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NWS OFFICE: Melbourne Florida
COMET PARTNERS PROJECT FINAL REPORT
PROJECT TITLE: *Ensemble prediction of estuary set-up and set-down using operational WRF winds and their error characteristics. Component 2: Hydrodynamic modeling*
AWARD #: Z12-98078
DATE: December 6, 2013

Project Overview

The goals of this project were 1) to examine the error characteristics of the NWS Melbourne configured WRF-EMS 10 m wind forecasts (see Dr. Lazarus's complementary proposal "Ensemble prediction of estuary set-up and set-down using operational WRF winds and their error characteristics. Component 1: Error Analysis."), and 2) use the errors to generate a poor man's wind ensemble to force a hydrodynamic model of the Indian River Lagoon, IRL, for Brevard county and examine the surface elevation response with attention to storm generated high and low waters along the shores of the lagoon. To accomplish these goals, our hydrodynamic model for the IRL will be validated for tides against NOAA tide gauges in the vicinity. A suite of simulations using the meteorological forcing provided by Dr. Lazarus and his team will be run and evaluated at the available stations in the domain.

SECTION 1: Project Objectives and Accomplishments

1.1 Summary of Progress

The project is successfully completed. The model domain has been created, Figure 1, and tidal simulations have been run to validate against existing stations. With the tides validated on the model domain, the ensemble wind forcing based on the high and low wind error analysis corresponding to the passage of hurricane Sandy have been

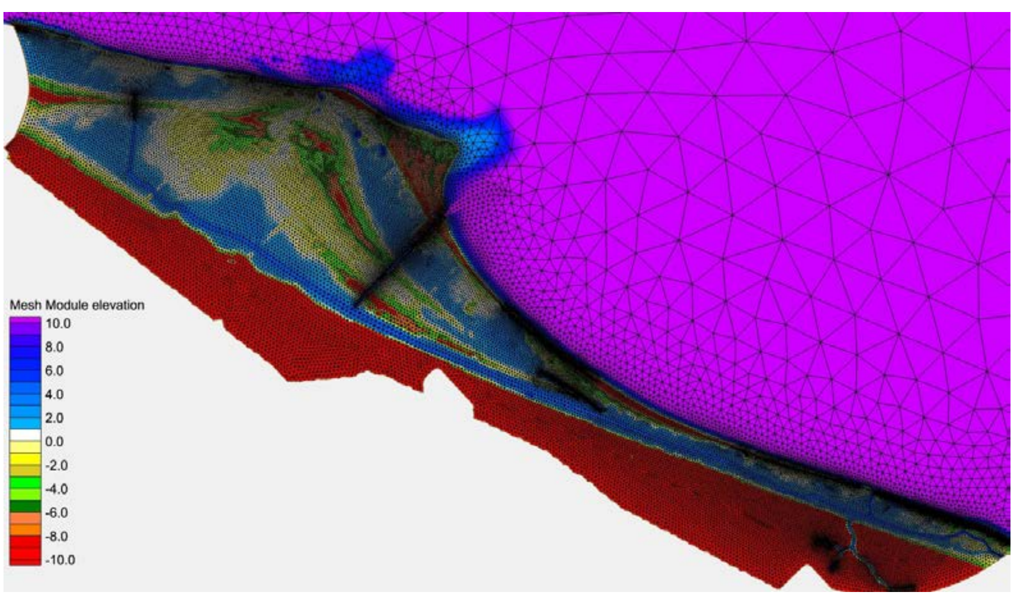


Figure 1: Domain for Brevard County and IRL

used to force a suite of ADCIRC model simulations. The ADCIRC results for the Sandy event are evaluated at available stations, for model performance. With the model validated, maximum elevations from each of the ensemble members are compared, with an emphasis on the maximum surface elevation responses.

a. <u>Tidal Validation Simulation</u>

The tidal simulation was configured to allow enough time for the tides to spin up without introducing instabilities. Studies have shown that ramping up the tidal forcing using a hyperbolic ramp function over a period of 20 days is more than sufficient for ensuring a smooth solution, additionally the tides are allowed to reach equilibrium by simulation an additional 40 days of tides before we start to reach the time period of interest, in our case the time period corresponding to hurricane Sandy. The researchers chose to spin-up the tides over such a long time period in order to allow the solution to equilibrate within the IRL. Shallow water interactions between the tidal constituents require more time to spin-up and equilibrate than will the tides on the open coast. We use 8 tidal constituents to force the tides on the open ocean boundary far from our region of interest: M2, S2, N2, K2, K1, O1, P1, and Q1. The constituents are calibrated to coincide with a model start date 60 days prior to 2012/10/18 00:00:00. A snapshot of the sea surface elevation and 2D depth averaged current velocities, Figure 2, illustrates the resolution of our domain. The domain captures flow from Banana River into the IRL as well as the exchange between the coastal Ocean and the IRL through Sebastian Inlet.

