Validation of WAVEWATCH III Simulations Under Hurricanes in Shallow and Deep Water

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Introduction

Hurricanes are natural hazards that are typically destructive as they bring strong wind speeds, heavy rain and storm surge. This research focuses on:

- Testing the National Oceanic and Atmospheric Administration's (NOAA) WAVEWATCH III (WWIII) - wave simulator - under hurricane conditions
- Five (5) different models were simulated using WWIII to investigate sensitivity to different wind forcing and model grids
- Focused on Hurricane Irene (2011) due to the wealth of near shore observations (Fig. 1)
- Deduce which model best replicates the observed wave heights in shallow and deep water

The implications of our research is to better predict the ocean atmosphere along the coastline and surface wave predictions could assist in predicting storm surge.

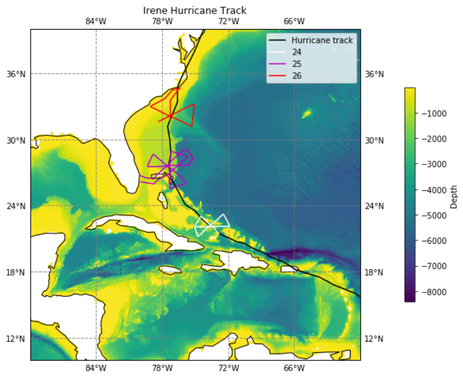

Figure 1: The hurricane track (black) of Hurricane Irene (2011). The NOAA Hurricane Hunter flight paths are colored white, purple and red, which indicate where wave height observations were taken during the storm (Fan et al., 2009).

Experiment Design

Five Models are tested using WAVEWATCH III, Models 1-4 used standard latitude-longitude grids:

1. Real bathymetry and used the wind from the enhanced Tropical Cyclone best track
2. Constant depth (-4000m) with the same wind as model 1
3. Constant depth (-4000m), reduced wind speed model
4. Real bathymetry, reduced wind speed model

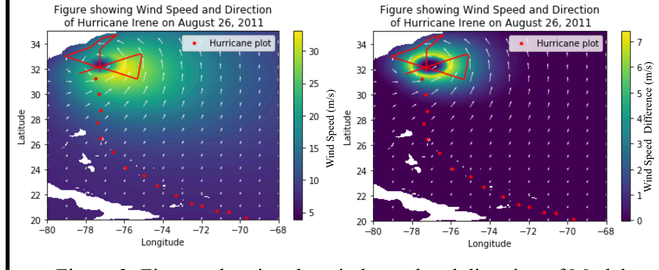

Figure 2: Figures showing the wind speed and direction of Model 4 and the difference in wind speed between Model 1 and 4

5. Unstructured grid (Abdolali et. Al, 2018) with reduced wind speed

Analysis

We implemented a suite of Jupyter notebooks to:

- Draw comparisons between observations and each of the models to identify the most skillful model.
- Perform spatial analysis via scatter bias plots (See Figure 3. (a –c.)),
- Utilize statistical analysis by calculating the root mean square error (RMSE) and the normalized root mean square error (NRMSE). The following equations were used:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}(Predicted_i - Actual_i)^2}{N}} \qquad NRMSE = \frac{RMSE}{\bar{y}}$$

$\bar{y}$ = mean of the observed data

Results

Statistical and visual analysis (focusing on significant height) for models 1 and 4 are below. Models 2 and 3 were less skillful because they did not account for depth.

Visual Analysis: Scatter Biases – took the difference between the model and observed data for significant height

