

# **Calibration of Storm Surge Model for Hurricane Dorian in Jacksonville, FL**

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## **Abstract**

Storm surge induced by hurricanes causes a significant threat to coastal communities. With rising sea levels and climate change, the need for accurate storm surge modeling has become more critical. This study presents the calibration of the storm surge model, GeoClaw, to simulate Hurricane Dorian (2019) and its impact on Jacksonville, Florida. GeoClaw solves the shallow water equations with additional source terms and employs adaptive mesh refinement to resolve coastal flooding dynamics efficiently and accurately. The model was calibrated using synthetic gauges along the Jacksonville coast, including one placed in the exact area of the Mayport tide gauge, which the model was validated against observations from. The calibration involved optimizing friction parameters, mesh refinement levels, and adjusting locations of synthetic gauges to ensure alignment with observed peak surge and timing. Results show that GeoClaw successfully captured the spatial and temporal evolution of storm surge in Jacksonville during Dorian, with modeled surge closely matching tide gauge data. This calibrated model lays the groundwork for future simulations under climate change scenarios, including sea level rise and synthetic hurricane tracks. Accurate storm surge modeling is important for storm preparedness, resilient infrastructure design, and effective long-term climate adaptation strategies.

**Keywords:** Storm surge, Hurricane

# 1. Introduction

Tropical cyclones have devastating impacts on coastal cities, destroying lives and communities as they tear through land. Some of the catastrophic hazards associated with tropical cyclones include strong winds, storm surges, torrential rainfall, and flooding. Among these, storm surge is the leading cause of death caused by hurricanes in the USA, with flooding from rainfall following as second most leading cause (NWS Hurricane Hazards; Rappaport 2014).

Storm surge is the abnormal rise of sea level on the coast brought upon primarily by the extreme winds generated by a tropical cyclone (Bode and Hardy 1997; Resio and Westerink 2008). Climate change is projected to lead to an increase in both the intensity and frequency of major hurricanes in the current and upcoming decades (Emanuel 2021; Bhatia et al. 2018). Not only does this pose an increased risk for storm surge flooding, but sea level rise (SLR) increases the risk significantly because the baseline at which storm surge begins is higher in height. The Florida coast is more at risk to SLR because of the low elevation of the land, the sinking of the land, and erosion on the coast (United States EPA 2016; Neumann et al. 2000). Jacksonville, FL has experienced catastrophic storm surge caused by recent hurricanes such as Hurricane Matthew (2016), Hurricane Irma (2017), and Hurricane Dorian (2019).

Hurricane Dorian formed as a tropical depression on August 24th, 2019 in the Atlantic Ocean. Its path moved from the Atlantic, to the northwest where it made landfall in Barbados and brought devastating impacts to the Bahamas. After its impact in the Bahamas, it continued to move northwest towards the southeast U.S. during which it strengthened to a major hurricane in this time. Although it never made landfall in Florida, Dorian's track scraped the entire east coast of Florida as the hurricane moved north. The storm field still expanded over Florida, affecting our research area of interest, Jacksonville, FL, as well as the rest of the coast of Florida. It's impacts reached Jacksonville, FL around September 4th, 2019, and, according to the National Hurricane Center (NHC), a tide gauge in Jacksonville recorded a wave filtered water level of 3.6 feet (~1.1 m) mean higher high water (MHHW), and there were inundation levels of around 1 to 3 feet (~0.3 to 1 m) above ground level. Hurricane Dorian continued to move north across the southeast U.S. coast until it made landfall again in North Carolina, causing more devastating effects there (Avila et al. 2020).

Storm surge events induced by tropical cyclones will continue to impact coastal cities, with deadly consequences and significant economic cost from infrastructure damage. Thus, it is critical to understand how to model storm surge events. Storm surge models can be used to assess how storm surge will change in a changing climate. The coast is extremely vulnerable to climate change, and the many large cities with large populations lie on the coast. Modeling storm surge is important for storm preparedness, creating long-term climate change adaptation strategies, and for whenever new infrastructure is being designed. By calibrating storm surge

models to accurately represent present-day events, we can gain greater confidence in their use for simulating future conditions. Once calibrated, these models can be applied to assess how storm surge hazards may change under climate change scenarios, incorporating factors such as sea level rise and shifts in tropical cyclone characteristics.

