National Oceanographic Partnership Program (NOPP) – Hurricane Coastal Impacts (NHCI)

https://nopphurricane.sofarocean.com/

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NOPP
National Oceanographic Partnership Program

What is the NOPP?
www.nopp.org

- The National Oceanographic Partnership Program (NOPP) is a collaboration of Federal agencies which facilitates partnerships between Federal agencies, academia, industry, and others in the ocean scientific community to advance ocean science research and education
- Through this collaboration, Federal agencies can leverage resources to invest in priorities that fall between agency missions or that are too large for any single agency to support
- The program was established by the 1997* National Defense Authorization Act to:
    - Promote national goals of assuring national security, advancing economic development, protecting quality of life, and strengthening science education and communication through improved knowledge of the ocean; and
    - Coordinate and strengthen oceanographic efforts in support of those goals by identifying and carrying out partnerships among Federal agencies, academia, industry, and other members of the oceanographic scientific community in the areas of data, resources, education, and communication; and reporting annually to Congress

What defines a NOPP project?

- The project addresses important research objectives or operational goals
- The project has, or is designed to have, appropriate participation within the oceanographic community of public, academic, commercial, private participation or support
- The partners have a long-term commitment to the objectives of the project
- The resources supporting the project are shared among the partners
- The project has been subjected to adequate review
- The project is brought forward to the NOPP-IWG for interagency consideration of support
- At least 2 partners, Federal or non-Federal, invest in the project
  - Note that a partner is not limited to direct financial participation, but may also contribute ship time, loan instruments, or personnel time, among other possibilities
- Is related to ocean science or ocean-related technology
  - "Ocean" includes the open ocean, coasts, estuaries, coastal watersheds, and Great Lakes

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NOPP Hurricane Coastal Impacts (NHCI)

- Nearly every year during hurricane season US Gulf and Atlantic coastal communities are threatened by large storms, which can inflict flooding, erosion, coastal breaching and destruction of property and infrastructure. While forecasts of hurricane intensity and track have improved considerably over the last decade, uncertainty remains as to what will actually happen above mean sea level on land as a result
- Studies of past hurricanes, using accurate winds, track, and groundtruth, indicate coastal wave-current, surge and sediment transport models have skill in predicting impacts
- The greatest uncertainties are not in the numerical models, but on land, in terms of boundary conditions for elevation, sediment type, vegetation, infrastructure and buildings
- NHCI will begin to forecast/predict hurricane coastal impacts during the hurricane seasons of 2022-2024. These will be “research-grade” forecasts and are not to be confused with operational ones from the National Hurricane Center.
- To tackle this monumental challenge, NHCI is comprised of 10 teams, each of which is critical to success and must work cohesively to produce the forecasts and quantitative evaluation of performance
- The ultimate goals are: skillful forecasts of hurricane coastal impacts; the ability to initialize models, data bases and ground truth solely from satellite remote sensing to allow worldwide application; AND to identify topics which need additional research investment

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Five NHCI Tasks/Thrusts

Task 0) Year 1, COAMPS-TC[1] provide a hindcast of Hurricane Michael; Years 2-4, provision of hurricane track and intensity predictions for 3 CONUS landing hurricanes; Winter – reanalysis of the 3 hurricanes following best-track and intensity. Provides Apples:Apples forcing for Task 4;

Task 1) Year 1, the building of a Digital Elevation Model (DEM) and in Years 2-4 regular updates and quantitative post-hurricane impact summaries; Provides Apples:Apples boundary conditions and ground truth for Task 4;

Task 2) New quantitative capabilities in satellite remote sensing for both building a ground-truth DEM and quantitative geophysical measurements during the storms, for comparison to and possible assimilation into model forecasts;

Task 3) In situ measurements to include offshore waves, and both offshore and inland water levels, for assimilation prior to landfall and ground truth evaluations afterward; Provides Apples:Apples observations for Task 4 assimilation and ground truth; and

Task 4) Forecasting of wave, surge, sediment transport (erosion and accretion above and below mean sea level), structure interaction and damage

[1] Coupled Ocean Atmosphere Model Prediction System-Tropical Cyclone

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4 Years of Activities

The CY21 (first 1.5 year) developed the supporting DEM's; began development of quantitative DEM satellite remote sensing techniques for use before, during and after storms; developed methods to rapidly deploy wave (airborne) and water level sensors (moving to airborne); and set up model's with sufficient nesting capabilities to forecast the above properties, from Mexico to Maine, during the following three hurricane seasons (CY 2022, 2023 and 2024). The DEM's will be continually updated, with the most frequent updates to include bathymetry and topography, before landfall and quantitative summaries of the damage to infrastructure and buildings post landing.

Goal: During each of the CY 2022-2024 hurricane seasons, provide a single daily forecast of hurricane coastal impacts (see below), beginning five days prior to landfall, for three named hurricanes per season. Data collected after the event (bathymetry/topography, inundation, erosion, accretion, infrastructure & structure damage) will quantify the abilities of the model to forecast the coastal response. A number of teams, across all tasks will funded and will work collectively together to meet the overall challenge. Forecasting teams must provide documented computational capability, priority run-time and storage ability (either dedicated institutional computational assets or those from cloud services), to be eligible. Prior experience indicates that it is roughly 5000 CPU hours, per forecast, using 400 cores and at least 3 dedicated Terabytes of storage.

CY2022 – Hurricane Ian was forecast, with ground and air deployments for verification.

Winter Analysis

In CY22-24, outside of hurricane season, a hind-cast of COAMPS-TC which follows the agreed upon “best-track” will be provided to investigators for use in forcing the storm impact prediction models. These hindcasts will be used to determine strengths and weaknesses of the different models and whether they stem from too few observations, physics-based understanding, numerical implementation, or boundary conditions, etc. These analyses will help to improve the effort for the following season and guide future research investments.

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Task 0: COAMPS-TC Supplied Variables, at 4km resolution, hourly, beginning 5 days from projected landfall

COAMPS-TC [1], which is coupled to the Navy Coastal Ocean Model (NCOM), will provide the following variables to each team, updated once daily, beginning 5 days (T-5) from projected landfall.

10-m Winds	Surface Relative Humidity
Surface Pressure	Surface Wind Stresses
2-m Air Temperature	Long Wave and Short Wave Radiation at the Surface
Surface Latent and Sensible Heat Fluxes	Surface Net Radiation
Hourly Precipitation	

[1] Coupled Ocean Atmosphere Model Prediction System-Tropical Cyclone

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Task 1: Digital Elevation Models (DEM), to include topography and bathymetry

Develop, at the scale of 1-5m, digital elevation models (DEM) of the US coastline subject to land-falling hurricanes that includes; the US Gulf of Mexico coast, the Florida Keys, mainland Florida, and the Eastern Atlantic Seaboard. From the shoreline, these high resolutions need to extend inland 2km and seaward to close out depths (depths of minimal sediment movement). Inland, they can then blend with coarser DEM's suitable for inundation only, i.e., possible > than 1-5m, and seaward of closeout depths to resolutions sufficient to support wave and current modeling. Where large inland bays are located, focus should start with characterizing the main stems, leaving branches to be added in the later years of the project.

Variables should include:

1. Elevation (10 cm) and sediment type
2. Vegetation type including root depth
3. Structures (construction type/materials) and number of stories/elevation
4. Inland water bodies and waterways, lakes, marshes, inlets
5. Roads, bridges, boardwalks, and any other man-made alterations, jetties, piers, etc.

To the degree possible, leverage existing public and government databases and develop methods, perhaps AI/ML-based, using remotely sensed satellite data to more rapidly turn such data into geophysically useful fields, e.g., Landsat 8 vegetation data to vegetation type, then root depth and drag coefficients. As NOPP is a partnership at both the sponsor and performer level of industry, government and academia, it may be that, under the guise of national emergencies and disaster prevention and response, that arrangements may be made with commercial entities for use of their databases (e.g., Google Earth, Airbus). At the end of the project, said project databases are to be compatible with existing US Gov't provided databases and reside in the public domain.

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Task 2: Remote Sensing (collect imagery sufficient to image the entirety of the coastline each year, with localized imagery prior to, during and after any landfall for ground truth purposes)

Develop the ability to produce digital elevation models of the beach, foreshore and backshore from Synthetic Aperture Radar (and/or any other modalities), such that data bases can be rapidly built from space, and measurements of the coast made before, during and after a hurricane. The resolution should match the above databases, at horizontal resolutions between 1 and 5m, and 10cm in elevation (relative to the geoid). Quantitative ground truth/comparison of SAR wind and wave products with the deployable, measured wave and wind field during the storm should also take place.

To the degree possible, leverage existing databases and imagery and develop methods, perhaps AI/ML-based, for use on remotely sensed satellite data to more rapidly turn such data into geophysically useful fields, infrastructure, roads, and buildings and building characteristics.

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Task 3: In Situ Measurements (up to three teams to be funded, including equipment purchase, deployment, recovery and refurbishment)

Air Deployed Wave Buoys: Airborne deployed, real-time satellite reporting (and internal recording) directional wave-spectra buoys in sufficient numbers to entirely encircle a hurricane, with re-seeding to occur on the landward portion, 48 and 24 hours prior to landfall. The real-time measurements are to be used to predict wave heights, periods and directions on an hourly basis, from the hurricane eye, to 300 km to either side of the predicted landfall location. Airborne deployment flights will be provided and should not be included in costs.

Coastal and Inland Water Levels and Wave Measurements: The ability to rapidly [air/helicopter?] deploy water level measurement capabilities along coasts both to seaward and to inland waterways where such bodies exist and back immediately to the backshore of the beach. Real-time satellite reporting (and internal recording) will enable observation and assimilation into models and used to assess breach potential. Directional wave-spectra buoys (as above), will be as well. Airborne deployment flights will not be provided and should be included in costs, if appropriate.

It is expected that much of the equipment will be retrieved after the storm as possible and re-used, though losses are expected. Iridium Satellite SBD cards can be provided for all sensors as needed.

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Task 4: Wave, Surge, Sediment Transport (moveable bed), Structure Response Forecasting (WSSTSR Forecast); Up to three teams to be funded. Only one team will be funded to utilize any one particular model

COAMPS-TC [1], which is coupled to the Navy Coastal Ocean Model (NCOM), will provide the following variables to each team, updated once daily, beginning 5 days (T-5) from projected landfall.

Using open source community code [2] and supplied boundary conditions [3] from the other teams, for each daily hurricane forecast supplied by COAMPS-TC, forecast the coastal/shoreline waves, currents, sediment transport, coastal erosion and accretion (above and below MSL), inundation, breaches and structure response at human scale (1-5m along and inland), to a distance inland that encompasses all inundation from the seaward side (not from rainfall). Days T-5 and Day T-4 may be probabilistic, but Day T-3 to landfall must be deterministic. These forecasts will be provided to first responders as a research product, not an operational (certified/verified) one. Structural response in this case means to indicate whether a coastal structure will survive the storm, and/or how it will be damaged or compromised.

[1] Coupled Ocean Atmosphere Model Prediction System-Tropical Cyclone

Nominal Funding By Task and Year

Task	Number of Teams	Year 1 Funding per team	Year 2 Funding per team	Year 3 Funding per team	Year 4 Funding per team	Total Per Task
0. Wind Forcing (COAMPS-TC)	1	$112,000	$208,000	$236,000	$188,000	$744,000
1. Digital Elevation Models (DEM)	2	$500,000	$200,000	$200,000	$200,000	$1,100,000
2. Remote Sensing	1	$455,879	$776,332	$666,365	$669,234	$2,569,000
3. In Situ Measurements	3	$930,000	$887,000	$800,000	$651,000	$3,266,000
4. Forecasting (WSSTSR)	3	$918,000	$1,517,000	$1,524,000	$1,468,000	$5,428,000
Total Project Funding		$2,916,000	$3,588,000	$3,426,000	$3,176,000	~$13,407,000

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10 NHCI Teams, By Task

Team/Task/E-mail	Lead PI	Title
NHCI_T0_Komaromi	Will Komaromi	COAMPS-TC Deterministic, Ensemble, and Nowcast Model Support of the NOPP Project: Predicting Hurricane Coastal Impacts
NHCI_T1_Gesch	Dean Gesch	Coastal Elevation Models and Land Surface Variables for Predicting Hurricane Impacts
NHCI_T1_Peeri	Shachak Pe'eri	NOPP Predicting Hurricane Coastal Impacts, Task 1
NHCI_T2_Romeiser	Roland Romeiser	Remote Sensing of the U.S. Coastline Impacted by Land-Falling Hurricanes
NHCI_T3A_Centurioni	Luca Centurioni	Lagrangian Drifter Laboratory Ocean Wave In Situ Measurements
NHCI_T3A_Thomson	Jim Thomson	Air-deployed wave buoys
NHCI_T3B_Brown	Jenna Brown	In-situ Measurements of Coastal and Inland Wave and Water Levels
NHCI_T4_Luettich	Rick Luettich	Forecasting Coastal Impacts from Tropical Cyclones along the US East and Gulf Coasts using the ADCIRC Prediction System
NHCI_T4_Nederhoff	Kees Nederhoff	Wave, Surge, Sediment Transport, Structure Response Forecasting.
NHCI_T4_Olabarrieta	Maitane Olabarrieta	Coupled Ocean Atmosphere Waves Sediment Transport Waves, Sediment, Surge and Structure Response

10 Teams, ~90 Participants: 15 Universities, 18 Gov't Labs, 9 Companies

National Oceanographic Partnership Program

Summary Status & Hurricane Ian Activities (slides 16-203); This Years Plans

- COAMPS-TC did an excellent job with real-time forecasts, but landfall was north. Working to correct landfall in hindcast to follow NHC Best Track and Intensity.
- DEM's at 1-3m along/cross cross coast were essential to accurately modeling inundation, erosion and breaching. Inland waterway islands needed to be included, and once they were, observed erosion (Sanibel Bridge Island), matched that modeled.
- Remote Sensing with SAR was quite successful at imaged locations. There are issues with targeting locations, which are based on hurricane forecasts 3 days prior, misses occur and given demand, you don't always get your shot(s). SfM and DEM's from SAR are promising.
- *In situ* verification at coastal sites are logistically difficult to instrument, given 100's of miles of uncertainty in 5-3 day track forecast. Working strategies to stash equipment prior, and/or switch to all air-deployed instrumentation from Navy P-3.
- Deepwater buoy deployments were near flawless, but again, biased by early forecast tracks. Working sensor trials with NOAA for additional deployments on other air assets as space available, in addition to Navy P-3. Chris Fairall is NOAA POC.
- All 3 modeling groups, ADCIRC (Luettich), COAWST (Olabarrieta), and Deltares (Kees) matched wave and water levels well. Erosion of inland waterway and beach matched observations. Damage to infrastructure, buildings and roads is ongoing, but promising. Rainfall should be included.
- CY23 – Address up to 3 CONUS Landing Hurricanes; Welcome additional

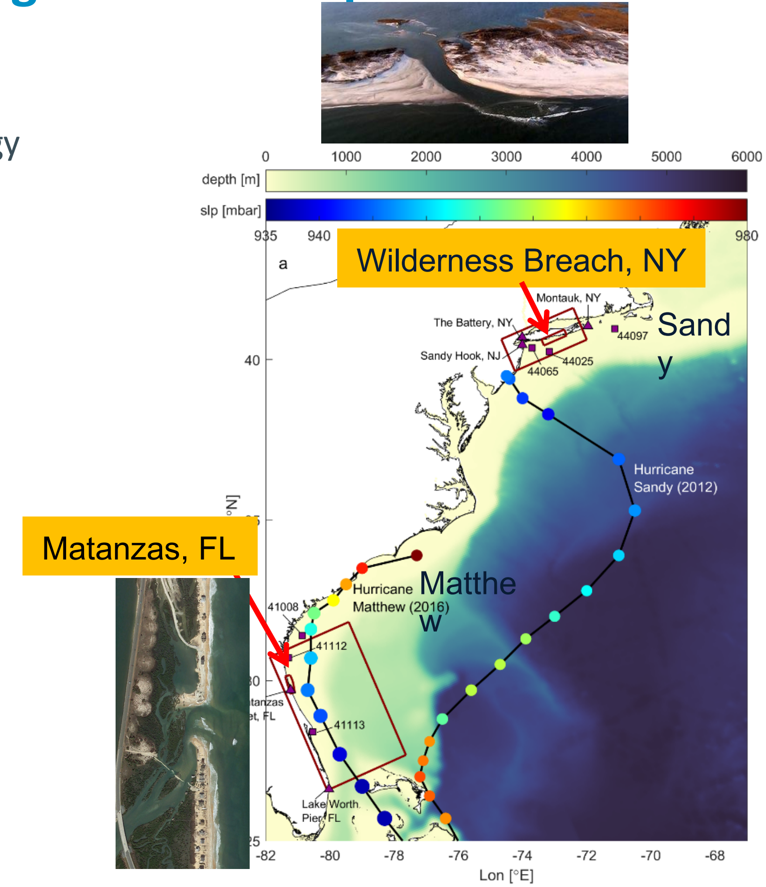
Background
How this project came about; 13 slides

IFMSIP: Increased Fidelity of Morphological Storm Impact Predictions – results and take homes

Ap van Dongeren

Deltares
USGS science for a changing world
UF UNIVERSITY of FLORIDA
U.S. NAVAL RESEARCH LABORATORY
UNIVERSITY OF DELAWARE

IFMSIP: Increasing the Fidelity of Morphological Storm Impact Predictions



- Hindcasting the hurricane impact on U.S. barrier island morphology
- Improve accuracy of event-driven morphological predictions by
  - Best-estimate meteo forcing and initial conditions
  - constraining free parameter space
  - assessing sensitivity to variations in input
- Modelled with Delft3D/Xbeach and COAWST/Inwave
- Collaboration with partners: U.S. Geological Survey, University of Delaware, University of Florida and Naval Research Lab
- Funded by the Office of Naval Research, contract N00014-17-1-2459

Deltares

Matanzas and Wilderness Breach - before

Complex barrier island case with:

- Sandy beach
- Vegetated dunes
- Buildings and roads
- Back-bay marsh
- Adjacent tidal inlets

Deltares

Matanzas and Wilderness Breach - after

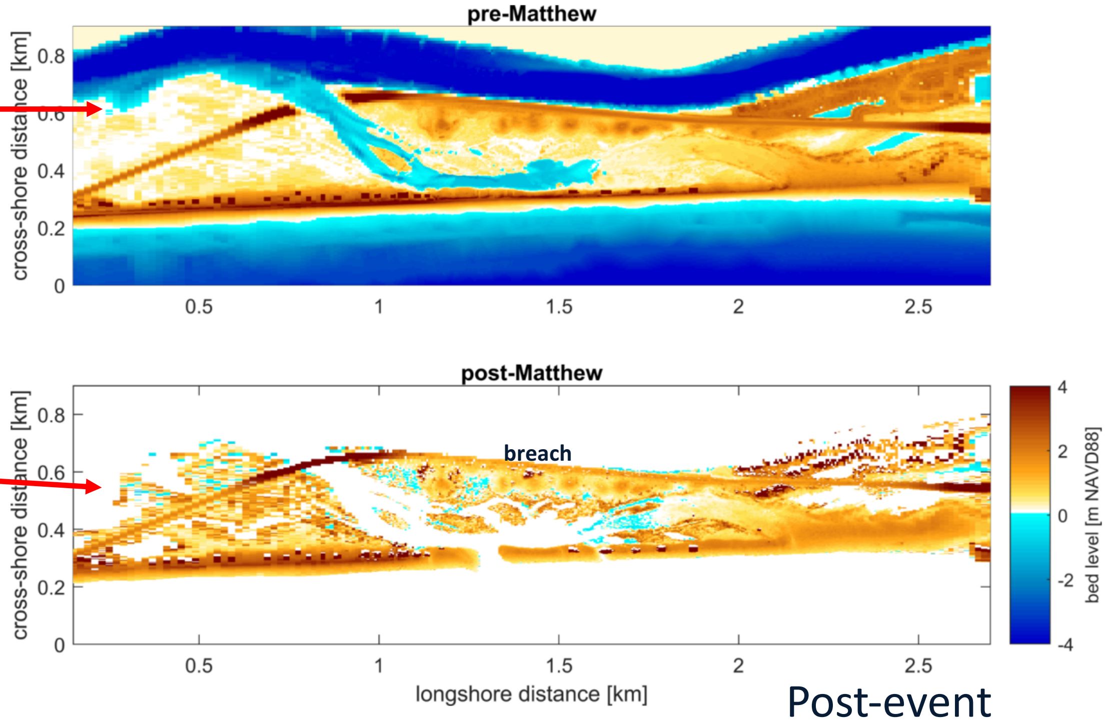
- Hurricane Matthew caused overwash, erosion and 120m wide breach
- Hurricane Sandy caused overwash, 4 m vertical erosion and 80 m breach

Deltares

Model inputs

- Topo/bathymetry:
  - Pre-event LIDAR
  - Post-event "Structure for Motion" or LIDAR

Pre-event

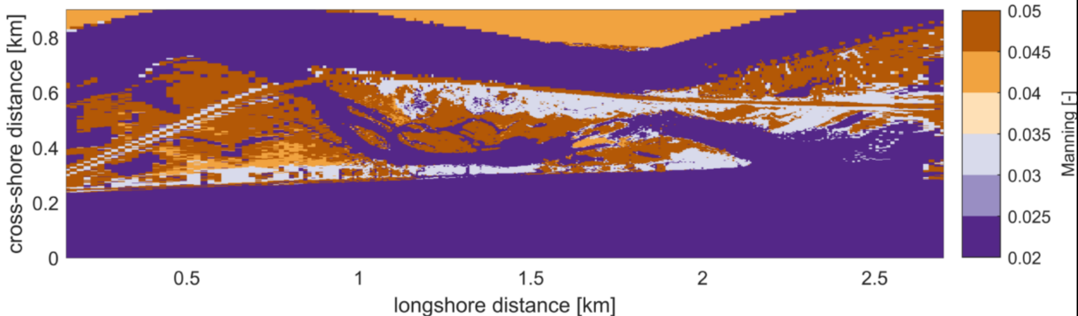


Post-event

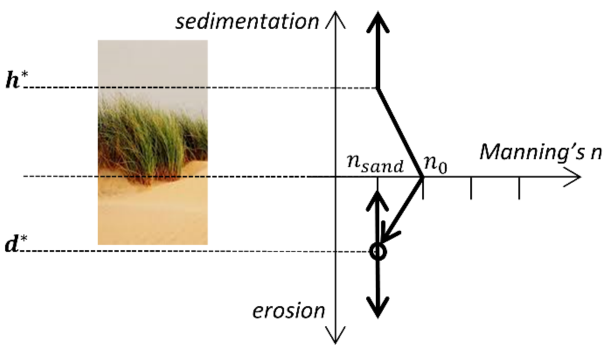
Temporal and spatial variation of vegetation roughness

- Spatial variation of roughness
  - Used pre-storm NAIP (National Agriculture Imagery Program) 1m x 1 m data
  - Each pixel classified using Conditional Random Field (CRF) method
  - Visually tag regions to Land Cover Classes
  - Converted Land Cover Classes to Manning's n roughness

- Temporal variation of roughness (Xbeach)
  - Variation of Manning's n roughness due to burial or veggie erosion



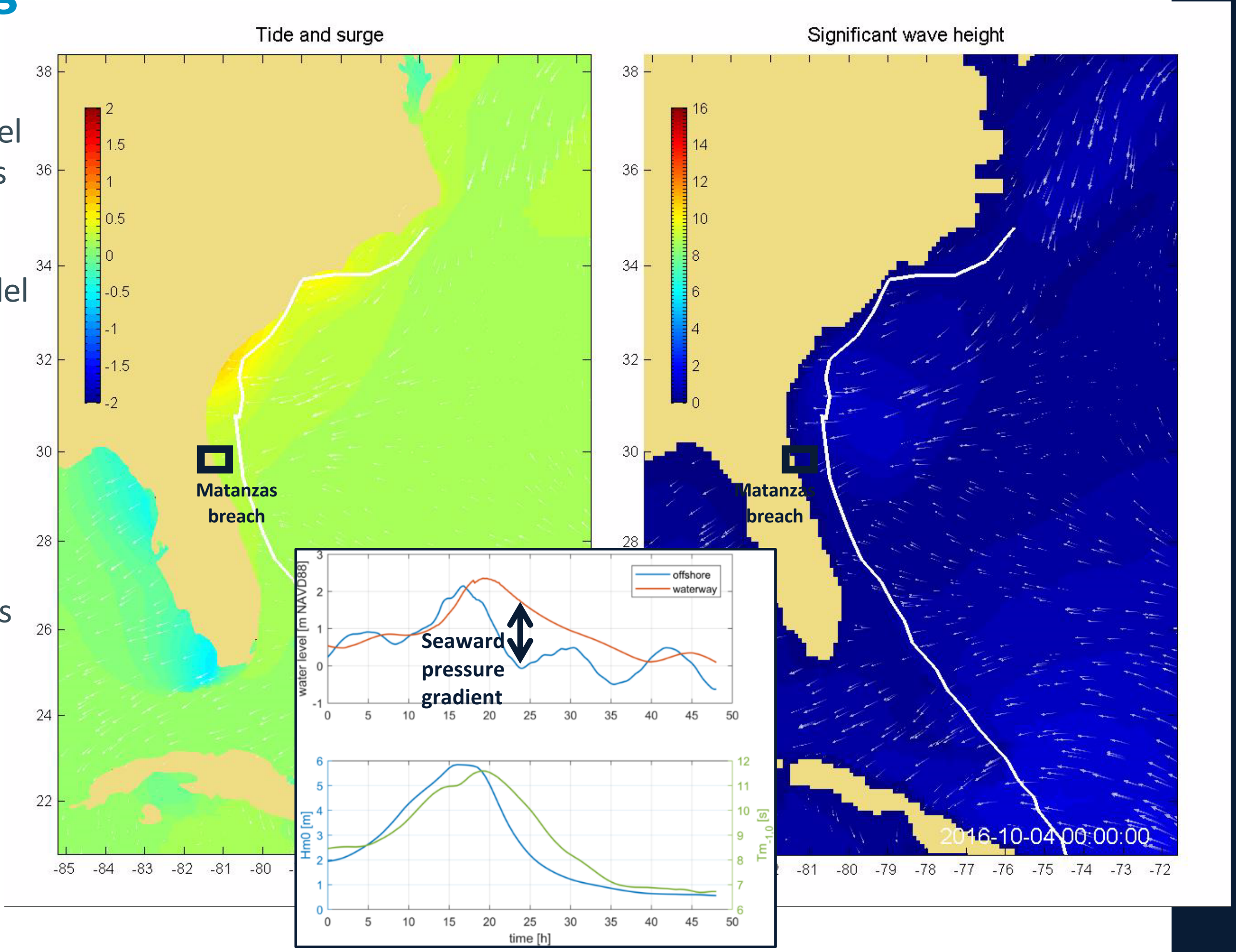
Classification	NLCD class name	Manning's n
Sand	Open Water	0.02
Wetland Vegetation	Emergent Herbaceous Wetlands	0.045
Water	Open Water	0.02
Dune Grass	Grassland/Herbaceous	0.034
Woody Vegetation	Shrub/Scrub	0.05
Anthropogenic coverage	Developed – Low Intensity	0.05



Deltares

Hydrodynamic forcing

- NRL CoAmps Meteorological model provides wind- and pressure fields
- Drives Delft3D-Flexible Mesh model and SWAN model for NE Atlantic
- Provides boundary conditions to XBeach model
- Similar approach of nested models with COAWST



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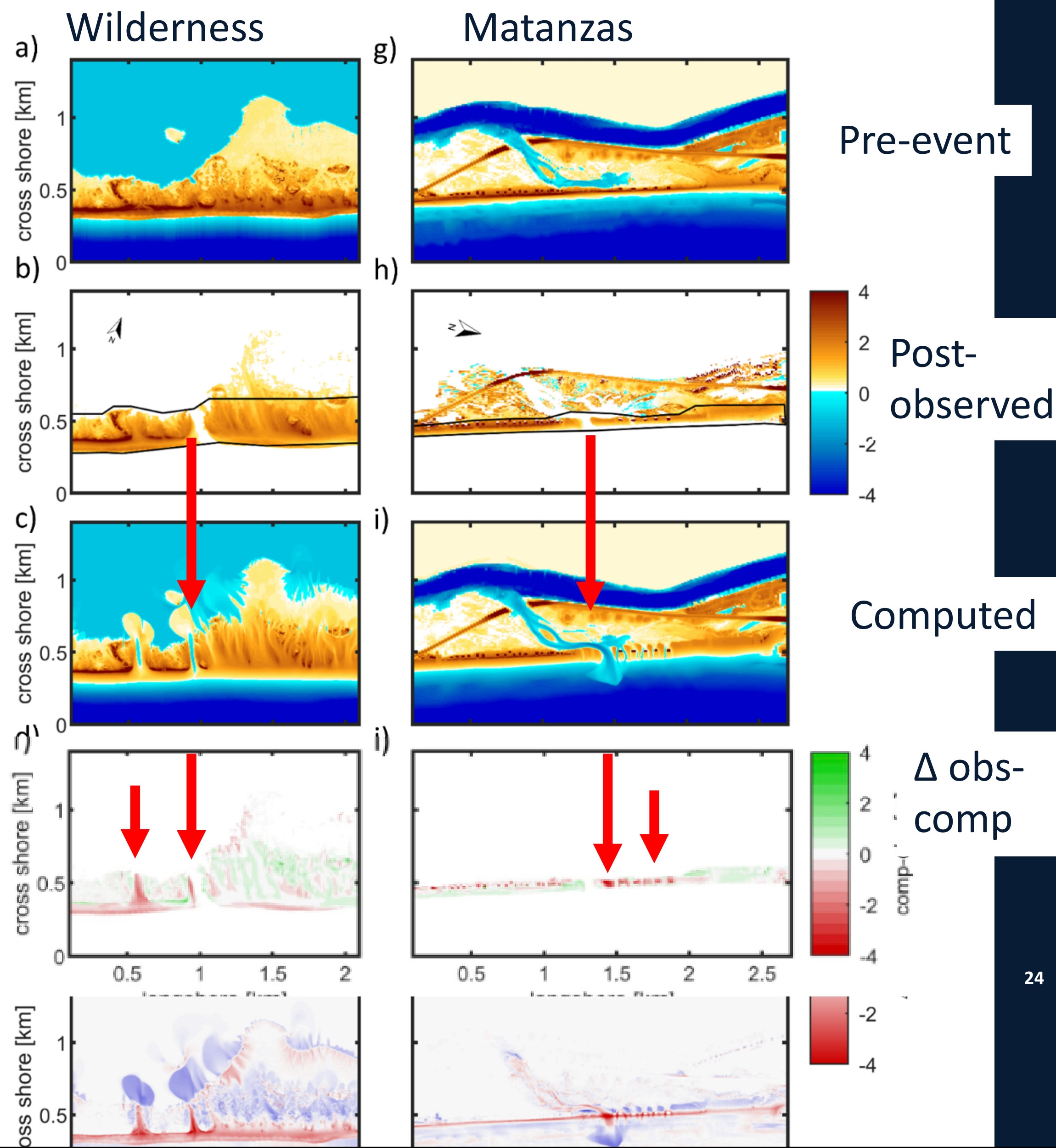
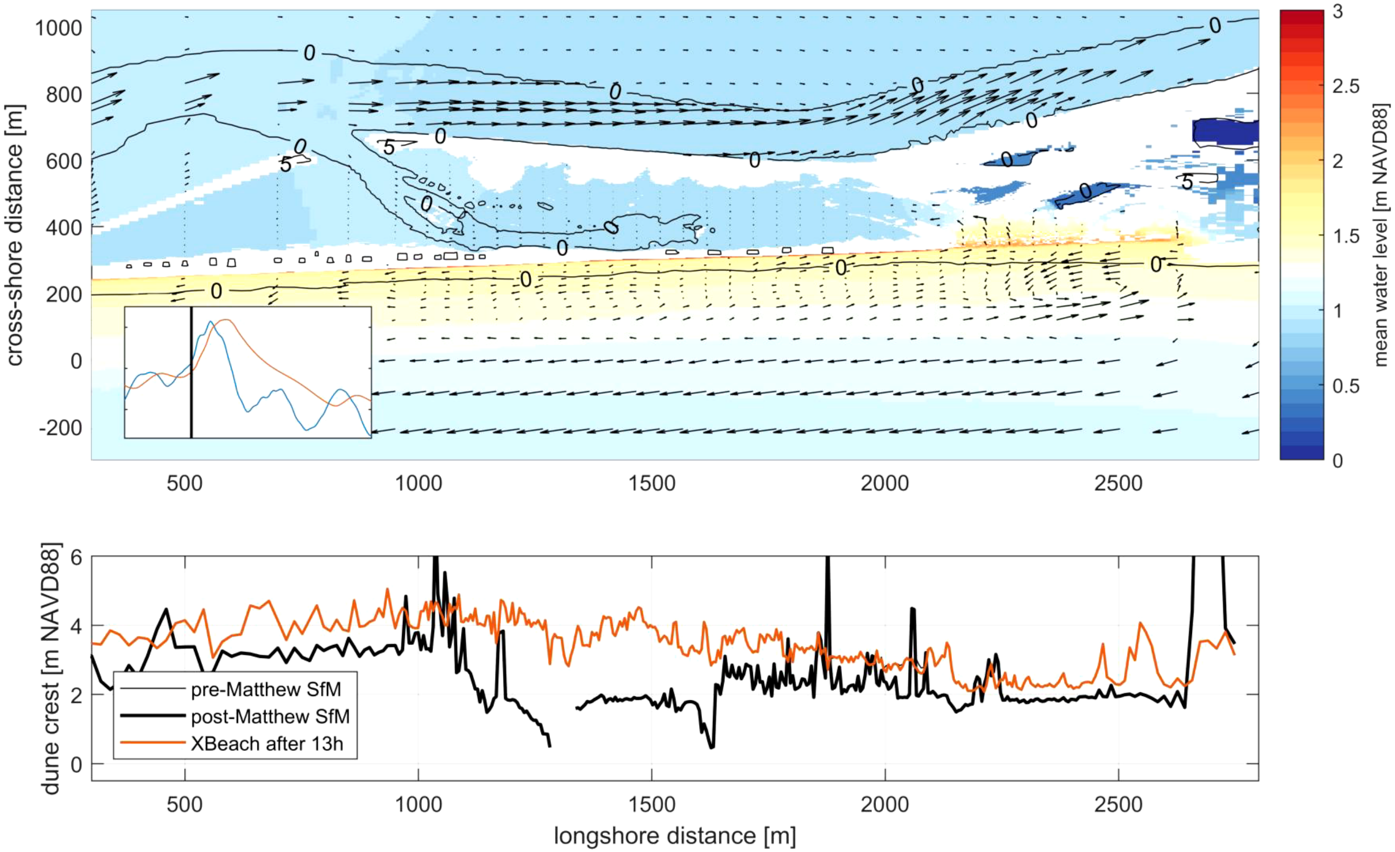
XBeach results

- Default “XBeachX” settings with “facua” calibrated on Wilderness case
- XBeach predicts breach formation(s)
- Wilderness: second breach at location which reduced in height but did not breach
- Matanzas: location is off by 100m, and secondary breaches predicted
- Breach location is sensitive to back bay configuration, channel positions, and presence of vegetation.