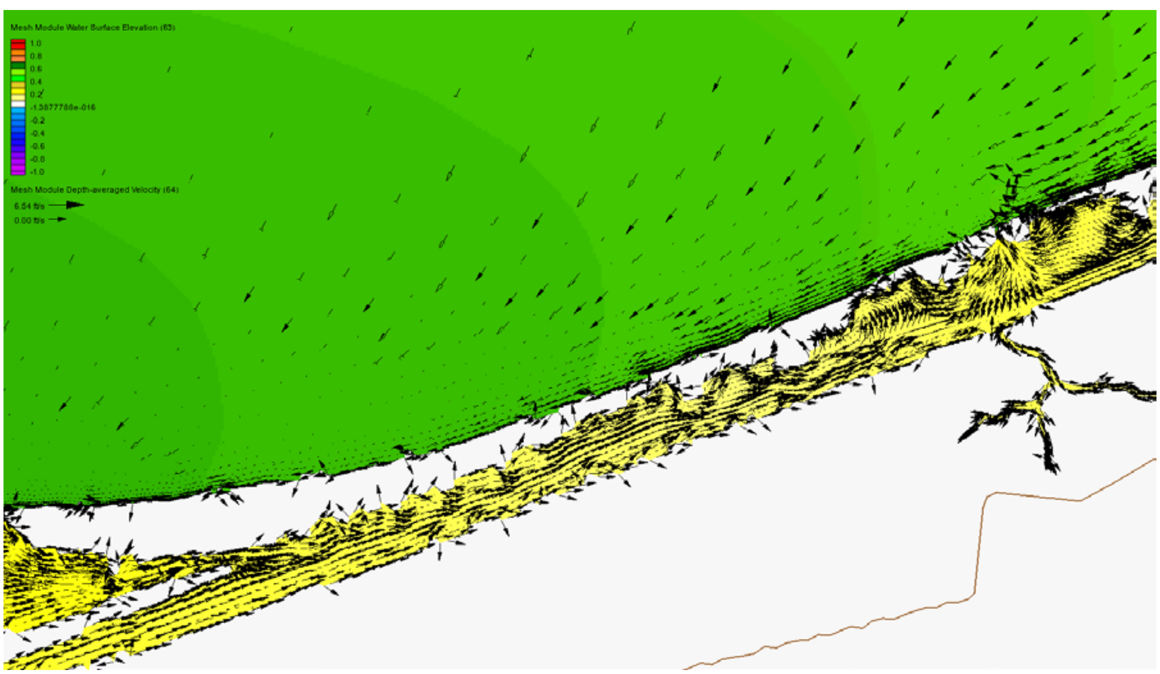


Figure 2: Tidal elevations and currents for Brevard County IRL.

To validate the model performance, model tidal output is compared to historical station data in the region surrounding our high resolution domain. Open coast stations are more easily matched than those stations that are located inside an inlet or estuary. The closest NOAA gauge to our study area is the station at Trident Pier inside Port Canaveral, Figure 3. Additional gauges maintained by FIT are located on the north jetty

