

A Comparison of ADCIRC Storm Surge Predictions Given Different Forcing Inputs

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ABSTRACT

In September of 2008, Hurricane Ike swept across the Gulf of Mexico and hit the coast of Galveston, Texas causing high storm surges that led to billions of dollars in damage and killed hundreds of people. Predicting storm surges is difficult, due to limits in computational ability and forecasting errors, which hinders emergency evacuations and preparation.

Simulations of Hurricane Ike were used to better understand the usefulness of different methods of constructing and imposing the storm in the surge model environment in an attempt to explore the resulting surge and to increase predictive abilities. The ADvanced CIRCulation (ADCIRC) model was forced with two different representations of the storm, both originating from forecast data generated with the Weather Research and Forecasting model (WRF). The comparison was made between the storm surge simulations forced with the full WRF wind and pressure fields, and a simplified storm approximation constructed from the WRF data, partly developed in this work. The simplified approach used for forcing, developed here, was obtained by measuring the nautical distance from the center of the hurricane, at 6 hour intervals, for the maximum extent of the 34-, 50-, 64-knot, and strongest winds. Differences were found among the resulting storm surges, most noticeably in the points of inundation near where the storm made landfall. Given further investigation, the simplified storm model may produce results more consistent with WRF, but currently the complicated WRF model is a better tool for determining where evacuation and emergency preparation efforts should be focused.

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1. INTRODUCTION

The ability to predict hurricanes with more than a 24 hour lead time has been one of the leading limiting factors for predicting storm surge, and thus predicting damage to communities. This limited predictive ability is due to the basic concept of most hurricane models. They begin with a series of deterministic equations, modeling specific aspects of the storm – wind and water velocity, air temperature, etc. (Butler, et al. 2011). These equations are highly sensitive to initial conditions, which are often unreliable, due to limited data or observations. Due to differences in the available data used as forcing inputs to build hurricane models, they differ in accuracy and computational power required. These limitations and differences lead to innaccuracy when trying to predict storm surge, a result of the hurricane predictions (speed, track, max wind velocity, etc.).

After a determined time step, t , the output values from the equations show a future snapshot of the specified storm. However, the further from the initial conditions, $t = 0$, the more the error compounds and the less accurate the output. Additionally, this occurs for many aspects of the model all at the same time. This compounding of error over time and over many aspects is what leads these models to be so unreliable as we move further from the initial conditions (Fossell, et al. 2017).

Improving observation technology and modeling of the surrounding environment has reduced the sensitivity of these models to forecast errors. The storm surge research, led by Fossell et al. (2017), most recent findings shed a light on the above, pinpointing sensitivity to forecast errors ranked by track, intensity, and translation speed.

Hope, et al. (2013) looked at Hurricane Ike as well due to the high number of observation stations with reliable data. This group, however, focused on the bathymetry and surrounding environment of a storm, measuring how the differences in the Louisiana and Texas coastlines affected the storm surge, rather than looking at how the data affected the storm surge. They point to the wide coast shelf, the Mississippi River, and the remaining physical properties as contributing to the storm surge and needing to be researched more closely.

This study builds on work completed by Fossell et al. (2017) and Hope et al. (2013) by filling in more theoretical concepts, using environment and timing as constants. Hopefully this information can be used to improve modeling hurricanes and storm surges, shining a light on which inputs are likely to provide better predictions in a longer lead time with less computational requirements. This will aid in overall efforts to provide more accurate information in evacuation and emergency preparation information before and after hurricanes hit the coastline. Similar to Fossell, et al. (2017) we used Hurricane Ike as the case study for these experiments, due to the large size and nature of the storm.

2. METHODS

The ADCIRC model is a time dependent numerical model, allowing for free surface circulation in a 2 dimensional environment. We used two different forcing methods with varying degrees of complexity for representing the hurricane in the ADCIRC model

a. Model Setup of ADCIRC

ADCIRC version 51 is built from a high resolution mesh. The mesh we use here contains three million nodes and is spaced at a minimum 200 m apart. It transitions from water to land along the East Coast of the US, stretching from Texas to Maine and inland to a 10-m contour. The National Ocean Service (NOS; Feyen et al. 2015) provided the grid, which was originally created and validated by Riverside and AECOM (Riverside and AECOM 2015).