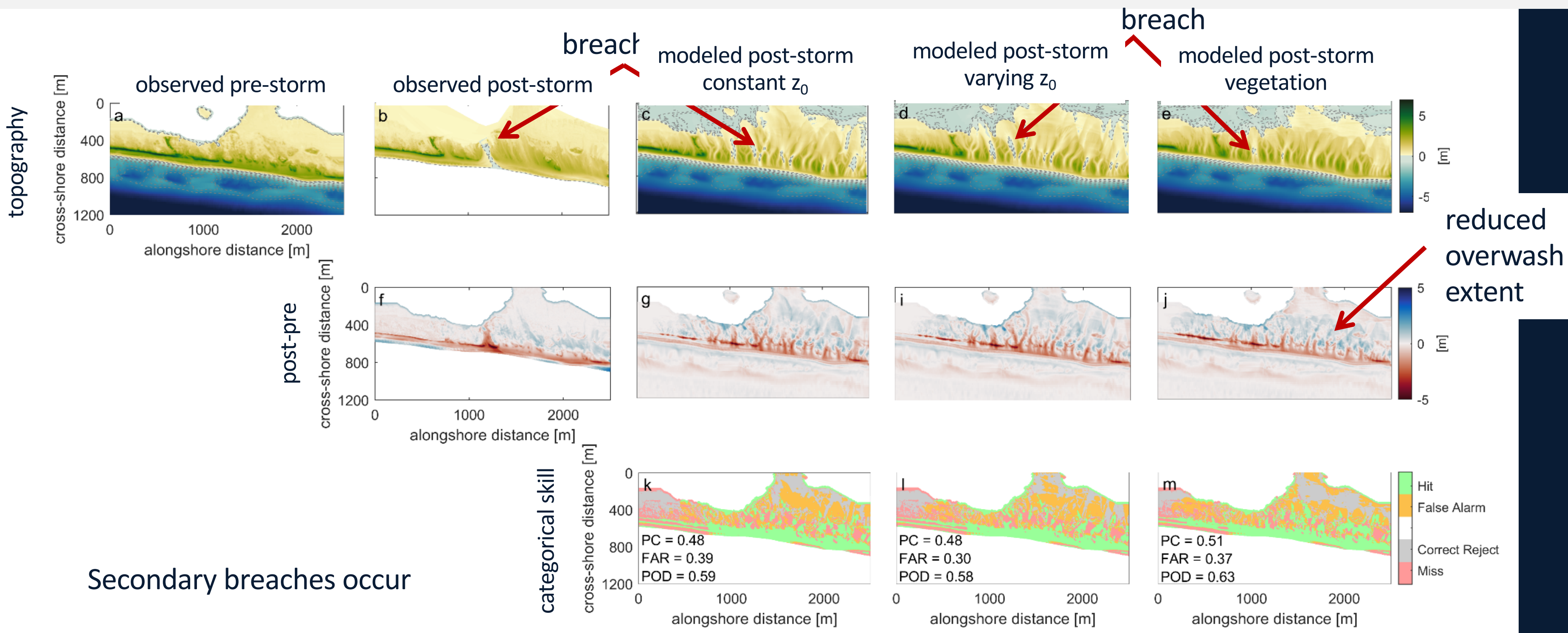
Why does the breach not occur in the right place at Matanzas?
MOVIE



Deltares

COAWST: Wilderness Breach on Fire Island, NY (2012).

Breach simulations were improved by inclusion of landcover characteristics.
However, COAWST results were not sensitive to a spatially-varying roughness of landcover.
Instead, landcover was included by activating the vegetation model that provided a vertical structure of momentum loss, resulting in reduced overwash and deposition in the back barrier to improve model skill.



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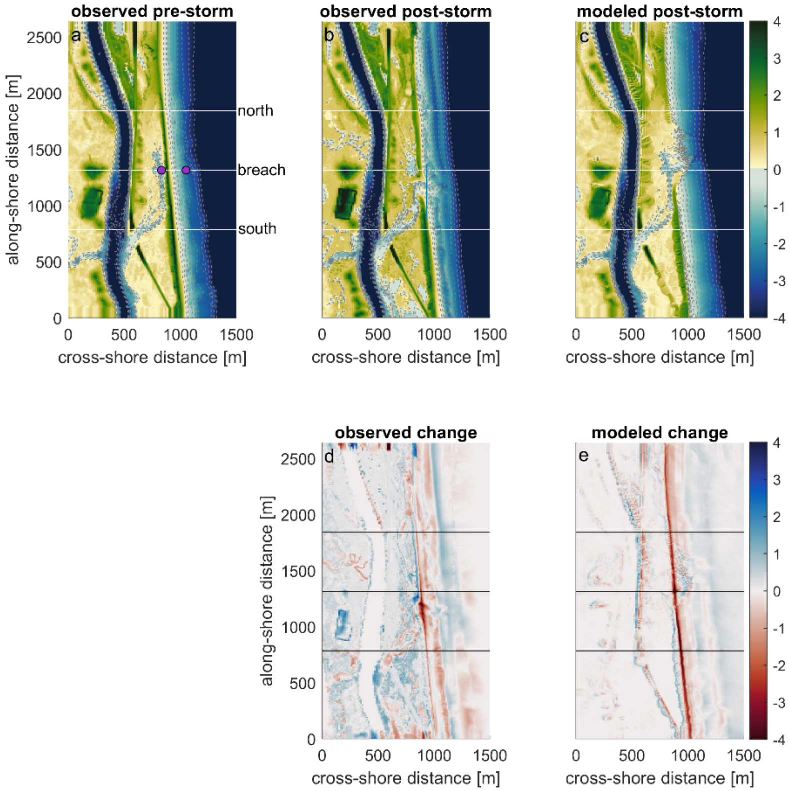
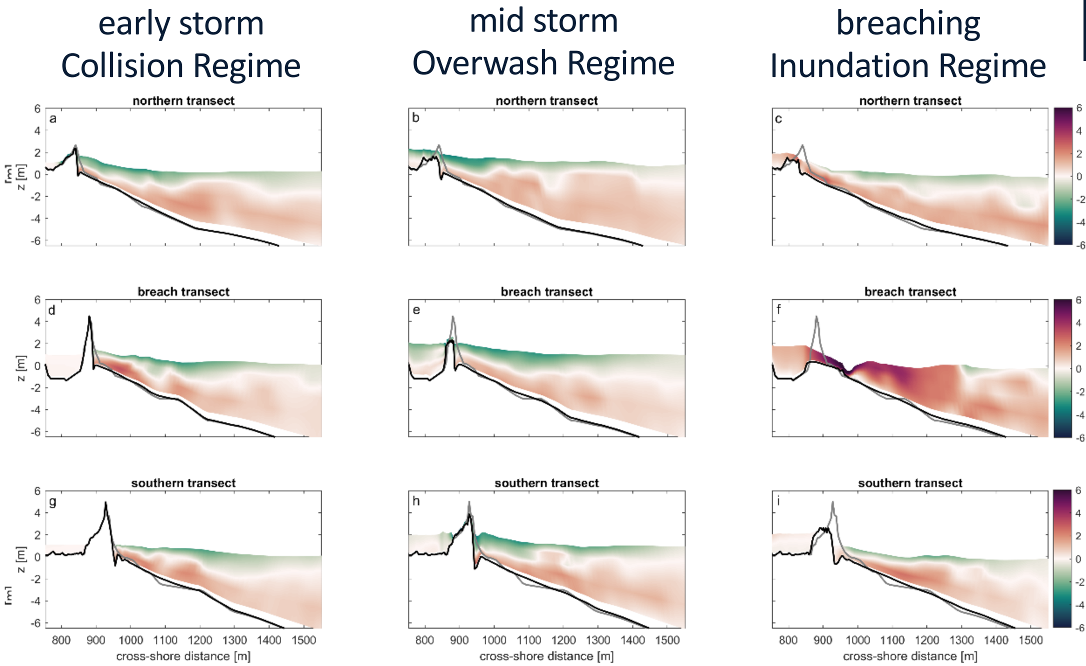
COAWSTBreach near Matanzas, FL developed during Hurricane Matthew (2016).

COAWST hindcasted breach developed ~150 m north of the observed breach location. Breaching occurred from back-barrier to ocean due to elevated water levels in the Intracoastal Waterway, pointing the importance of downscaling regional hydrodynamics and resolving alongshore variations.





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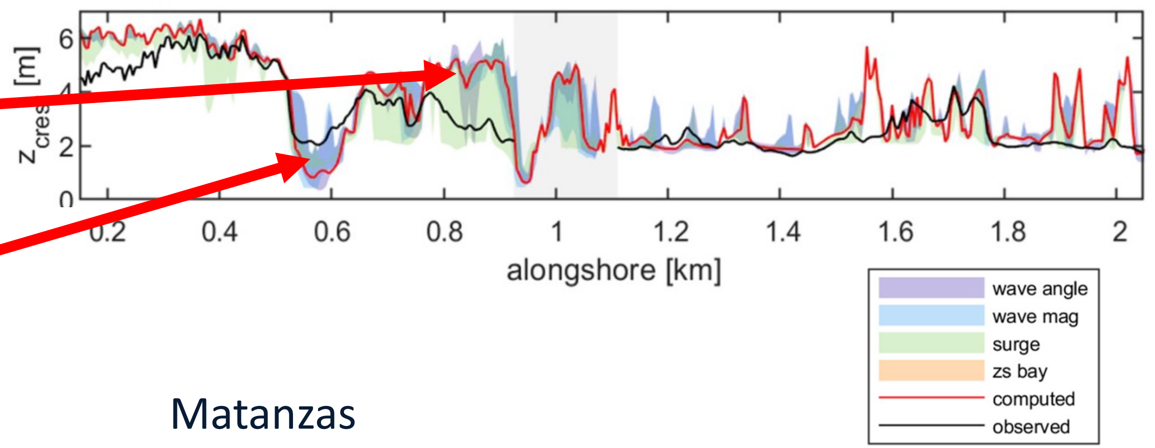
Sensitivity to input BCs

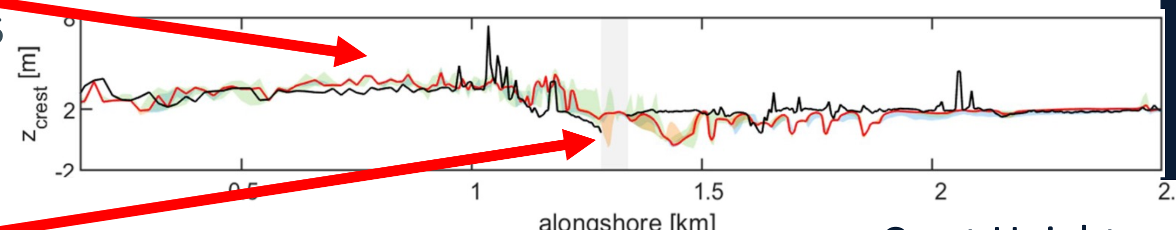
Wilderness Breach

Crest Height



- Areas of large morphological change are sensitive to 10% variations in offshore surge
- Secondary breach are is sensitive to 10% variation in wave angle, wave height

Matanzas



Crest Height

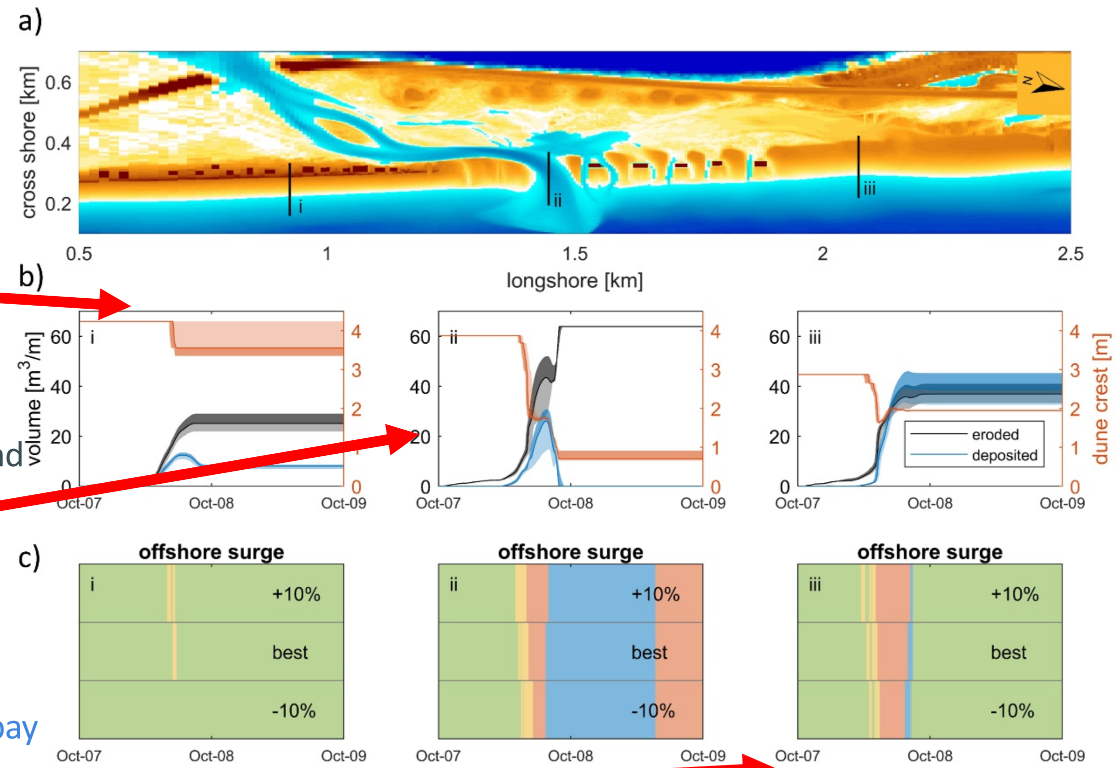
- Largest impact by 10% offshore surge variations (surge level +/- 15 cm)
- 10% higher bay surge (+15 cm) results in a second breach at the observed location

Take home: morphological change sensitive to relatively small variations in forcing

Deltares

Sallenger
Regime changes

- Cross-section i:
  - Mostly in collision regime
  - Short interval of overwash
  - Morpho-change during overwash and 2nd collision regime
- Cross-section ii:
  - Earlier shift to overwash and inundation due to lower initial crest height
  - Morpho-change during inundation and bay surge
- Cross-section iii:
  - Lowest initial crest height: earlier shift to overwash and inundation
  - Deposition on crest prevents breaching
  - Brief period of bay surge, no morpho change



- Collision regime = max water level < dune crest
- Overwash = min water level < dune crest < max water level
- Inundation = min water level > dune crest
- Bay surge = inundation with flow reversal

Deltares

Take homes

- **Hydrodynamic models predict surge and waves well given good quality meteo forcing**
  - Timing is key! An error of 3-6 hrs in landfall makes all the difference, given HW and LW.
  - Downscaling hydromodels from ocean basin to nearshore scales improves prediction
  - High temporal resolution of meteo forcing to avoid interpolation errors .
- **Morphodynamic models predict dune erosion, deposition, and breach formation reasonably well**
  - Accurate topo-bathy at 1-10 meter resolution of barrier islands and back bays is important
  - Spatially-varying vegetation roughness improves model-skill (Xbeach)
  - Morpho results are sensitive to forcing conditions, e.g. 10% change in offshore surge
- **Observation needs (also appended slides)**
  - Pre-event: bathy, topo and veggie at 1-10 meter resolution
  - During event: nearshore waves, water levels in bays, currents and winds (on- and offshore)
  - Post event: timely surveys as pesky residents, local authorities and nature don't wait for us.

Sherwood et al (2021, in press) "Modeling the Morphodynamics of Coastal Responses to Extreme Events: What Shape Are We In?" Ann. Rev. Mar. Sci

Van der Lugt et al. (2019), Estuarine, Coastal and Shelf Science 229 https://doi.org/10.1016/j.ecss.2019.106404

Hegermiller, C.A., et al. , in review. Barrier island breach dynamics during Hurricanes Sandy and Matthew. JGRES.

Deltares

Summaries of
The 10 Teams Of NHCI Through Hurricane Ian

“Task 0”: COAMPS-TC support of the NOPP Hurricane Coastal Impacts project

Will Komaromi, Jim Doyle, Jon Moskaitis, Hao Jin

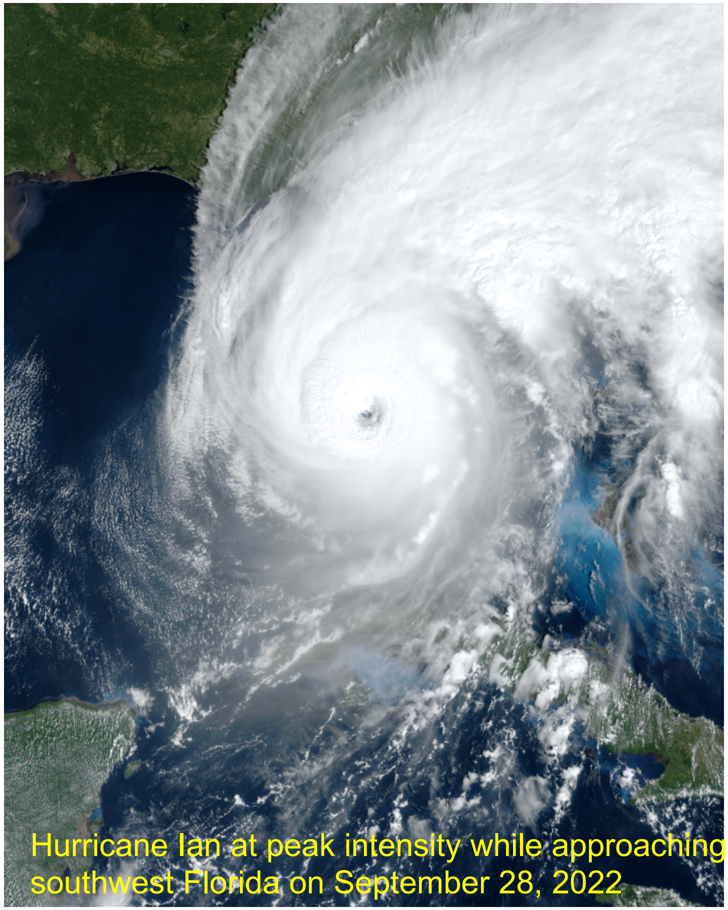
U.S. Naval Research Laboratory
Monterey, CA

NOPP workshop – Nov 2022
Chapel Hill, NC

U.S. NAVAL RESEARCH LABORATORY

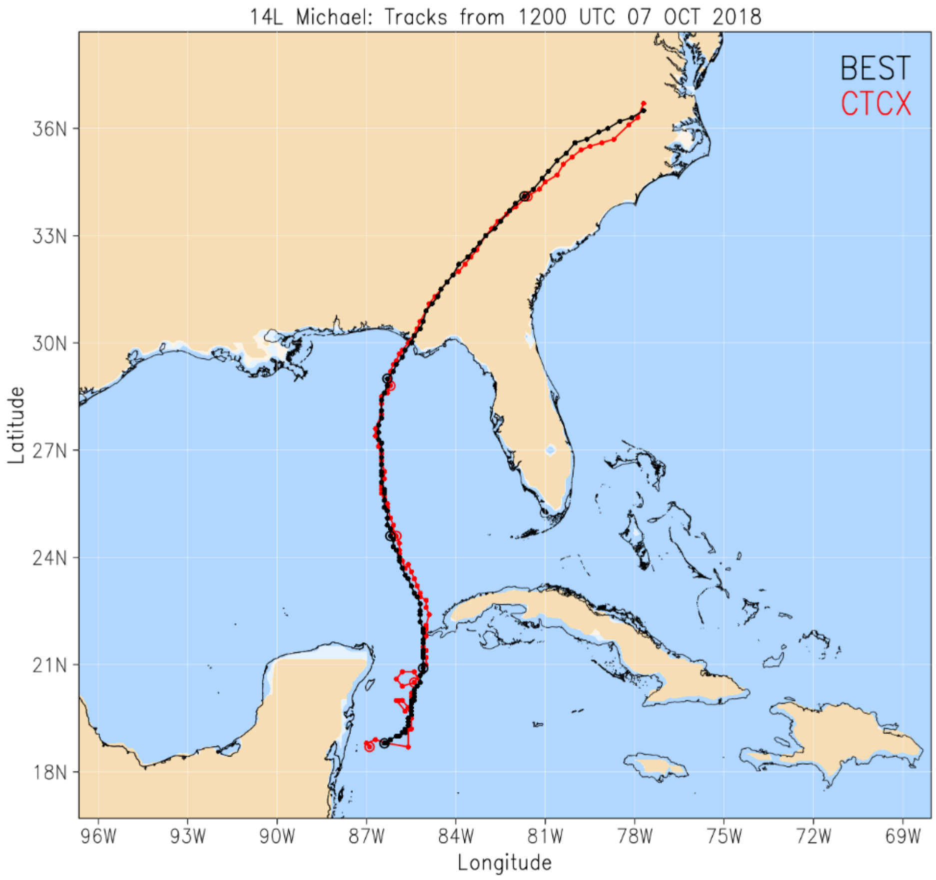
Overview

- Hurricane Michael (2018) reforecast
- Real-time COAMPS-TC forecast products and support for 2022 Atlantic Hurricane Season
- Overview of the COAMPS-TC Ensemble forecast system
- Hurricane Ian (2022) real-time forecast validation
- Hurricane Nicole (2022) real-time forecast validation
- Plans for 2023



Hurricane Ian at peak intensity while approaching southwest Florida on September 28, 2022

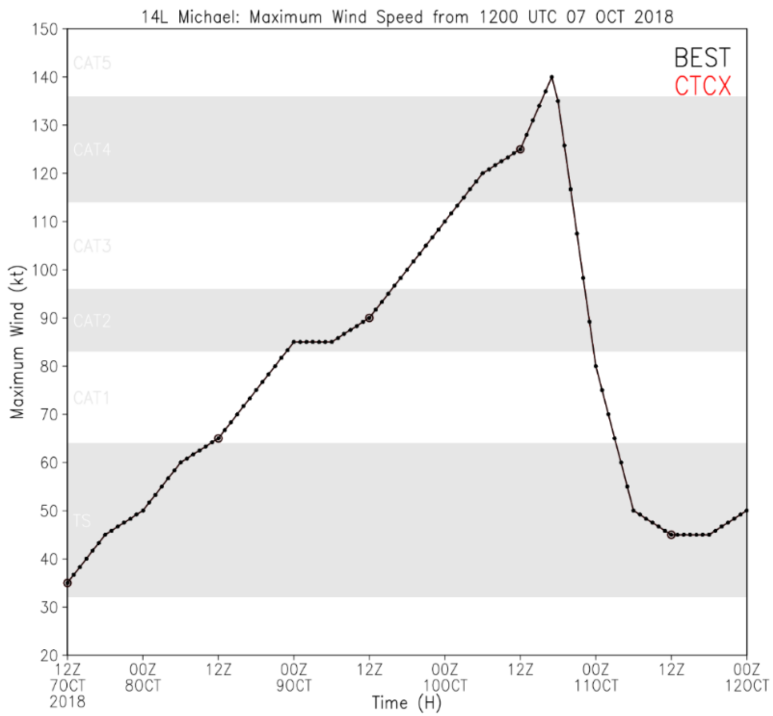
Hurricane Michael (2018) reforecast: track & technique

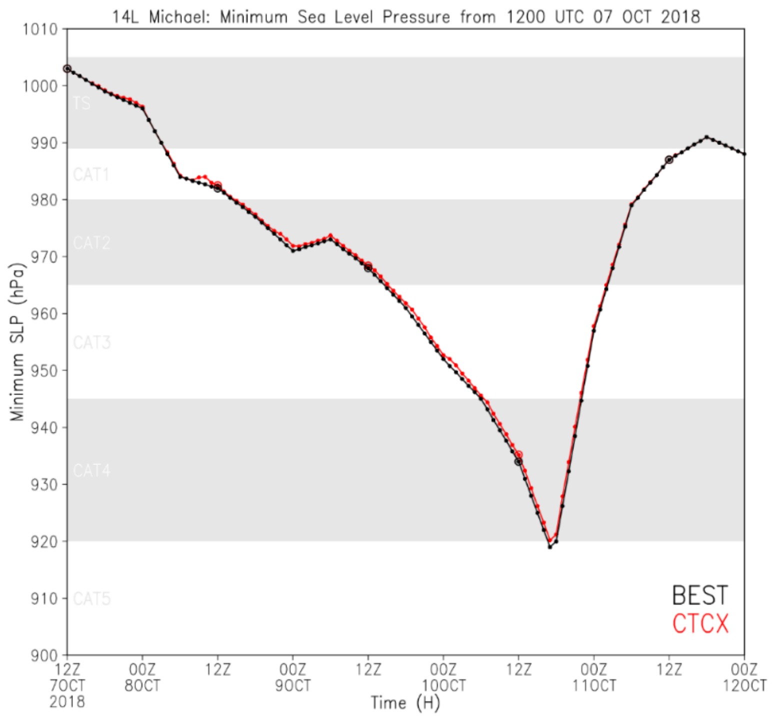


Reforecast Technique:

- NRL's reforecast technique concatenates successive 1-6 h COAMPS-TC forecasts, initialized every 6 h
- The 36/12/4-km native grids are interpolated to a uniform 4-km grid
- Maximum sustained wind (Vmax), sea-level pressure, storm center position, and wind radii (R34, R50, R64) are adjusted hourly to match NHC's best track
- Other fields, such as surface fluxes and precipitation, are position-adjusted and scaled to match changes in wind and pressure fields
- LEFT: For Hurricane Michael (2018), the reforecast track (red) is a very close match to the best track (black)

Hurricane Michael (2018) reforecast: Vmax and MSLP





The adjusted reforecast Vmax (left) and MSLP (right) are an excellent match to the NHC best track

Hurricane Michael (2018) reforecast
Select surface pressure observations vs forecast

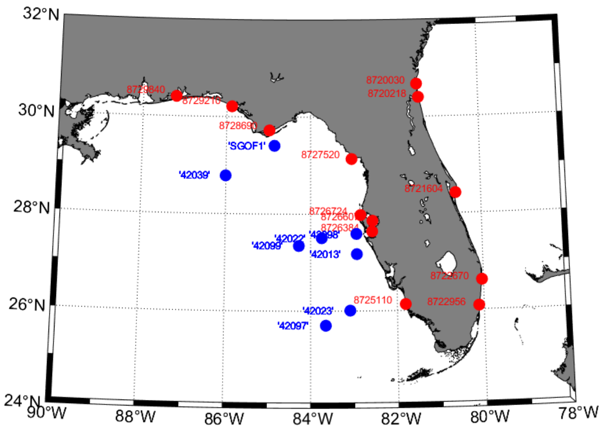
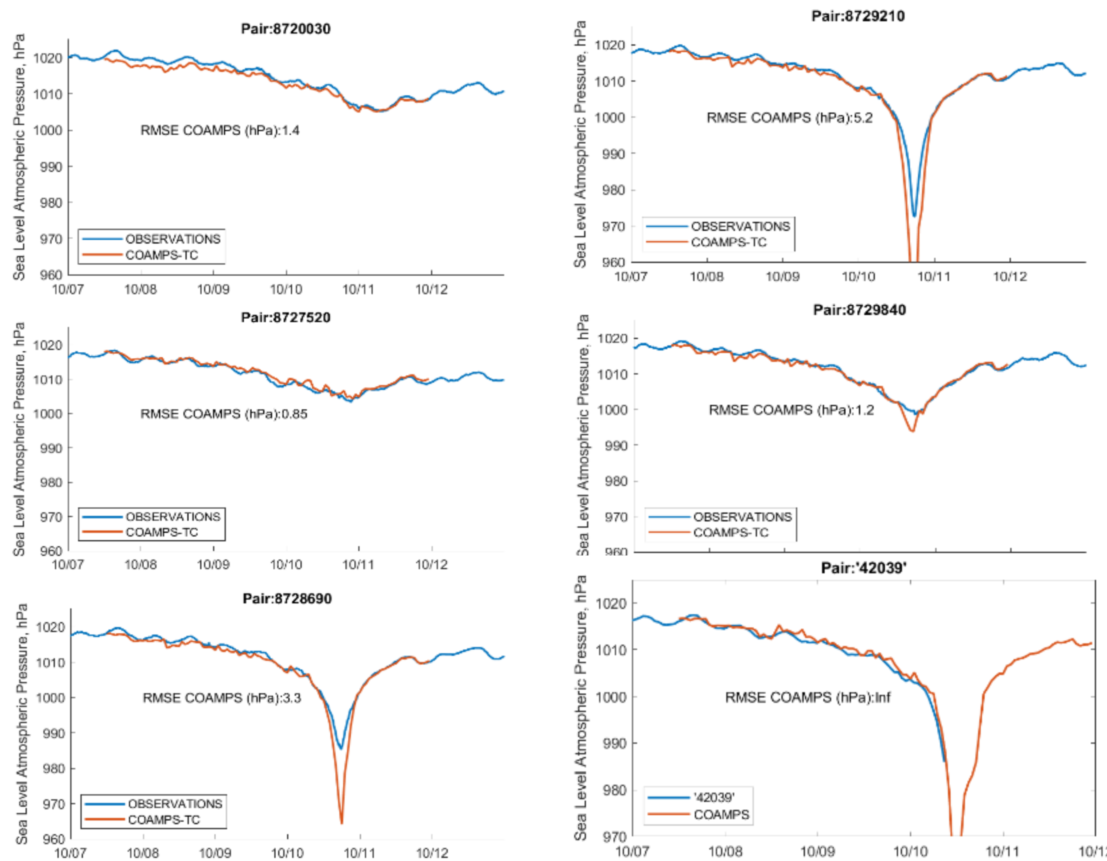


Fig 2. Location of the NOAA tide gauges (red) and NDBC buoys (blue).



- Timing of passage of minimum surface pressure is highly accurate
- Center of compact storm is too broad at 4-km resolution, bringing more observation sites into eye of storm than in reality, creating low pressure bias near center

Hurricane Michael (2018) reforecast
Select surface wind observations vs forecast

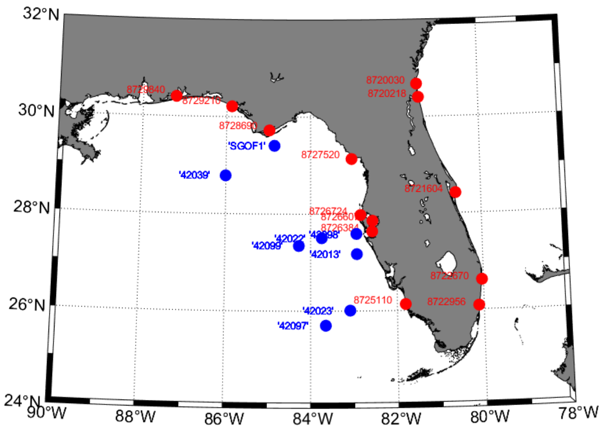
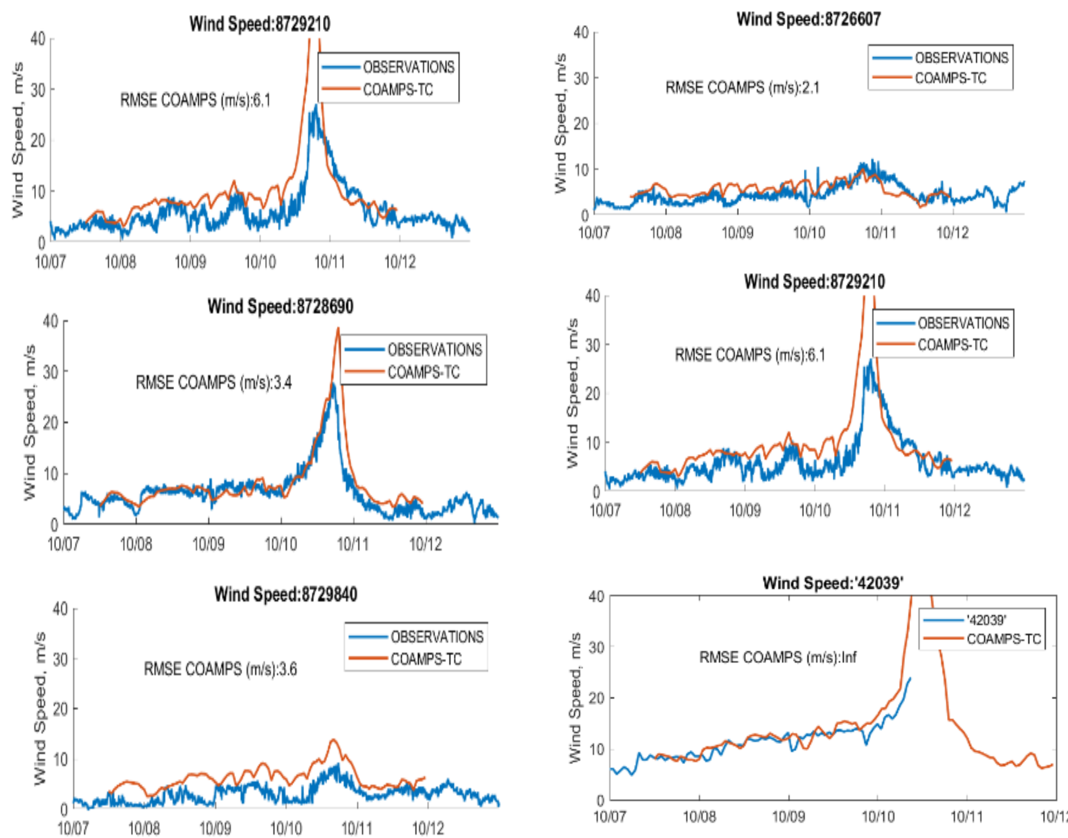


Fig 2. Location of the NOAA tide gauges (red) and NDBC buoys (blue).