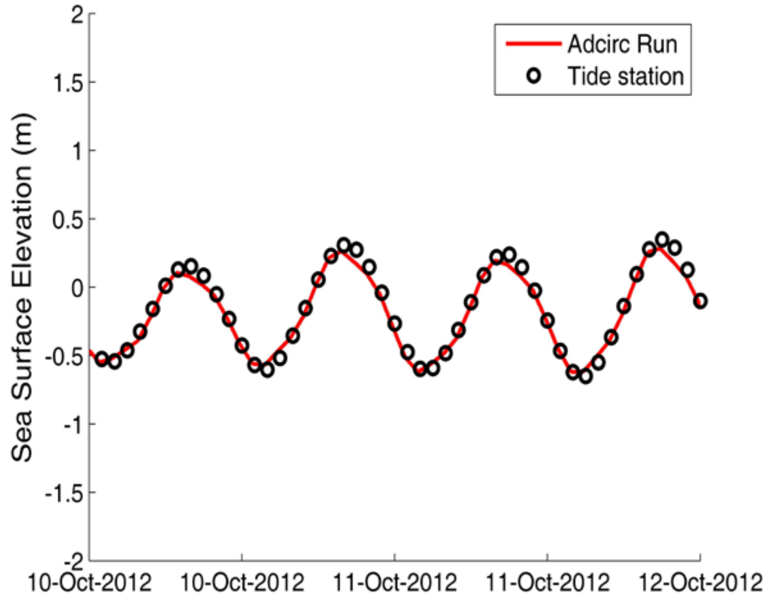
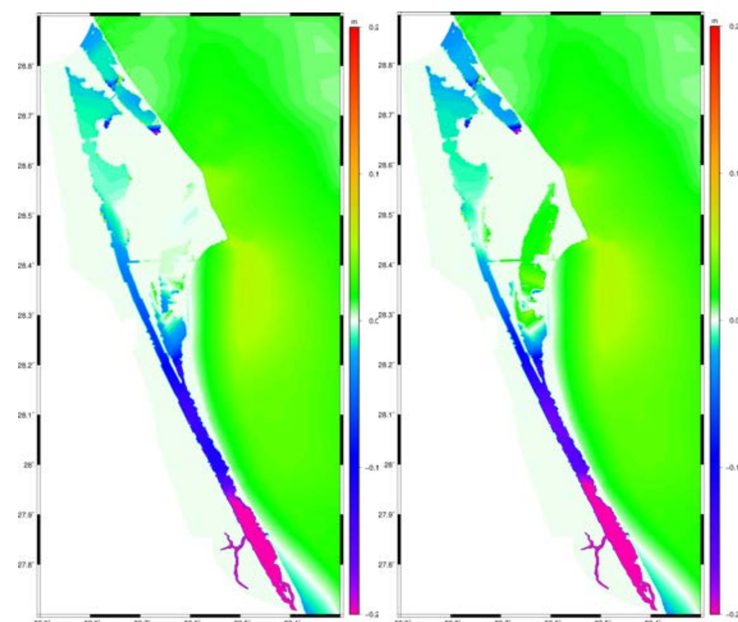


Figure 3: Comparison of ADCIRC tidal simulation to the predicted station data at Trident Pier for time period corresponding to the passage of Hurricane Sandy**.**

of Sebastian Inlet, and two inside the IRL, one on the West side at the Ted Morehouse Lagoon House, and the second across the lagoon at the Melbourne Beach fishing pier. There is also data available inside the Haulover Canal maintained by USGS. The ADCIRC tidal simulation does not include wind forcing or pressure forcing, for that reason deviations between the predicted elevations and the actual elevations are expected and indicate a time period where a strong meteorological event passes through the domain.

Due to the physical nature of the inlet at Port Canaveral, deep wide inlet closed to the IRL, we expect to have a better match between the model tidal prediction and the station data. ADCIRC accurately predicts both the amplitude and phasing of the tidal water elevations at Trident Pier, Figure 3.

A closer examination of the sea surface elevations at the interior stations will be conducted once we begin simulations that include a full suite of model forcing.



(a) (b)

Figure 4: Side-by-side comparison of differences in surface elevation response between (a) the F00 wind (no downscaling) and F03 wind (dynamically downscaled through high resolution (300 m) FIT-WRF nest and (b) the F00 wind downscaled by ADCIRC using LULC data and F03 wind (dynamically downscaled through high resolution (300 m) FIT-WRF nest.

