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Tide-surge historical assessment of extreme water levels for the St. Johns River: 1928–2017

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ABSTRACT

An historical storm population is developed for the St. Johns River, located in northeast Florida—US east coast, via extreme value assessment of an 89-year-long record of hourly water-level data. Storm surge extrema and the corresponding (independent) storm systems are extracted from the historical record as well as the linear and nonlinear trends of mean sea level. Peaks-over-threshold analysis reveals the top 16 most-impactful (storm surge) systems in the general return-period range of 1–100 years. Hurricane Matthew (2016) broke the record with a new absolute maximum water level of 1.56 m, although the peak surge occurred during slack tide level (0.00 m). Hurricanes and tropical systems contribute to return periods of 10–100 years with water levels in the approximate range of 1.3–1.55 m. Extratropical systems and nor'easters contribute to the historical storm population (in the general return-period range of 1–10 years) and are capable of producing extreme storm surges (in the approximate range of 1.15–1.3 m) on par with those generated by hurricanes and tropical systems. The highest astronomical tide is 1.02 m, which by evaluation of the historical record can contribute as much as 94% to the total storm-tide water level. Statically, a hypothetical scenario of Hurricane Matthew's peak surge coinciding with the highest astronomical tide would yield an overall storm-tide water level of 2.58 m, corresponding to an approximate 1000-year return period by historical comparison. Sea-level trends (linear and nonlinear) impact water-level return periods and constitute additional risk hazard for coastal engineering designs.

1. Introduction

The objective of the present study is to analyze extreme water levels for the St. Johns River, a low-gradient estuarine system located in northeast Florida (Fig. 1a), from a long-term, fully continuous record of 1928–2017. The analysis of water-level extrema is based on the 89-year-long dataset of hourly water levels for a gaging station located 20 river km inside the St. Johns (Mayport—Fig. 1b). The storm surge extrema and corresponding (independent) storm systems are extracted from the historical record as well as the linear and nonlinear trends of mean sea level. The St. Johns River, like most of the estuaries of the South Atlantic Bight, experiences mesotidal conditions with spring tide ranges in excess of 2 m (Bacopoulos et al., 2011). Given the high activity of tides, it is crucial to understand the tidal contribution to overall storm tide from an extreme-scenario perspective, which currently is not well-defined for the region. To address this matter, a tide-surge assessment of the 89-year-long record is conducted to draw out the timing and magnitude of extreme storm surge with respect to the astronomic tides, i.e., when the peak surge occurs relative to high tide, higher high tide, the fortnightly spring tide, the seasonal cycles (semi-annual and annual) and the 18.6-year tidal epoch. Discrete probability methods (Weibull plotting position and generalized extreme-value distribution) are employed to calculate return periods of water levels based on the historical record, from which risk hazards are generated for scenarios without sea-level rise and with linear and nonlinear sea-level rise. Albeit from an historical perspective, the tide-surge assessment illuminates the importance of the astronomic tides with respect to extreme storm surge in the St. Johns River (and other estuaries of the region) and the related coastal-hazard risk. In addition to establishing water-level return periods based on historical extreme (storm surge) events, projections of relative sea-level rise (10, 25, 50 and 100 years) and the effect on the associated water-level return periods are statically estimated.

Probabilistic storm surge hazard assessment is approached using an empirical simulation technique (EST) (Scheffner et al., 1996) or JPM-based methodologies (Resio and Westerink, 2008). EST involves the numerical simulation of historical events, the analysis of the event parameters, the application of statistical pro-

