CSTAR Final Project Report *(Period from Jan-Jun 2019)*

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Project Title:	An Ensemble-based Approach to Forecasting Surf, Set-Up and Surge in the Coastal Zone
Recipient Name:	Florida Institute of Technology
Investigator(s):	Steven Lazarus (PI) and Robert Weaver (co-PI)

SUMMARY OF FINAL PROJECT GOALS (per CSTAR proposal bullets)

- Make products and data available to the NWS (ALL)
  (See Multistage and Parameterization sections).

1. ADCIRC/SWAN

MultiStage (ADCIRC-Lite) and Real-Time Simulations:

FIT is running a real-time atmospheric/hydrodynamic forecast system referred to as Multistage. The Multistage, which is comprised of two models – ADCIRC and SWAN, integrates a high-resolution computational mesh with a large-scale coarse grid via conventional one-way nesting. The Multistage system has a tropical cyclone-based module that includes both ensemble and deterministic forecasting components. Ensembles are generated using the three-hourly output from the NCEP Global Ensemble Forecast System (GEFS, 1 degree spatial resolution) and the regional Short-Range Ensemble Forecasting (SREF, 16 km spatial resolution). Three members (ensemble mean, and +/- 1 standard deviation with respect to the wind speed) are selected from both the GEFS (21 members) and SREF (26 members) for a total of 6 members (Fig. 1). The deterministic

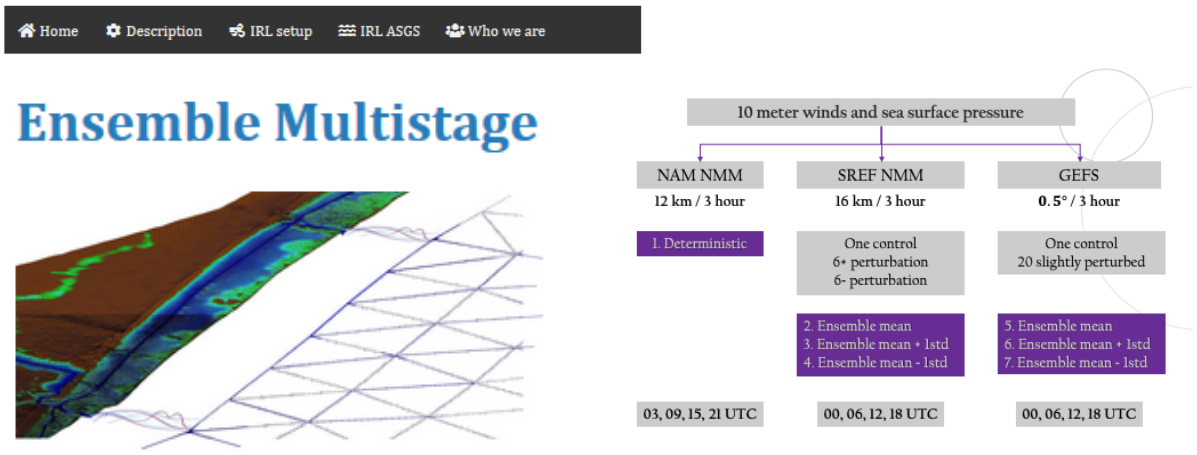


Figure 1. LEFT: The web page marquee for the real-time FIT Multistage operational ensemble forecast system. RIGHT: The ensemble members and cycle times.