b. Meteorological Forcing

ADCIRC is designed to be able to downscale winds from a large scale NWP model or directly use the forcing from high resolution model output (e.g., the 300 m inner nest of the FIT-WRF configuration). We will briefly examine the ADCIRC applied winds with the full model downscaling based on land use maps and the meteorological downscaled FIT-WRF winds supplied by our partners. Figure 4 allows insight into how the ADCIRC model downscaling affects the resulting wind and consequentially the circulation. With no downscaling by the ADCIRC model, Figure 4(a), the winds are not reduced due to the land use characteristics and the coarse NWP winds are applied directly in the ADCIRC model. When comparing the circulation model result against the F03 high resolution model output, and the NWP wind adjusted based on the LULC data, we see that the adjusted result predicts a higher water level in the Banana River due to the reduction of the wind off of the land. The results from this comparison reinforce the modeler's responsibility to be sure that the land use is not double counted. If the meteorological model is sufficiently resolved to account for the land use, the reduction features in the circulation model should be turned off. For the ensemble prediction of circulation we will turn off the ADCIRC wind downscaling features and rely on the meteorological model for the dynamic downscaling.

c. Ensemble Meteorological Forecasting of Hurricane Sandy

i. Model description

Meteorological forcing components from each of the ensemble predictions are used to generate a prediction of the water elevations for the time period corresponding to the passage of Hurricane Sandy. The hydrodynamic model ADCIRC will spin up the tides as described above, Part (a), through 00:00 UTC 18 October 2012. At this point the ADCIRC model will start reading in the F03 winds; comprised of a sequence of F03 forecasts from successive NWS WRF forecast cycles (see Dr. Lazarus' complementary report). This simulation will run from 00:00 UTC 18 October 00:00 through 00:00 UTC 30 October 2012 and write out a hotstart file at 00:00 UTC 26 October 2012. The meteorological ensemble members representing the perturbed wind fields based on the high- and low-end error analysis developed by COMET partners, referred to as F03p_hi and F03p_low respectively, will then generate a one day prediction of circulation starting from the F03 prediction at 00:00 UTC 26 October 2012 and simulating through 00:00 UTC 27 October 2012. As noted above all land use adjustments are made by the meteorological model.

Surface elevation predictions from each simulation will be compared to available station data in the region, to evaluate the hydrodynamic model performance. Once validated the flow generated by each of the forcing ensemble members will be compared.

ii. Evaluation

Permanent stations exist at Trident Pier, FL (NOAA/NOS/CO-OPS Station ID: 8721604), Haulover Canal (USGS 02248380), and North Jetty of Sebastian Inlet (FIT research station). Temporary gauges were installed during the summer of 2012 on the Melbourne Beach Town fishing pier and in the waters adjacent to the Ted Morehead

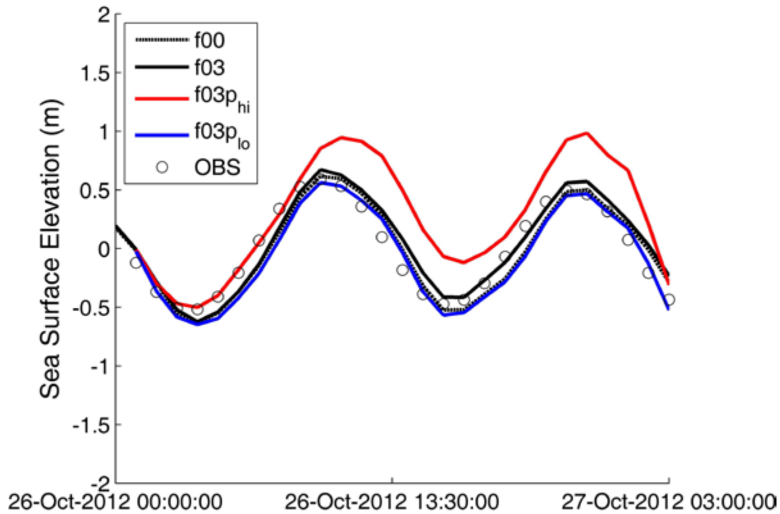


Figure 5: Comparison of ensemble member results with historic station data at Trident Pier, FL.

Lagoon House in Palm Bay, FL. These gauges remained in the water through January of 2013. The model performance will be evaluated at these four stations.

At Trident Pier, Figure 5, the F03 model best matches the station data. There is little difference between the F03_low and the F03 model results, and as one would expect the F03_hi over predicts the peaks. The phasing for all 4 models matches the phasing of the water levels recorded by the station gauge. The model accurately predicts the both the magnitude and the phase of the changes in water levels outside the Lagoon, in the deep Port.