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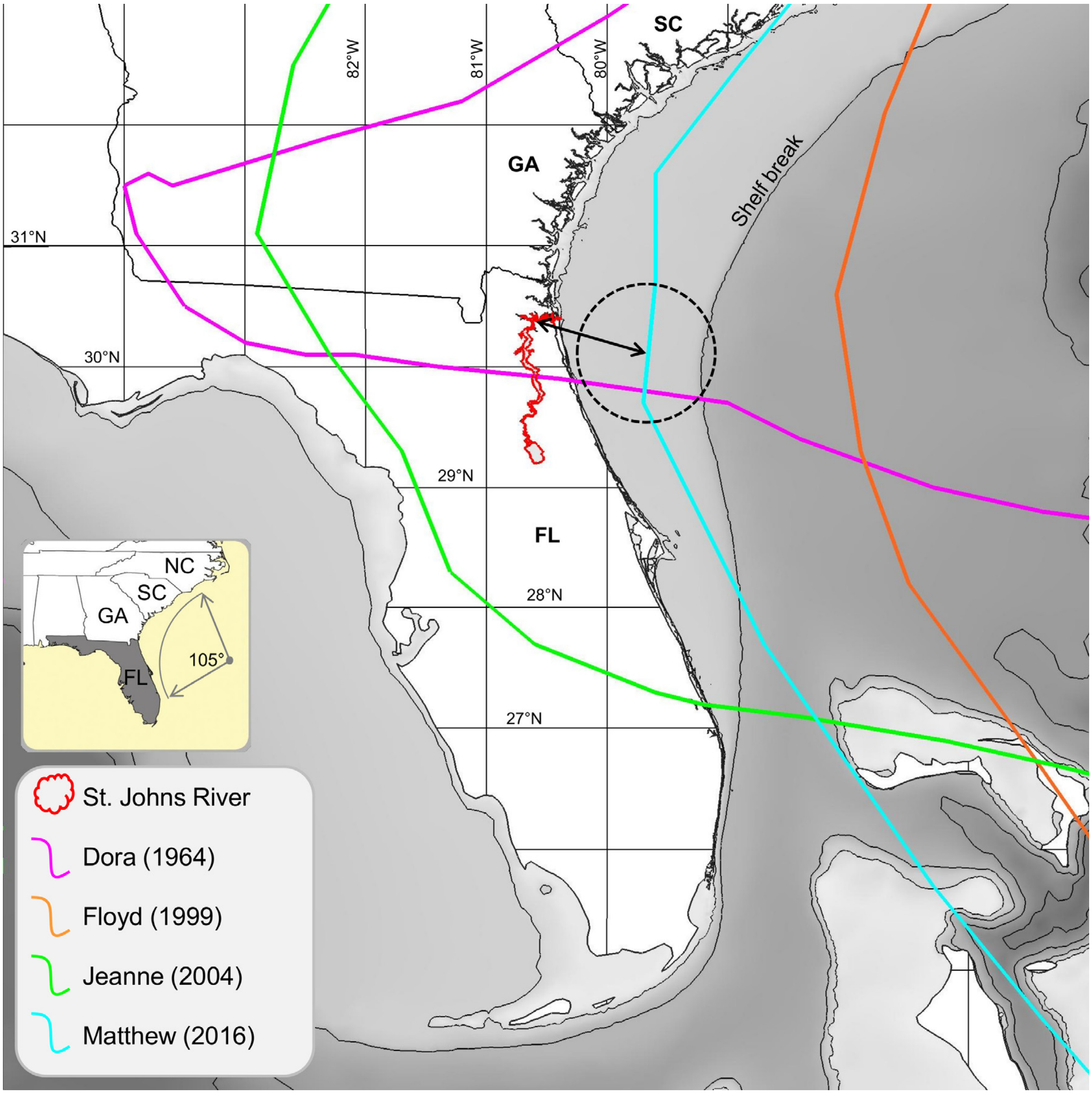

Fig. 1a. Geographic map of Florida, including an outline of the St. Johns River, Georgia and South Carolina showing the storm tracks (published best-track data—NHC, 2016) for Hurricanes Dora, Floyd, Jeanne and Matthew. The arrowed line (←→) represents the 90-km distance of Matthew's nearest approach to downtown Jacksonville. The dashed circle (– –) represents the 75-km radius to maximum winds at the time of Matthew's closest approach.

cedures and the generation of frequency relationships for the study area. To that end, the implementation of EST requires an established historical storm set. For this, historical storm methods are employed which analyze an historical record based on annual maxima series and peaks-over-threshold approaches (Palutikof et al., 1999). Both methods (EST and JPM) rely on a storm (parameter) set for use in physics-based modeling. However, JPM-based methodologies expand beyond EST by examining a storm (parameter) set that is fuller than that extracted from an historical record (Toro et al., 2010; Irish et al., 2011). Some exemplary concentrated effort of JPM with high-resolution modeling has been published for the northern Gulf of Mexico (NGOM) (e.g., see Niedoroda et al., 2010).

JPM utilizes a storm sample (a probabilistically based ensemble of storm parameters—usually six storm characteristics are considered) and numerical modeling (e.g., ADCIRC, Delft3D, FVCOM and others) to formulate a rate of occurrence associated with an exceedance water level, $R(z)$, as diagnosed from a multi-dimensional integral of the storm-sample parameters (storm characteristics) (Resio et al., 2009; Irish et al., 2009). $R(Z)$ is typically based on a mid-tide level for the calculation of surge levels; otherwise, a randomization of tidal amplitude and phase is applied in the calculation of surge levels, but this method is time-consuming to implement, and for large tidal amplitudes, it can obscure the relative error of risk assessments for more frequent scenarios (e.g., 10% or 2% water levels). To that end, some assumptions initially adopted for JPM's application to the NGOM are in need of review for JPM's application to other regions (Resio and Irish, 2015), that is dealing with the implementation of astronomic tides in the high-resolution modeling of storm surge. For example, a (microtidal) high-tide condition has typically been applied for storm-tide simulations of the NGOM (Taflanidis et al., 2013), whereas the mesotidal environment of the US east coast would yield greater effect (i.e., tide-surge superposition) with regard to extreme water levels and coastal hazard.

Tide-surge superposition can be linear or nonlinear. Linear superposition is where the storm tide equals the independent storm surge plus the independent astronomic tide. Nonlinear superposition entails the interaction that occurs between storm surge and astronomic tides to establish a storm tide that is greater