- Timing of passage of maximum 10-m wind is also highly accurate
- Center of compact storm is too broad at 4-km resolution, bringing more observing sites into strong eyewall winds than in reality, creating high wind bias at some locations

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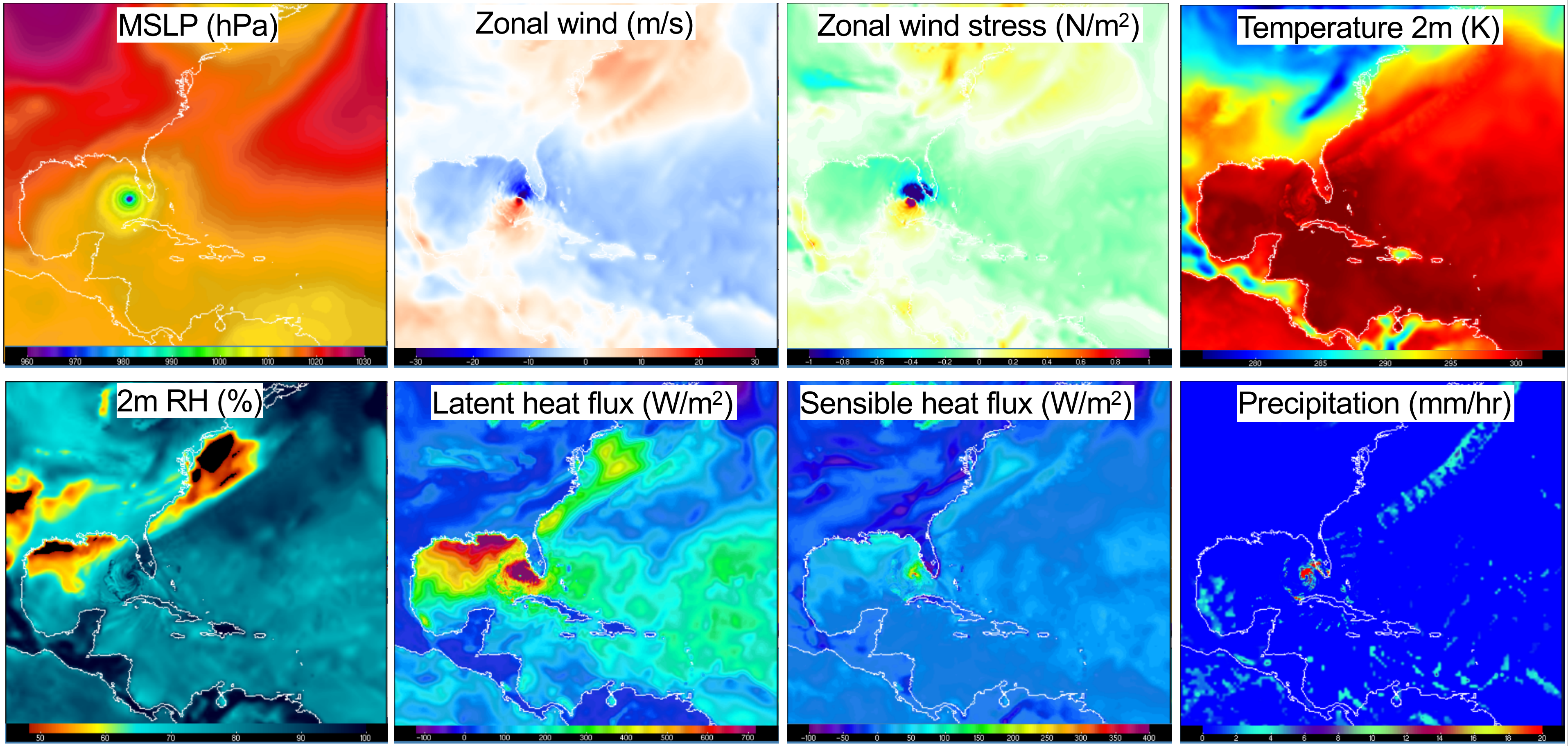
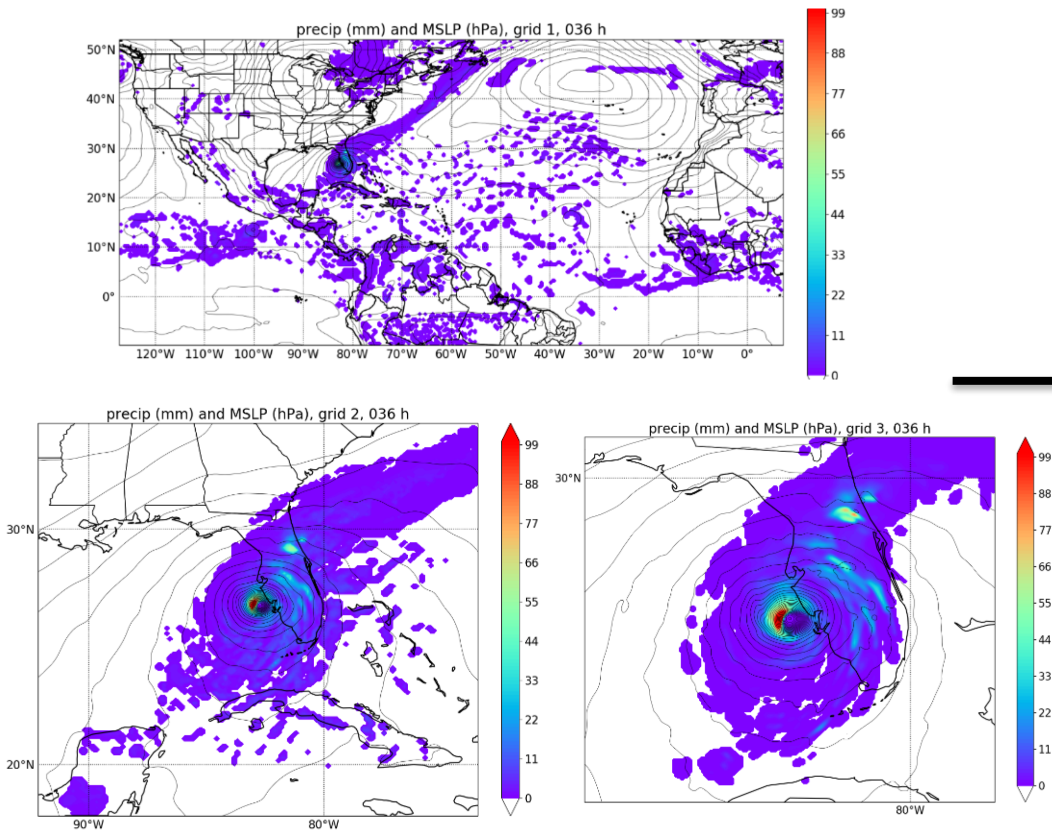
2022 Hurricane Season: Real-time support for NOPP project

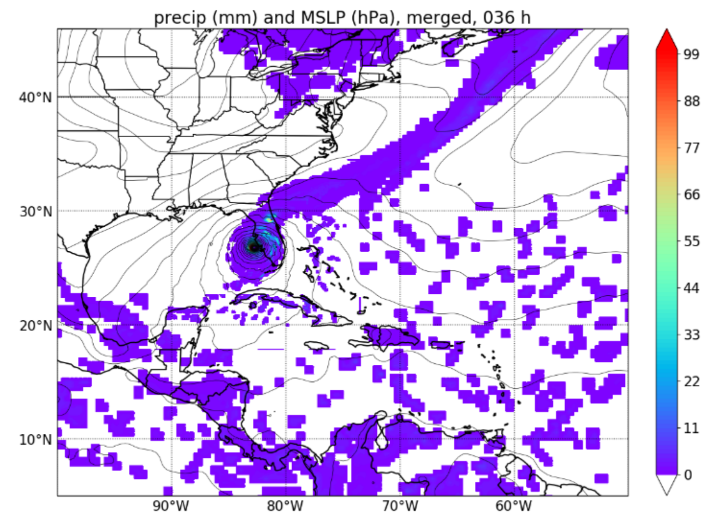


2022 Hurricane Season: Example of merged precipitation fields

Native Grids



Merged (uniform, 4-km) Grid



2022 Hurricane Season: Real-time support for NOPP project

COAMPS-TC supplied variables, at 4-km resolution, hourly, beginning 5 days from projected landfall:

10-m winds	**2-m relative humidity**
Surface pressure	**Surface wind stress**
2-m air temperature	**Surface longwave radiation**
Surface latent heat flux	**Surface shortwave radiation**
Surface sensible heat flux	**Hourly precipitation**

To get the fields on the native grids:
wget ftp://ftp-ex.nrlmry.navy.mil/send/{TCID}_{DTG}_netcdf.tar

To get the merged fields:
wget ftp://ftp-ex.nrlmry.navy.mil/send/{TCID}_{DTG}_netcdf_merged.tar

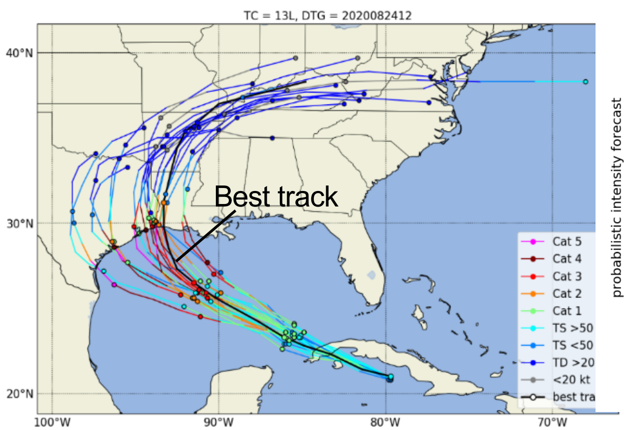
TCID: e.g. “09L”
DTG (date-time group): e.g. 2022092612

Fields are only available for 6 days before they are scrubbed from ftp server

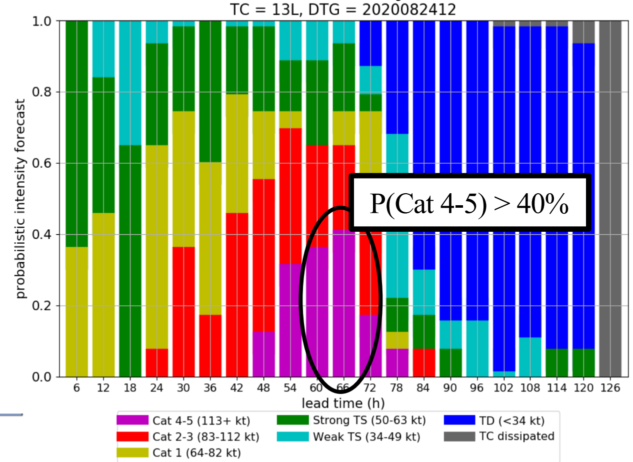
COAMPS-TC Ensemble: Graphical Products

Example: Hurricane Laura (2020)

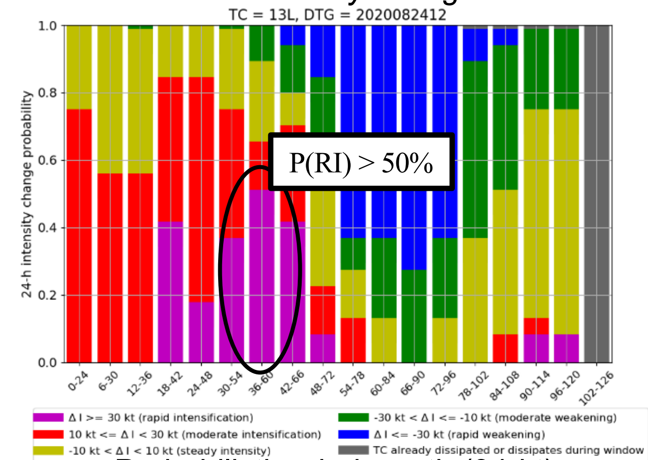
Tracks colored by intensity



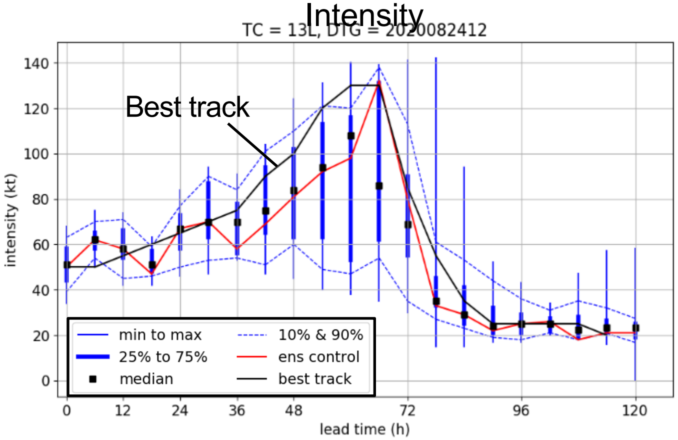
Probabilistic *intensity* forecast



Probabilistic *intensity change* forecast

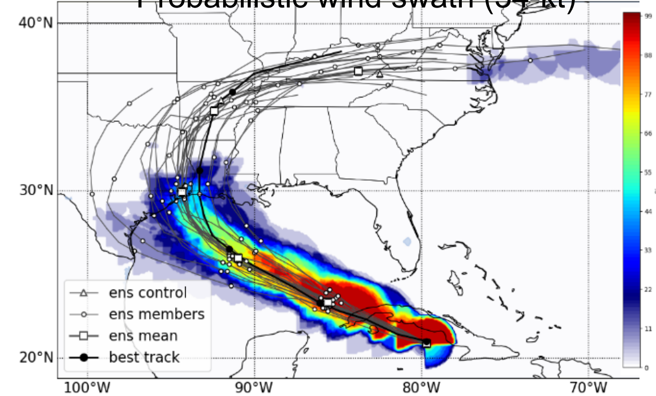


Intensity

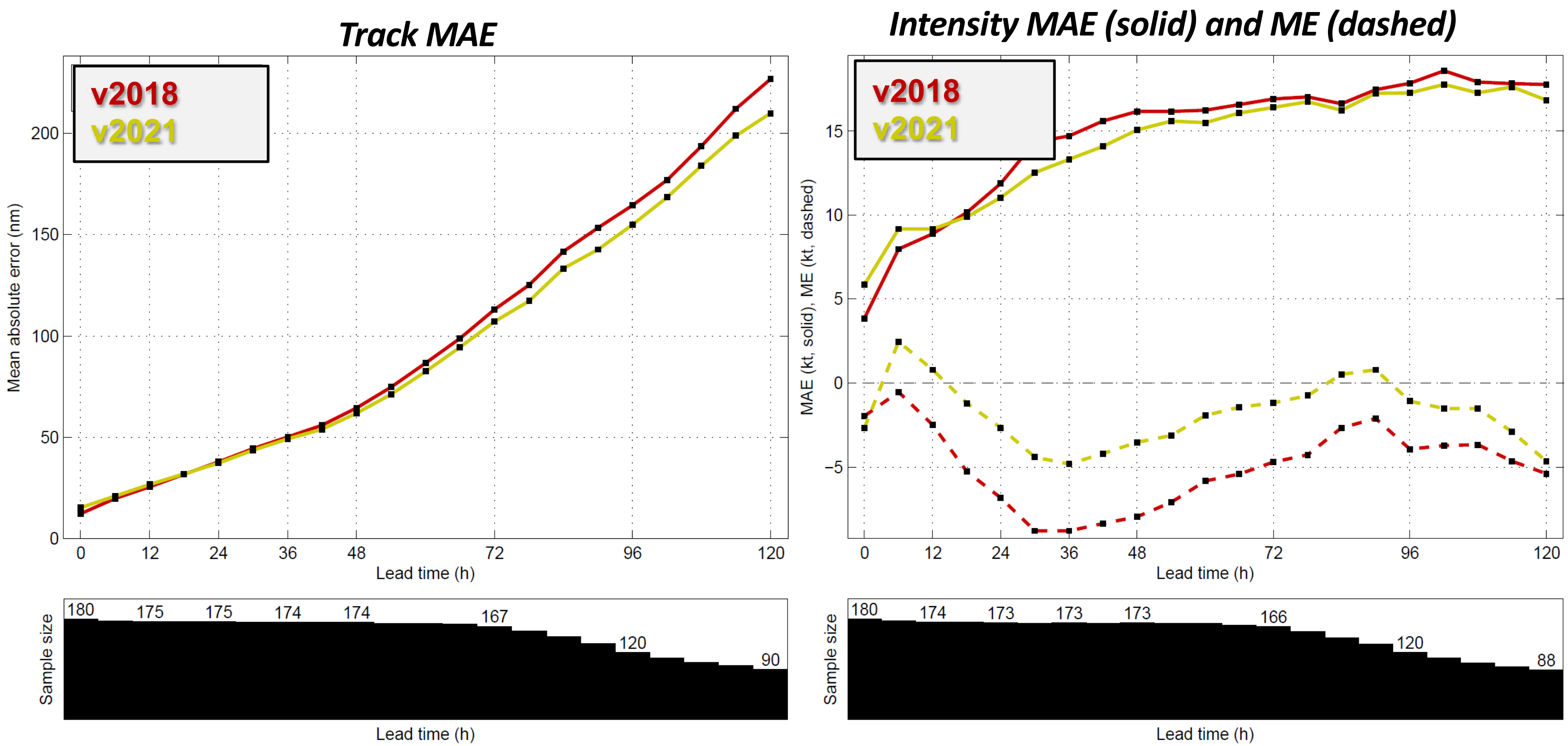


A variety of graphical forecast products have been developed by NRL to depict probabilistic track, intensity, chances of RI, and various wind thresholds

Probabilistic wind swath (34-kt)



COAMPS-TC Ensemble: Mean track & intensity error, all basins



- 2-5% improvement in ensemble mean track error from 24-48 h, 5-7% improvement from 60-120 h
- 2-13% improvement in ensemble mean intensity error beyond 12 h
- Substantial improvement in intensity bias (dashed)

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Hurricane Ian CTCX Forecast Validation

- Here we assess the track and intensity performance of deterministic CTCX, COAMPS-TC run with GFS initial and lateral boundary conditions, for Hurricane Ian. CTCX is run in real-time by NRL for operational use.

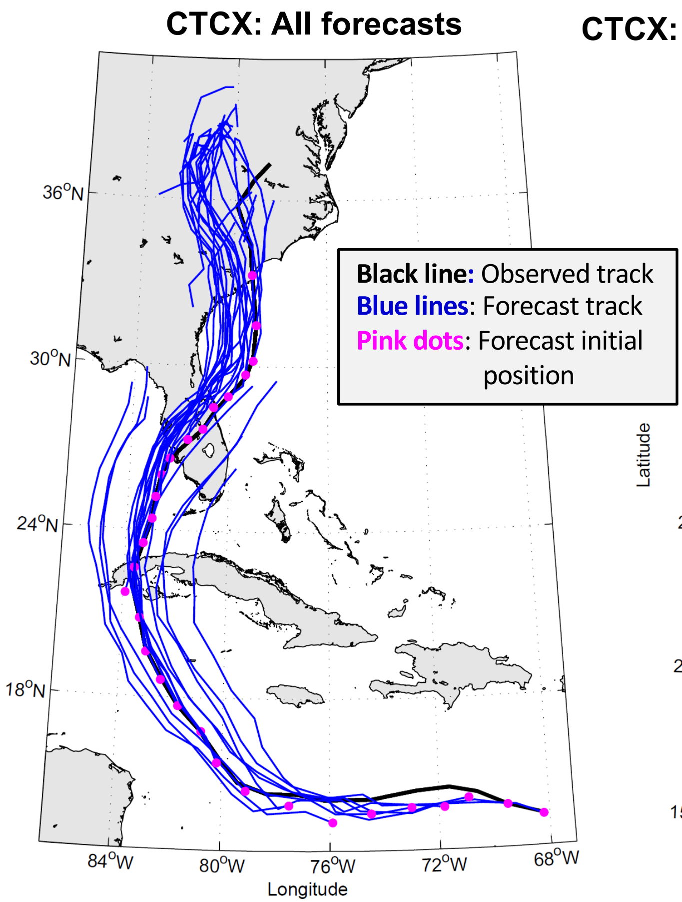
- Forecasts are validated against the National Hurricane Center (NHC) working best track. Note that Florida landfall occurred at 19z on Sept 28 (130 kt) and the South Carolina landfall occurred at 18z on Sept 30 (75 kt)

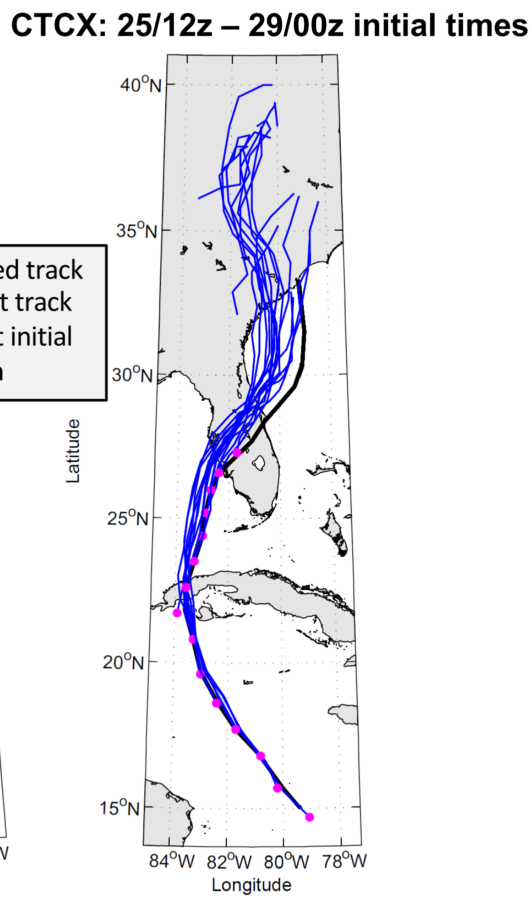
BLUF

- CTCX made excellent track forecasts for Ian, more accurate than GFS, UKMET, ECMWF, HMON, and GFS
- CTCX routinely predicted Ian to become a major hurricane in the Gulf of Mexico, and along with HMON and HWRF supported NHC in making an extremely aggressive forecast for Ian's intensification

Track Validation

- Some early CTCX forecasts took the storm over the Florida Keys or towards the Big Bend region on the Florida Gulf coast, but starting with the 25/12z initial time CTCX locked on to a landfall position between Fort Myers and Tampa
- All CTCX track forecasts issued with five days of the South Carolina landfall correctly indicated that Hurricane Ian would emerge off the Florida east coast and make a second U.S. landfall in SC
- See track forecasts for GFS, HWRF, and HMON on the next slide





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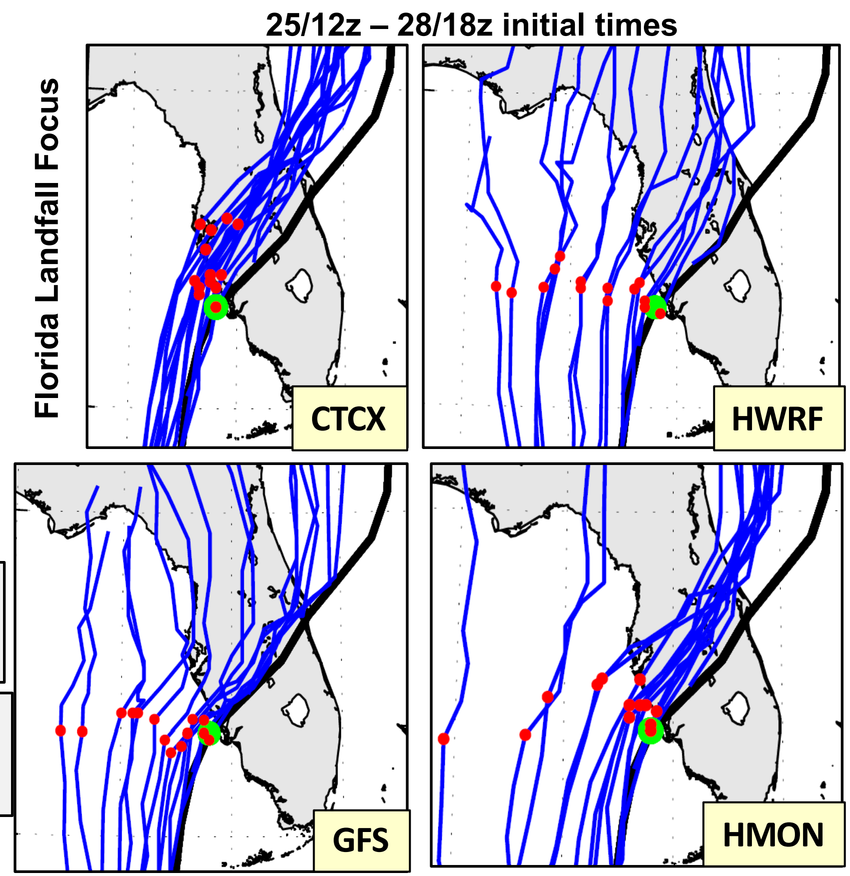
Track Validation

- Within three days of Florida landfall, COAMPS-TC forecasts did exceptionally well to predict the timing of landfall on the Florida west coast, but erred a bit north on position

- GFS, HWRF, and HMON tended to track the storm too far west, with landfall too late and too far north/west along the west coast of Florida



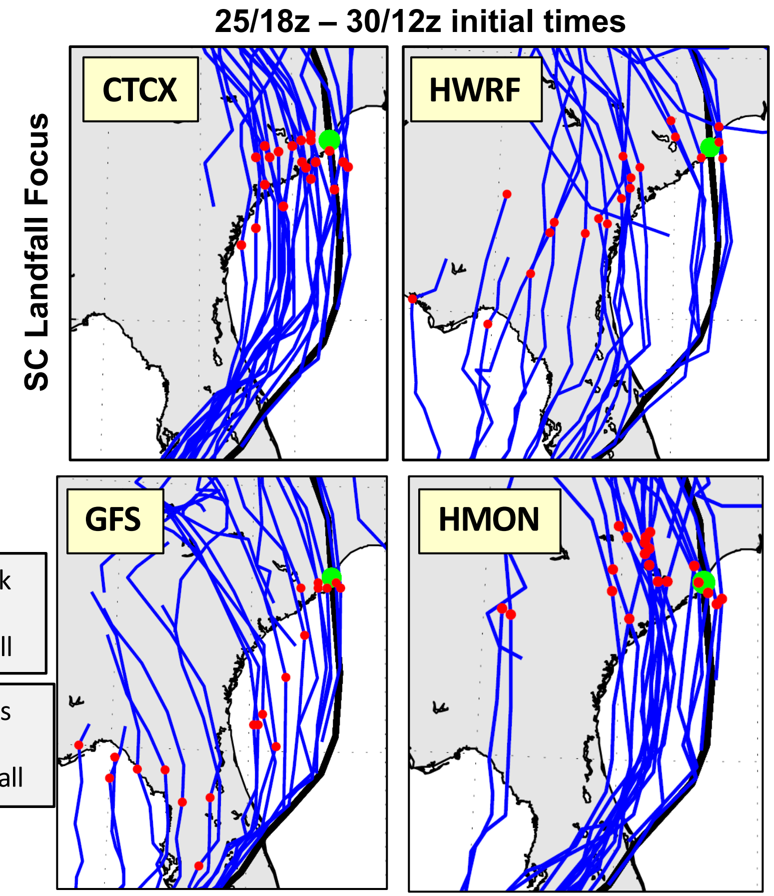
Black line: Observed track
Green dot: Observed TC position at time of landfall

Blue lines: Forecast tracks
Red dots: Forecast TC positions at time of landfall

Track Validation

- Within five days of South Carolina landfall, COAMPS-TC forecasts did well to predict the timing of landfall (+/- 6 h) but for the most part placed the landfall too far south along the Atlantic coastline

- GFS tended to take the storm too far west and was too slow to move it north. HWRF did better to bring the storm north, but was too far west. HMON did the best of the NOAA models, but was too fast to make landfall and place the landfall too far south

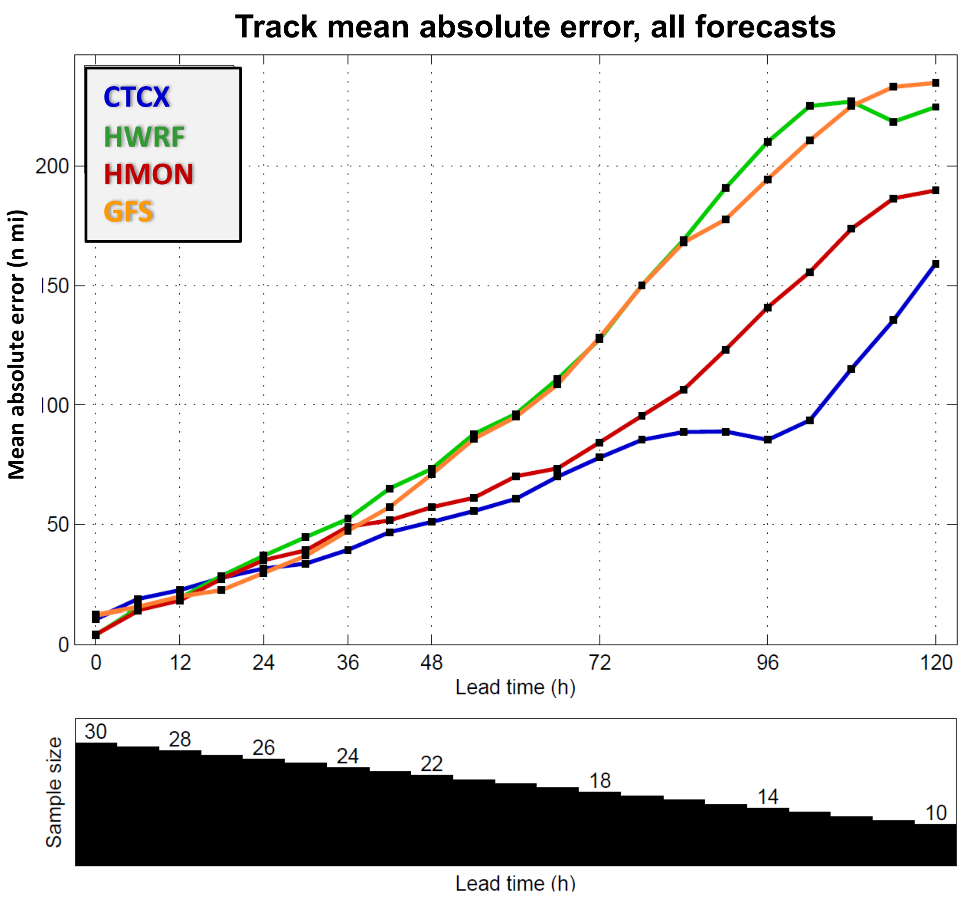


Black line: Observed track
Green dot: Observed TC position at time of landfall

Blue lines: Forecast tracks
Red dots: Forecast TC positions at time of landfall

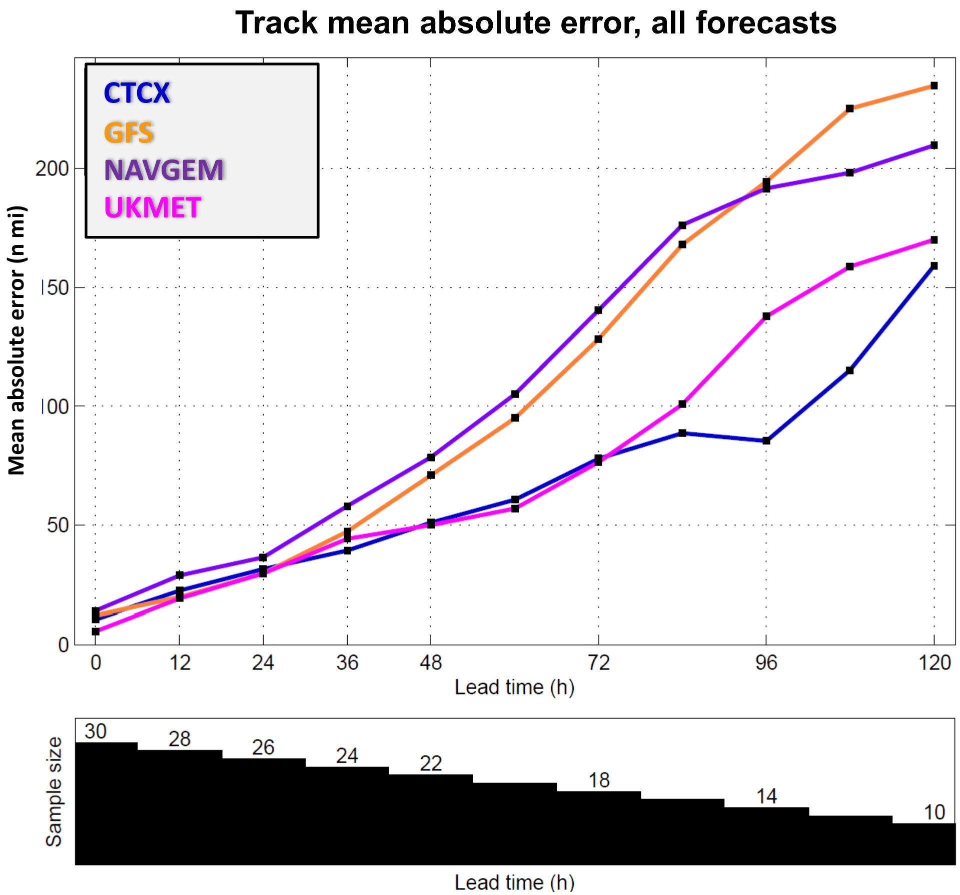
Track Validation: Accuracy

- For overall track MAE, CTCX was the best of the "GFS family" of models



Track Validation: Accuracy

- For overall track MAE, CTCX was the best of the "GFS family" of models
- COTC (COAMPS-TC with NAVGEM initial and lateral boundary conditions) performed reasonably well but had higher track MAE than CTCX
- CTCX outperformed UKMET at the later lead times, but the two were close through 72 h