Looking at the connection between the coastal ocean and the Indian River Lagoon at Sebastian Inlet, Figure 6, we continue to see agreement between the F03, F00 and F03_low predicted results. The model matches the magnitudes, peak and trough, as well as the phasing of the signal in the throat of the inlet. The F03 prediction best matches the station data at this location. The high perturbation, F03_hi, produces a narrow peak

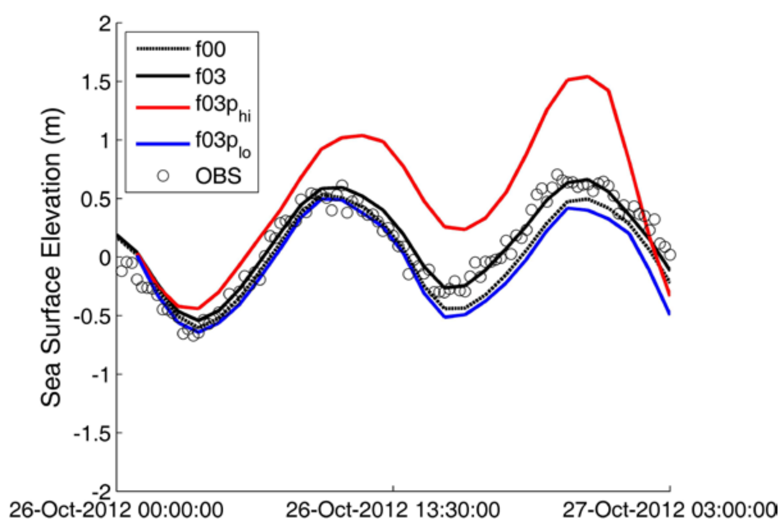


Figure 6: Comparison of ensemble member results with historic station data at FIT Sebastian Inlet Weather Station

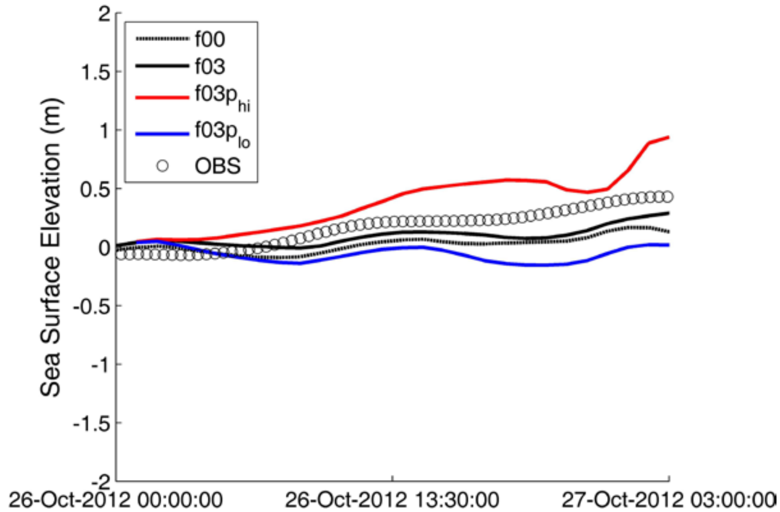


Figure 7: Comparison of ensemble member results with historic station data at HOBO temporary gauge located on the West side of the Lagoon at Ted Morehouse Lagoon House.

overnight of the 27th of October, as Sandy makes her passage.

Model performance starts to decline as we make our way into the IRL. As we examine results moving north from Sebastian Inlet, at the location of our HOBO water level logger station, Figure 7, the model begins to under predict the surface elevations. The F03 and F00 predictions remain closely related as would be expected, since the winds forcing these simulations are three hours out of phase. The F03_low prediction begins to deviate from the F03 as the simulation progresses in time. The integrated effects become more pronounced as the time increases. The station data is closely bounded by the model with the high end error perturbation, F03_hi, and the F03 predictions. It is interesting to note that even in the micro-tidal IRL, we are able match the harmonic signal noticeable in the station data.

