

Examining the Role of Tropical Cyclone Rainfall Motion in Coastal Compound Flooding

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INTRODUCTION

Compound flooding, involving the interplay between pluvial, fluvial, and storm surge components, poses a significant threat to estuarine areas. Previous studies, such as Kossin (2018), have reported potential changes in tropical cyclone motions under the influence of climate change. Consequently, understanding the impact of tropical cyclone rainfall movement on coastal compound floods is critical for flood risk assessment, particularly in regions frequently impacted by cyclones. Such understanding is pivotal in refining predictive models, enhancing urban planning strategies, and better preparing communities for these devastating events. This study aims to examine the impact of tropical cyclone (TC) rainfall movement on coastal compound flooding. A stochastic generation approach for TC rainfall was employed, applied to synthetic TC tracks, and the resulting compound flood scenarios were modeled using Delft3D-FM. This will elucidate how TC rainfall motion affects each component of compound flooding.

TROPICAL CYCLONE RAINFALL

Instead of relying on observations or numerical weather prediction models, this study necessitates the stochastic generation of tropical cyclone (TC) rainfall. This approach is chosen due to the high randomness of TC events and the need for a simple, yet computationally efficient, method to predict rainfall. This methodology enables the free construction of synthetic tracks once basic information such as location and wind speed is available. We adopted and enhanced the parametric rainfall model proposed by Bader (2019), facilitating the stochastic determination of spatial rainfall distribution. This model assumes a correlation between the radius of maximum wind speed (v_{max}) and the radius of maximum rain rate (p_{max}). Consequently, it replaces the v_{max} in the Holland model with p_{max} , allowing the computation of the radial rainfall profile.

Utilizing the QSCAT-R dataset (Chavas, D. R., Vigh, J., 2014), we derived a stochastic relationship between v_{max} and p_{max} . The Multivariate Copula Analysis Toolbox (MvCAT) was employed to fit various copula families, ranking them based on performance metrics (Sadegh et al., 2017). This enabled bivariate analysis of v_{max} and p_{max} . We discovered that the Frank copula, with a parameter of 3.886, was the most effective (Figure 1). This copula was subsequently used to sample p_{max} values for a given v_{max} . The radial rainfall profile, akin to the Holland model, was generated using the sampled p_{max} values.

To assess the variability of this stochastic method, we compared the medians, upper bounds, and lower bounds of the sampled p_{max} with an observed dataset (Figure 2). The results demonstrated a strong agreement between the stochastic method of conditional sampling from a copula and the observational dataset for v_{max} up to 25

m/s. However, for v_{max} values greater than 25 m/s, the higher percentile values of p_{max} (up to the 95% upper bound) more closely aligned with the median of the dataset. This pattern was also evident in the radial rainfall profiles, where the 95%-sample fit profiles corresponded more closely with observations for v_{max} values over 25 m/s (Figure 3). To address the underestimation of TC rainfall, we refined the model by selecting optimal percentile values of p_{max} samples and introduced a regression learner to predict TC rainfall for v_{max} values greater than 25 m/s. The improved stochastic generation method for TC rainfall will be applied to generate synthetic scenarios that consider the TC's motion.

COMPOUND FLOOD MODELING

While few studies have examined the use of a fully hydrodynamic model for simultaneously calculating the rainfall-runoff process and storm surge, most research has relied on hydrological-hydrodynamic coupled models. These models are often limited by boundary conditions and other specific settings. In this study, the hydrodynamic model Delft3D-FM was employed to simulate compound flooding. To validate the model's capability in simulating pluvial floods, we tested it on a simple rainfall-runoff event in the Goodwin Creek watershed (Figure 4). Additionally, we are in the process of modeling Hurricane Harvey (2017) in the Houston-Galveston region for further validation. Once validated, this model will be instrumental in assessing flood risks associated with various TC rainfall motion scenarios.

SCENARIOS AND EXPECTED RESULTS

While the comprehensive application to the Hurricane Harvey-induced compound flood in Houston is underway, the primary focus of this study is the development of various rainfall scenarios on synthetic tracks (Figure 5). These scenarios are designed to explore the effects of changes in the translation speeds and directions of tropical cyclone rainfall. This research aims to illuminate the critical, yet often underappreciated, role of tropical cyclone rainfall motion in flood modeling.