Track Validation: Accuracy

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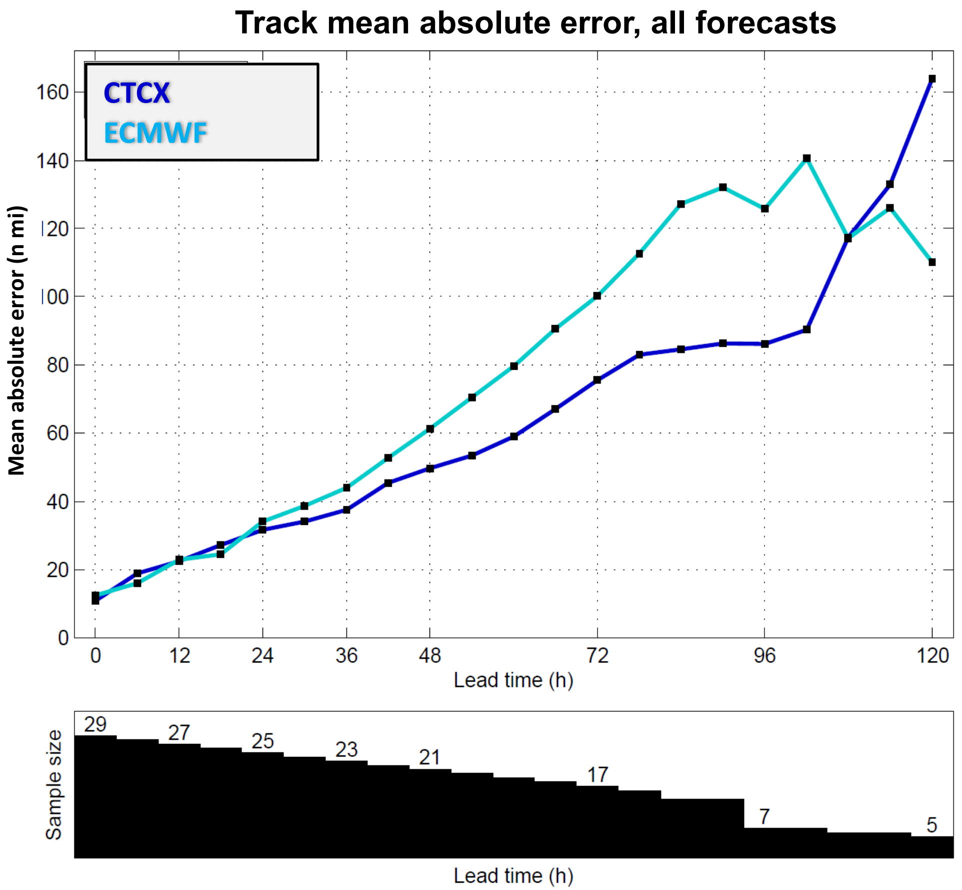
- COTC (COAMPS-TC with NAVGEM initial and lateral boundary conditions) performed reasonably well but had higher track MAE than CTCX
- CTCX outperformed UKMET at the later lead times, but the two were close through 72 h
- For Ian, CTCX also had a lower track MAE than ECMWF for all but the latest lead times



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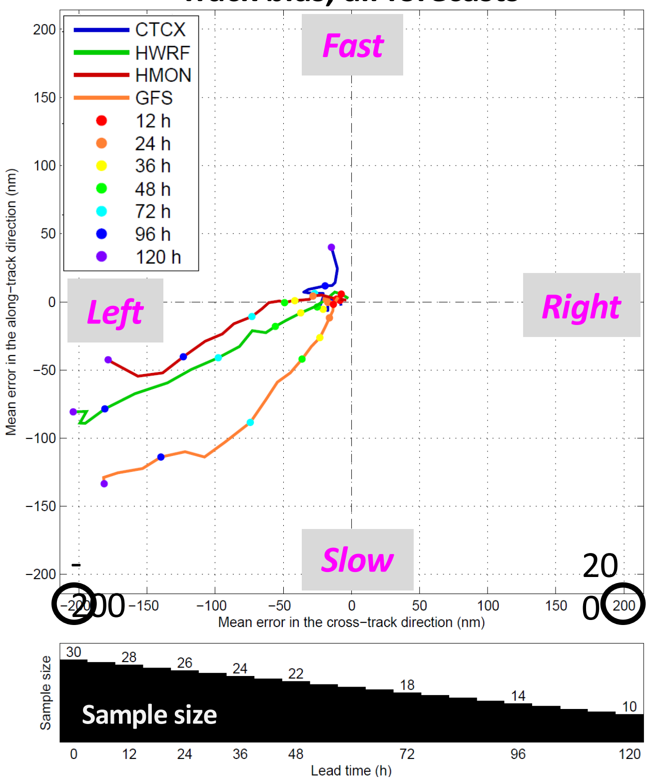
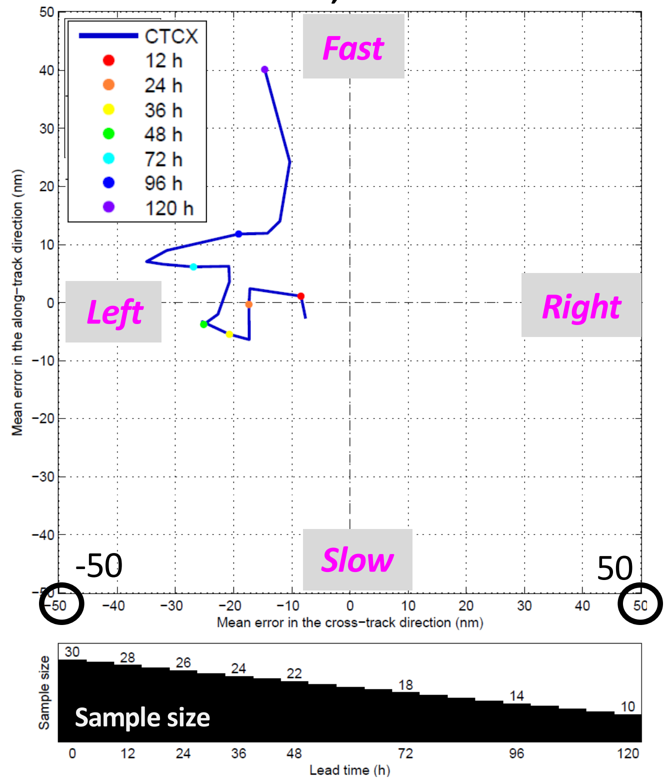
Track Validation: Bias

Track bias, all forecasts



Track bias, all forecasts



- CTCX track forecasts were biased left-of-track at all lead times, but only by 10 – 30 n mi
- CTCX had little bias in the along-track direction, except for a 40 n mi fast bias at 120 h
- GFS, HWRF, and HMON had huge left & slow biases compared with CTCX

CTCX Ian Track Forecast Performance in Context

	Track mean absolute error (n mi)		
Lead time	CTCX Ian	CTCX LTA*	NHC LTA**
12 h	***22.6***	30.9	23.6
24 h	***31.6***	42.5	35.6
36 h	***39.4***	57.0	47.6
48 h	***51.1***	74.1	61.4
60 h	***60.8***	92.7	78.2
72 h	***78.0***	116.4	91.3
96 h	***85.3***	166.0	125.6
120 h	***159.2***	220.7	172.1

Lowest value in bold italics

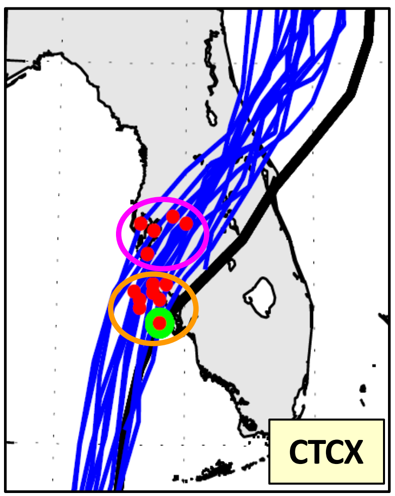
*CTCX long-term average (LTA) calculated for all TCs worldwide Apr 2020 to Apr 2022.
**NHC long-term average (LTA) calculated over all Atlantic TCs 2017-2021

- CTCX track MAE for Ian was lower at all lead times w.r.t. the CTCX long-term average (LTA) track MAE. ***The accuracy of the CTCX Ian track forecasts was about 30% better than the CTCX long-term average***.

- Over the long run, National Hurricane Center (NHC) track MAE is lower than that of any individual model. However, for Ian the CTCX track MAE was lower than the NHC long-term average at all lead times. ***The accuracy of the CTCX Ian track forecasts was about 15% better than the NHC long term average***.

Track Validation: Time of Observed Landfall

- CTCX forecast positions at the time of observed landfall were not perfect, but typically had errors that were superior to the NHC long term average



25/12z to 26/12z Initial times

26/18z to 28/18z Initial times

Blue lines: Forecast tracks
Red dots: Forecast TC positions at time of landfall

Black line: Observed track
Green dot: Observed TC position at time of landfall

CTCX Forecast Position & Error at the Time of Observed Landfall

Florida

Initial time	Forecast Position Lat (deg N)	Forecast Position Lon (deg W)	Error (n mi)
25/12z	27.9	82.7	79.4
25/18z	27.9	82.0	80.7
26/00z	27.5	82.6	54.9
26/06z	28.0	82.2	84.4
26/12z	27.8	82.5	72.0
26/18z	27.1	82.5	30.4
27/00z	27.0	82.8	32.1
27/06z	26.8	82.7	20.1
27/12z	26.9	82.7	24.1
27/18z	27.0	82.5	24.5
28/00z	27.1	82.5	30.4
28/06z	27.1	82.3	30.4
28/12z	26.9	82.4	17.9

CTCX forecast mean: 27.3 N, 82.5 W
Observed position: 26.6 N, 82.4 W
Error of CTCX mean: 42.2 n mi

South Carolina

Initial Time	Forecast Position Lat (deg N)	Forecast Position Lon (deg W)	Error (n mi)
27/12z	32.5	80.6	85.4
27/18z	33.0	80.8	82.6
28/00z	33.1	80.3	56.7
28/06z	33.2	80.0	40.7
28/12z	32.9	79.8	38.6
28/18z	33.0	80.5	67.9
29/00z	33.2	80.6	70.7
29/06z	33.3	79.6	20.1
29/12z	33.3	79.8	30.2
29/18z	32.8	79.9	46.3
30/00z	33.4	79.6	21.0
30/06z	32.9	78.9	28.3
30/12z	32.8	78.8	36.1

CTCX forecast mean: 33.0 N, 79.9 W
Observed position: 33.3 N, 79.2 W
Error of CTCX mean: 39.6 n mi

Green shading indicates CTCX error < NHC long term average error

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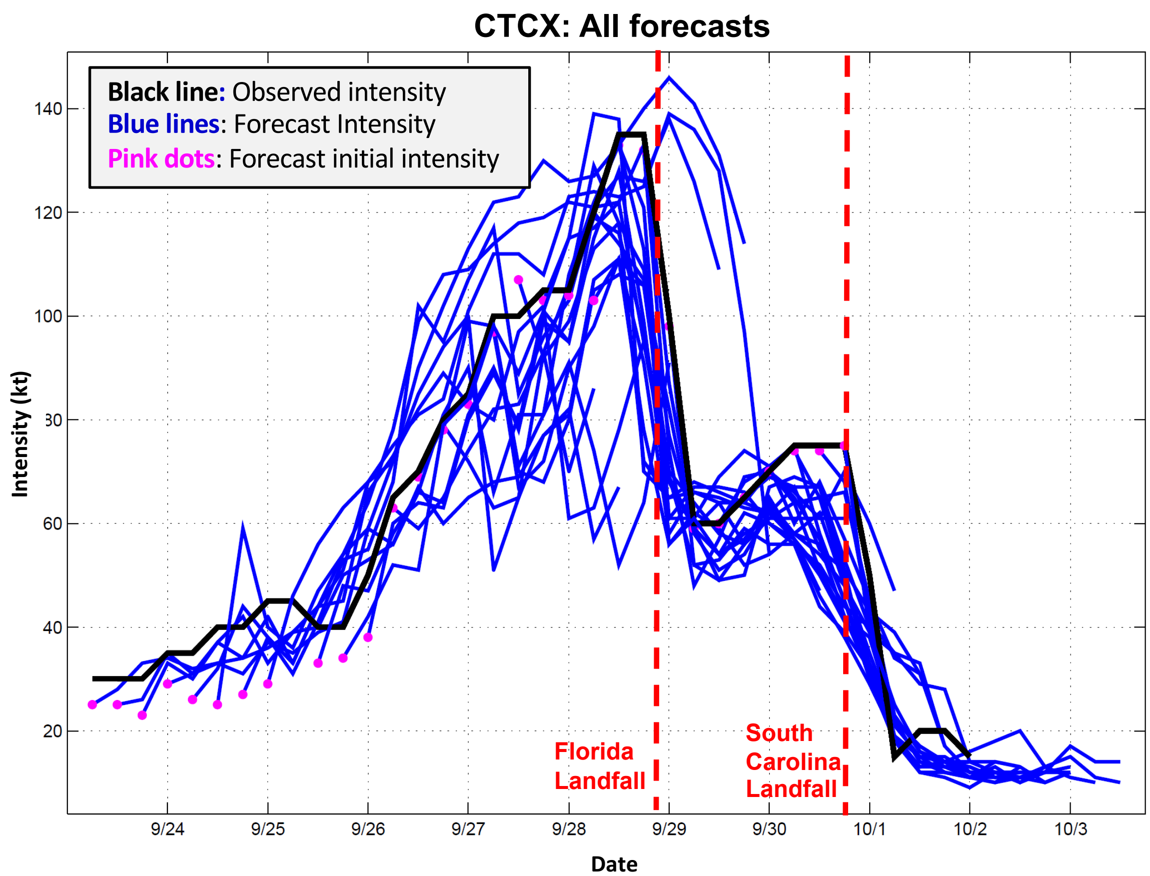
Intensity Validation

- Even in early forecasts 4 to 5 days in advance, when Ian was a weak tropical storm, CTCX predicted Ian to be a major hurricane in the Gulf of Mexico

- CTCX tended to somewhat underestimate
the intensity at landfall, both for Florida and South Carolina



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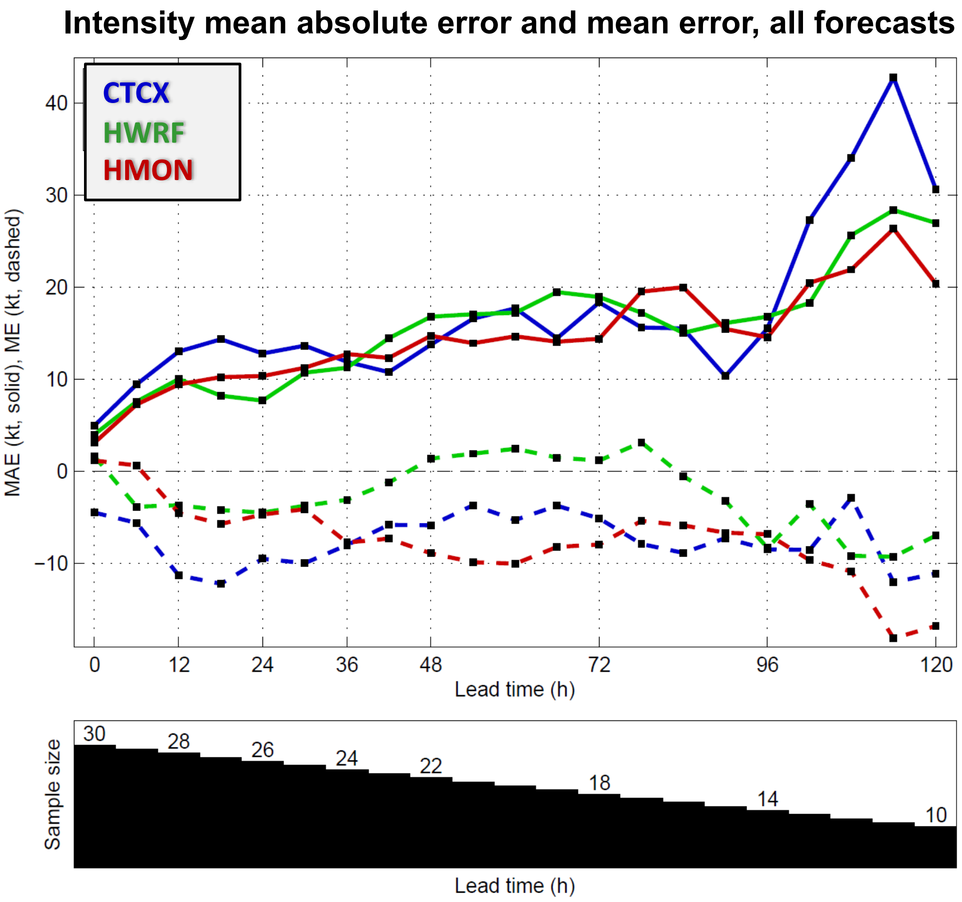
Intensity Validation: Accuracy & Bias

- CTCX has competitive intensity error statistics for most lead times w.r.t. HWRF and HMON, but weakening the storm too much over land hurt CTCX performance (especially) at early lead times
- Within three days of Florida landfall, CTCX, HWRF, and HMON all (usually) predicted a Category 4 peak intensity, as was observed (135 kt)

	Forecast Peak Intensity (kt)		
Initial Time	*COAMPS-TC*	*HWRF*	*HMON*
25/18z	139	118	124
26/00z	128	117	132
26/06z	129	120	122
26/12z	111	121	119
26/18z	133	116	118
27/00z	111	121	123
27/06z	108	122	127
27/12z	118	128	126
27/18z	122	128	124
28/00z	119	128	129
28/06z	111	115	133
28/12z	133	142	139
Average	**121.8**	**123.0**	**126.3**

Category 3: 96 - 112 kt
Category 4: 113 - 136 kt
Category 5: 137+ kt



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Intensity Validation: Pre-landfall Intensity

- The tables show CTCX "pre-landfall" intensity, which is the forecast intensity for the final lead time (6-hourly) for which the TC inner core is entirely offshore
- For the Southwest Florida pre-landfall intensity, CTCX generally predicted a Category 4 intensity (which was as observed). Still, the average CTCX pre-landfall intensity was 15 kt too weak.
- For the South Carolina pre-landfall intensity, CTCX predicted either a tropical storm (earlier forecasts) or a Category 1 hurricane (later forecasts). All forecasts were weaker than the observed 75 kt, on average by 17 kt

Pre-landfall Intensity: Southwest Florida

Initial time	Intensity (kt)
25/12z	114
25/18z	138
26/00z	128
26/06z	129
26/12z	111
26/18z	133
27/00z	106
27/06z	106
27/12z	118
27/18z	122
28/00z	116
28/06z	111
28/12z	133

CTCX forecast mean: 120 kt
Observed: 135 kt

Pre-landfall Intensity: South Carolina

Initial Time	Intensity (kt)
27/12z	51
27/18z	57
28/00z	44
28/06z	51
28/12z	54
28/18z	57
29/00z	56
29/06z	67
29/12z	58
29/18z	67
30/00z	65
30/06z	65
30/12z	68

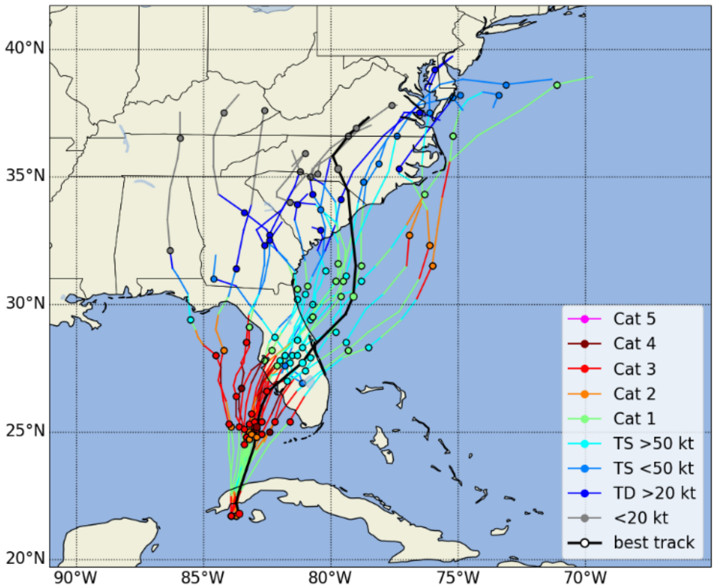
CTCX forecast mean: 58 kt
Observed: 75 kt

Tropical Storm: 34 - 63 kt
Category 1: 64 - 82 kt
Category 2: 83 - 95 kt
Category 3: 96 - 112 kt
Category 4: 113 - 136 kt
Category 5: 137+ kt

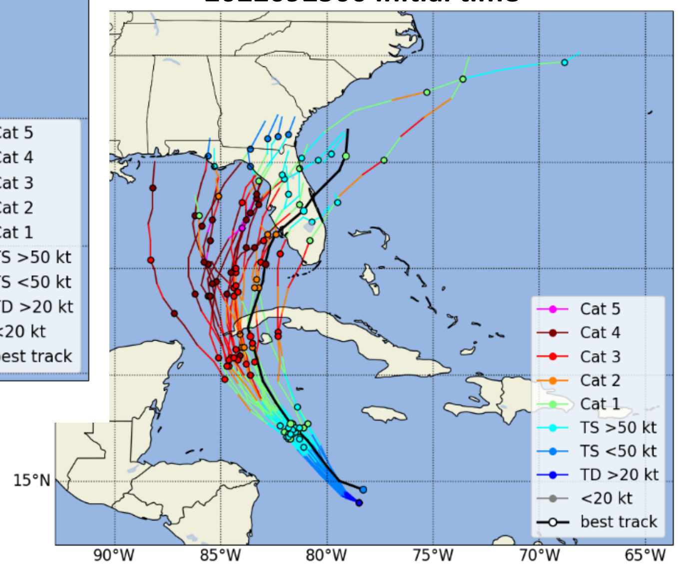
COAMPS-TC Ensemble Forecasts for Ian

Ensemble forecasts consistently indicated a high degree of track uncertainty, with implications for position and timing of Florida and South Carolina landfalls

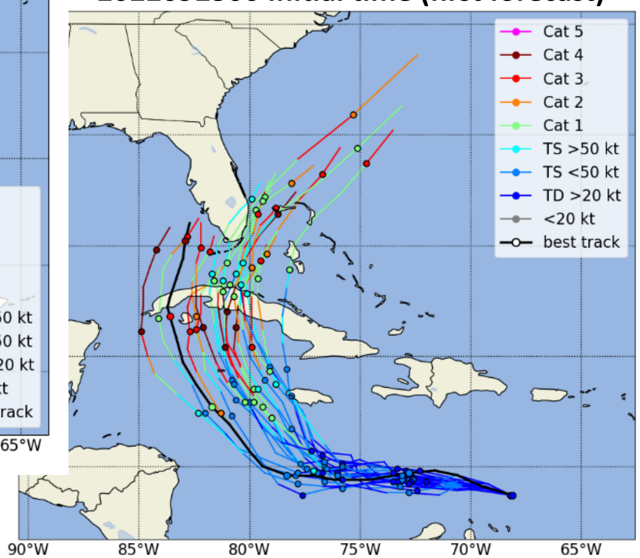
2022092706 Initial time



2022092506 Initial time



2022092306 Initial time (first forecast)



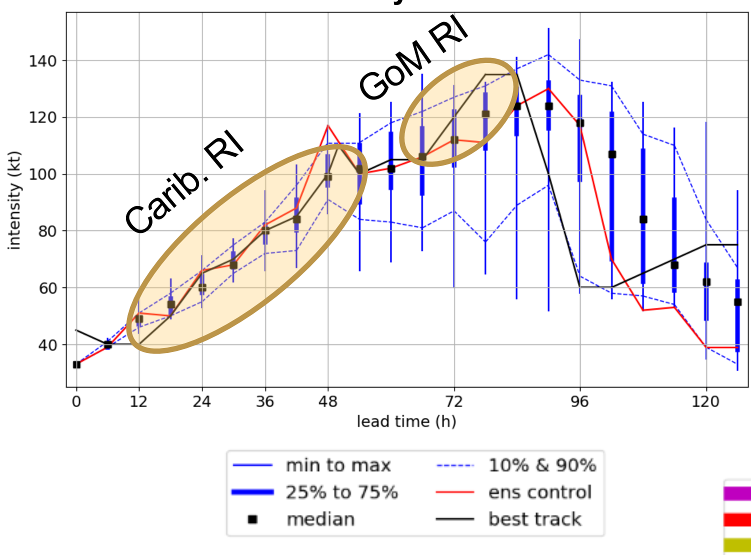
CTCX 21-member real-time ensemble prediction system (EPS): Track colored by intensity

COAMPS-TC Ensemble Forecasts for Ian

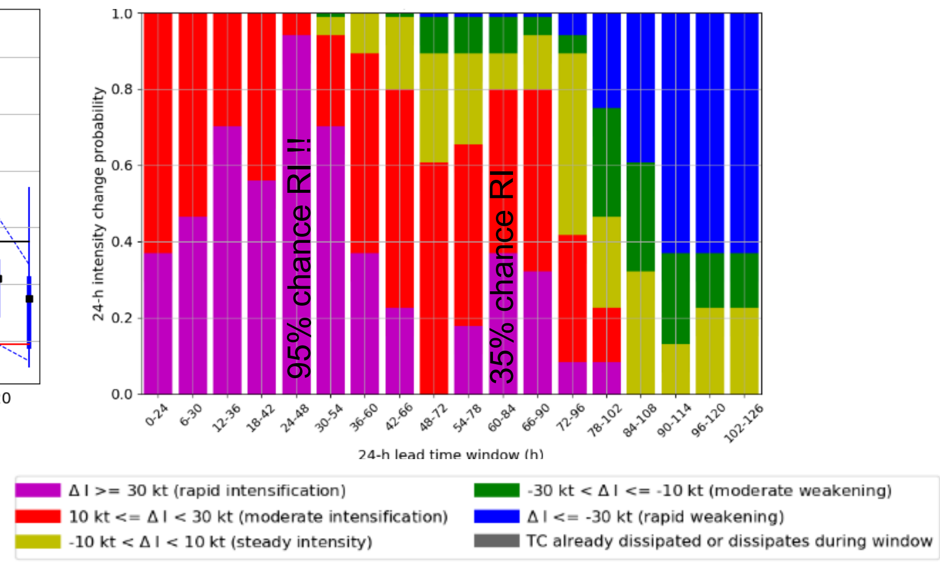
CTCX EPS forecasted very high probability for RI over the Caribbean, and showed a secondary maximum in RI probability over the GoM

CTCX EPS: 2022092506 Initial time

Intensity Forecast



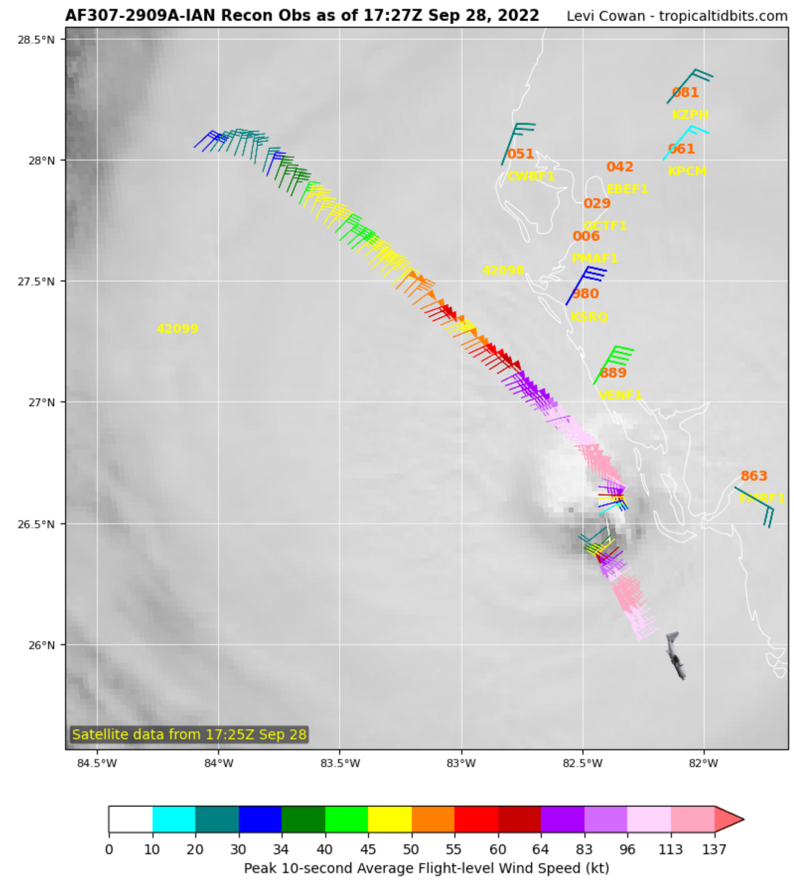
Categorical Intensity Change Forecast



Hurricane Ian: Future Work

(1) Validate COAMPS-TC pre-landfall forecast radial wind speed profile, using Air Force reconnaissance 10-m SFMR wind speeds as ground truth

(2) COAMPS-TC re-analysis for Hurricane Ian



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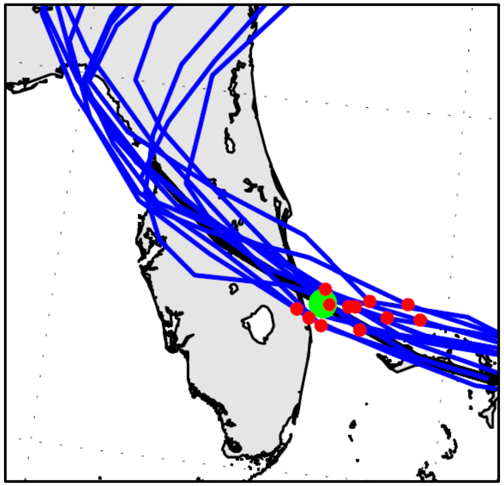
CTCX Nicole Forecast Validation

- CTCX forecast positions at the time of observed landfall were quite accurate, with errors superior to the NHC long-term average. Early forecasts had a slight slow bias

- CTCX pre-landfall intensities were all within 7 kt of the observed value



Blue lines: Forecast tracks
Red dots: Forecast TC positions at time of landfall

Black line: Observed track
Green dot: Observed TC position at time of landfall

CTCX Forecast Position & Error at the Time of Observed Landfall

Initial time	Forecast Position		Error (n mi)
	Lat (deg N)	*Lon (deg W)*	
07/06z	27.2	78.4	80.4
07/12z	27.2	78.9	53.8
07/18z	27.4	78.6	69.7
08/00z	27.4	79.2	37.9
08/06z	27.0	79.3	36.8
08/12z	27.3	79.4	26.7
08/18z	27.3	79.5	21.4
09/00z	27.2	80.3	22.2
09/06z	27.1	80.1	16.0
09/12z	27.5	79.9	12.0
09/18z	27.0	79.9	17.9
10/00z	27.3	79.8	5.3

CTCX forecast mean: 27.2 N, 79.4 W
Observed position: 27.3 N, 79.9 W
Error of CTCX mean: 24.9 n mi

CTCX error < NHC long term average error

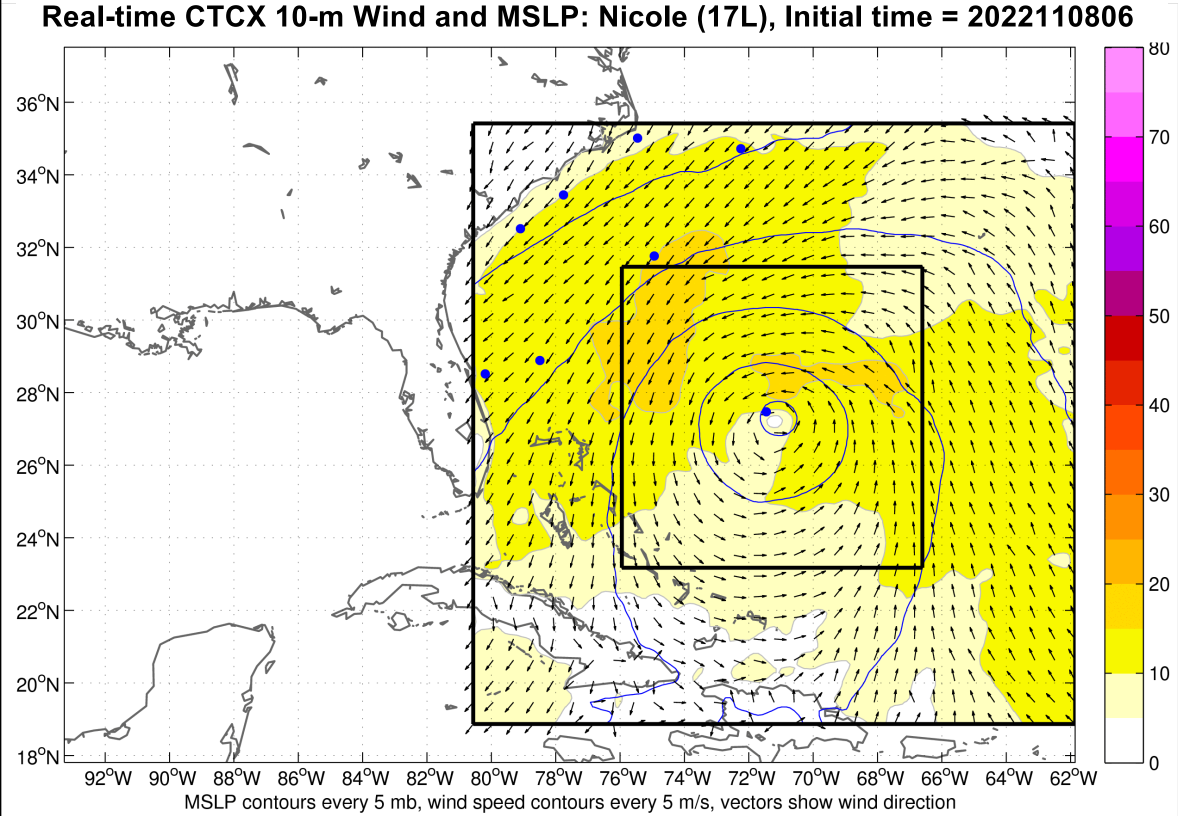
Pre-landfall Intensity: Florida East Coast

Initial time	Intensity (kt)
07/06z	60
07/12z	60
07/18z	62
08/00z	65
08/06z	60
08/12z	59
08/18z	58
09/00z	65
09/06z	64
09/12z	58
09/18z	65
10/00z	71

CTCX forecast mean: 62 kt
Observed: 65 kt

Tropical Storm: 34 - 63 kt
Category 1: 64 - 82 kt
Category 2: 83 - 95 kt
Category 3: 96 - 112 kt
Category 4: 113 - 136 kt
Category 5: 137+ kt