At the Haulover Canal station, Figure 8, we are seeing the effects of the blow-

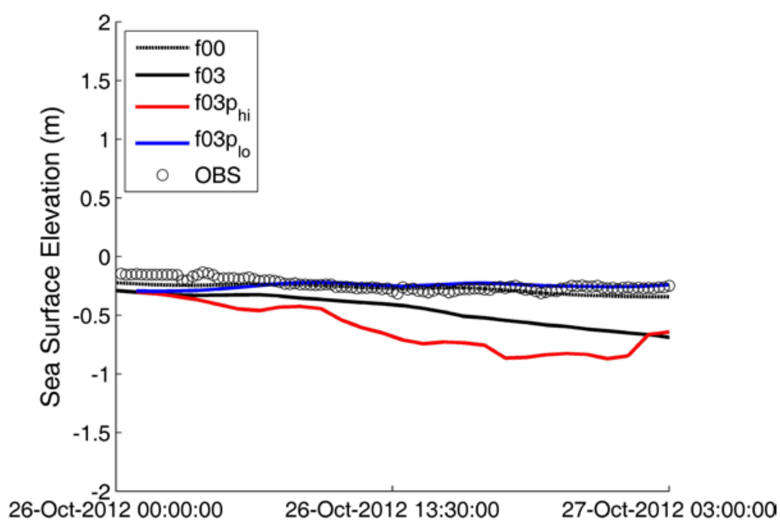


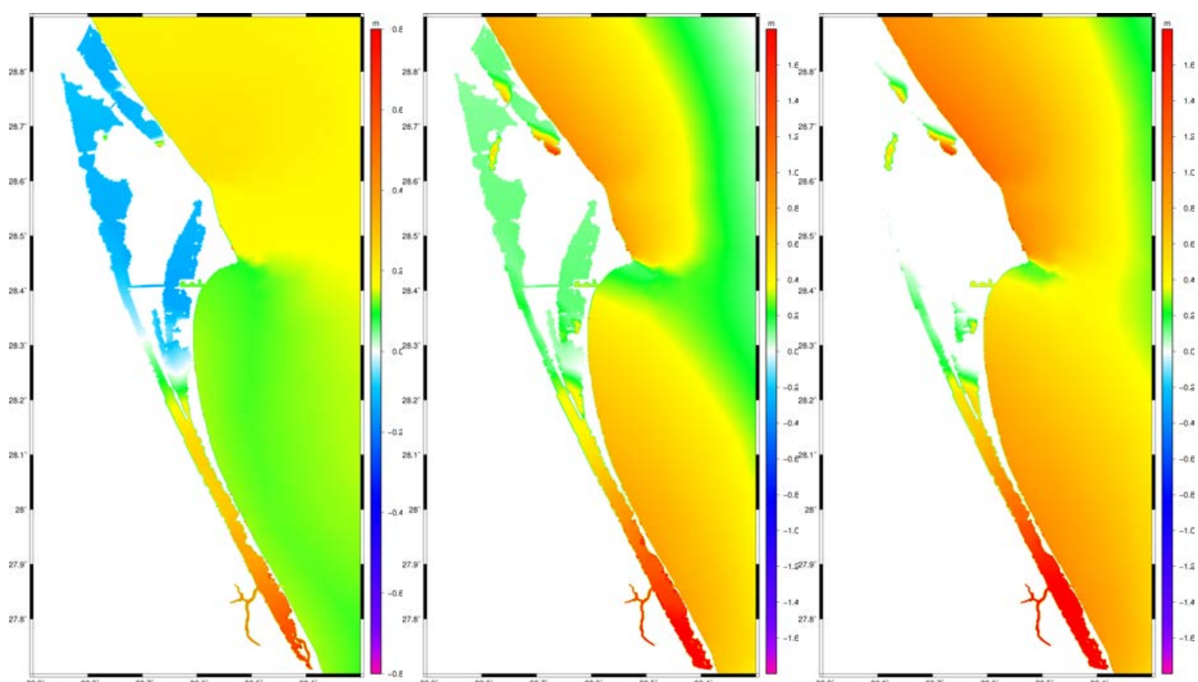
Figure 8: Comparison of ensemble member results with historic station data at Haulover Canal USGS Station

down. This station is located in the northern end of the Lagoon. With northerly winds we expect the water to be blown south, out of the northernmost reach of the lagoon. As the winds are increased, F03_hi, this blow-down becomes much more pronounced. In this region of the domain, the F03_low and the F00 model prediction most closely match the station record. Interestingly enough the F03_hi prediction, after predicting greater blow-down than the F03, merges back with the F03 prediction toward the end of the simulation.

