# CP44E-1410 U.S. East-Coast Shoreline Wave Climate during Intense Hurricane Forcing: Landfall Case Studies from 2016-2019

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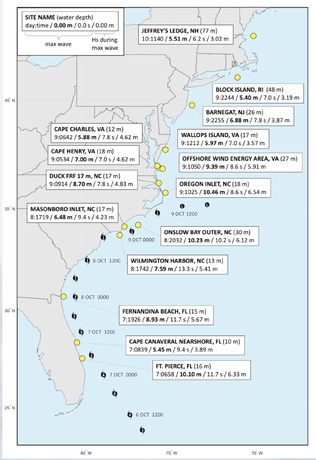
## INTRODUCTION

In light of sea level rise, accurately predicting nearshore waves is increasingly important for informing management strategies that require adapting to a changing climate, with the most impactful waves originating from high intensity storms. The active hurricane seasons of 2016-2019 resulted in several devastating landfall hurricanes whose coastal wave climate was captured by an array of directional wave gauges deployed on the entire eastern seaboard. These named storms include Hurricanes Matthew (2016), Irma, Jose, and Maria (2017), Florence (2018), and Dorian (2019). The array provides a unique capability to assess the skill of operational forecasts. Here we focus on NOAA's operational WaveWatch 3 forecasts, and extend a performance analysis beyond significant height to include properties of the directional wave field and highest individual wave statistics on a per storm basis. For purposes of understanding impacts of model-data mismatch to shoreline erosion prediction, the time-cumulative alongshore component of stress applied by the waves (Sxy) is assessed as that is the principal forcing in the prediction of alongshore sediment transport. This analysis highlights the need for persistent in-situ observations as model errors are too large to predict the annual Sxy budget.

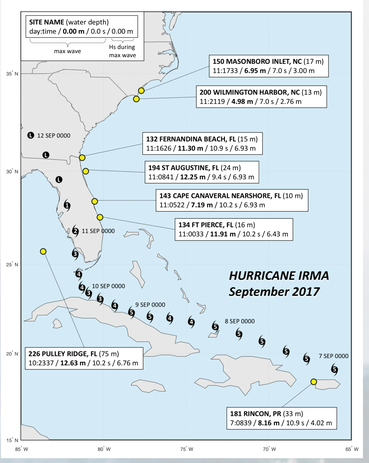
The data used in this assessment is provided by the Coastal Data Information Program (CDIP), an operational wave monitoring and prediction program based at Scripps Institution of Oceanography, University of California, San Diego. CDIP maintains an array of Datawell™ Waverider directional wave buoys in US and territorial waters, with primary funding provided by the US Army Corps of Engineers. In recent years, collaborations with NOAA's (IOOS) program, including UNC's Coastal Ocean Research and Monitoring Program (CORMP), have expanded the CDIP array to include over 20 active buoy stations deployed along the U.S. East Coast from Puerto Rico to New England.