ADCIRC was run with only tidal forcing for 17 days to reach a state of equilibrium before applying meteorological forcing for Hurricane Ike (section 2b). The storm begins on September 9, 2008, using the data provided in the file for wind, pressure, and location measurements.

b. Meteorological Forcing

The meteorological forcing input datasets both originate from a 96 member ensemble created by Torn and Davis (2012) using the Weather Research and Forecasting (WRF) model (Skamarock et al. 2005). The first member, used for the experiments in this study, was used as a reasonably plausible storm surge case and serves as a hypothetical example to begin investigating the differences in two versions of the same storm: a detailed wind field and a simplified wind field. The full run measured 22 days total, allowing adequate time for setting up tides, ramping, and modeling the full storm.

The simplified wind field method (SWRF) was created from WRF data and models the storm from three points within each quadrant. For each 6 hour time step, beginning on September 9 00:00:00, and the wind contours were displayed visually, and the maximum reach of the 34-, 50-, and 64-knot winds, as well as maximum wind speeds were manually measured in nautical miles from the center of the storm in each quadrant. All other values (center location, central pressure, wind speeds, etc.) are diagnosed by WRF or interpolated from the input data using the ADCIRC aswip program. The ADCIRC meteorological forcing option is set to NWS = 20, allowing for an asymmetric storm, using all available isotachs as measurements.

The detailed wind field method (WRF) was also created from the WRF data but uses all values in domains 2 and 3, with 12km and 4km grid spacing, respectively. We used NWS = 12, where the wind vectors and sea level pressure are interpolated onto the ADCIRC nodes.

c. Post - Processing

The maximum water elevation time series and overall maximum water elevation were compared between the forcing methods. FigureGen (Dietrich et al. 2013) was used to build the images, allowing for detailed comparisons of the wind fields as well as the visible storm surge and changes in water level over time.

3. RESULTS

The results of running ADCIRC show that the storm surge produced from the experiments are fairly similar. The largest differences are in the inundation points furthest inland (Figure 3).

a. Maximum Water Levels

The maximum water levels for WRF and SWRF are shown in Figures 1 and 2. These two images display, after the full 22 day run, where the furthest and highest points of inundation are along the coastline. The tracks are shown in the black lines, and it is difficult to use these figures to track where the differences are between the storm surge of the storms.

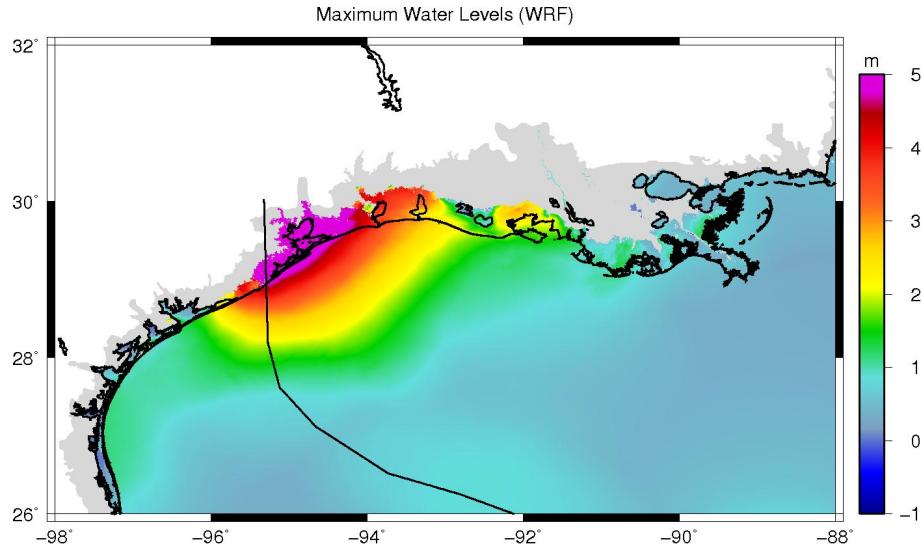


Figure 1: Maximum water level in meters using WRF.