Examining each of the plots at the four stations representing the open coast, inlet, and lagoon stations, the ADCIRC model as designed for this project accurately predicts the phasing and magnitude of the surface elevations changes measured at the stations. As expected the F03 model prediction deviates more from the station data as we move farther from the connection to the coastal ocean at Sebastian Inlet. The deviation is most likely a result of the domain size, boundary conditions inside the lagoon, and friction coefficient in the shallow lagoon.

iii. Interpretation

Having evaluated the model performance at each of the station locations available, model results and the station data both indicate movement of water to the south. The water is blown down in the northern end of the lagoon and starts to pile up just south of Sebastian Inlet. We now look at the contours of maximum elevation at each model point in the domain. Comparing the maximum water levels that each of the perturbations predicts, Figure 9, provides insight into the sensitivity of the IRL to the fluctuations in the wind field. From that we can determine the need for an ensemble approach, and which ensembles are most important. Comparing the F03_low with F03,



(a) (b) (c)

Figure 9: Side-by-side comparison of differences in the maximum surface elevations at each location in the domain: (a) the F03 minus F03_lo; (b) the F03_hi minus F03; (c) the F03_hi minus F03_lo

Figure 9(a), the weaker wind field predicts ~0.2 meters less blow-down in the Northern IRL and Mosquito Lagoon, and the F03 predicts 0.5 meter greater elevation in the Southern IRL. This piling of water in the Southern IRL may be an artifact of the small boundary at the southern end of the domain; however, the model results at the HOBO stations indicate the model is slightly under-predicting the elevation in the central portion of the Northern Lagoon. This under-prediction would indicate that there may be greater piling of water at the constriction. A strategically placed gauge just south of the Inlet near Wabasso would aid in model interpretation.

Comparing the maximum surface elevations between F03_hi minus F03, Figure 9(b), we notice that the surface elevation is higher at the majority of the locations in the lagoon. Comparing F03_hi with F03_lo, the differences are more pronounced in the southern boundaries of the domain. The maximum water level differs by nearly 2 meters in the southern boundary of the IRL, and over 1.5 meters in the southern Mosquito Lagoon. This represents significant flooding potential if the storm were to behave differently than the forecast prediction.

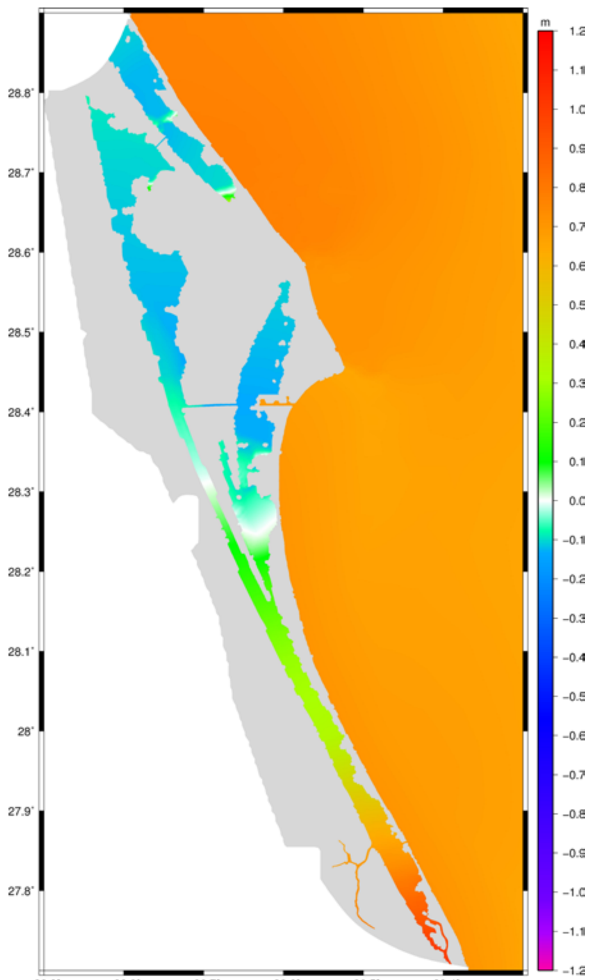


Figure 10: Maximum surface elevations referenced to NAVD88 at each location in the domain F03.

An interesting observation is that there is a location in the Banana River that is an inflection point, where the Maximum elevations for each model prediction is uniform. Between the Pineada Causeway and the Eau Gallie Causeway, Just north of Mathers Bridge, each of the perturbations predicts the same elevation.