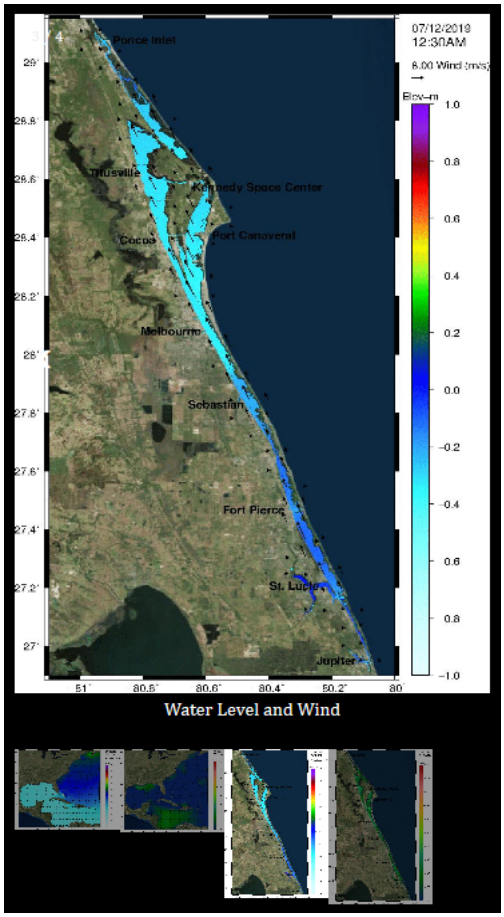
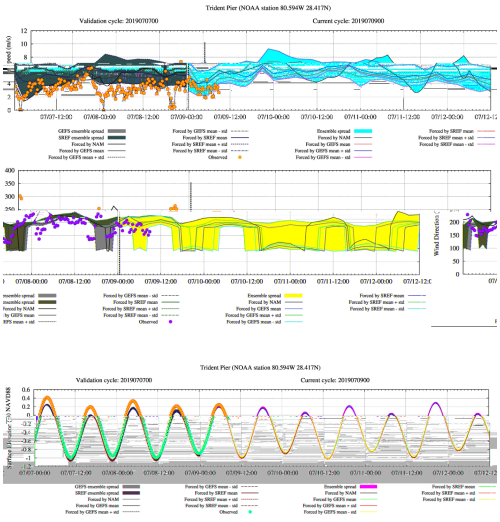


Figure 2. ABOVE: Snapshot of a 3.5 day animation (starting 0 UTC 9 July 2019) of the operational FIT real-time Multistage output water level (m) and IRL wind vectors (https://ptaeb2014.github.io/Multi-stage/).



forecasts are launched using NAM surface pressure and 10 m winds and are run four times per day to provide daily forecasts as well as initial conditions for the tropical cyclone module. The tropical cyclone component, activated when a hurricane approaches, downloads the latest advisory and storm parameters (i.e., track, intensity) from the National Hurricane Center (NHC, see previous report for details).

A web presence for the hydrodynamic validation graphics (at the locations for which there are available real-time observations) **has been developed** and is live hosted at https://ptaeb2014.github.io/Multi-stage/ (see Fig. 1). Model-predicted water level is validated at NOAA's Trident Pier station and at the nearshore Sebastian Inlet gauge operated by the FIT Coastal Process Research Group (CPRG). *The hydrodynamic forecasts at these two locations are provided by the stage one (S1) coarse mesh simulations*. The predicted significant wave height, H_s, is validated at the CPRG station and at NDBC buoy 41113 (nearshore Cape Canaveral). Within the estuary, water level validation is limited to two locations (one in the north IRL at the Haulover Canal and the other in the south IRL in Wabasso Florida). These are the only hydrodynamic observations that are available in real-time on the IRL. Both of these stations are operated by the US Geological Survey (USGS). **Multistage time series output (water level and H_s) are also available at 16 locations along the IRL – ranging from the North Indian River to Jupiter Inlet**. The model output and observational data are accessible via point and click. The site contains information on the model setup, processing, software, and computational resources (Figs. 2 and 3).

Figure 3. LEFT: Trident Pier (see Fig.2) ensemble validation cycle (gray shading) for 00 UTC 7 July 2019 wind speed (top, m/s), wind direction (middle, degrees) and 3.5 day forecast cycle 00 UTC 9 July 2019 (cyan shading). The shading depicts the ensemble spread and the observations are filled orange circles. Water level is also shown (m, bottom).

2. PARAMETERIZATIONS: Setup and Waves

Set-Up

As previously reported, the operational version of the set-up parameterization runs four times per day (cycles with the GEFS). The output is updated on GitHub. The "pseudo-observations" (i.e., the calibrated set-up forced with the KMLB winds) as well as the GEFS estimate of the ensemble mean, median, maximum, and minimum set-up have been archived since July 2018. Based on our 7 June 2019 meeting/discussion with NWS personnel, we have since revised the output graphic so that there are now four *consecutive* GEFS cycles posted at 24 h intervals[1] (blue arrows in Fig. 4).