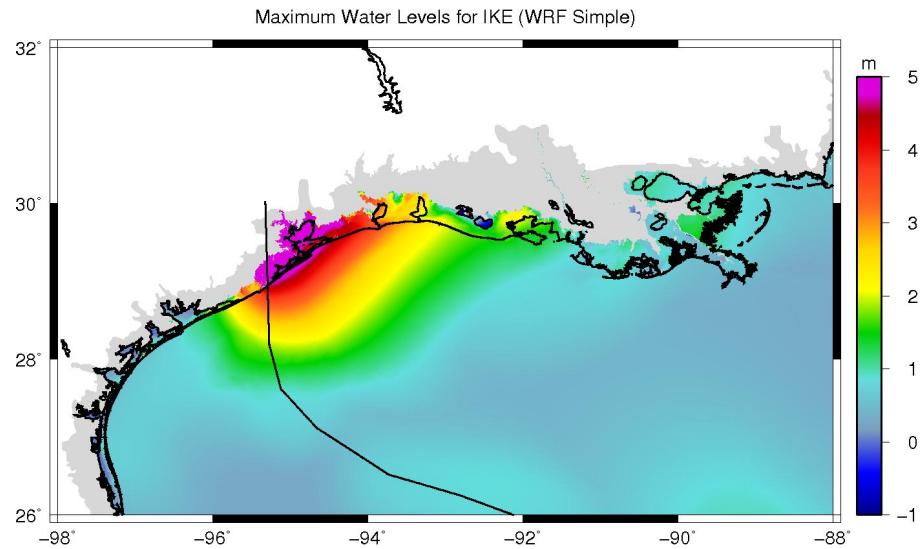


Figure 2 : Maximum water level in meters using SWRF.

b. Differences

Figure 3 shows the difference between the WRF and SWRF highest water levels, displaying the discrepancies in water level and location of surge. The darkest red and deepest blue indicate where the biggest differences occurred in the ocean and on land. There is a deep red trailing the entire northeast of the coast above Galveston, showing major differences in the water levels in these areas. This is showing that SWRF was underestimating the surge along this entire

stretch, as well as further inland in all of these areas. However, the blue to the furthest points northeast show that SWRF overestimated the inundation.

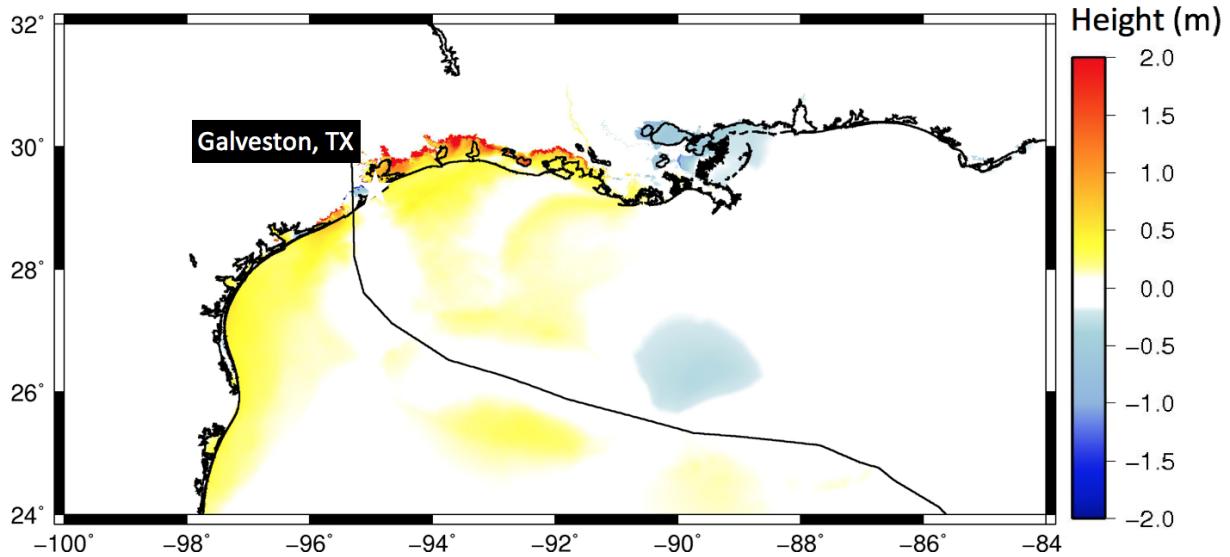


Figure 3: Differences in the maximum water height of WRF minus SWRF.

4. DISCUSSION

a. Possible Explanation

The two possibilities we have identified for the differences in maximum water level and inundation are oddities expressed in the wind field contours (*Figure 4*) and incorrect measurements as the hurricane approached the coastline (*Figure 5*).