By integrating these rainfall scenarios into a fully hydrodynamic model, we expect to gain detailed insights into how changes in the dynamics of cyclone rainfall can influence flood outcomes. This understanding is vital, as it has the potential to significantly impact flood risk management strategies, infrastructure design processes, and community preparedness plans. The results of this study could offer valuable contributions to the field, highlighting the need for considering the dynamic nature of tropical cyclone rainfall in flood risk assessments and mitigation strategies.

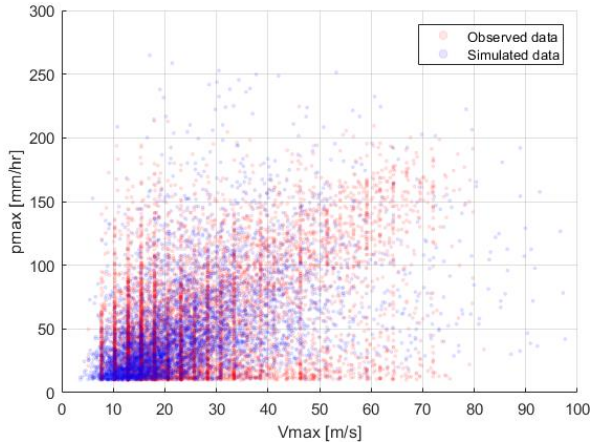


Figure 1 - The copula simulated data versus the observed data. Red scatters are observed data, blue scatters are simulated data.

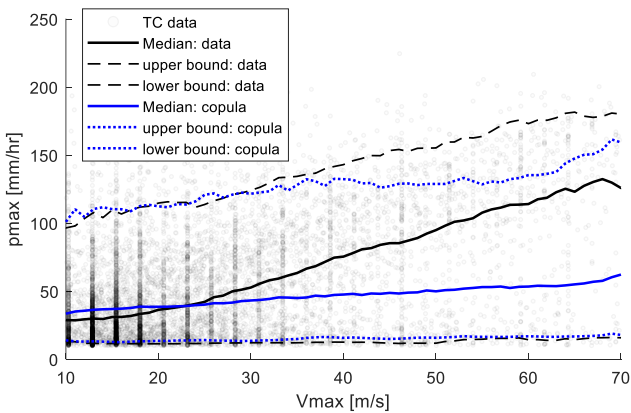


Figure 2 - Statistics (median, 95% and 5% bound) of the data sampled from copula and the observed data. The scatterplot describing pmax as dunction of vmax.

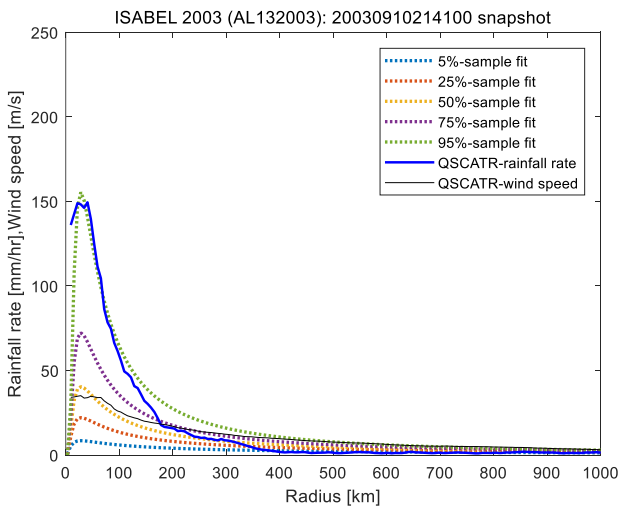


Figure 3 - Radial rainfall profile for Hurricane Isabel (2003) at a certain moment. Different colored dash lines are the fits for different percentile value of samples. The blue solid line indicates the observed rainfall rate. The black solid line is the observed wind speed profile.

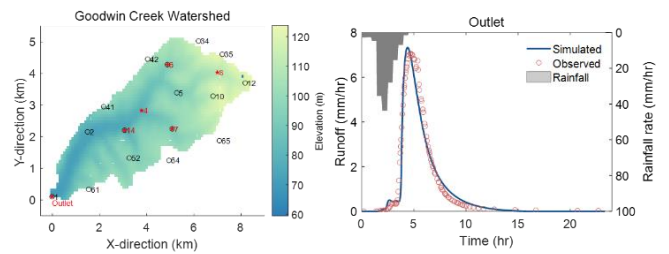


Figure 4 - The map of Goodwin Creek Watershed, and the simulated runoff plotted with the observed runoff.



Figure 5 - The track of Hurricane Harvey (2017) and the zoom-in region is Huston-Glaveston area with the simple schematic of the synthetic tracks (orange line).

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