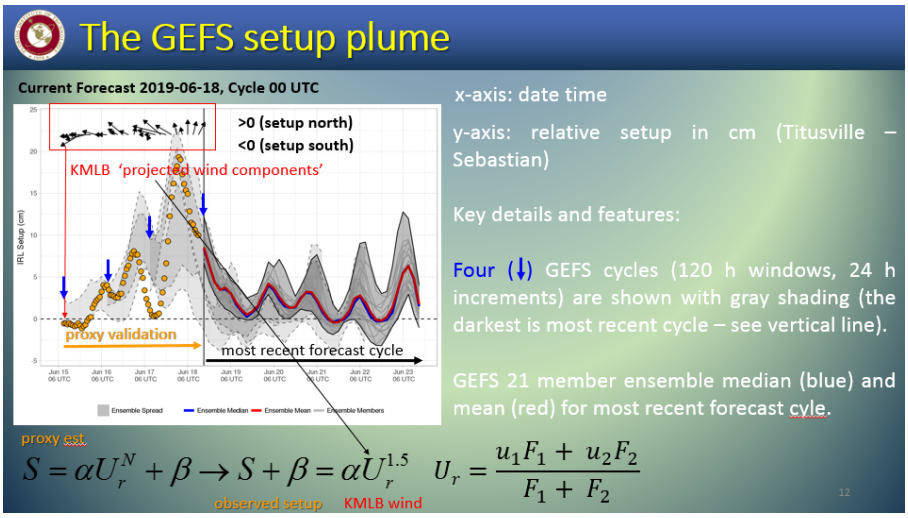


Figure 4. Powerpoint slide from the 7 June 2019 "product tutorial" and project wrap-up meeting at the NWS Melbourne WFO. Annotations highlight key aspects of the setup plume including: validation interval (orange arrow and text); the projected (IRL oriented) wind components (red box and text); forecast cycle (black arrow and text) and the setup nomenclature (> north, < 0 south, black text).

IRL Significant Wave Height

In our previous report, we indicated that the SMB wave height parameterization would be evaluated using output from SWAN simulations forced using the same single time series of wind that was used to generate the parameterized estimates. **This work has been completed** by Vanessa Haley and is published in her MS thesis "A Probabilistic Approach to Generating Representative Wind Forcing and Wave Heights within an Estuarine Environment". Based on our 7 June 2019 meeting at the WFO in Melbourne, we are publishing the images (Fig. 5, on-line at the GitHub

[1] This was not the case in the previous operational version as it varied from one-to-two days. It was pointed out by the NWS staff that this was somewhat confusing.

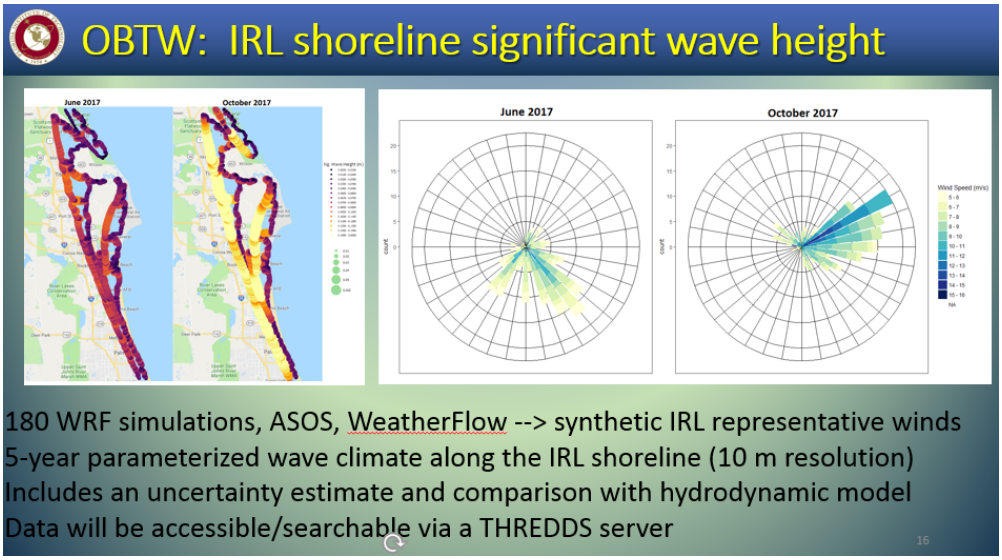


Figure 5. Powerpoint slide from the 7 June 2019 "product tutorial" and project wrap-up meeting at the NWS Melbourne WFO. Left panels contain two (June and October 2017) of the 60 monthly average significant wave height IRL shoreline climatologies (m, shading ranges from 1 cm in purple to 20 cm in yellow). Right panels are the corresponding wind roses (excluding winds under 5 m/s).

site) the 2013-2017 monthly wave climate from Ms. Haley's work. The NWS indicated that having this information would be useful for future forecasting purposes.