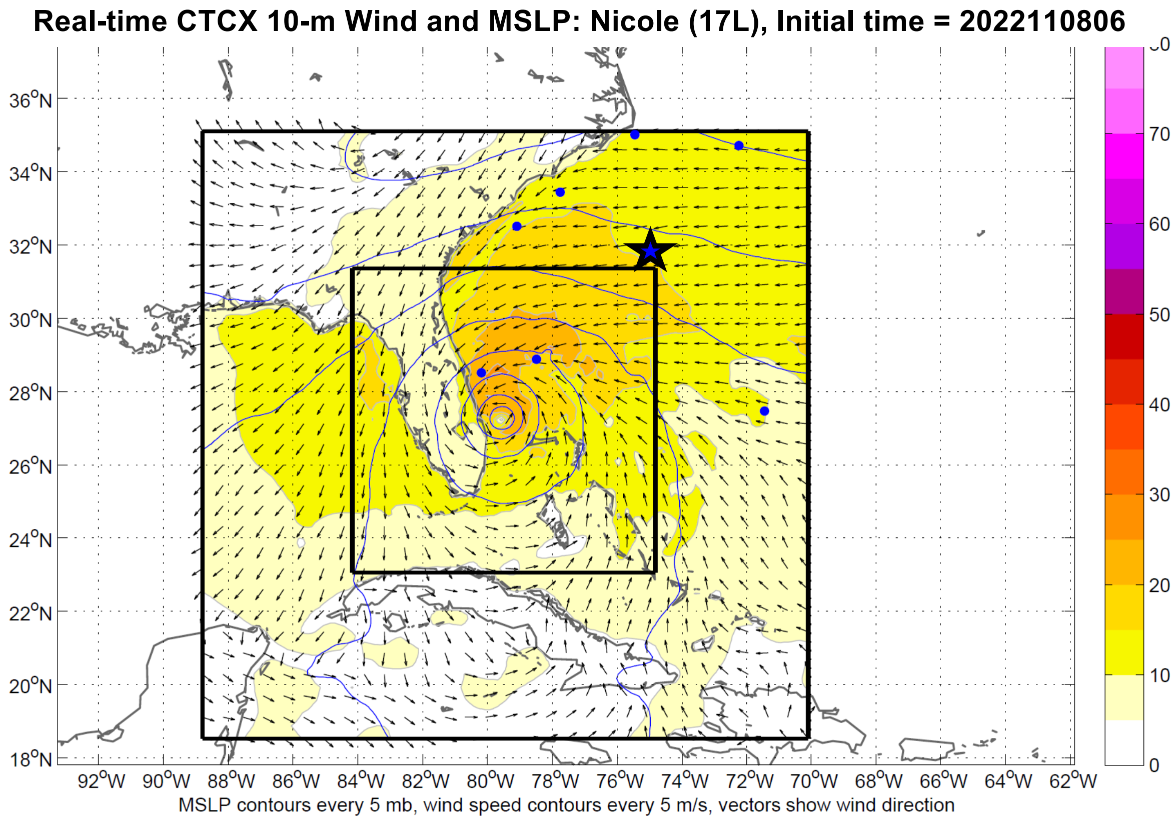
CTCX Nicole Forecast Validation

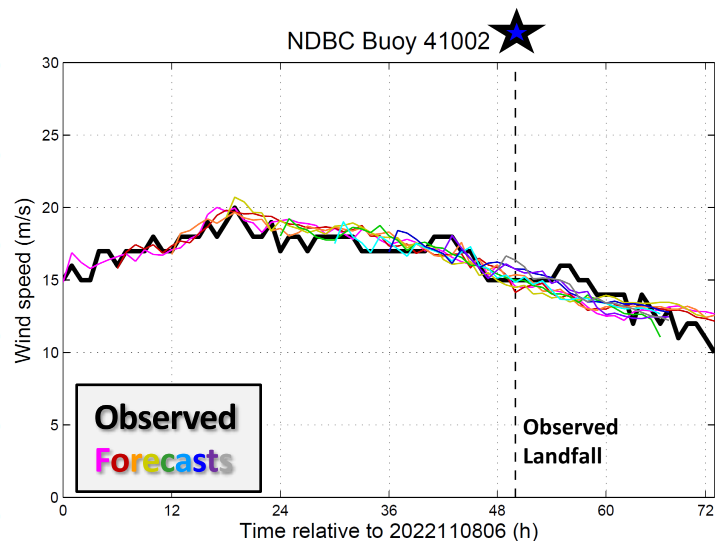


Loop shows 0 to 72 h lead time, every 6 h

Blue dots: Select NDBC buoy locations

CTCX Nicole Forecast Validation



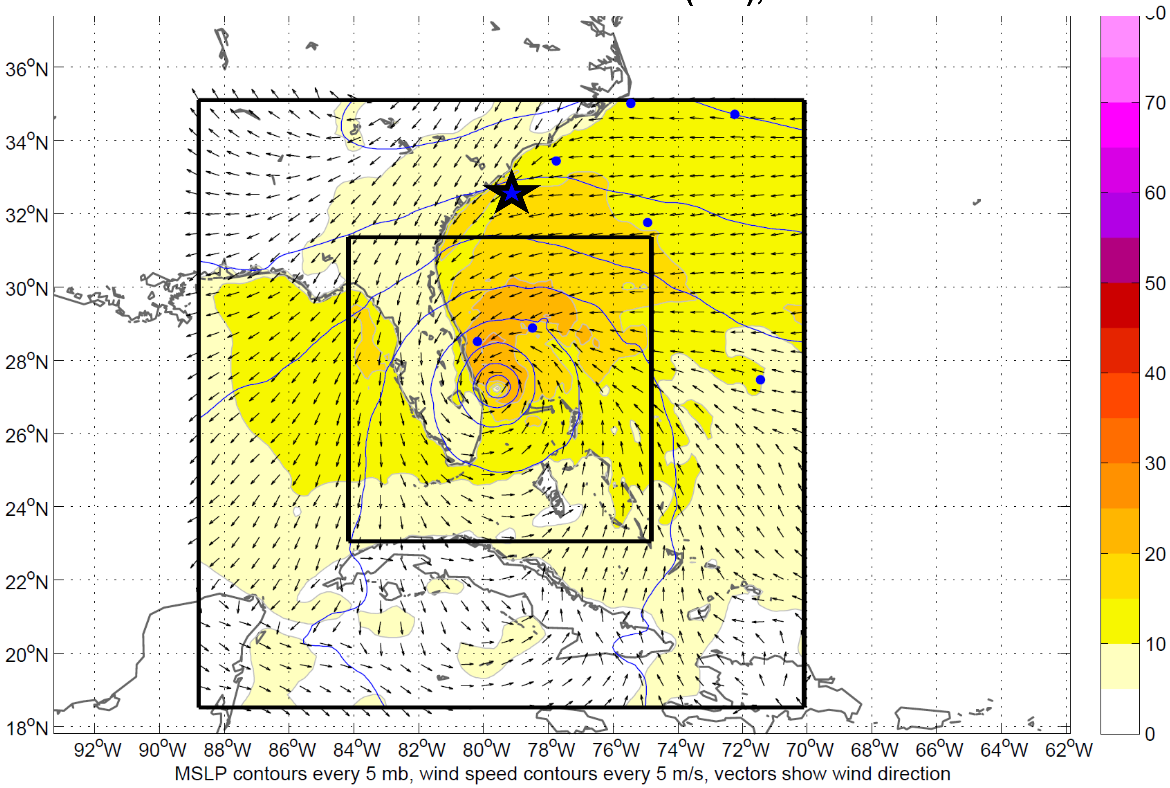


Forecast wind speed over the ocean well N & NE of the storm closely matches buoy obs

50 h forecast valid at time of observed landfall

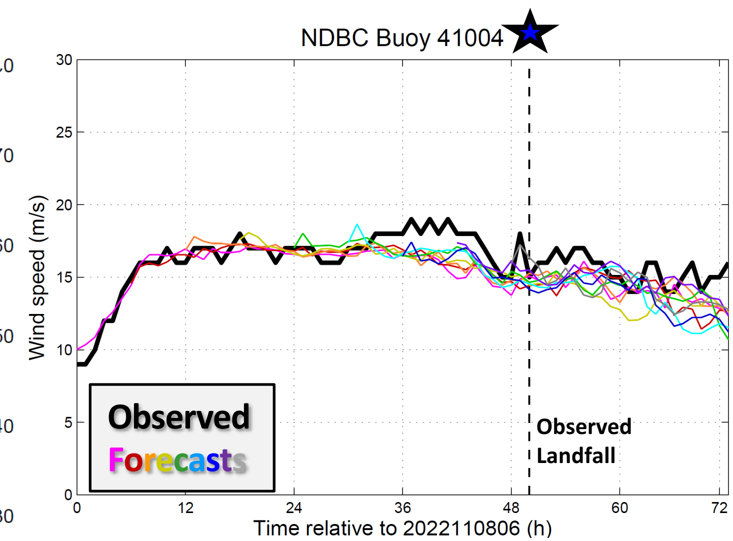
Blue dots: Select NDBC buoy locations

CTCX Nicole Forecast Validation



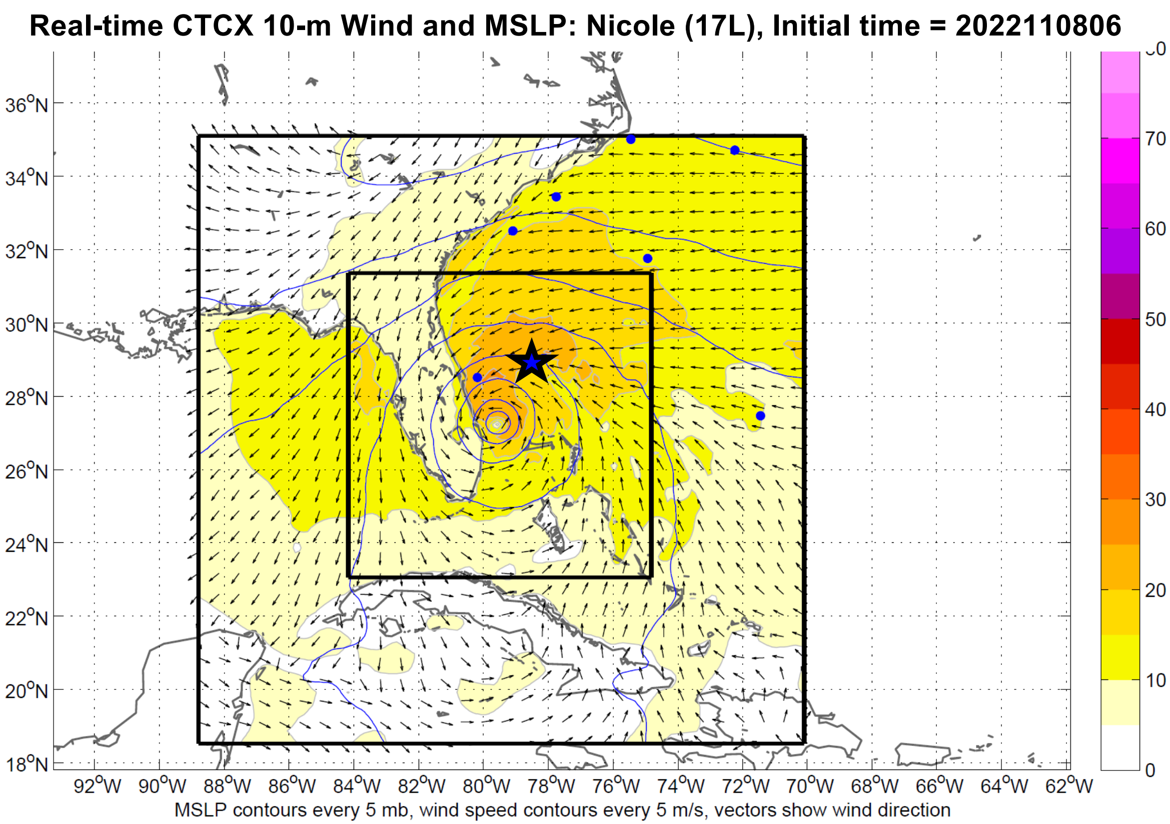
50 h forecast valid at time of observed landfall

Blue dots: Select NDBC buoy locations



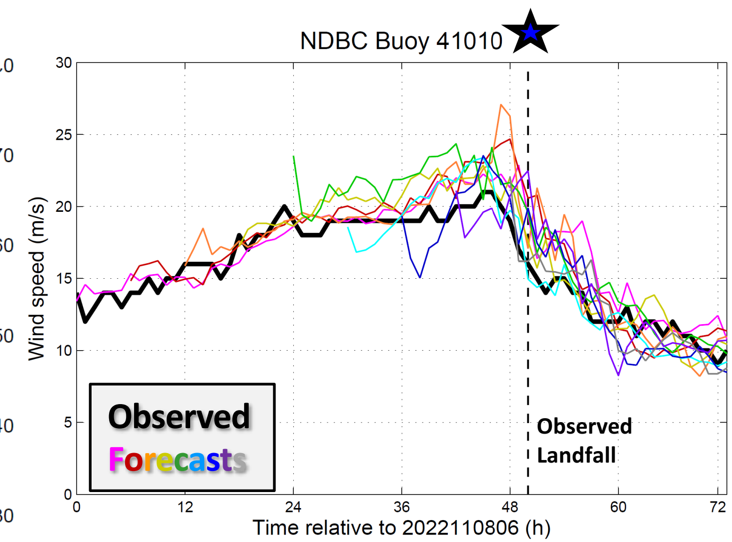
Off the Carolina coast, forecast wind speeds were good except for a slight low bias in the 14 h before observed landfall

CTCX Nicole Forecast Validation



50 h forecast valid at time of observed landfall

Blue dots: Select NDBC buoy locations



Forecast winds were typically somewhat too strong as Nicole passed south of Buoy 41010. Exceptions are the early lead times of a few later forecasts (**09/12z**, **09/18z**, **10/00z**).

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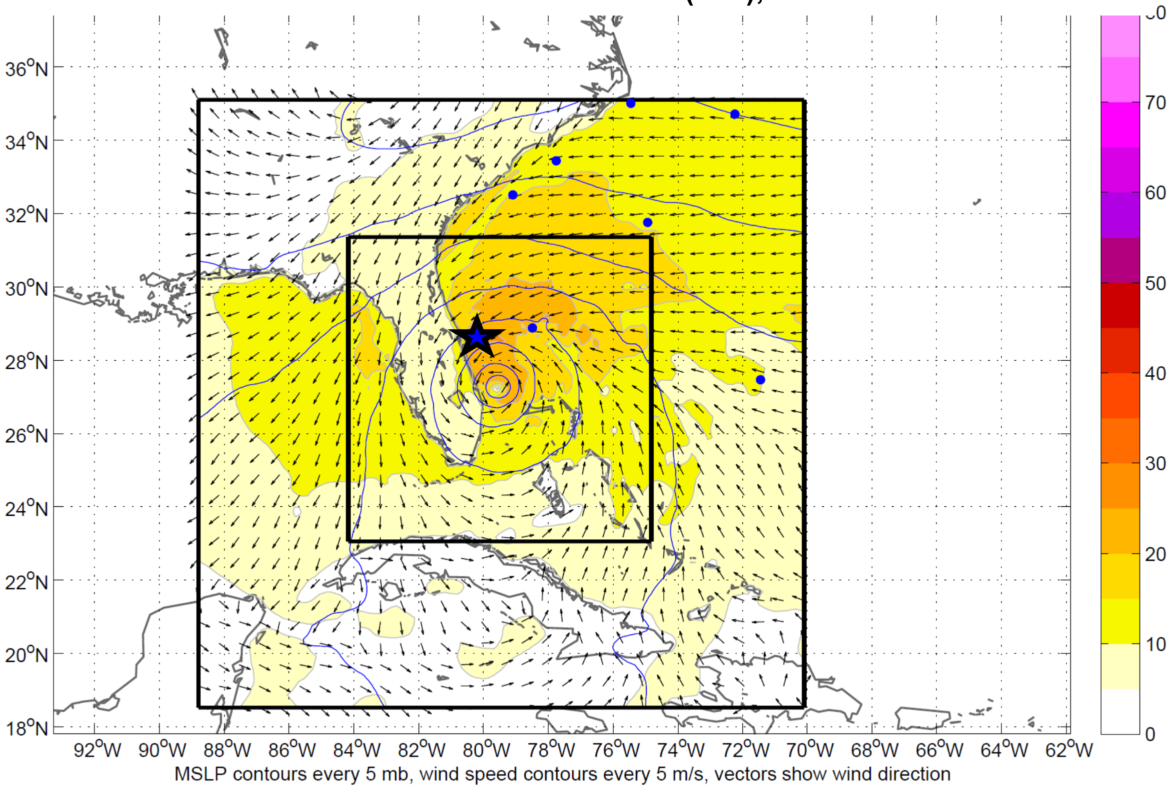
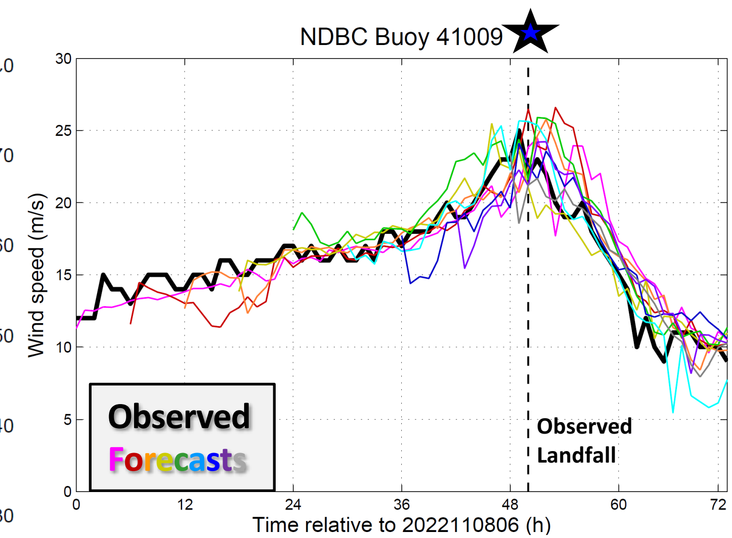
CTCX Nicole Forecast Validation

Real-time CTCX 10-m Wind and MSLP: Nicole (17L), Initial time = 2022110806



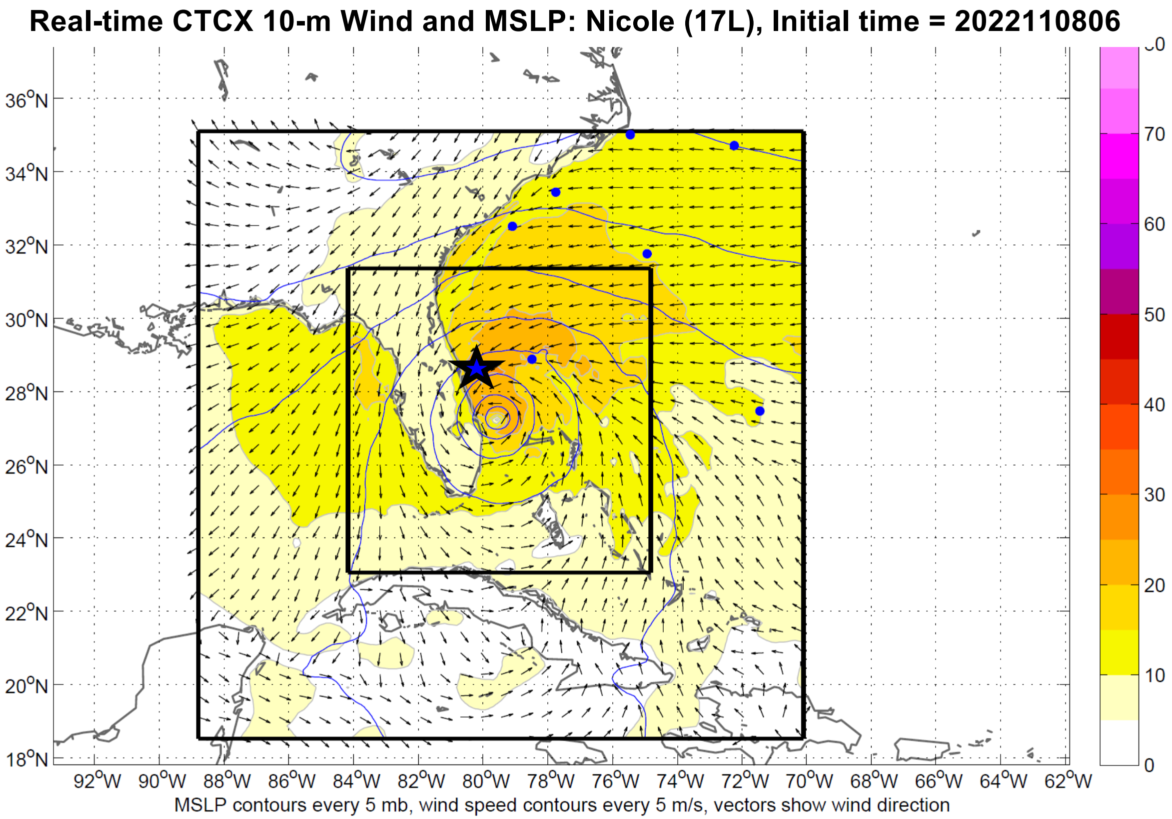


50 h forecast valid at time of observed landfall

Blue dots: Select NDBC buoy locations

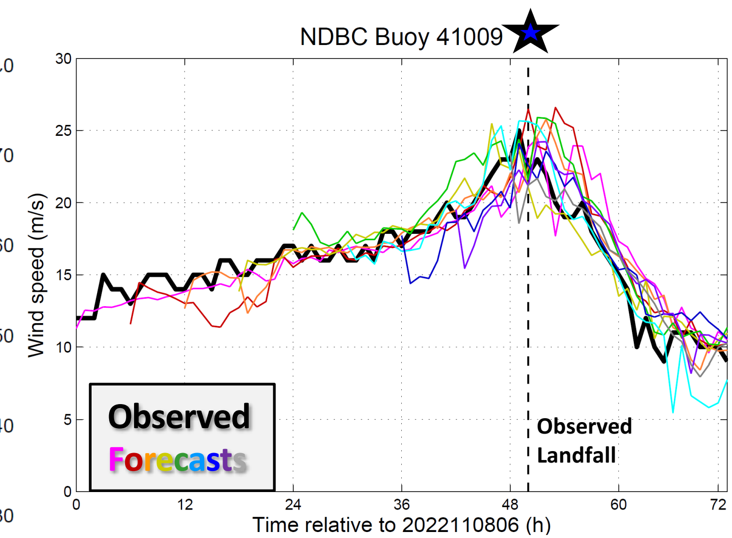
Peak wind speed forecast just off Cape Canaveral is very good, but there are timing errors. Note a couple forecasts are too weak at a few early leads (**09/18z**, **10/00z**).

CTCX Nicole Forecast Validation



50 h forecast valid at time of observed landfall

Blue dots: Select NDBC buoy locations



On balance, COAMPS-TC forecast 10-m wind speeds compare favorably with the NDBC buoy observations north of the storm track

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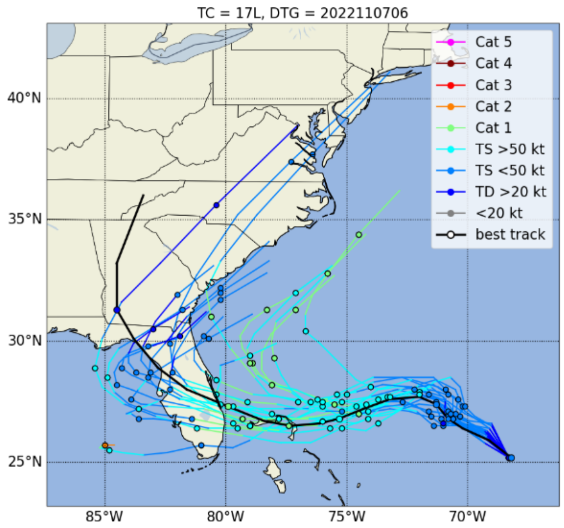
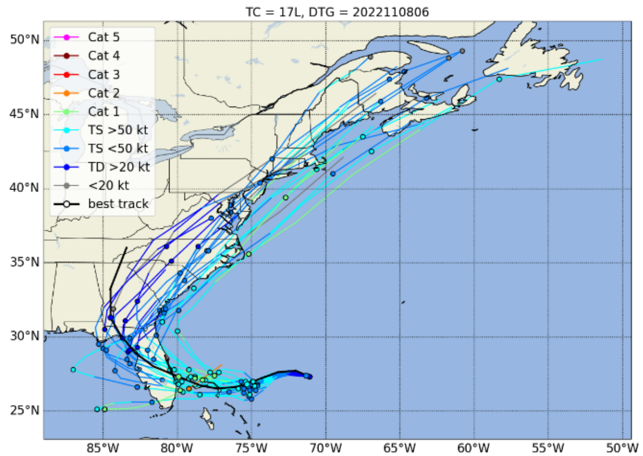
COAMPS-TC Ensemble Forecasts for Nicole

Ensemble forecasts indicated a high degree of track uncertainty at early lead times, but with verifying track location close to center of distribution of most forecasts

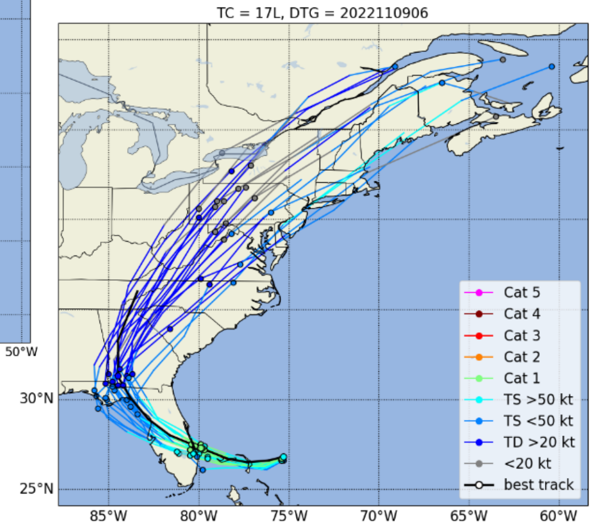
2022110706 Initial time (first forecast)



2022110806 Initial time



2022110906 Initial time



CTCX 21-member real-time ensemble prediction system (EPS): Track colored by intensity

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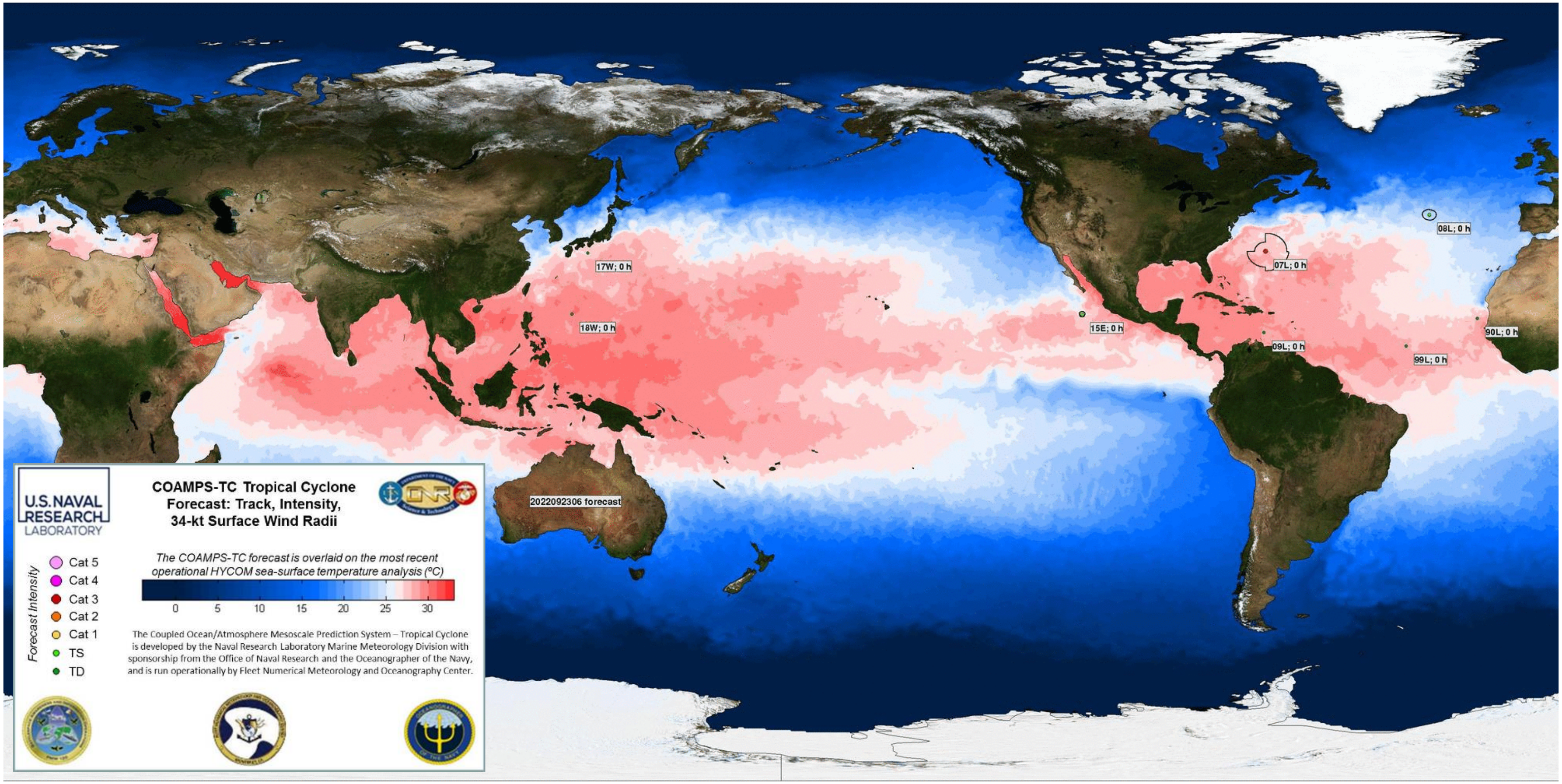
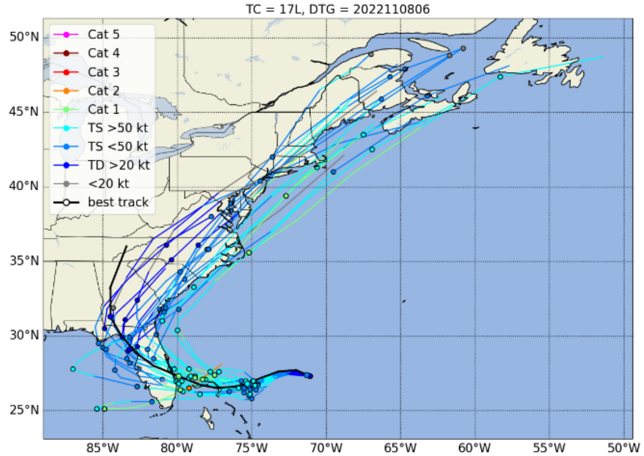
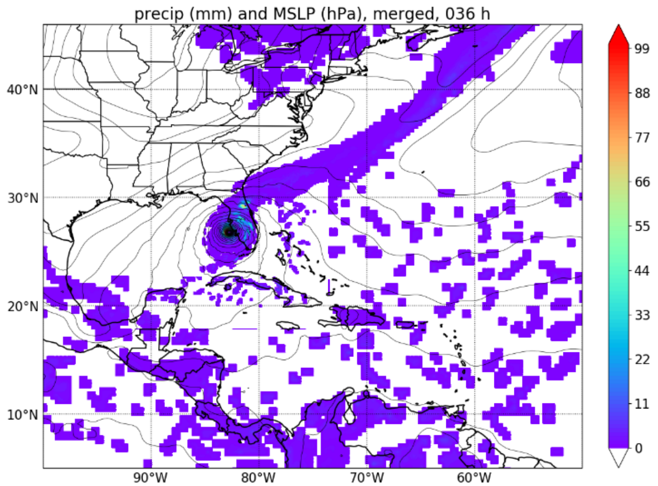
COAMPS-TC real-time forecasts on the Omniglobe



"Task 0" Plans for 2023

- Complete Hurricane Ian (2022) reforecast and distribute to NHCI collaborators
- Provide real-time forecast products, forecast support and guidance for 2023 Atlantic Hurricane Season
- Produce and distribute additional probabilistic products, leveraging the COAMPS-TC Ensemble
- Work with collaborators on Hurricane Michael (2018), Hurricane Ian (2022) reforecast analysis, collaborate on conference presentations and publications