The objective of this research is to calibrate a storm surge model that can be used to model hurricane-driven storm surge events under current and future climates in Jacksonville, FL. In the next section, we will discuss the storm surge model used as well as how this was applied to the case of Hurricane Dorian. The results will focus on the calibration and the model's outputs of storm surge from Hurricane Dorian, with a detailed discussion of the results and possible future work avenues to follow.

## **2. Data Set and Methodology**

### **2.1. Description of GeoClaw**

As defined previously in this paper as well as in previous studies, storm surge is defined as an anomalous increase in the height of sea level relative to the local relative sea level (RSL). Tropical cyclones induce storm surge as a result of both extreme wind as well as the minimum sea level pressure at their surface centers (Sarhadi et al. 2024). To calculate the total flood height caused by a tropical cyclone, tidal storm surge and RSL must be taken into account. Since sea level is rising, this will increase the amount of flooding because it raises the baseline at which the storm surge starts (Reed et al. 2015).

The model being calibrated to simulate storm surge is "GeoClaw," which, in comparison to other models, has been shown to be more accurate while maintaining computational efficiency (Mandli and Dawson 2014). Other storm surge models include the Advanced Circulation (ADCIRC) model, which uses an unstructured grid to achieve high resolution results but is computationally costly (Luettich and Westerink 2004) along with the Sea, Lake, and Overland Surges from Hurricanes (SLOSH) model (which is used and was developed by the National Weather Service, or NWS). SLOSH utilizes local gridding, and it is more computationally efficient compared to other storm surge models, however model accuracy is not as robust (Jelesnianski et al. 1992). A study has used both of these models in combination to produce more accurate but computationally efficient results. Specifically, SLOSH was used to identify the most critical extreme events, while ADCIRC provided high-resolution results (Lin et al. 2012). Miura et. al (2021) introduced another storm surge modeling method, the GIS-based subdivision-redistribution (GISSR) methodology, which is significantly more computationally efficient but less accurate than methods like GeoClaw and ADCIRC (Miura et al. 2021). While GISSR is useful for applications not requiring precise results, it is unsuitable for study's objectives. Additionally, other methods rely on a statistical model to estimate storm surge

changes. However, these models lack physical principles, which are crucial for accurately simulating storm surge dynamics. Geoclaw simultaneously identifies the most critical extreme events and produces high resolution results; in other words, the strengths of both SLOSH and ADCIRC are realized (Mandli and Dawson 2014). GeoClaw is selected for this study to obtain high resolution, accurate results that are computationally efficient.

