect of the storm surge modeling effort. In relatively deep water, tidal superposition (effect of tides on water level produced during a storm) can be considered an approximately linear process (with the storm-generated water level added to the tide level to achieve the total water level providing a reasonable answer). However, in shallow water with restricted access to the ocean, tide and surge superposition can be nonlinear such that simple addition of the storm surge and tide does not accurately produce the total water level. The paper and presentation will focus on the development of the Modified Linear Superposition (MLS) method to analyze the interaction of the storm surge with the tide: a method that produces accurate, unbiased results while at the same time not requiring excessive computer resources.

METHODOLOGY DEVELOPMENT

Many previous methods of including tidal contributions in statistical estimates of coastal storm surges have used models that couple storm surges with tides at a small number of randomly sampled phases. Applying a small number of samples can introduce substantial aleatory uncertainty into the total water levels in areas where tide ranges are of comparable magnitude to the storm surges, such as much of the East Coast of the United States. The standard deviation of the uncertainty is related to the standard deviation of the tides (σ_{tides}) by inverse of square root of the number of tide samples. The authors applied a data set (provided to FEMA) consisting of 30 historical extra-tropical storms, each run at 4 tide phases (chosen such that two approximately coincided with high tide and two with low tide). For the MLS method, 8 storms were selected from the set of 30 as a training case. The analysis examined tide-only, surge-only and tide coupled to surge model results at 34 stations located by the authors to cover the spatial extent of the study area and to include both open coast and sheltered inland waterways.

ANALYSIS

To obtain station-specific generalized relationships for all storms, we developed a regression relationship between the nonlinear deviation and the normalized maximum linear superposed water level. This approach preserves the separation of the predictors from the predictands, while allowing the user to visualize effects due to variations in depth, bottom friction, and tidal variations during a particular storm at a particular site. In this approach, eight storms and four phases for each storm provide the basis for estimating the regression equation. With the station-specific regression equations determined, the authors applied the tide-only and 30 storm-only simulations to develop water level versus frequency curves. The analysis applied a simple linear superposition method and the new MLS method. The results show the influence of the regression-derived non-linear correction at each station with results varying by station depending on the stations location and depth.

RESULTS

The statistical results of this study are consistent with the observation that non-resonant interactions between two waves (even long waves (tides) and surges) tend to be significantly smaller than the two primary components. Thus, while the standard deviation in tides for the U.S. north Atlantic coastline is from 1 to 3 ft, the standard deviation in the interaction term (the nonlinear deviations) is only 0.15 to 0.3 ft – about an order of magnitude smaller than the tide amplitude range. Obtaining a result with the same range of accuracy as the linear combination of a surge and all possible tidal phases would require about 100 simulations as the standard deviation reduction depends on the square root of the number of executions. Importantly, the stations selected for this study cover a wide range of coastal features, which suggests that the results of this study provide a defensible methodology for a wide range of coastal areas along the U.S. East Coast.

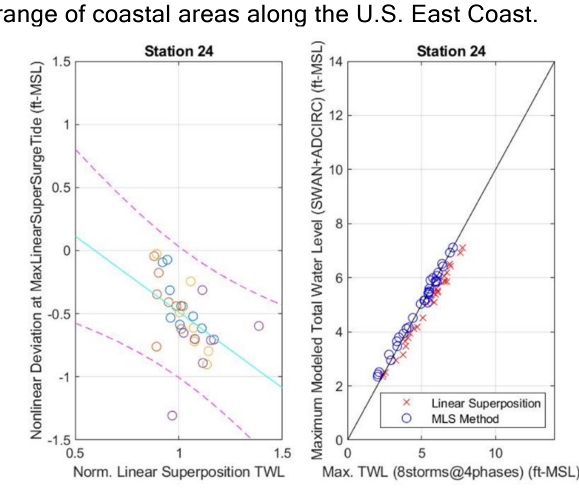

Figure 1 – Comparisons of Maximum Total Water Level for SWAN+ADCIRC Versus Linear Superposition and MLS Method with Side-by-side Plot of MLS Method Results