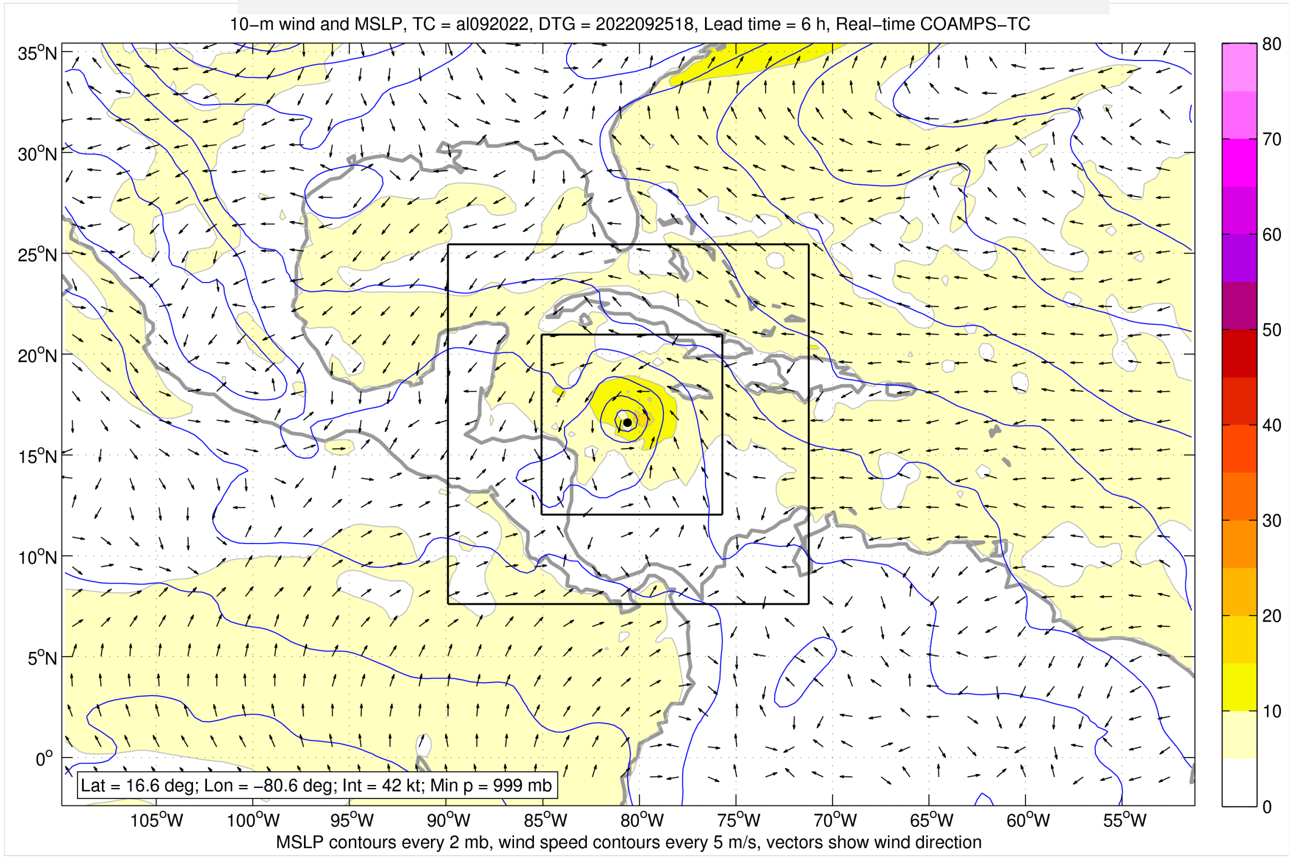




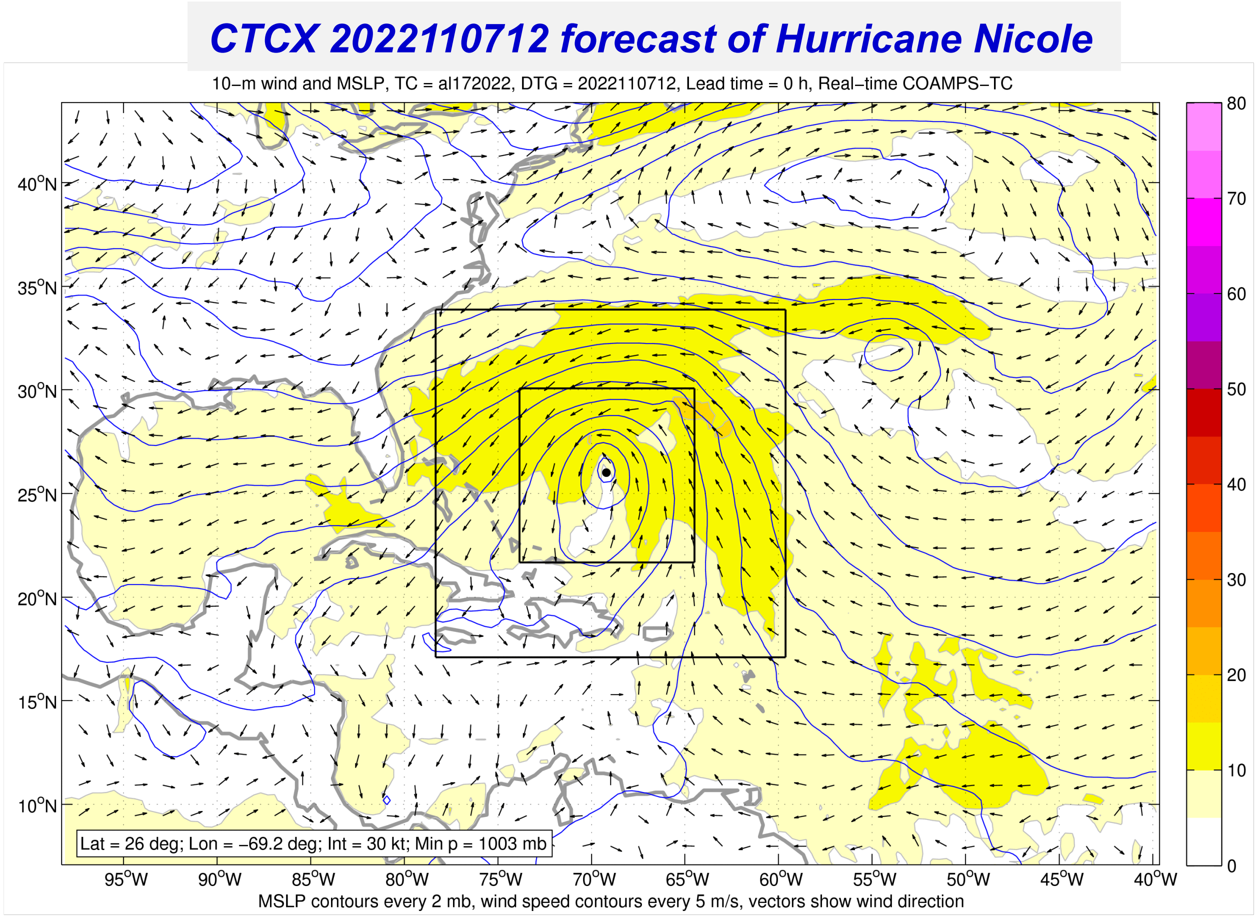
Extra Slides

Hurricane Ian

CTCX 2022092518 forecast of Hurricane Ian



CTCX Nicole Forecast Validation



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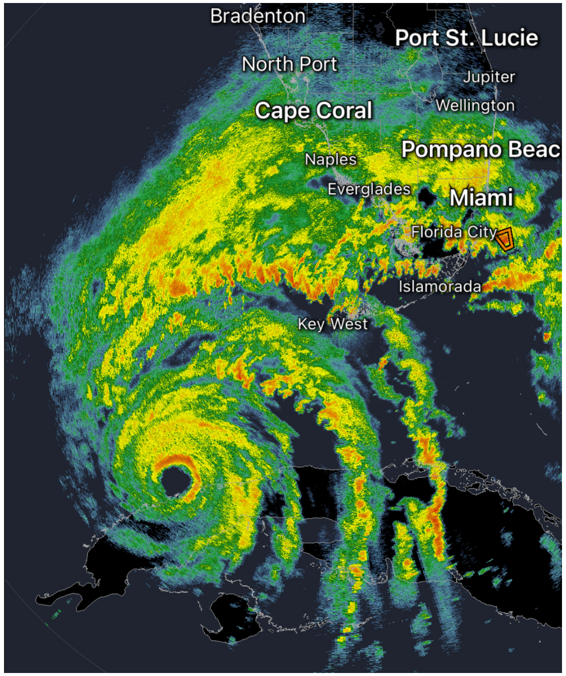
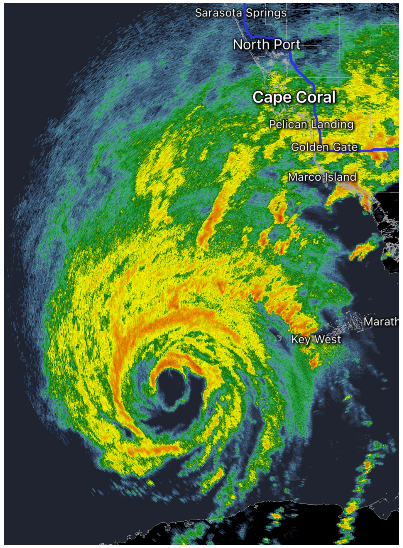
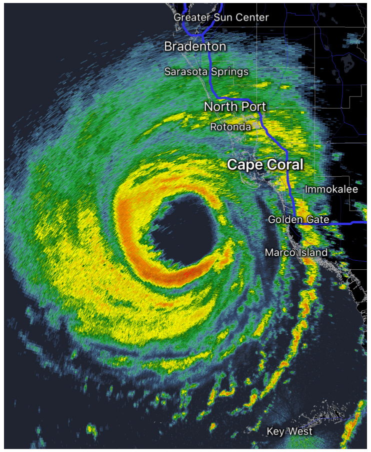
COAMPS-TC Ensemble Forecasts for Ian

The prediction challenge presented by Ian is that of late-stage structural evolution, in this case RI coming out of an ERC







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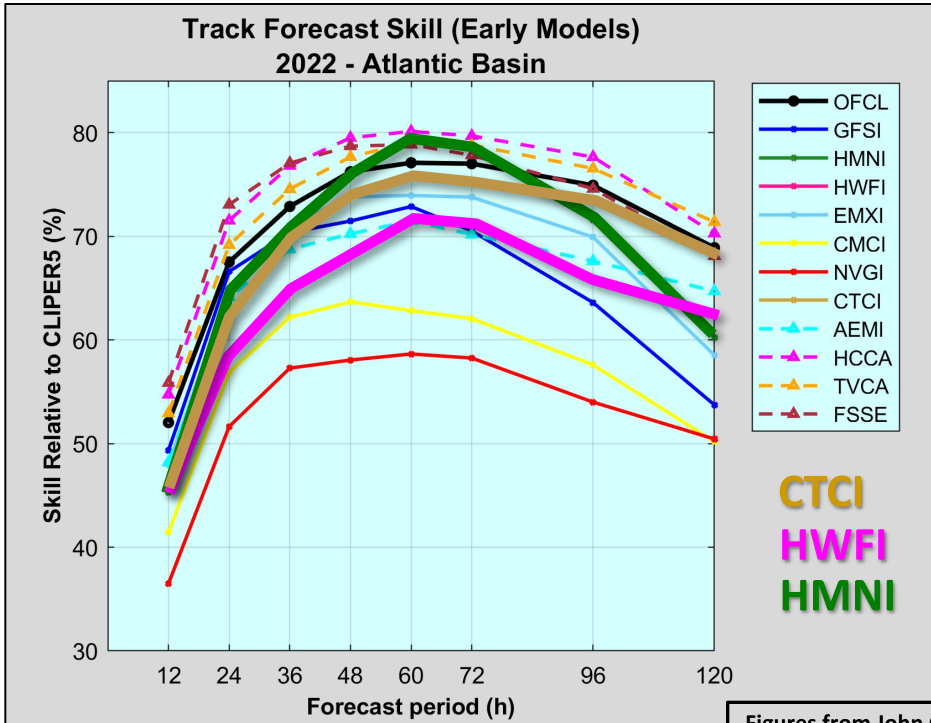
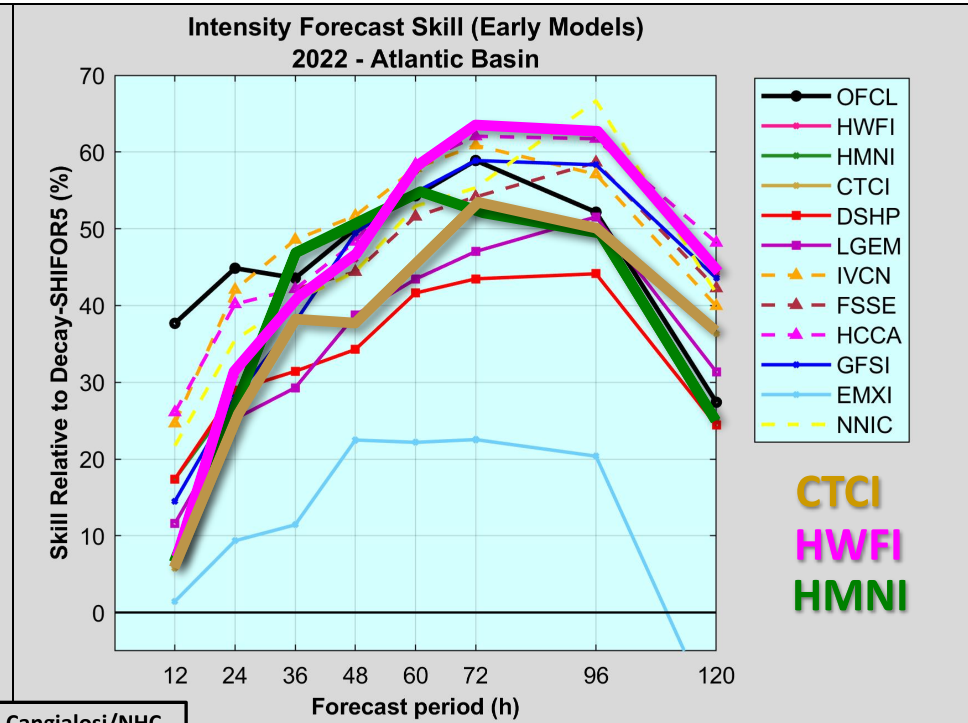
2022 Atlantic Summary Performance Statistics





Figures from John Cangialosi/NHC

Strong performance from the regional dynamical models in the 2022 Atlantic: CTCI and HMNI were the best individual models for track. HWFI was the best individual model for intensity, CTCI/HWFI/HMNI all ahead of DSHP/LGEM.

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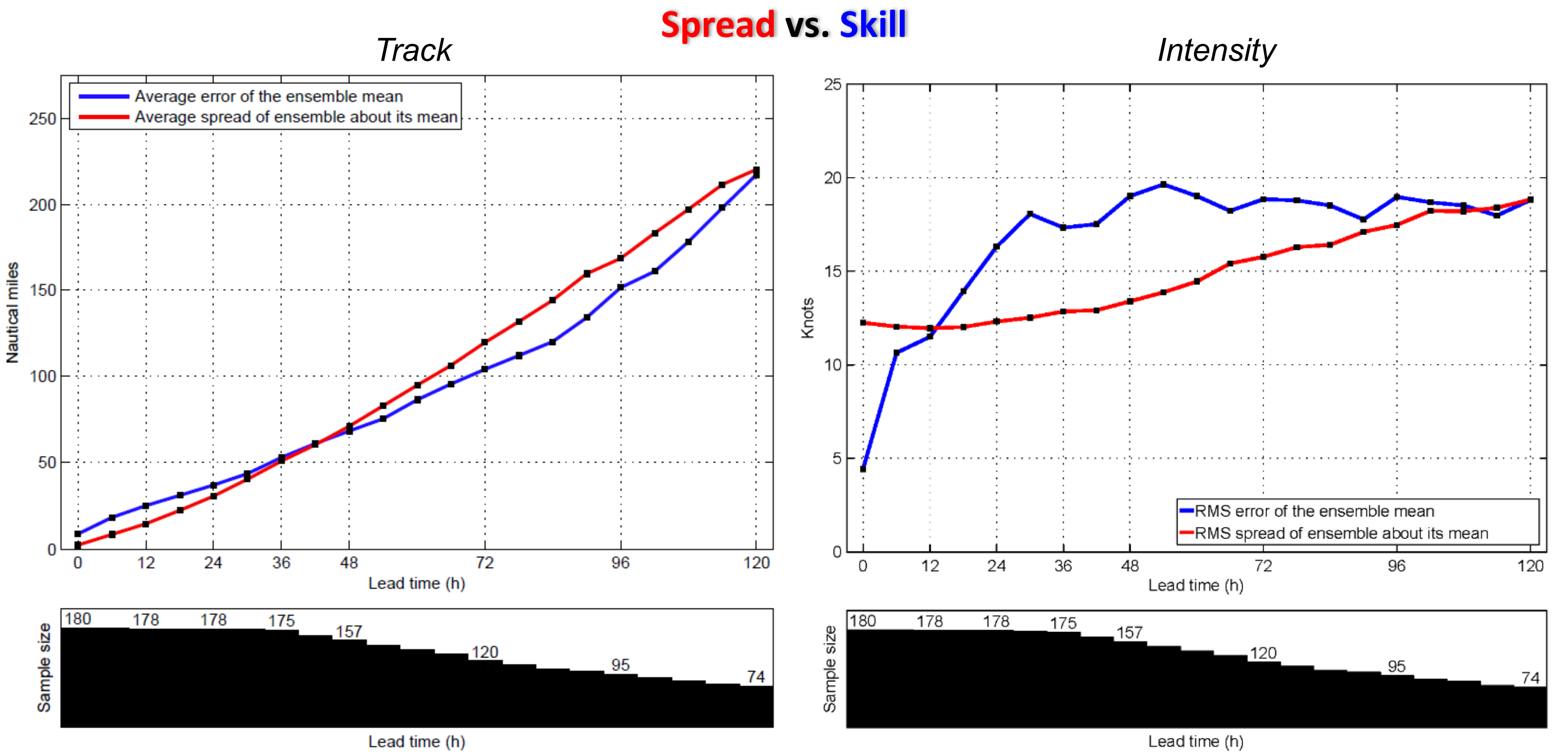
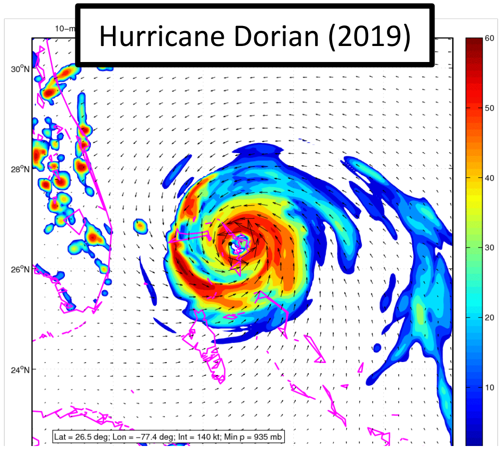
COAMPS-TC Ensemble: Spread vs skill scores



- Ensemble spread is well-calibrated for track
- Ensemble is under-dispersive for intensity at most lead times

COAMPS-TC Ensemble: Operational and Demonstration Systems

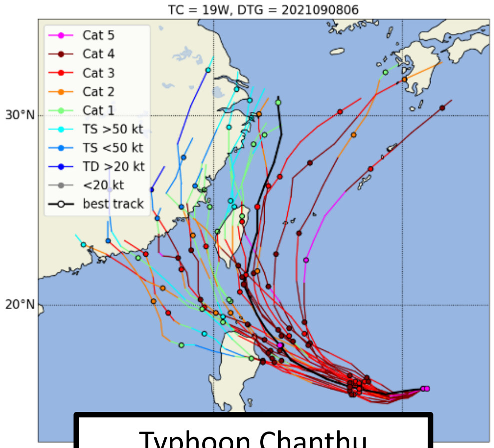
- COAMPS-TC is a specialized version of the Navy's mesoscale numerical weather prediction (NWP) model, COAMPS, designed to predict tropical cyclone (TC) track, intensity and structure (wind radii)
- Features: TC-following nested grid meshes (36/12/4-km resolution, 40 vertical levels), Specialized TC physics (Drag coefficient; boundary layer); TC Vortex initialization, GFS initial conditions (ICs) and boundary conditions (BCs)
- COAMPS-TC Ensemble: Perturbed synoptic-scale ICs, BCs, vortex initial intensity, and drag coefficient (see extra slides if interested)
    - 11 members run operationally at FNMOC
    - 21 members run experimentally (demo mode) by NRL



Hurricane Dorian (2019)

New in v2021 (operational at FNMOC as of June 2022)

- Now running Invests
- Adjusted IC/BC perturbation magnitudes
- Updates to shallow cumulus parameterization
- GFS downscaling for weak TCs (<= 55 kt), modified (smaller) initial vortex for TCs > 55 kt
- Improved parameterized 1-D SST cooling (uncoupled)
- Graupel-radiation interaction
- Updated surface drag coefficient for higher wind speeds
- Modified nested grid blendzone (improves track performance)



Typhoon Chanthu (2021)

COAMPS-TC Ensemble: Ensemble Perturbations

A variety of perturbation techniques are employed to perturb ICs/BCs in synoptic environment, initial vortex, and physics

Synoptic environment perturbations

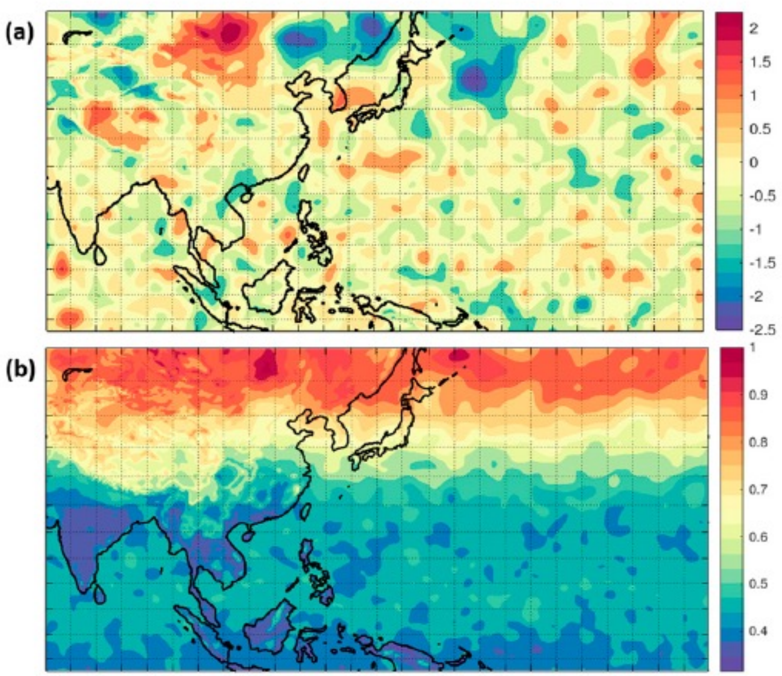
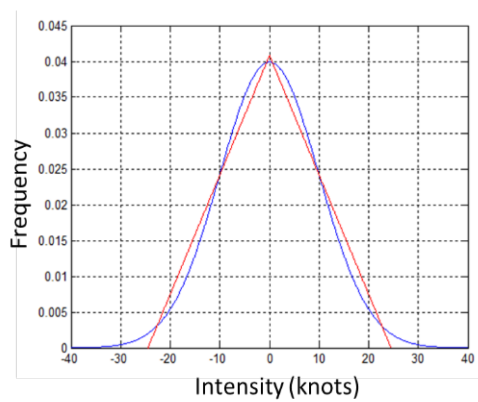


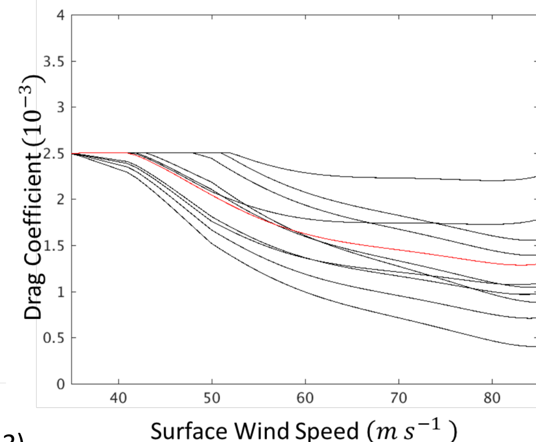
FIG. 2. (a) Single realization of the initial condition perturbation of potential temperature at model level 20 (~630 hPa) for the western Pacific COAMPS-TC ensemble domain. (b) The standard deviation of potential temperature perturbations at model level 20 for the western Pacific COAMPS-TC ensemble domain.

Initial vortex perturbations



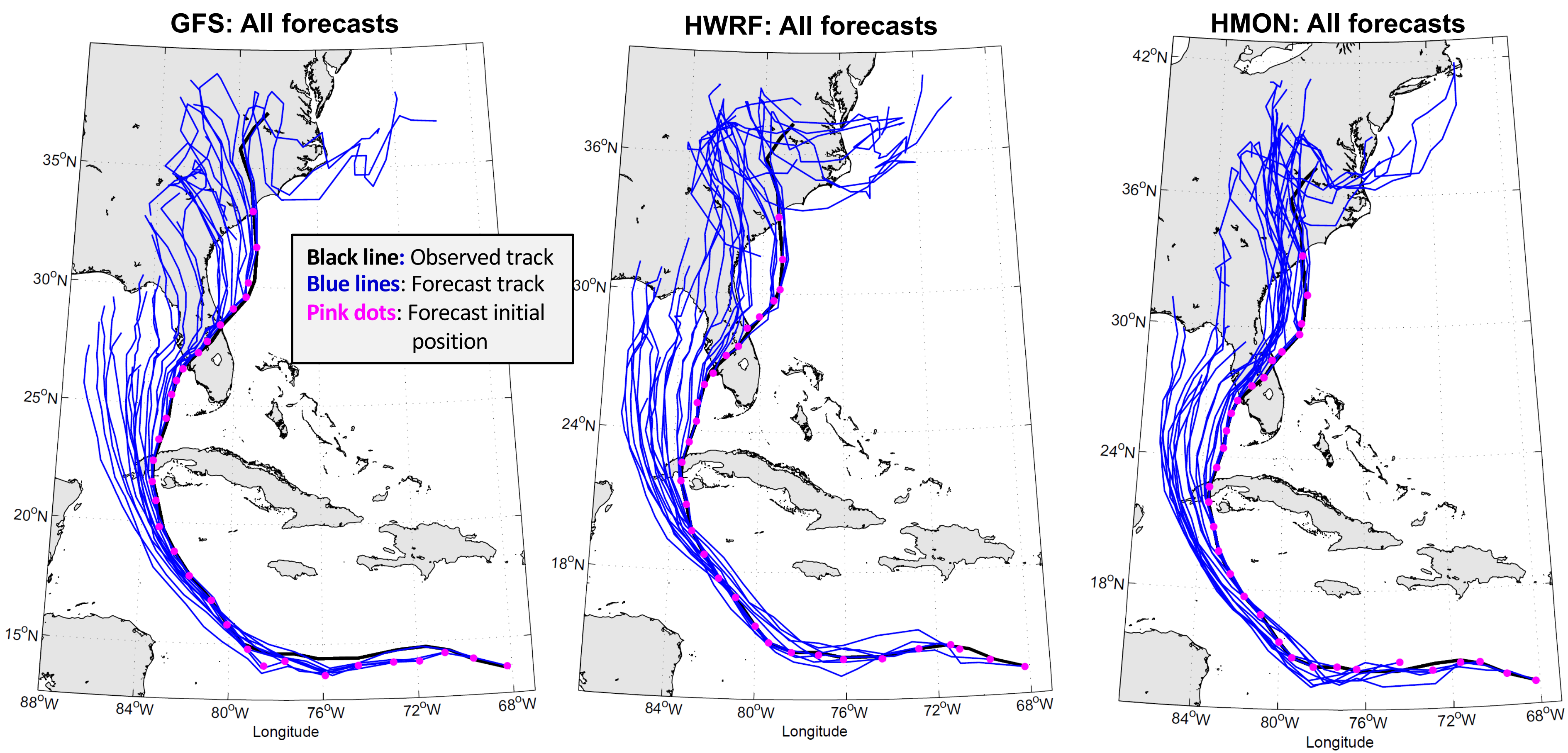
Following Landsea and Franklin (2013)

Drag coefficient perturbations



Powell et al. (2003), Donelan et al. (2004), Donelan (2018), Soloviev et al. (2017)

Track Validation



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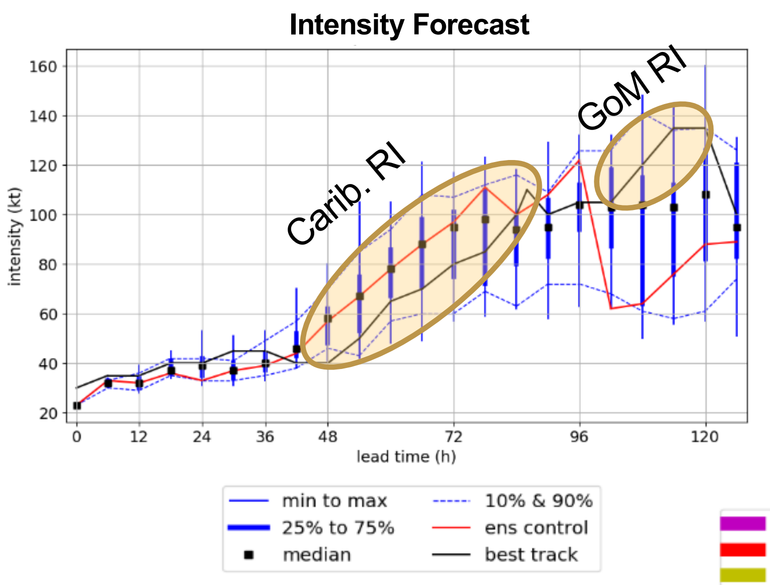
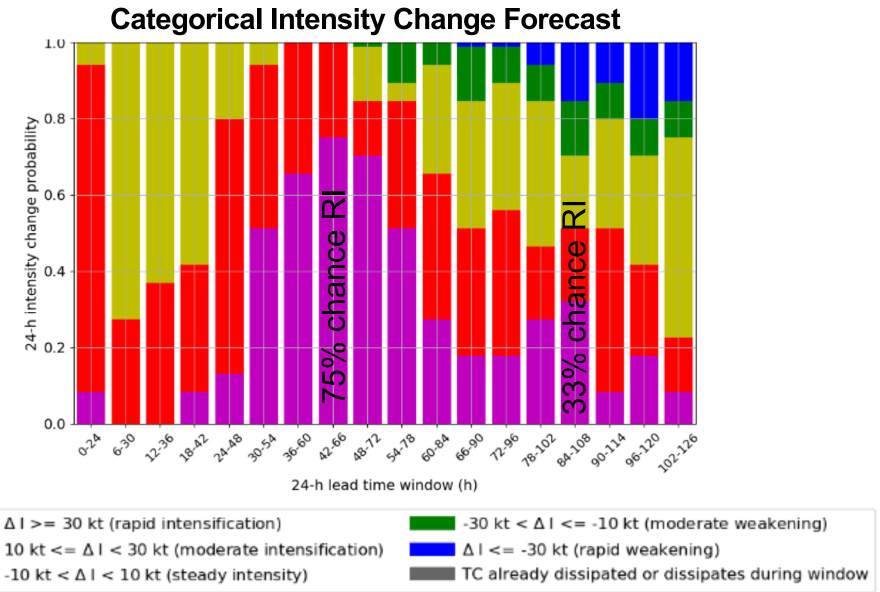
COAMPS-TC Ensemble Forecasts for Ian

CTCX EPS forecasted very high probability for RI over the Caribbean, and showed a secondary maximum in RI probability over the GoM

CTCX EPS: 2022092318 Initial time





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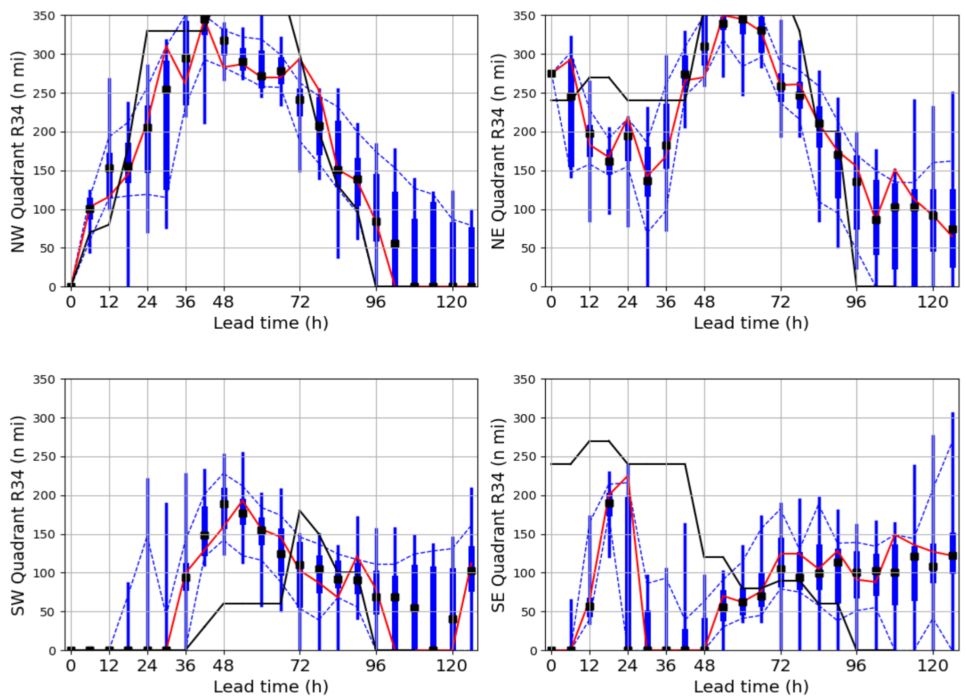
COAMPS-TC Ensemble Forecasts for Nicole

Nicole was also noteworthy for its very large 34-kt wind radii (R34), which were generally well-predicted by the CTCX Ensemble

R34, TC = 17L, DTG = 2022110706

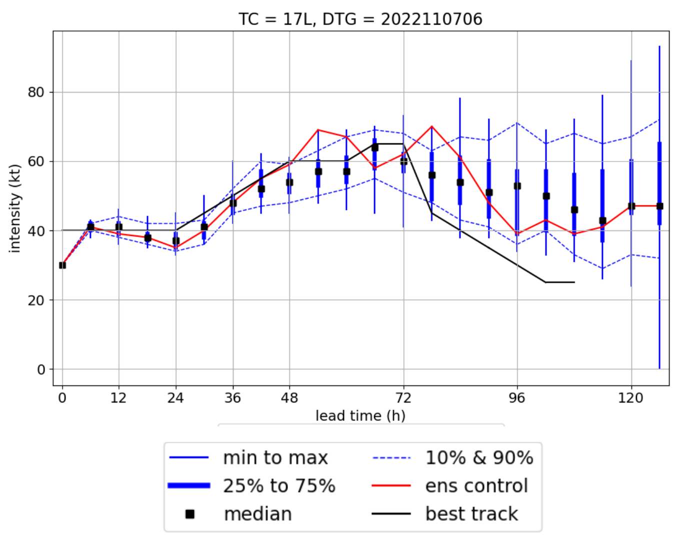


COAMPS-TC Ensemble Forecasts for Nicole

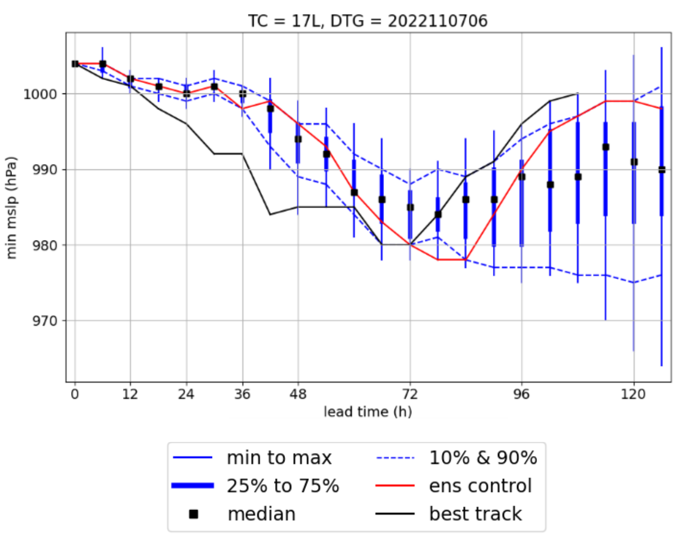
CTCX EPS correctly predicted a relatively steady intensity for Nicole, fluctuating between 35-65 kt throughout its lifetime
MSLP forecasts were a bit too slow to deepen storm at early lead times