Examining the Maximum elevation contour plot for the F03 prediction, Figure 10, the surface elevation at this point is at zero NAVD88. The location here in the Banana River is indeed an inflection point for the surface elevation. The water surface pivots about this point during this storm event, and this behavior is seen in each of the model simulations. Future studies will determine if this is unique to the Sandy storm event or if the behavior at this location is prevalent. Once the wind forcing subsides, a seich would be expected as the water seeks equilibrium. Deeper mining of the results from this COMET project provide a starting point for many interesting circulation studies.

1.2 Division of Labor

FIT: Model domain mesh generation; wind driven circulation simulations; in-house high-resolution circulation modeling forced by tides and the ensemble wind forcing developed by Dr. Lazarus and his team, model validation and ensemble assessment.

NWS: Operational WRF output; provided WRF configuration files; provided feedback/input.

SECTION 2: Related Accomplishments and Activities

This PI along with the Meteorological Project PI (Dr. Steven Lazarus) submitted a pre-proposal to the Florida Sea Grant in February, 2013 (the proposal did not go forward unfortunately). The 5 page pre-proposal, *Analysis of present and future inundation along the IRL as a function of wind direction and duration*, focused on the response of the Indian River Lagoon to non-tropical wind events and increasing sea level. The proposal was designed to expand the scope of the COMET partner projects to: 1) address the regional impact of set-up in the context of sea level changes and, 2) involve the Emergency Management personnel from Indian River and Brevard Counties.

A proposal was recently submitted to the CSTARS program for a 3 year project that expands on the works developed for this COMET. We are waiting for a determination on that proposal.

Working with two undergraduates over the Fall and Spring, this PI has co-authored a draft paper, *A Field Study of Wind Driven Circulation in the IRL*, which will be submitted for publication. Data collected in the field for this project was analyzed together with regional wind measurements, over three intervals as well as for the entire 9 month length. The paper investigates the wind driven circulation, up and down the lagoon, and through the Haulover Canal.

SECTION 3: Summary of Benefits and Current Work

3.1 FIT

This work improves insight regarding the circulation patterns in the IRL. Of particular interest is inundation along the banks of the IRL as well as the flow exchange between the Banana River and the IRL, the Mosquito Lagoon and the IRL as well as flow into and out of Sebastian Inlet during storm events. During the Sandy event, a southerly current developed in the IRL as water from the northern IRL was pushed south and then piled-up at the constriction south of Sebastian. Regions have been identified through this work, such as in the Banana River, where interesting flow patterns may exist. Future analysis will focus on the flow in these regions to better understand the circulation in the system during high energy events.

3.2 NWS:

NWS Melbourne now has a better feel for the character of the tidal circulations within the IRL, and an appreciation for related model spin-ups for such simulations. We have also acquired a better understanding of the nature of water piling and blow-down during significant events as Hurricane Sandy within the local lagoon system. Incorporating the uncertainty component speaks to the operational utility as a means for highlighting areas of shoreline flooding potential (especially in difficult wind forecast situations).

SECTION 4: Presentations and Publications

A paper in prep, *A Field Study of Wind Driven Circulation in the IRL*, will be submitted this winter for publication. This paper examines the wind driven circulation patterns for the IRL during 3 specific events, Hurricane Isaac, Hurricane Sandy and an October Nor'easter. The modeling efforts of this COMET project for the Sandy time period are instrumental in processing and understanding the field data examined for this paper. Additionally field data collected and used for the COMET project was also analyzed for this paper.

SECTION 5: Summary of Problems Encountered and Issues/Questions raised

5.1 FIT
No Problems

5.2 NWS
No Problems

SECTION 6: Project Future

The project has formed the foundation for future circulation studies in the IRL. The model domain has begun to grow outside of the Brevard County borders to encompass the entire IRL and will include inundation outside Brevard County in the future. Results from this project are being used to seed additional proposals that include participation between the PI's and with the local WFO's. The new domain is being used to run 3 day forecast simulations of circulation in the IRL, and will be the starting domain for future residence time and flushing studies. Results from this project will be mined in an attempt to develop a more complete understanding of circulation in the IRL, specifically looking at the flushing potential of the Banana River.