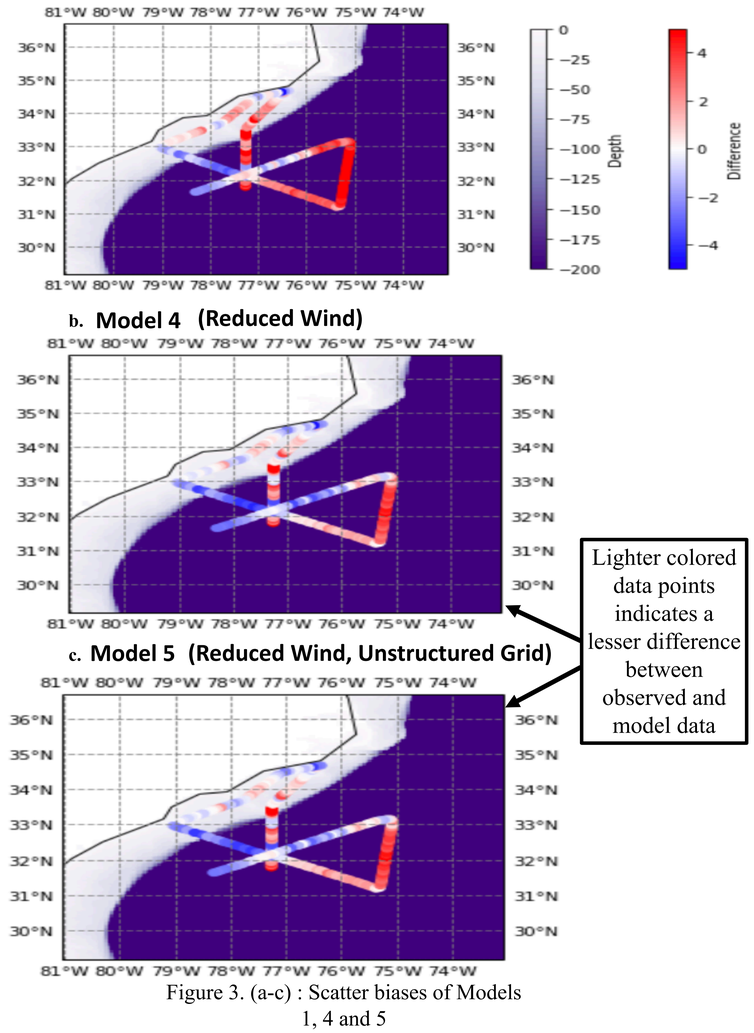

Figure 3. (a-c) : Scatter biases of Models 1, 4 and 5

Statistical Analysis: RMSE and NRMSE

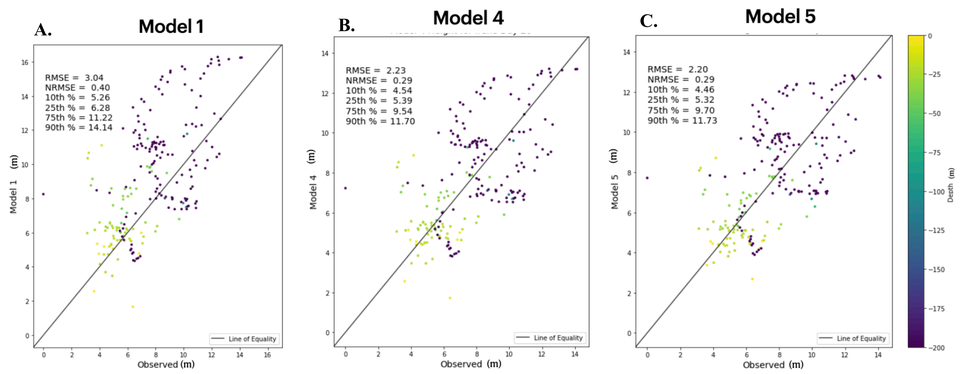

Figure 4: Scatter Plots of Models 1,4 and 5. (A) Model 1, RMSE = 3.04, NRMS = 0.40. (B) Model 4, RMSE = 2.23, NRMSE = 0.29. (C) Model 5, RMSE = 2.20, NRMS = 0.29. (A-C) Both model 4 and 5 had an overestimate of significant height across the latter (75th and 90th) quartiles, but Model 1 had overestimates across all quartiles.

The observed data at the 10th, 25th, 75th and 90th quartiles are as follows: 10th = 4.72m, 25th = 5.8m, 75th = 9.28m, 90th = 10.91m

There was a significant decrease in error when the wind speed was reduced for Models 4 and 5 when compared to Model 1.

Conclusions

- Models 4 and 5 are the most skillful models of the five models.
- Using the reduced wind modelled both shallow and deep water relatively well as seen in the scatter biases and had the closest to the observed data statistically.
- Possibilities of using an unstructured grid is promising as it allows us to concentrate grid resolution in coastal regions while maintaining quality solution throughout the domain.

Future research entails:

- Investigate biases due to wind error versus model physics as there is still some overestimation in wave height
- Look into the effects of coastal bathymetry features such as coral reefs, levees etc. with higher resolution unstructured grids
- Assess more hurricanes to understand if the different models react similarly and increase ability to differentiate shallow versus deep and the location within the storm.

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