CTCX EPS: 2022110706 Initial time

Maximum 10-m Wind Forecast (kt)

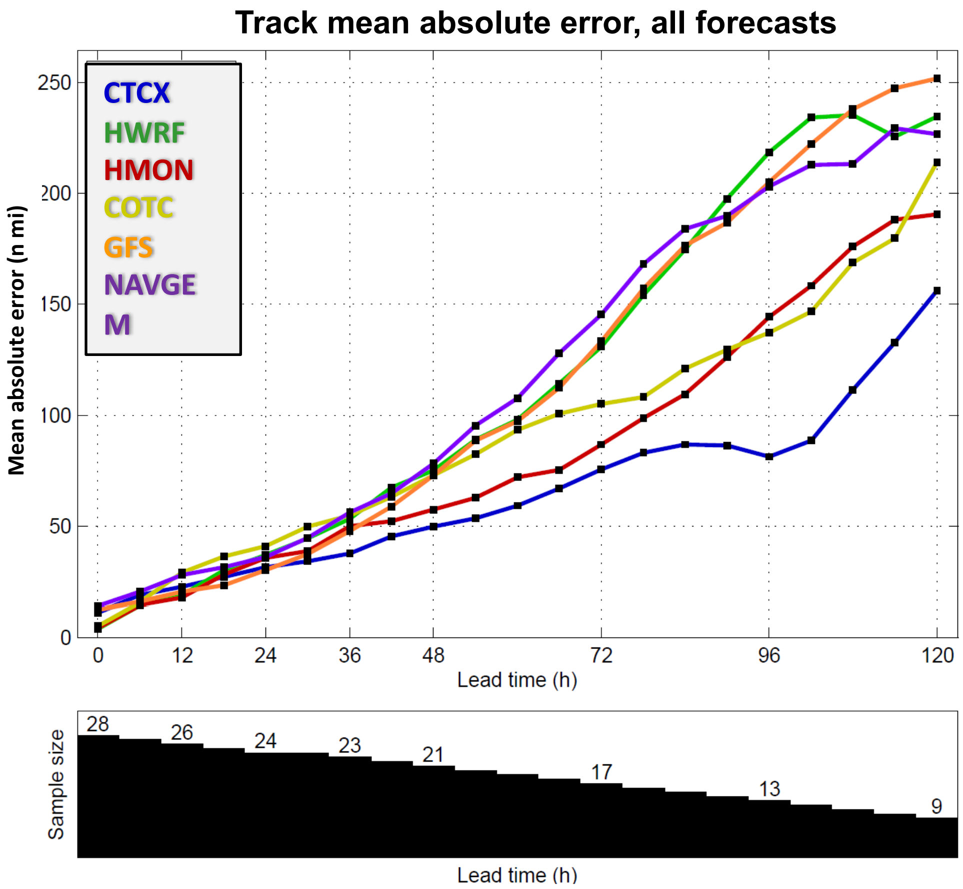


Minimum Central Pressure Forecast (mb)



Track Validation: Accuracy

- For overall track MAE, CTCX was the best of the "GFS family" of models
- COTC (COAMPS-TC with NAVGEM initial and lateral boundary conditions) performed reasonably well but had higher track MAE than CTCX



NOPP Hurricane Coastal Impacts
Task 1 – Digital Elevation Models

Dean Gesch
Jeff Danielson
Nicholas Enwright
Kristin Byrd
Jason Stoker

Chris Amante

Dan Buscombe

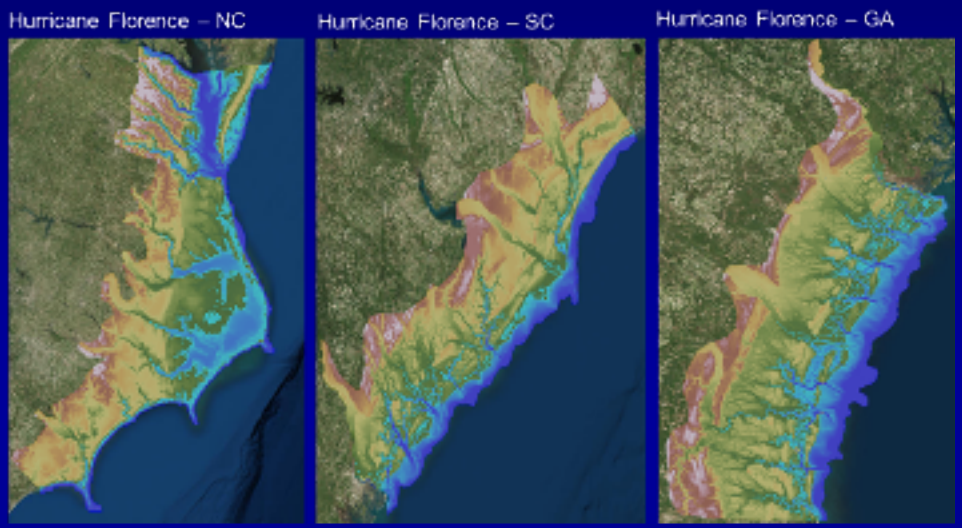
Evan Goldstein

NHCI Task 1: Digital Elevation Models

- *"Coastal Elevation Models and Land Surface Variables for Use in Forecasting Hurricane Impacts"*
- Objectives:
  - Develop & maintain updated *topobathymetric digital elevation models* (TBDEMs)
  - Develop coastal *vegetation characteristics* for inputs to models
  - Collate & characterize coastal *sediment type and grade* for inputs to morphodynamic models
  - Inventory & characterize *structures and infrastructure* types spatially so they can be ingested by models

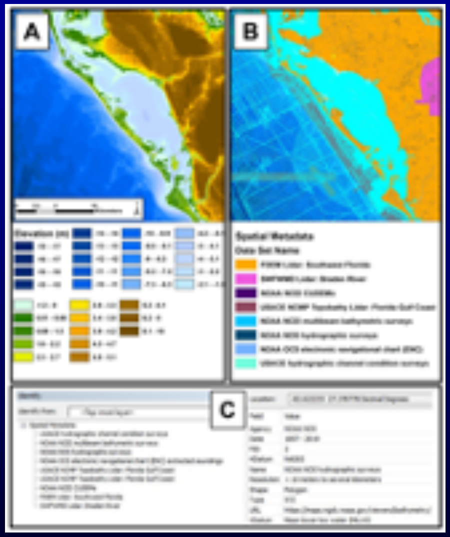
Topographic-Bathymetric Digital Elevation Models (TBDEMs)

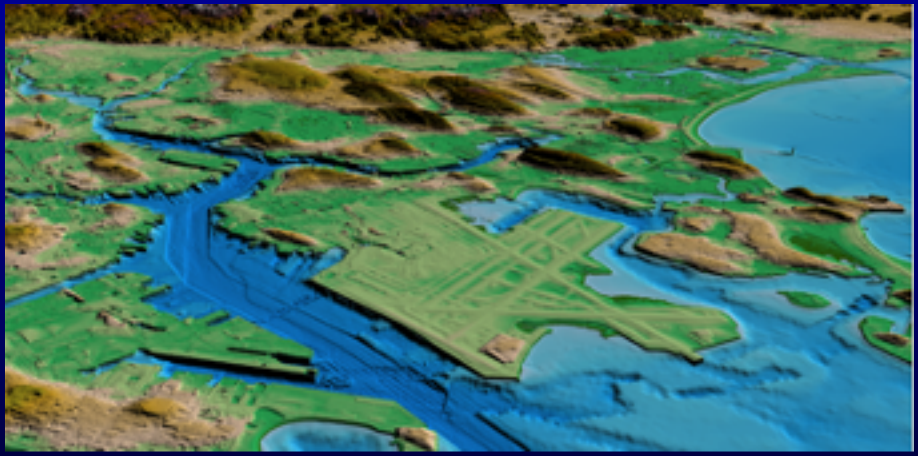
USGS Coastal National Elevation Database (CoNED)



- Complete coverage of Atlantic and Gulf coasts at 1-m or 3-m
- "Best available" elevation source data – often lidar
- Ongoing development and production to improve resolution, accuracy, and recency

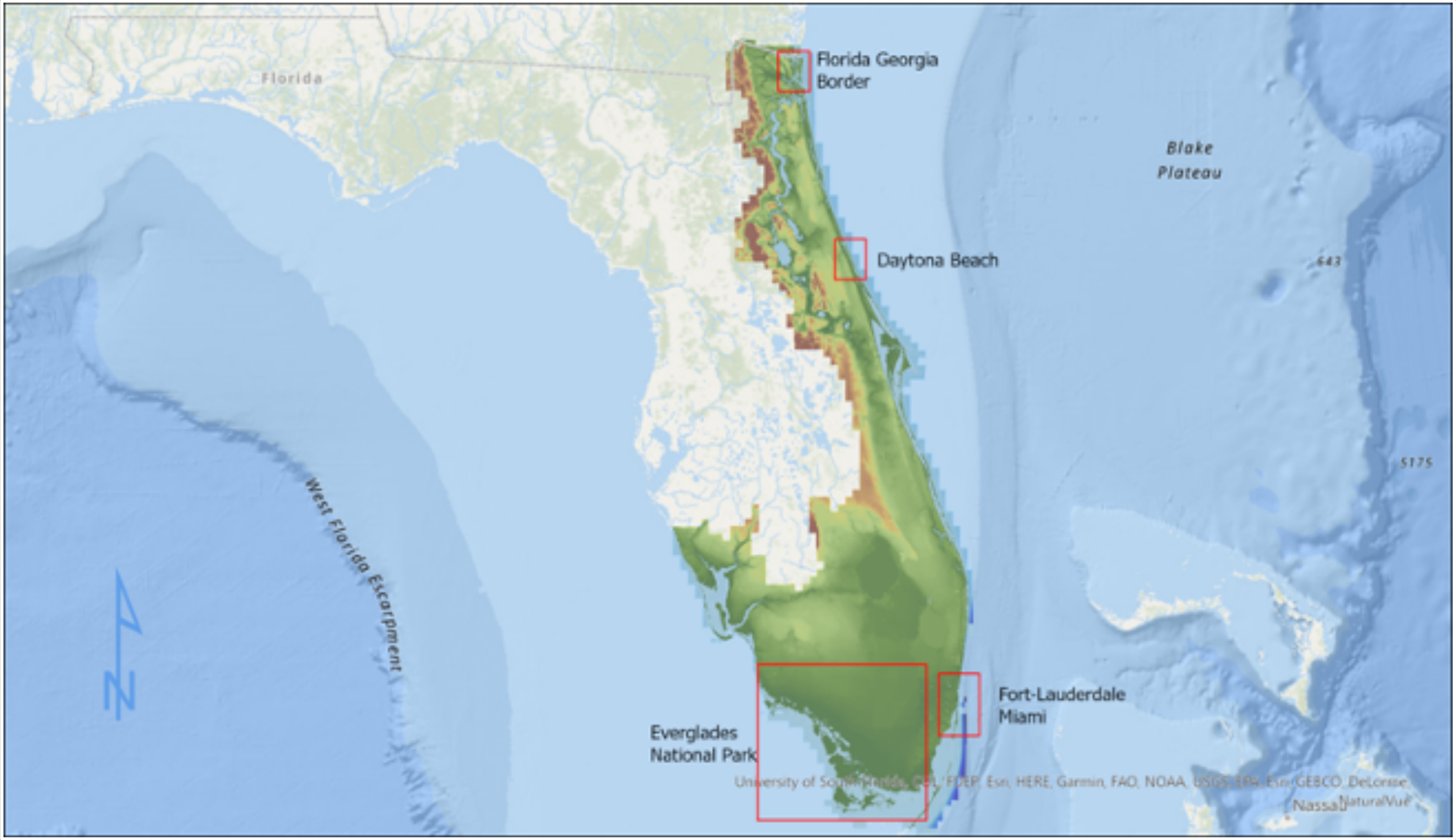
Spatial Metadata: tracks source data





NOAA Continuously-Updated DEM (CUDEM)

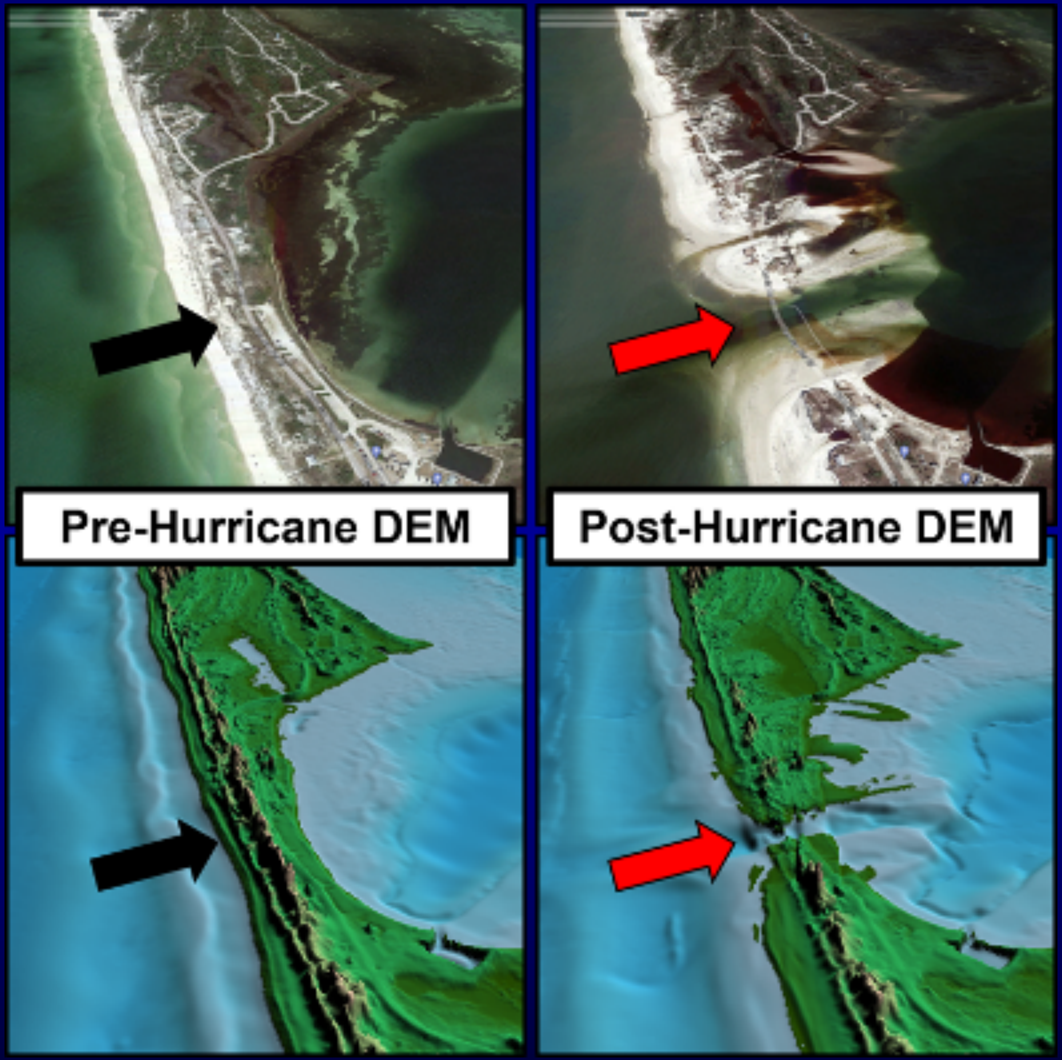
USGS CoNED - Atlantic Coastal Florida 1-Meter Integrated TBDEM (NEW)



USGS

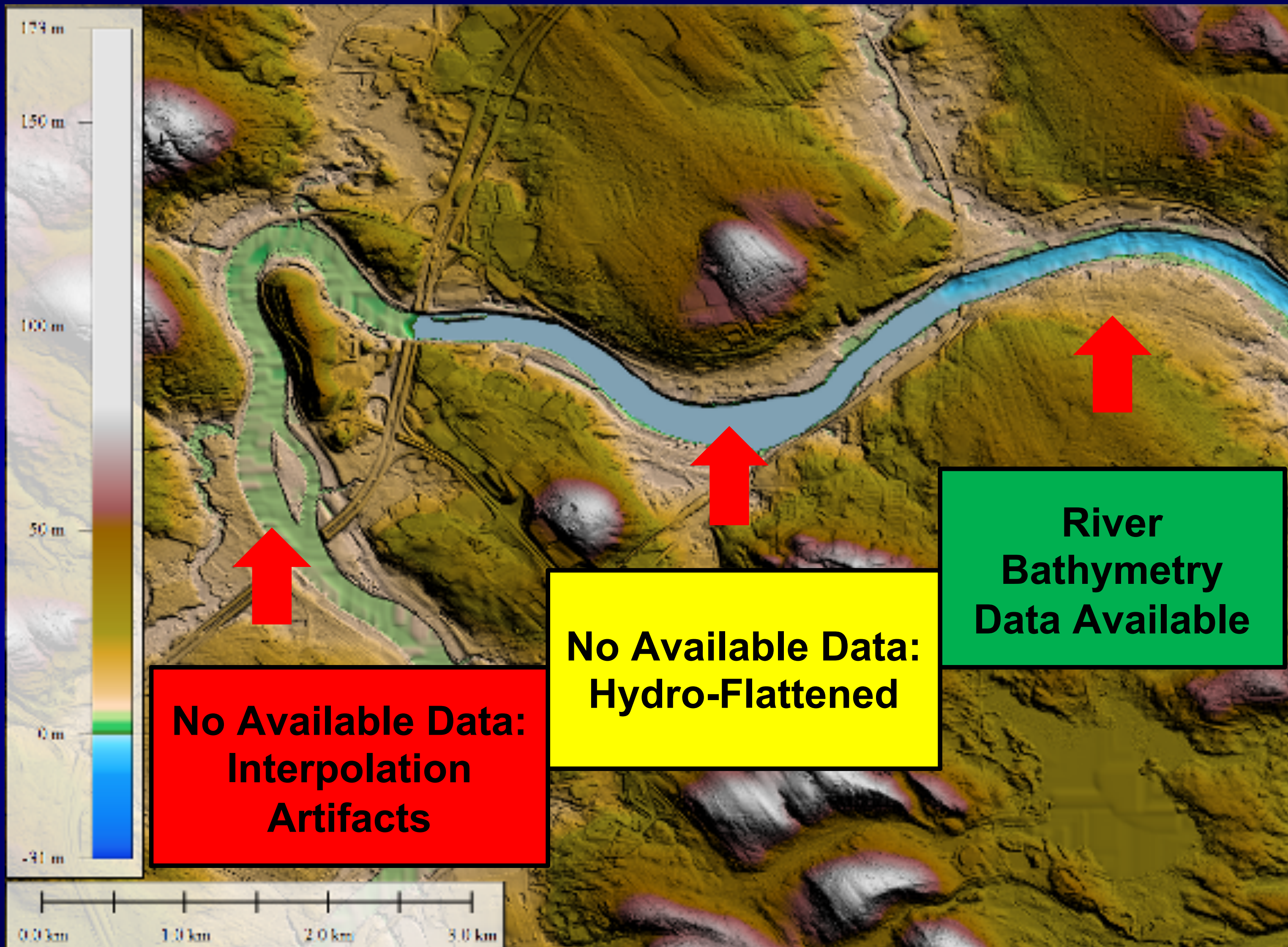
CUDEM – Version 2 DEMs

- Pre- and post- Hurricanes Sandy, Harvey, and Maria
  - Complete
- Pre-Hurricane Michael DEMs
  - Retrospectively generated for NOPP
- Post-Hurricane Irma DEMs
  - In progress



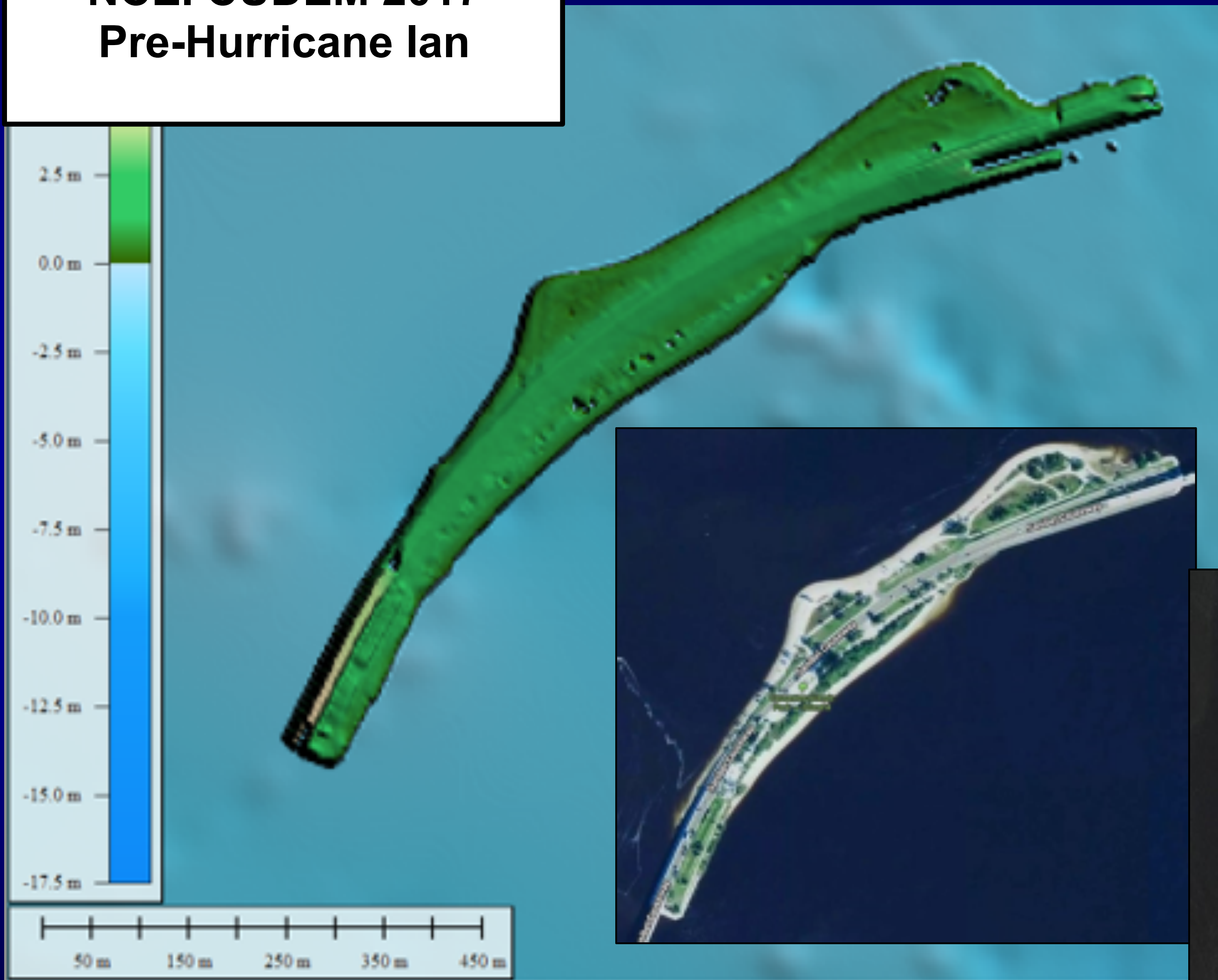
USGS

Issues & Challenges – River Bathymetry

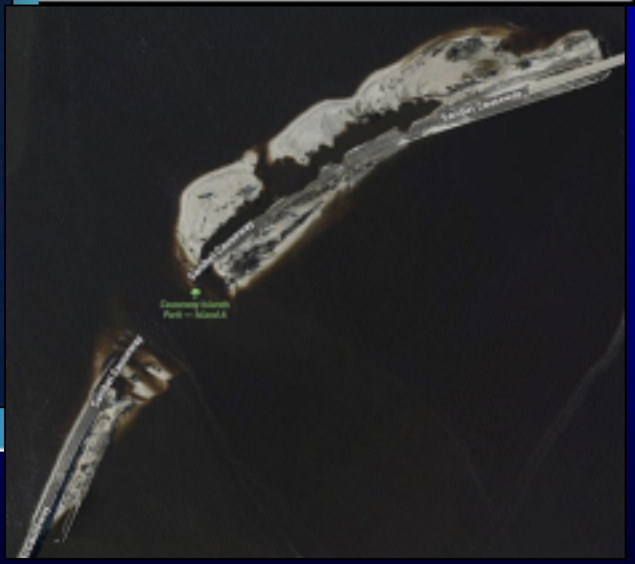


Issues & Challenges – Morphologic Change

NCEI CUDEM 2017
Pre-Hurricane Ian



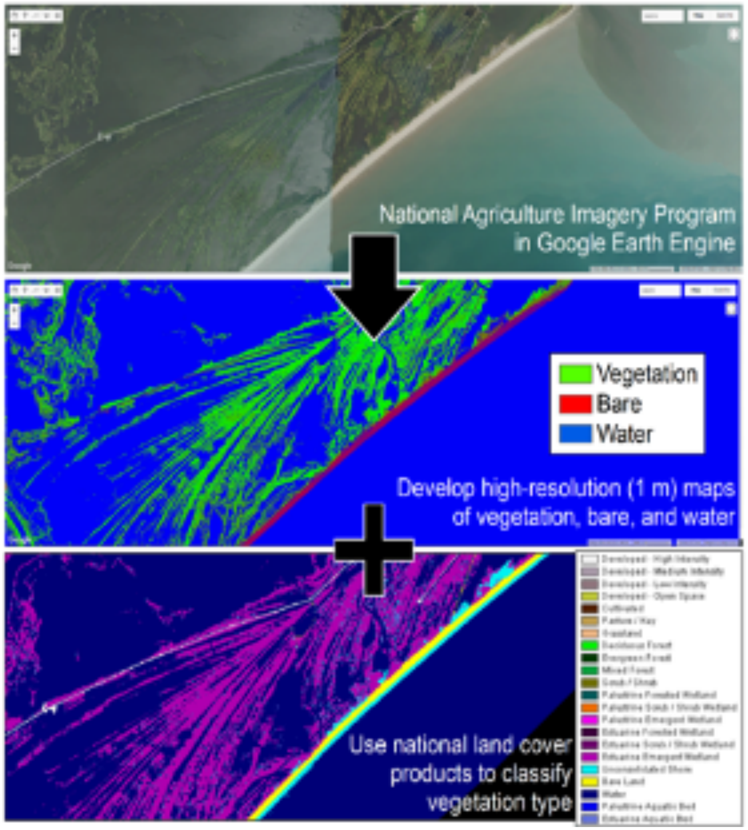
Post-Hurricane Ian



USGS

Vegetation

Enhanced land cover maps



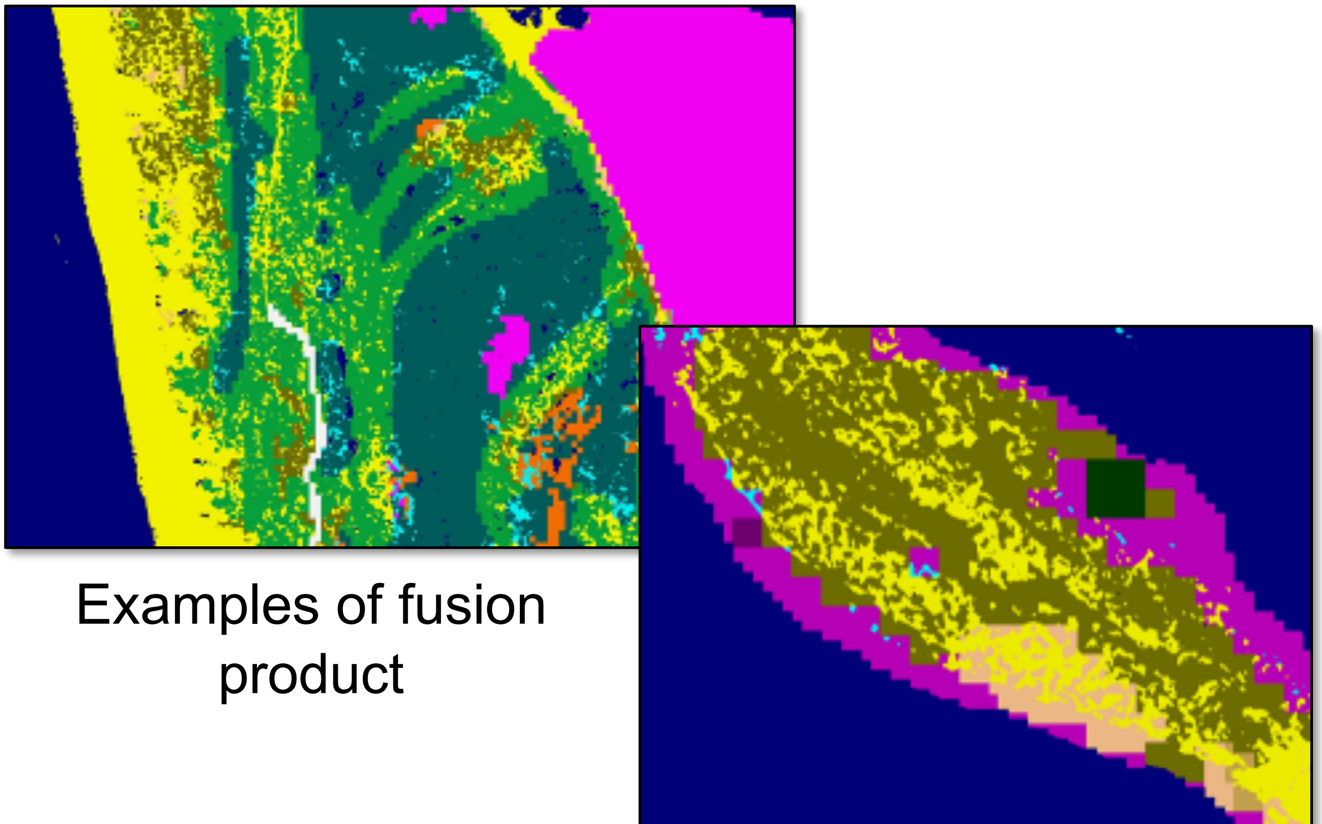
Objective: Provide a ***high-resolution layer*** that includes the ***latest available national aerial imagery*** and land cover types

In a nutshell…*fusion of simple from newer imagery with most recent land cover products*

Data sources:

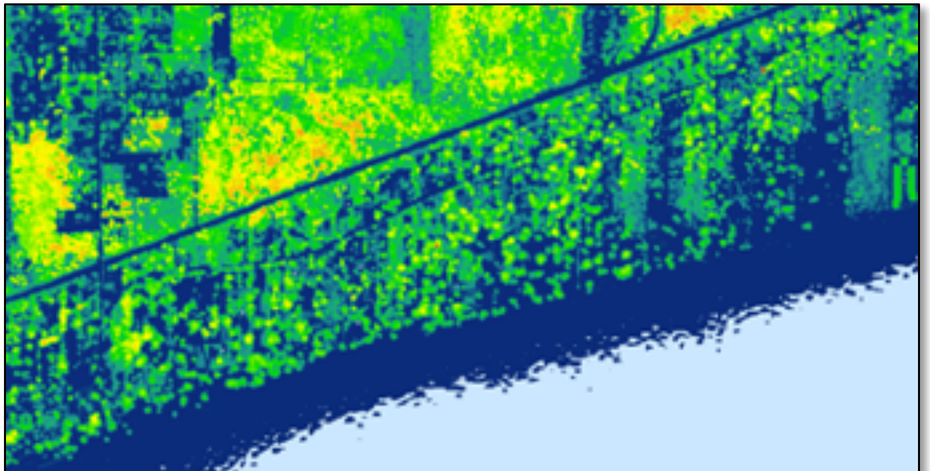
- Best-available orthoimagery from the National Agricultural Imagery Program (NAIP; spatial resolution: 1 m or less; date: varies by state 2019 or newer)
- National Oceanic and Atmospheric Administration's (NOAA) 2016 Coastal Change Assessment Program (C-CAP) land cover dataset (spatial resolution: 30 m)
- NOAA's C-CAP 10-m BETA Land Cover Product (used for water presence)
- Seagrass maps from NOAA's Marine Cadastre

Enhanced land cover maps



Examples of fusion product

Height Above Ground (HAG) Fusion Product



Objective: Provide an ***estimate of vegetation height*** using lidar point cloud data

Data sources:

- HAG layers from lidar point clouds were developed by Jason Stoker (USGS).
- NOPP/C-CAP Fusion product

Products:

Three different layers will be developed:

1) 3DEP HAG with gaps filled with median values by C-CAP class from the regional analysis **(*spatially explicit*)**
2) a seamless layer of the full region with the median values of HAG by C-CAP class from the regional analysis **(*same values for same land cover*)**
3) a seamless layer of the full region with interquartile range of HAG by C-CAP class from the regional analysis **(*same values for same land cover*)**

Vegetation products

Status:

- Preliminary maps for the Gulf of Mexico are completed and available on Google Drive
- Atlantic for both the fusion maps and the HAG fusion products are underway

Initial HAG product status

Next steps:

- Finish preliminary maps for Atlantic Coast
- Basic accuracy assessment for maps
- Publish products via USGS Data Releases
- Explore potential to update specific states as new national aerial imagery becomes available

USGS

Vegetation: Rapid-repeat maps

Objective: Develop a stand-alone Python script to produce high-frequency and high-spatial resolution coastal vegetation maps using Planet satellite imagery

Coastal vegetation classes: emergent marsh, dune grass, shrubs, forested wetland, bare ground, and open water