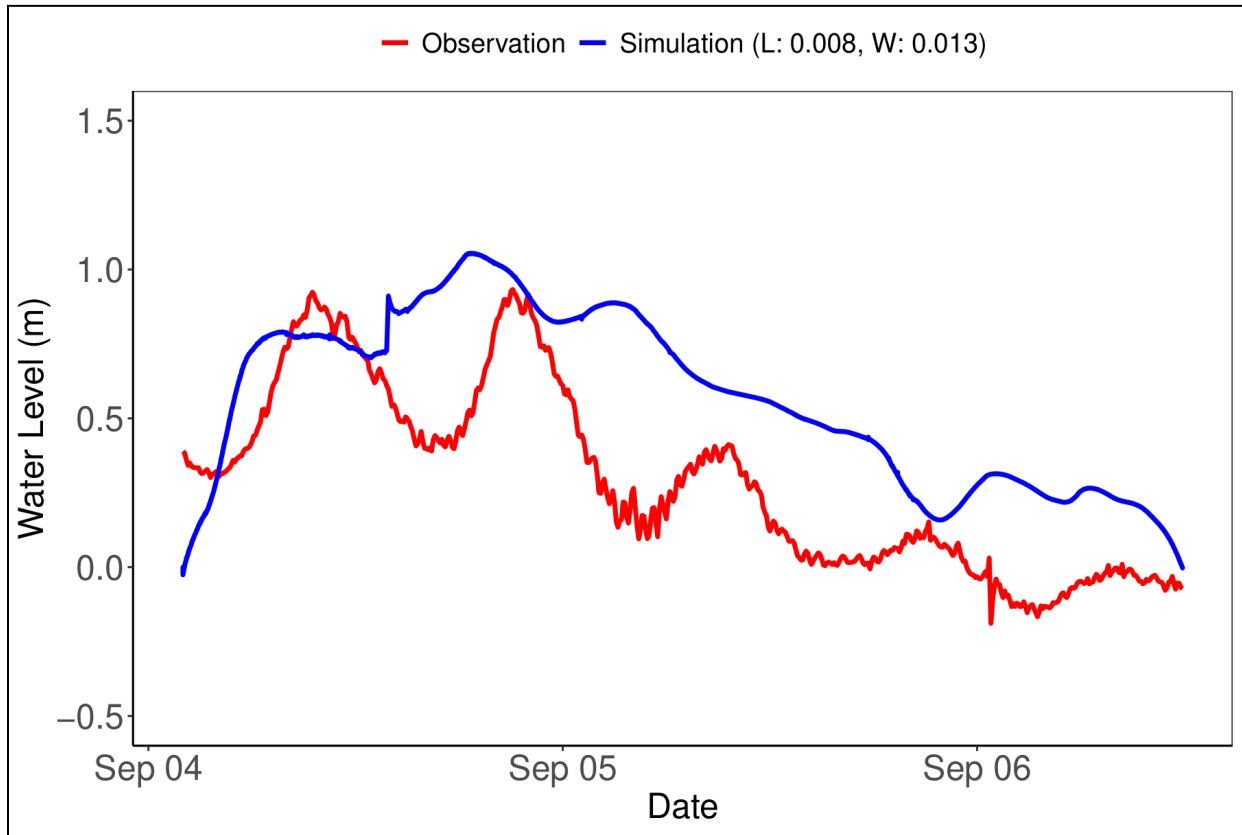
GeoClaw is based on the classical shallow water equations, incorporating additional source terms such as bathymetry effects, bottom friction, wind friction, non-constant surface pressure, and Coriolis forcing (Mandli and Dawson 2014). Geoclaw also employs adaptive mesh refinement (AMR) to provide high-resolution results while still being relatively computationally efficient. The Holland model (Holland 1980), which used the hurricane's features to generate wind speed and pressure fields, is an addition for GeoClaw to use it to model storm surge (Mandli and Dawson 2014). GeoClaw is based on the software known as Clawpack and is included within its standard distribution (Berger et al. 2011). GeoClaw has been used in many successful studies for modeling storm surge such as Sarhadi et al. 2024, Vogt et al. 2024.

## **3. Results**

### **3.1. Model Calibration**

Figure 1 shows the successful calibration of GeoClaw for Jacksonville, FL. The bathymetry friction values used are 0.008 and 0.013. These friction values were chosen by testing out different possible values and comparing them to the observational data. These values were the ones that calibrated best, and the calibration of this is shown in Figure 1. We also adjusted the AMR levels, specifically testing 3 AMR values, which is typical practice when investigating a smaller area. The peak surge of the simulation lines up with the peak surge of the observations, which implies that the model has been calibrated within reason.

In order to simulate the surge, we placed 23 synthetic gauges throughout the coastline of Jacksonville to maximize aerial coverages, including estuaries. The calibration also included confirming that all synthetic tide gauges were located within optimal areas that were not too close or far from the shore. If a synthetic tide gauge is not placed well, it can struggle to simulate the surge correctly and create values that do not fluctuate or are inaccurate. We also used the exact coordinates of a tide gauge in Jacksonville, specifically the Mayport tide gauge with a station ID of 8720218.