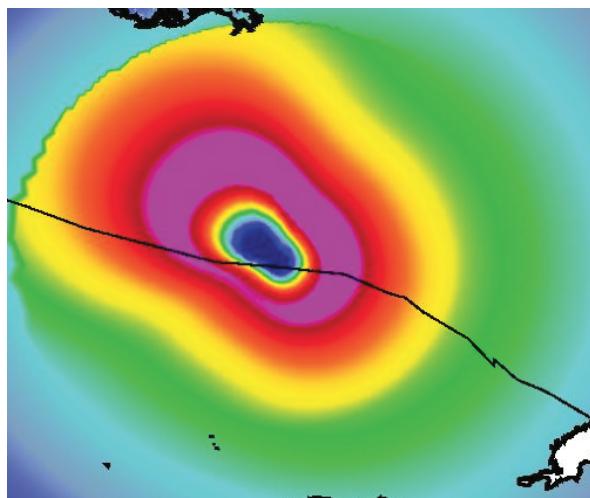


Figure 4: As the storm approached the 19th day of the run, the wind fields became distorted and pulsed into an oblong shape in all wind thresholds.

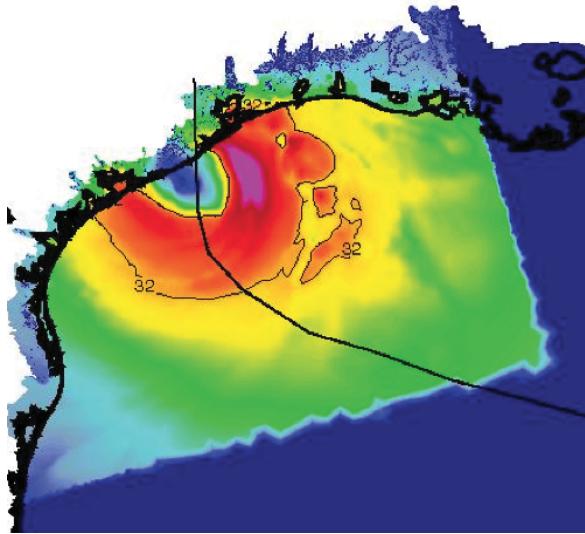


Figure 5: FigureGen was unable to show the wind fields as the storm approached the coastline, because of limitations in the ADCIRC mesh requiring manual interpolation for these quadrants, allowing for large human error.

1. Oddities in the Wind Field

There were various time stamps that showed oddities in the wind contours of the SWRF run. The cause of the oddities in the SWRF wind field is unknown and more exploration is needed before we can conclude why they were so contorted, particularly as the hurricane approached the coast on day 19. The oblong shape results after a pulsing motion in the fields, and returns to normal after a few more time steps, but does not match the data input into ADCIRC.

2. Measurement Errors

As the hurricane approached the coast for the original WRF run, and measurements were taken for each quadrant, a majority of the wind fields in quadrants one, three, and four were not displayed over land. The data available from ADCIRC does not extend past the mesh, shown above, limiting what FigureGen could produce. While making measurements, the quadrants without visuals had to be estimated from the data points that were plotted in the other quadrants. This manual interpolation left room for human error, often allowing the measurements to be underestimated, which could be a possible cause for the underestimation of the storm surge. To attend to this error, it would be more feasible to run FigureGen on the direct WRF output, and measuring the data points from those images.

c. Implications

The differences between the SWRF and WRF run, shown in Figure 3, show that SWRF underestimates the location and amount of water from storm surges. Therefore, the evacuation and emergency preparation efforts, if based on this run, would also support underestimates, endangering any number of lives. There is a roughly 100km area of high positive deviation between WRF and SWRF and every individual in and around the red areas needs to know which model is going to give them the best estimate of inundation. The differences between these runs is not simply a red area on a map, but the difference between individuals and communities prepared to be safe from storm surge, and those who are not.

5. CONCLUSION

The differences shown in Figure 3 lead us to conclude that investigating the differences between the initial, more detailed WRF run, regular WRF run and the less complex SWRF is worthwhile. The biggest improvement to make for the methodology is to create a script to automate the process of finding the distances in nautical miles. This would reduce the possibility of human error and allow for the first, third, and fourth quadrants to be accurately measured as the storm approaches the coast. This study was an act to compare in experimental space, but to draw more useful conclusions, there must be further testing and exploration for a real case, different or more members of the ensemble, and a variety of storms. This is the first step in understanding how valuable the complications inherent in WRF are, but it certainly should not be the last.

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