We have installed a Unidata THREDDS server and are in the process of publishing the IRL wave height data (approximately 32GB) which includes the following:

- 180 netCDF files consisting of significant wave heights (at four hour intervals) for the IRL shoreline (123,234 points) over the period 2013-2017. There are 60 files (1 per month) and three distinct synthetic wind forcing time series derived from the Weibull sampling of the IRL wind speed distributions from 180 WRF simulations (see previous reports).

- Supporting Python code to extract the data at any of the user specified 123234 shoreline nodes.

- The five-year wind time series (.csv files) for the ASOS at KMLB, KTTS, and KVRB; WeatherFlow at XRPT, XJEN, and XPAR (i.e., the station data used for the regressions for all six domains) and synthetic time series for the six Coastal Modeling System (CMS) subdomains.

In terms of the second bullet above, a user enters a latitude and longitude and the code returns significant wave heights from the nearest shoreline node. An example is shown in Fig. 6 for January 2015 at two IRL shoreline locations. There is up to 10-20 cm difference in wave heights (and variability) at the two locations. In order to facilitate the selection, a corresponding

kml file will be created that matches the domain boundaries (shoreline) of the dataset. A user can load this into their software (e.g., Google Earth) and select a location of interest.

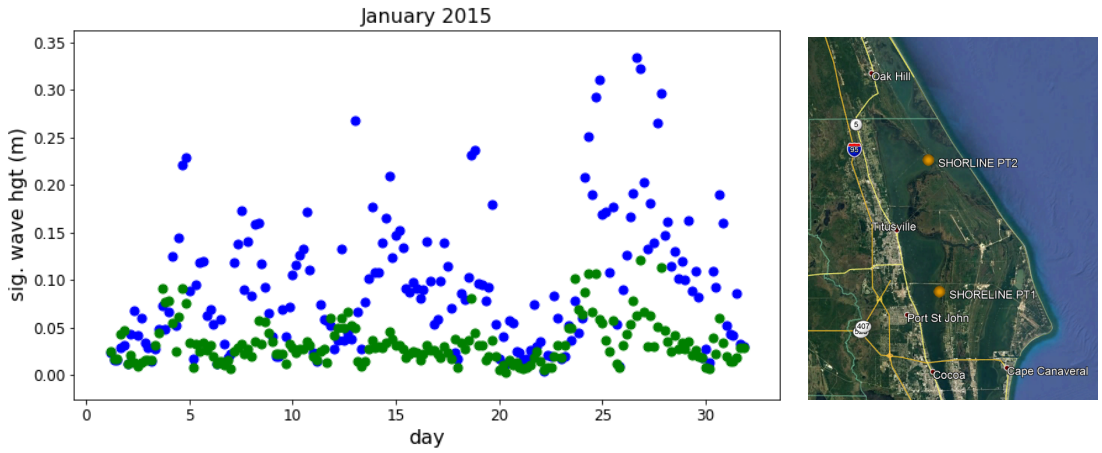


Figure 6. January 2015 significant wave height (m) time series extracted from SHORLINE PT1 and SHORELINE PT2 (dark green and blue filled circles, respectively). See text for details.

Since the emphasis is on local flooding and erosion, significant wave height calculations and their assessment are limited to the IRL shoreline locations only (as defined by the bathymetry data set).

3. NWS WRAP-UP MEETING: 7 June 2019

The PI and co-PI met with NWS Melbourne office staff to conduct a mini-workshop for the forecasters on the available forecast and analysis products (Multistage, Set-Up, and significant wave height climatology). We were introduced to the new marine forecaster (Krizia Negrón) for the Melbourne NWSFO. Drs. Lazarus and Weaver covered the parameterization and hydrodynamic/wave modeling products respectively. The following outcomes and issues were raised in the context of future and continuing work of wind/wave forecasting in coastal estuaries:

- The NWS was interested in the monthly IRL shoreline wave climate images and corresponding wind roses (these will be posted/shared with the NWS.
- Initializing ADCIRC / SWAN with model blend, i.e., a gridded forecast.
- The mini (seven member) hydrodynamic ensemble runs twice per day! FIT will maintain this as long as possible.
- The NWS is still waiting on the unstructured ADICRC/SWAN grids. It is not clear where is NWS going with their local wave modeling, however hey are definitely going to be using the WCOS grids (and computational resources).