## Hmax: TALLEST INDIVIDUAL STORM WAVES MEASURED AT EACH STATION

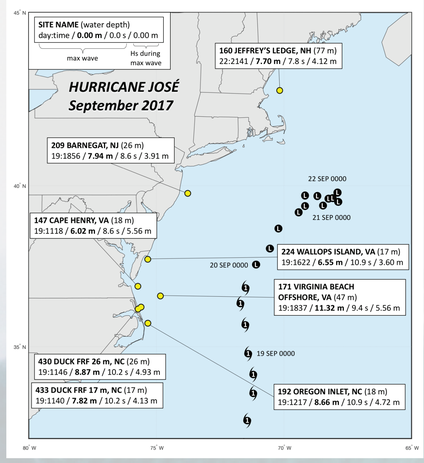
### 2016 Matthew



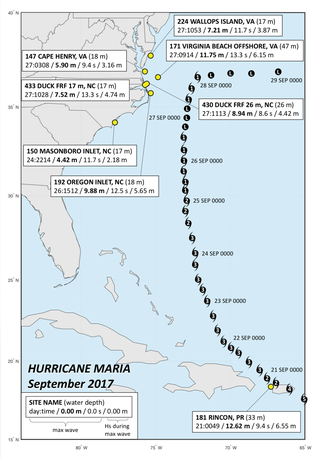
### 2017 Irma



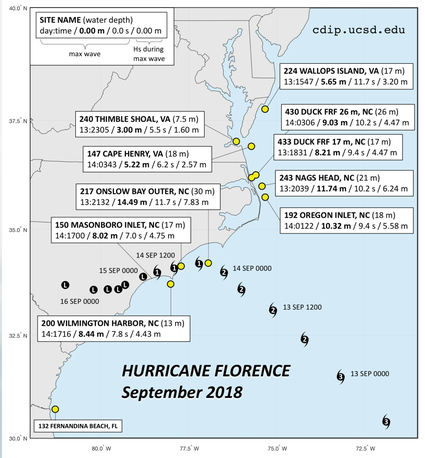

### 2017 Jose



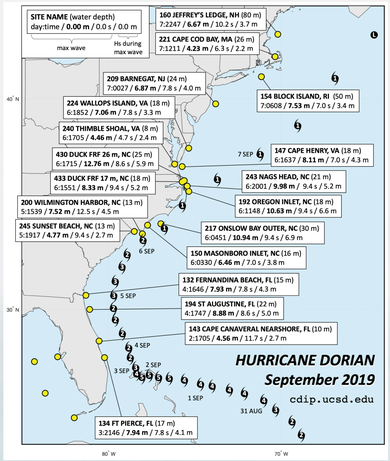

### 2017 Maria




### 2018 Florence




### 2019 Dorian




Breaking waves create spurious large amplitude peaks and long period oscillations in the computed displacements; these were identified and filtered from the record through visual review of the time series.
Following the example of Seymour and Castel (2017), the largest vertical displacement of either crest-leading or crest-following wave types was selected as the most valuable datum.
Hmax for all buoys and storms was found to be less than six times the standard deviation of the 30-minute data segment it occurred within.

## HURRICANE IRMA - EXTREME WAVES IN FLORIDA

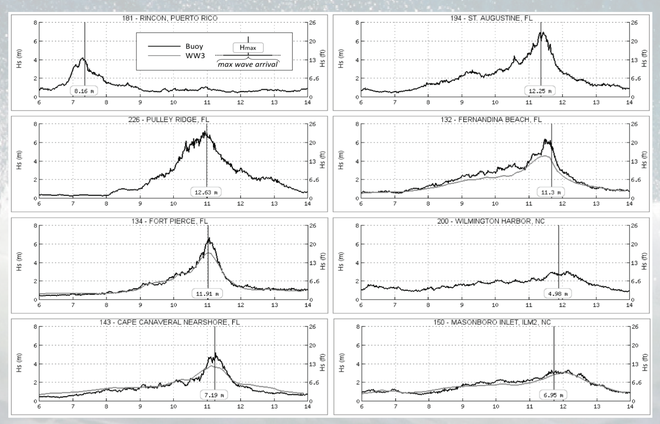


**Table 1.**

Maximum recorded wave heights during Hurricane Irma, September 2017 (listed from south to north).

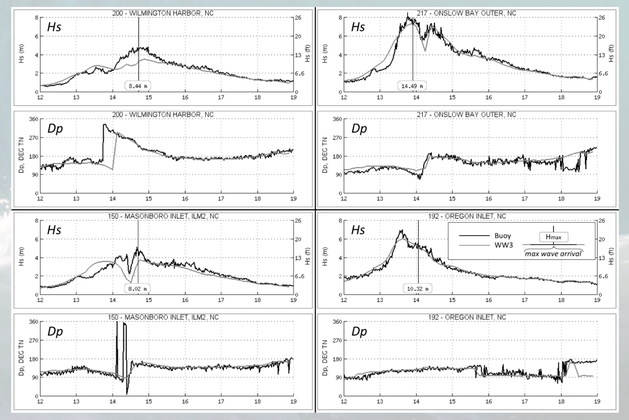
| Station name | UTC (DD-HH) | Hmax (m) | Tmax (s) | Hs (m) | Tp (s) | Dp (deg) | Delay (hr) | Hmax / Hs | Hmax / depth | Depth (m) |
|---|---|---|---|---|---|---|---|---|---|---|
| Rincon, PR | 07-08 | 8.16 | 10.9 | 4.02 | 9.9 | 337 | 1.4 | 2.03 | 0.25 | 33 |
| Pulley Ridge, FL | 10-23 | 12.63 | 10.2 | 6.76 | 10.5 | 007 | 0.9 | 1.87 | 0.17 | 75 |
| Ft Pierce, FL | 11-00 | 11.91 | 10.2 | 6.43 | 9.9 | 107 | -1.2 | 1.85 | 0.74 | 16 |
| Cape Canaveral, FL | 11-05 | 7.19 | 10.2 | 4.32 | 11.8 | 125 | -1.2 | 1.66 | 0.72 | 10 |
| St. Augustine, FL | 11-08 | 12.25 | 9.4 | 6.93 | 11.8 | 092 | -1.9 | 1.77 | 0.51 | 24 |
| Fernandina Beach, FL | 11-16 | 11.30 | 10.9 | 5.65 | 13.3 | 116 | 4.7 | 2.00 | 0.75 | 15 |
| Wilmington Harbor, NC | 11-21 | 4.98 | 7.0 | 2.76 | 10.5 | 149 | -5.9 | 1.80 | 0.38 | 13 |
| Masonboro Inlet, NC | 11-17 | 6.95 | 7.0 | 3.00 | 7.7 | 098 | 1.3 | 2.32 | 0.41 | 17 |

UTC: Universal Coordinated Time day and hour of Hmax arrival, October 2016
Hmax: Amplitude (trough-to-crest) of largest recorded individual wave
Tmax: Period of Hmax wave
HS: Significant wave height at time of Hmax arrival
Tp: Peak period corresponding to the measured Hs
Dp: Peak direction corresponding to the measured Hs (meteorological convention)
Delay: Time elapsed between Hs max and Hmax; Delay > 0 means Hmax occurred after Hs max
Hmax / Hs: Ratio of Hmax to Hs during the time interval of Hmax arrival
Depth: Water depth at buoy station

Hurricane Irma set wave height records at many of CDIP's stations. Buoy Hs data are compared against NOAA's WaveWatchIII operational 9-hour hindcast values.