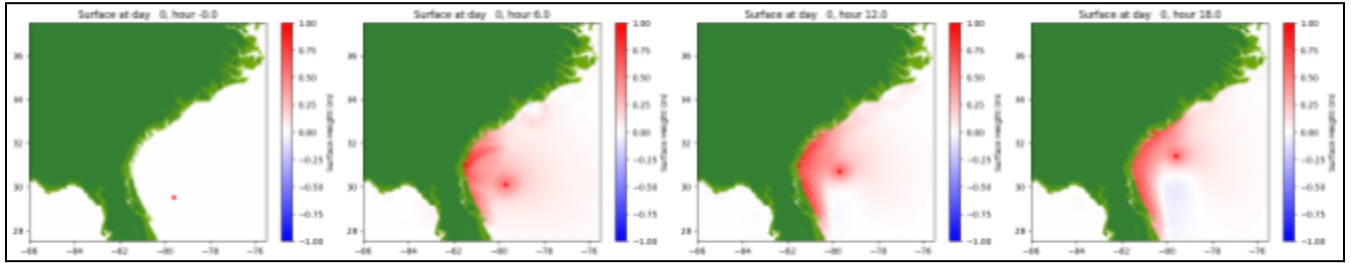


**Figure 1:** Water level (m) at the Mayport (Bar Pilots Dock), FL tide gauge in Jacksonville, FL (station ID 8720218). The red line is the observed values during Hurricane Dorian (2019), and the blue line is the simulation from GeoClaw.

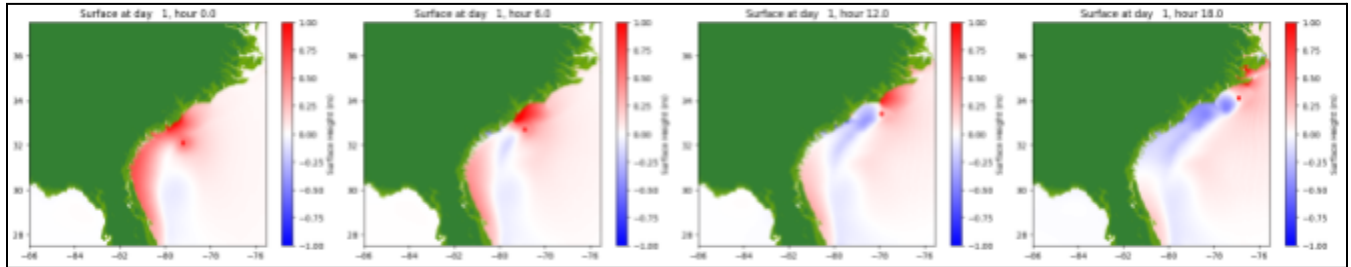
### 3.2 Surge Evolution

Figures 2-4 show the evolution of storm surge in Jacksonville, FL. The peak surge associated with Hurricane Dorian occurred in Jacksonville between approximately 12:00 UTC on September 4th and the early hours of September 5th, which is consistent with the tide gauge observations shown in Figure 1. The storm surge is drastically lower in height at 12:00 UTC, September 6th since Hurricane Dorian was significantly north of Jacksonville at that point to where we would expect there to not be a storm surge during that time.