- It was discussed as to whether there is anything in our wave output that represents the sea state that could be expressed in an IRL color map. It might be possible to take a combo of ADCIRC products to generate something like this.

- It is a possibility that the five-year wave height climate could be used to calculate anomalies on the fly. Regardless, the monthly wind and wave climatology provides the forecaster with potentially useful information along the IRL shoreline.

- Volusia county emergency management is installing gauges (with some guidance from us). It would be beneficial to receive support for additional water level (and weather stations) in an around the IRL.

- Drones are becoming ubiquitous, and if properly instrumented, could be used to observe wave heights in the IRL.

- Dr. Jeff Colvin's Go-Pro camera could possibly be installed on homes along the IRL to measure wave properties for extended periods.

- Need observations for possible neural network development/machine learning approach.

Figure 6. Lead PowerPoint slides from Drs. Lazarus (left) and Weaver (right) presentations at the NWS 7 June 2019.

4. NWS MELBOURNE FORECAST OFFICE PROJECT SUMMARY (Dave Sharp, SOO):

At the onset of this project, the NWS in Melbourne had a direct interest in understanding more about the high-resolution intricacies of coastal and estuarine flooding and associated erosion along the beaches and inlets of Brevard County, as well as within the Indian River Lagoon (IRL) system. In fact, very little is known about subsequent impacts to the local ecosystem, on humans living in close proximity and the nearby environment, during such occurrences. However, through this project we now have a better understanding of the physically coupled mechanisms which lead

to situations of significant impact and means to anticipate them. The FIT researchers did a wonderful job initially characterizing the tidal water flow in and out of the elongated lagoon. Yet the real challenge and accomplishment has been detailing significant wave height and water rise in forecast mode and in ways useful for real-time operations. A forecast tool which helps identify potential wind-driven setup (and setdown) within the IRL has been both enlightening and practical (when comparing water levels at Titusville and Sebastian). Inspection of validation cases offers reasonable confidence of the derived methodology, but when employing the GEFS forecasters get a sense of the subtleties involved when considering a spectrum of plausible outcomes as opposed to a single solution. The tool has been made readily available online with projections updated four times per day. A tutorial was presented to staff members, and to our new Marine Program Leader for internal sharing. The tutorial highlights the methodology, along with explanations for caveats regarding calibration and the absence of bias and/or dispersion corrections with the GEFS. Access to archive data has also been accommodated. NWS Melbourne is also pleased that FIT researchers will be making 5-year monthly climatologies of simulated IRL shoreline significant wave heights available for reference. Associated wind roses will also be provided. *Together, these will be helpful in highlighting situational character and IRL trouble spots to new forecasters*.

Moreover, much has been done to optimize configurations for a real-time atmospheric/ hydrodynamic forecast system FIT researchers have called Multistage. The ADCIRC-Lite employs the SWAN wave model and ADCIRC. It generates deterministic output based on the NAM model for daily forecasts. It can also provide a tropical cyclone component which leverages the latest track and intensity forecast from the National Hurricane Center to monitor the evolution of a potential coastal flood event. In all situations, uncertainty aspects are handled by using members from the GEFS and SREF ensemble systems. Water level and significant wave height output are offered at multiple locations along the IRL, which is a potentially powerful forecast tool. It is hoped that unique improvements can be made to IDSS briefings delivered to Brevard County during threatening situations. NWS MLB's operational SWAN will soon be moving to unstructured grids. Associated output will be based on forecaster provided winds, but the default will be from the National Blend of Models (NBM). Consistency issues will be an eventual and recurring concern.

Again, the advancements made through this project have been monumental and cannot be overstated. Projects such as these are essential in supporting NOAA's evolving mission, and in addressing pivotal issues related to **local** effects. Moving forward from here, collaborators will need to find ways to document realized shoreline flooding impacts, both big and small. Perhaps efforts can be made to employ the help of small boaters, and those living along the IRL. New techniques relative to crowd sourcing might offer unique avenues for data and feedback. Web camera deployments and drone surveys (post event) would also be helpful. Other product and service enhancements seem within reach, such as the ability to more accurately declare the forecast water-state of bay and inland waters within marine forecasts. A weekly IRL outlook is under consideration.