Maximum waves show examples of rogue wave heights (H/Hs > 2) and theoretical maximum height for a soliton (H/depth ~0.75).

## HURRICANE FLORENCE - WAVES UNDER THE EYE



Hurricane Florence passed directly over a number of CDIP wave guage stations. A detailed record of the directional wave field was obtained as the eye passed through, setting maximum wave height records at stations 150 and 217.

Comparison of timing and intensity of maximum Hs against operational WW3 highlights the value of nearshore wave observations.

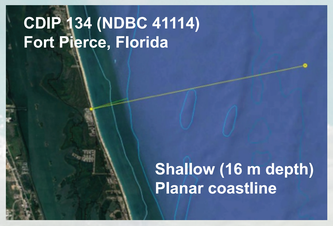
Comparison of maximum significant wave height (Hs max) values between buoy data and WW3 model output during Hurricane Florence, September 2018 (listed from south to north). "**Δ Hs**" is in meters, and a positive value means buoy Hs max data value is greater than WW3 output. "Δ t" is in hours, and a positive value means buoy Hs max occurred later than WW3 Hs max. "Hs ratio" is buoy Hs max divided by WW3 Hs max. Note that buoy data are available every 30 minutes and WW3 output every 3 hours.

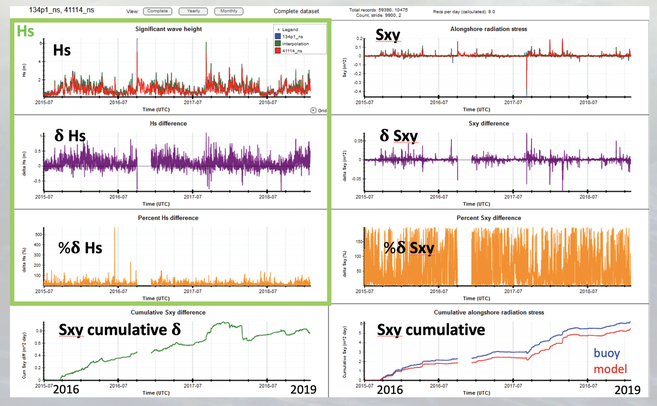
| Station Name | Δ Hs (m) | Δ t (hours) | Hs ratio |
|---|---|---|---|
| 200 Wilmington Harbor, NC | **1.35** | 2.55 | 1.39 |
| 150 Masonboro Inlet, NC | **1.42** | -1.95 | 1.39 |
| 217 Onslow Bay Outer, NC | **1.23** | -2.45 | 1.17 |
| 192 Oregon Inlet, NC | **0.98** | -0.18 | 1.16 |
| 433 Duck FRF 17m, NC | **1.86** | 3.05 | 1.71 |
| 430 Duck FRF 26m, NC | **1.00** | 1.80 | 1.25 |
| 147 Cape Henry, VA | **-0.88** | 12.55 | 0.74 |
| 224 Wallops Island, VA | **0.30** | -2.45 | 1.10 |

## WAVE RADIATION STRESS

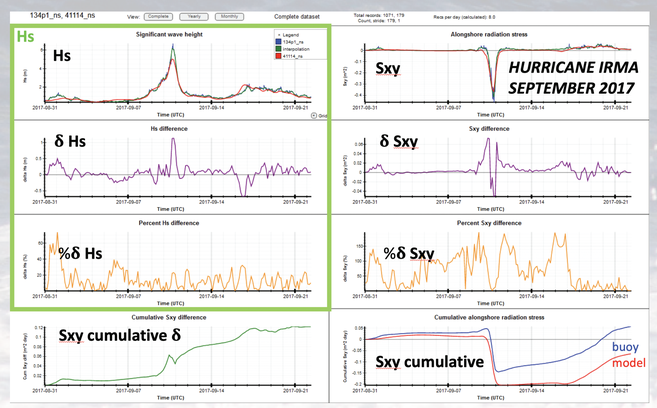
$$S_{xy} = \int_0^{\infty} \int_{-\pi}^{\pi} E(f,\theta) \frac{c_g(f)}{c(f)} \sin(\theta)\cos(\theta)\, d\theta df$$

Sxy, the alongshore momentum flux, drives alongshore currents in the surf zone, and thus, sediment transport.




Sxy has a cumulative effect on a coastline. Energetic events impart large amounts of stress, with significant mismatch between data and models.




## CONCLUSIONS

The most energetic waves have the greatest impact on storm surge, run-up, erosion, and along-shore sediment transport, giving the largest wave in each of the buoy hurricane records (Hmax) particular significance. Wave gauge data are used to identify biases in coastal wave models, and provide detail regarding the forces applied to the coastline. Alongshore momentum flux is shown to have significantly different estimated properties when computed using buoy data vs operational WaveWatchIII.

## REFERENCES

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