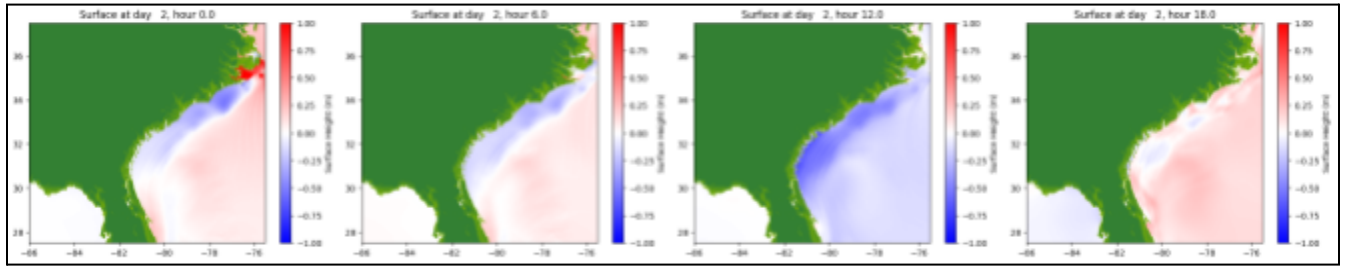
As shown in Figure 2, storm surge levels began rising around 12 UTC on September 4th, 2019, with increasing water levels as Dorian approached the coast. Surge intensity continued to grow throughout the day, peaking between 18 UTC September 4th and 00 UTC September 5th. This timing corresponds closely with the observed peak at the Mayport tide gauge (Figure 1), indicating a good match between modeled and observed surge evolution. The highest modeled surge occurred during the period from late September 4th into early September 5th, consistent with the strongest onshore winds impacting Jacksonville.



**Figure 2:** Modeled storm surge evolution in Jacksonville, FL, starting with 12 UTC, September 4th, 2019, then 18 UTC, September 4th, 2019, to 0 UTC, September 5th, 2019, to 6 UTC, September 5th, 2019.



**Figure 3:** Modeled storm surge evolution in Jacksonville, FL, starting with 12 UTC, September 5th, 2019, then 18 UTC, September 5th, 2019, to 0 UTC, September 6th, 2019, to 6 UTC, September 6th, 2019.



**Figure 4:** Modeled storm surge evolution in Jacksonville, FL, starting with 12 UTC, September 6th, 2019, then 18 UTC, September 6th, 2019, to 0 UTC, September 7th, 2019, to 6 UTC, September 7th, 2019.

#### 4. Discussion

The results show that we have successfully calibrated GeoClaw for storm surge modeling in Jacksonville, FL. We calibrated the model with 23 synthetic gauges throughout the Jacksonville coast, and one tide gauge placed in the exact area of the Mayport tide gauge with station id number 8720218.

It is important to calibrate the model for the specific area of interest because different areas along the coast can require different amounts of AMR layers, different friction values, and different base sea levels. By calibrating the model on a real event, we are able to validate it against historic data, and confirm that our model works for our area. Moving forward the model can be used to simulate storm surge tied to synthetic events (i.e., simulated TC events), or low frequency events of which pre-existing data does not exist.

The study is based on models and there can be errors in models and biases because of the complex dynamic and physical systems that are involved with the atmosphere, ocean, and tropical cyclones. Additionally, astronomical tides are not taken into account. The mesh refinement could also be increased because, as shown in Figures 2-4, the Jacksonville, FL coastline is not resolved clearly. An increase in the refinement levels could increase the resolution of this coastal area.

In the future, this calibrated model will be used to model storm surge in Jacksonville, FL to evaluate how the risk of storm surge will change with climate change. Now that it is correctly calibrated, synthetic hurricane tracks for future climates can be generated and investigated to understand more about climate change effects. These results should be used to help prepare coastal cities, including other cities along the Gulf and Atlantic coastlines, in developing and implementing adaptation strategies.

Accurate storm surge modeling plays a critical role in disaster risk reduction. By providing realistic forecasts of surge extent and timing, models such as GeoClaw enable emergency managers to issue timely evacuation orders, helping to save lives during tropical cyclone events. In addition, surge simulation informs the design of resilient infrastructure, ensuring that coastal defenses, buildings, and transportation networks are better prepared to withstand extreme flooding events. Calibrated models also support long-term planning for coastal adaptation strategies under climate change, offering critical insights into future risk scenarios. As coastal populations continue to grow and sea levels rise, the ability to accurately simulate storm surge hazards becomes even more essential for protecting communities, minimizing economic losses, and ensuring public safety.

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