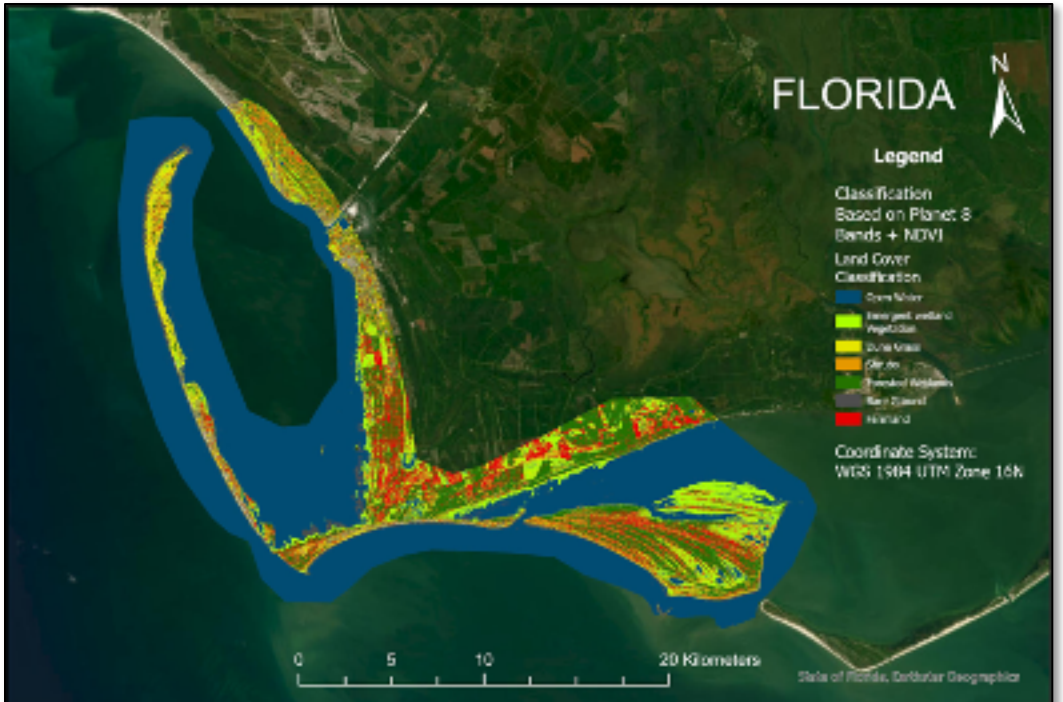
Test sites: North Carolina, Mississippi Delta, Florida Gulf Coast

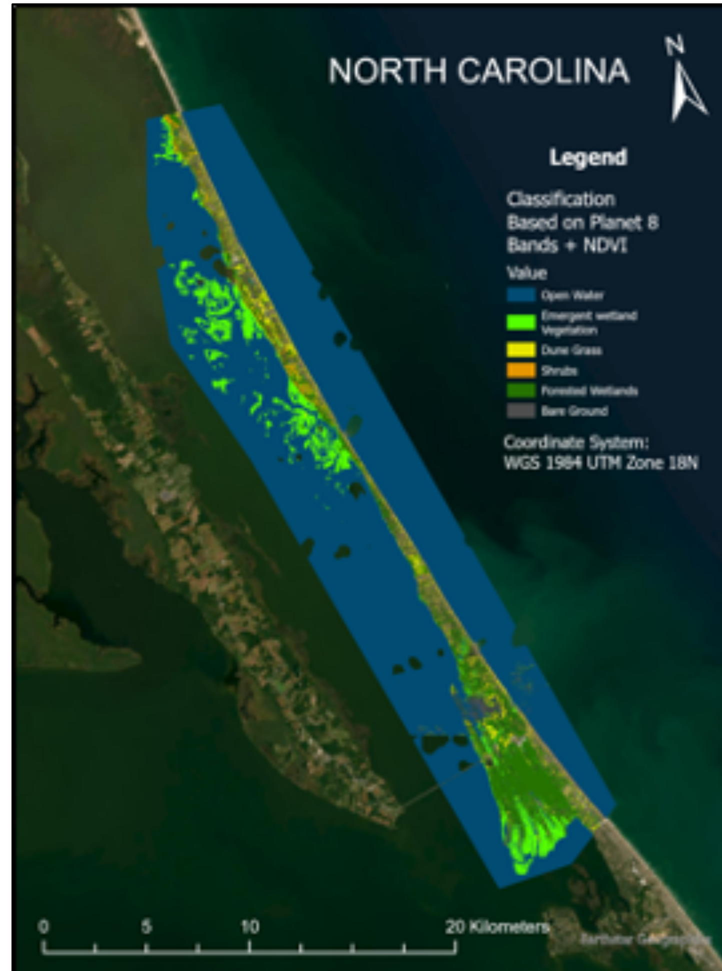
Maps of near-real time conditions will enable rapid updates of Manning's N values

USGS

Rapid-repeat maps

Preliminary maps





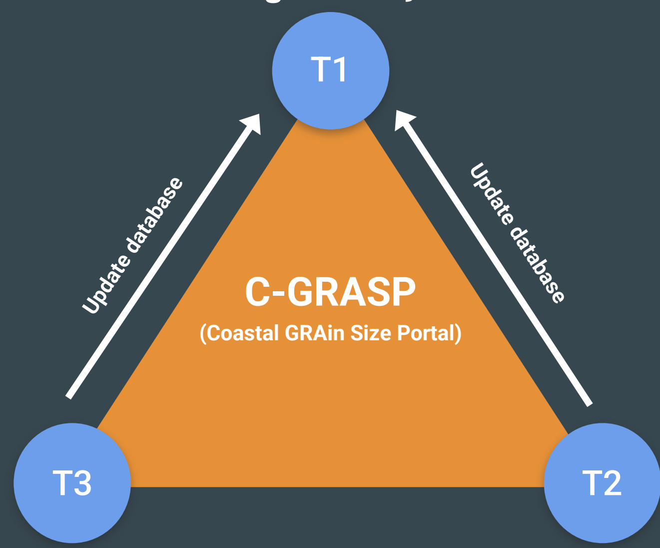
Sediments

Objective: develop tools for estimating and mapping ‘best available’ sediment type and grade

Daniel Buscombe (Marda Science / USGS-PCMSC)

Evan Goldstein (Uni. N. Carolina @ Greensboro)

T1. A database providing “best available info” of sediment type, grain size and sorting for every location



T3. Estimating grain size information using ML and data assimilation techniques on satellite imagery

T2. Provide tools for creation of morpho-sedimentary maps from NAIP imagery or user-uploaded imagery

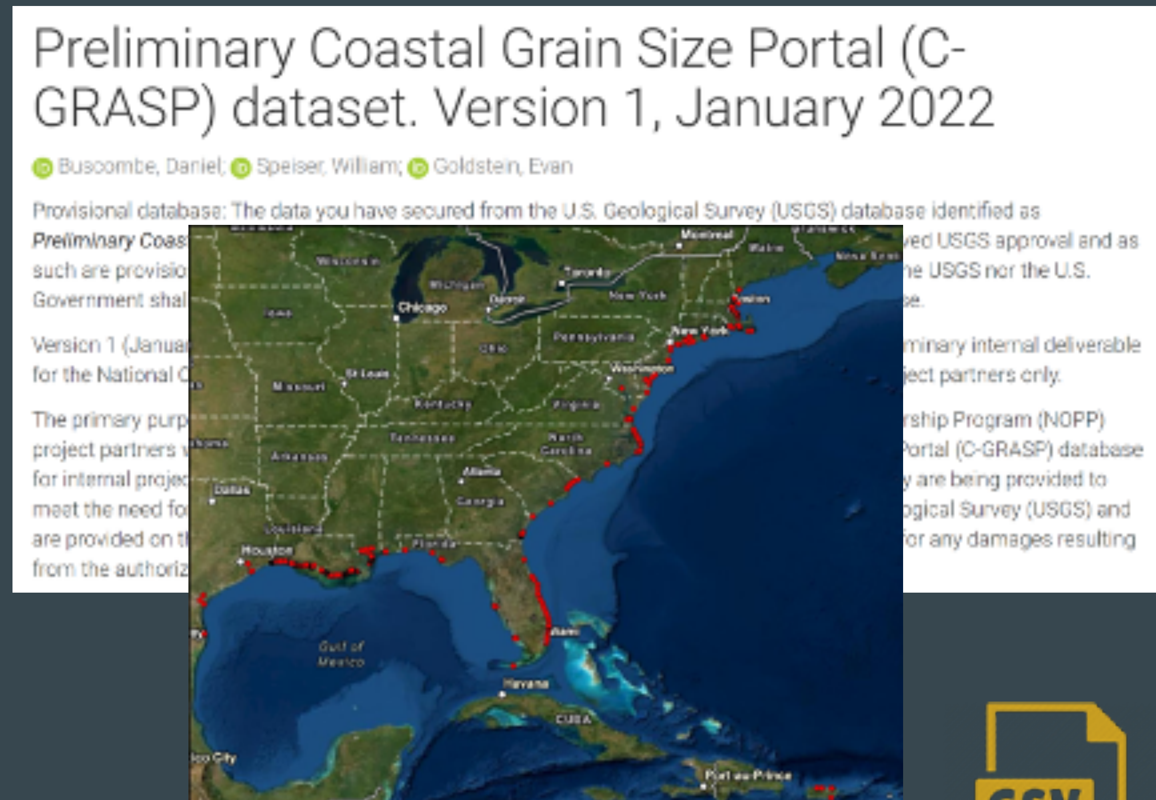
T1

C-GRASP database (updated throughout the project)

Version 1 (Jan 2022)

Standardized fields

1. All known data that is found to be within 10km of shoreline (onshore + offshore) [70,305 onshore samples]
2. All known data that is estimated to be onshore (above MLW)
3. All known data that was able to be verified onshore [5,356 samples]
4. All known data that was able to be verified onshore collected after 2012 [2,902 samples]
5. All raw source files



https://zenodo.org/record/6099266

CSV

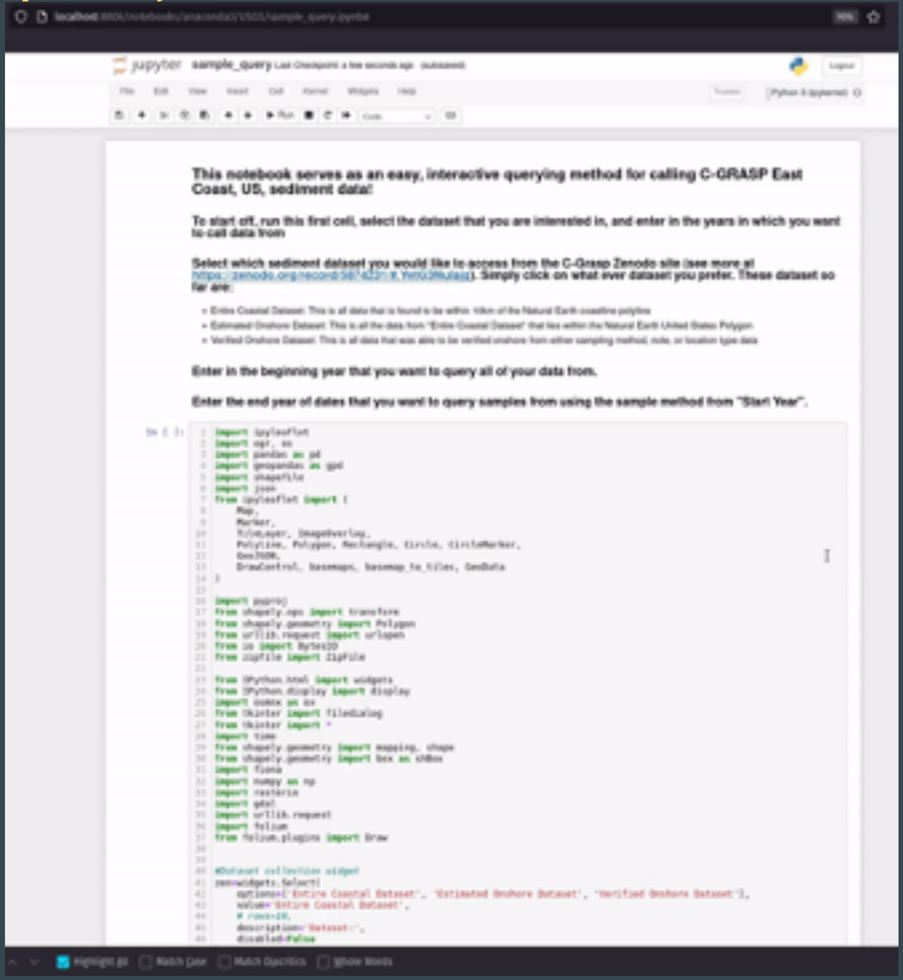
T1

C-GRASP database (updated throughout the project)

https://github.com/C-GRASP/AnalysisNotebooks

Jupyter notebooks to query the data

1) Search by time and location / area of interest (AOI)
2) Assign sample water depth from CUDEM
3) Compute Cohesive, Sand, and Coarse Fractions per sample
4) Compute distance to shore per sample
5) Compute grain size percentile interpolation error
6) Compute custom grain size percentiles



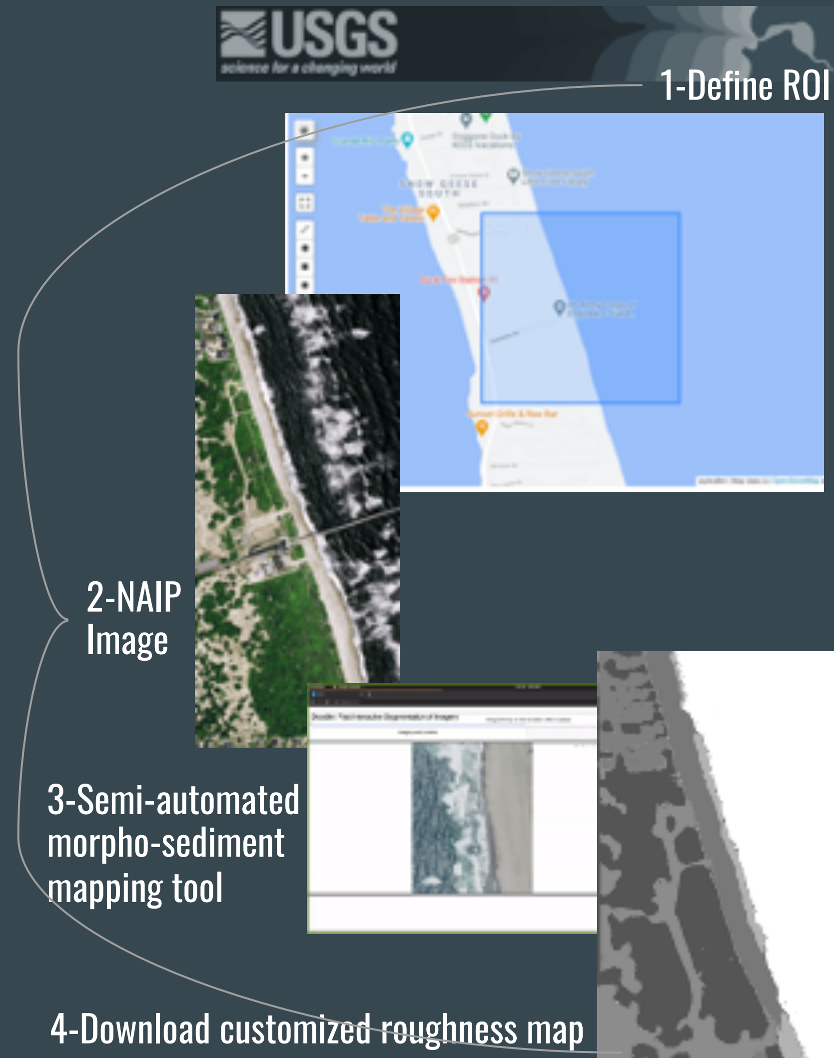
T2

Roughness mapping tool

Inspired by Van der Lugt et al. (2019) Xbeach hurricane morphodynamic modeling using spatially variable roughness mapping from imagery

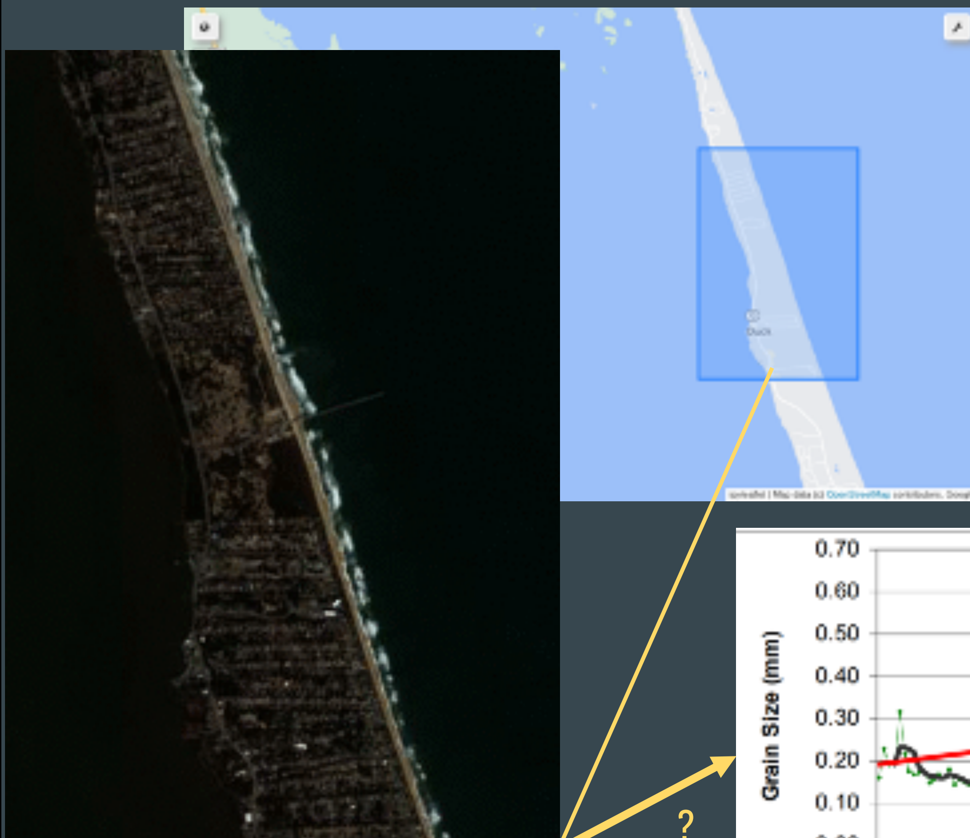
New python software tool based on Google Earth Engine:

- Search by location (AOI)
- Download <=1-m imagery from NAIP catalogue (every ~2 years) or most recent Sentinel-2 image
- Download NLCD raster for same AOI
- User identifies landcover and landforms on imagery and ML completes the scene
- Look-up Manning's N based on published tables (Mattocks & Forbes, 2008; Passeri et al. 2018)

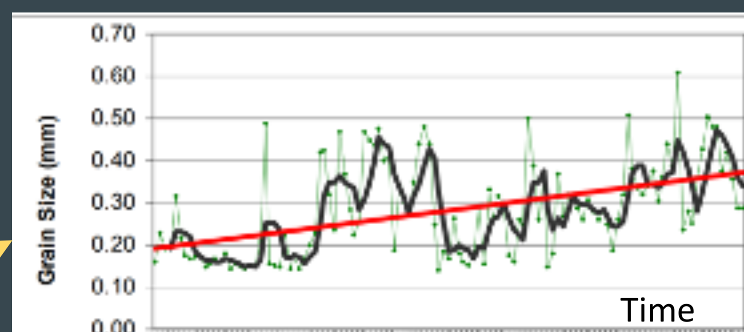


T3

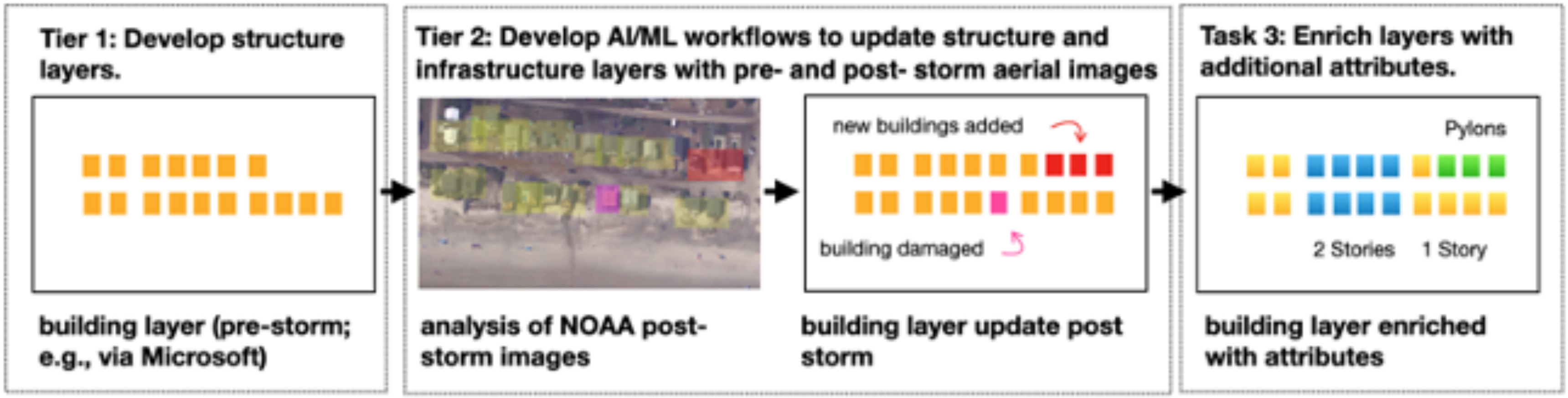
Time-updating grain size using ML and remote sensing



- Proof-of-concept work
- Leverage existing work and tools based on
  - Image segmentation
  - "Optical wave gauging"
- New tools specifically for sand beach grain size based on ML and data time-series
- First paper examines possibility of estimating grain size from existing wave and beach slope data



Structures and Damage



Done: https://github.com/CoastalBuildings/BuildingRasters

Tools to make raster & vector building layers

https://github.com/CoastalBuildings/BuildingRasters

Microsoft Building dataset
https://github.com/Microsoft/USBuildingFootprints

Open Street Map Buildings and Roads
via Boeing OSMnx

(HIFLD to be included soon)

Method from Heris et al 2020
“A rasterized building footprint dataset for the United States"

Ongoing: Pipeline to Detect of Building Footprint changes relies on deep learning models (Segmentation Gym):

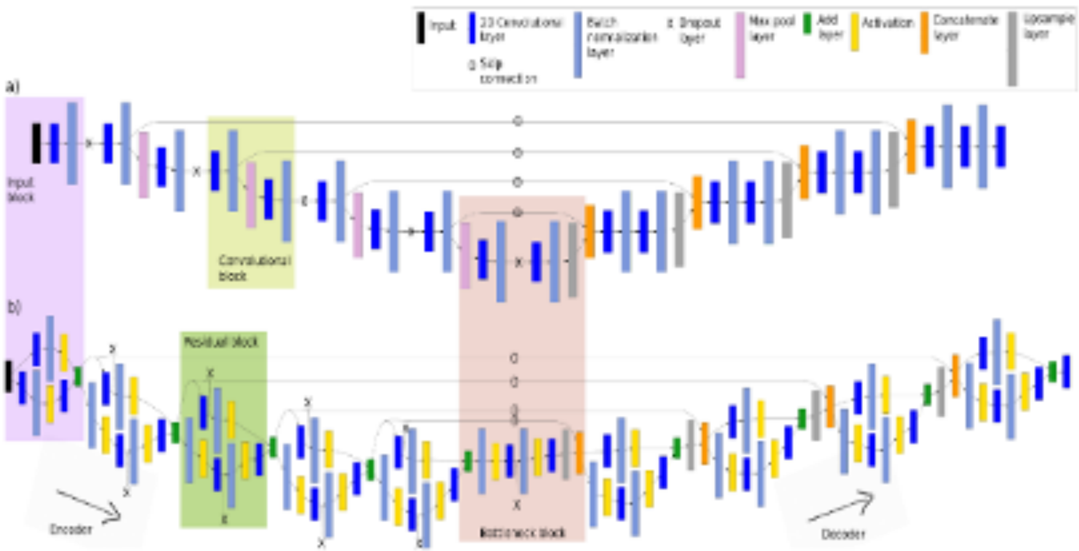
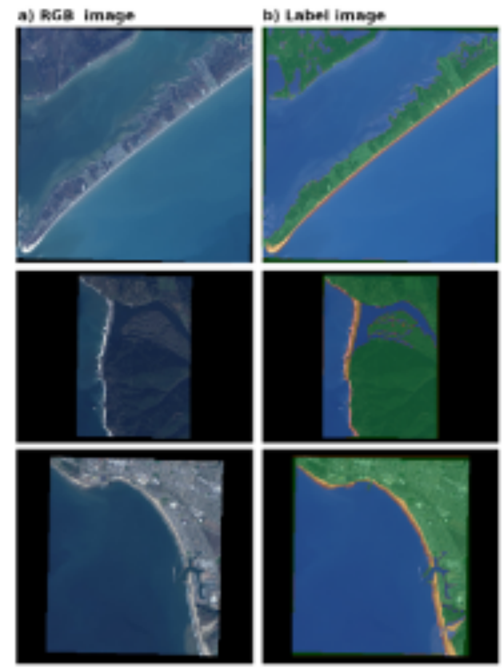


Figure 2. The a) UNet and b) Res-UNet fully convolutional model architectures used in the present study. There are several forms of these models available in the software 'Segmentation Gym'.

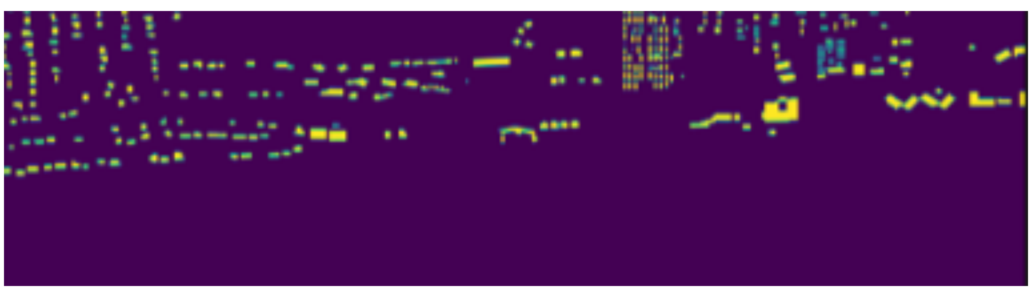


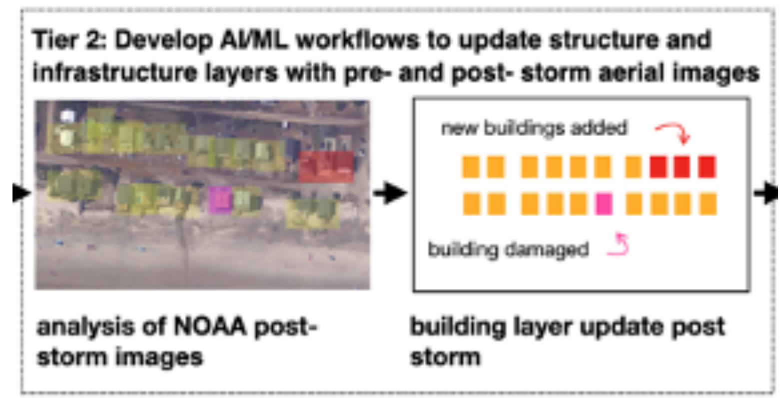
Buscombe & Goldstein: https://github.com/Doodleverse/segmentation_gym

Buscombe, D & EB Goldstein, (2022), A Reproducible and Reusable Pipeline for Segmentation of Geoscientific Imagery, Earth and Space Science, https://doi.org/10.1029/2022EA002332

Ongoing Work: Continue on this path, make more training data.

Use MS buildings (enabled by our previous work !!) as a mask for NOAA TIFFs

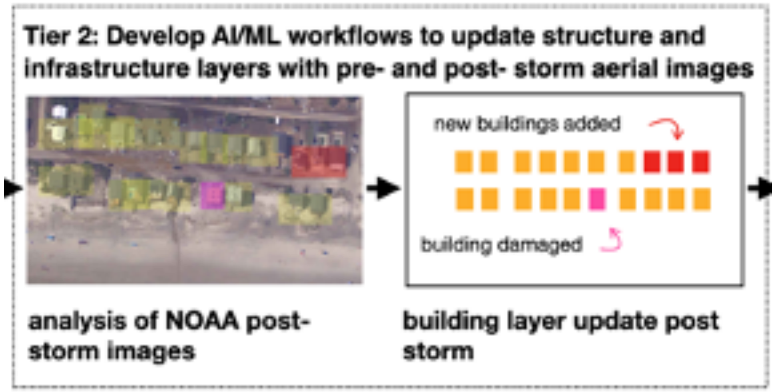


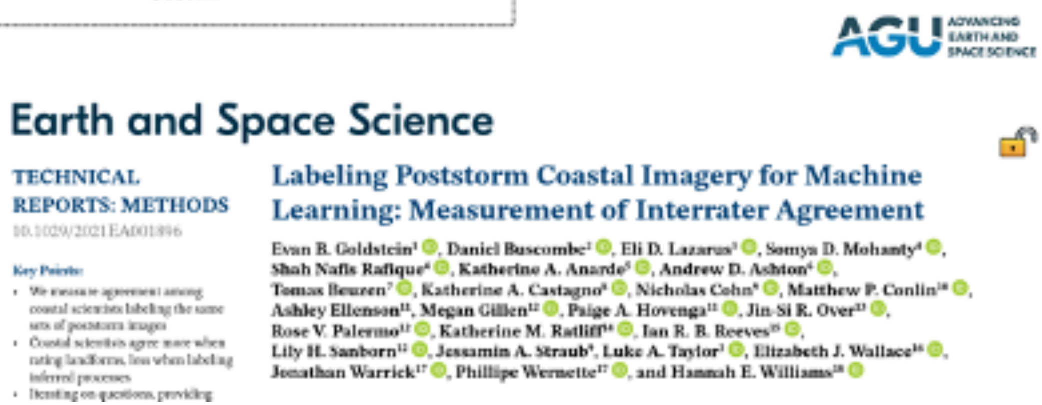


https://github.com/ebgoldstein/BuildingsFromERI

Building Damage detection

(different than last ML model, but part of ‘model cascade’)





AGU ADVANCING EARTH AND SPACE SCIENCE

Earth and Space Science

TECHNICAL REPORTS: METHODS

10.1029/2021EA001896

Labeling Poststorm Coastal Imagery for Machine Learning: Measurement of Interrater Agreement

Evan B. Goldstein, Daniel Buscombe, Eli D. Lazarus, Somya D. Mohanty, Shah Nafis Rafique, Katherine A. Anarde, Andrew D. Ashton, Tomas Beuzen, Katherine A. Castagno, Nicholas Cohn, Matthew P. Conlin, Ashley Ellenson, Megan Gillen, Paige A. Hovenga, Jin-Si R. Over, Rose V. Palermo, Katherine M. Ratliff, Ian R. B. Reeves, Lily H. Sanborn, Jessamin A. Straub, Luke A. Taylor, Elizabeth J. Wallace, Jonathan Warrick, Phillipe Wernette, and Hannah E. Williams

Key Points:

- We measure agreement among coastal scientists labeling the same sets of poststorm images
- Coastal scientists agree more when rating landforms, less when labeling inferred processes
- Iterating on questions, providing

Now ~3000 labeled images, ~700 show building damage

Task 2 Team Presentation

Remote Sensing of the U.S. Coastline Impacted by Land-Falling Hurricanes

a) Status Report on TerraSAR-X Based DEMs (Roland Romeiser)

b) Other University of Miami / CSTARS Products (Michael Caruso)

c) Status Report on Capella SAR Based Activities (Stephen Frasier)

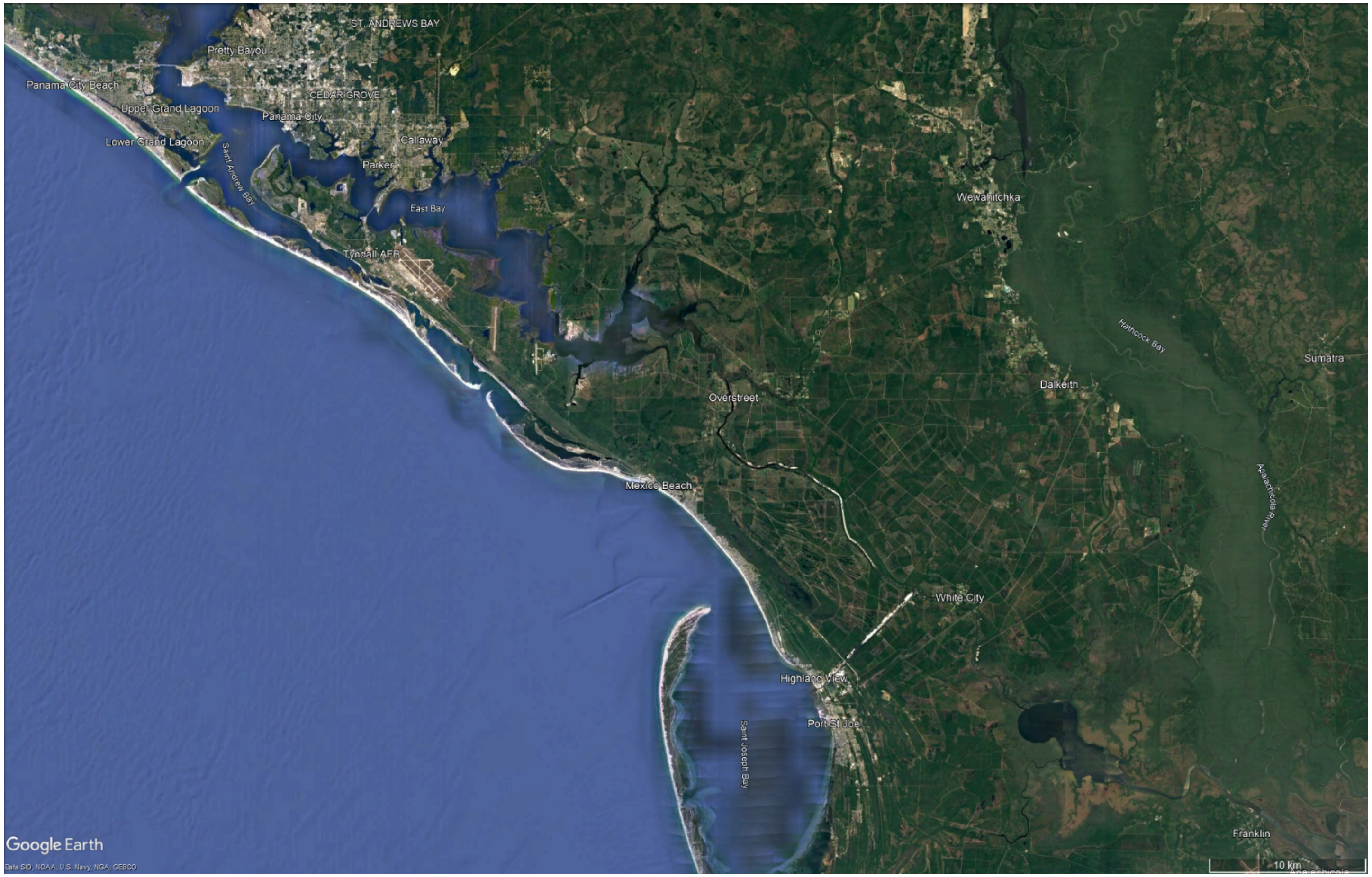
Task 2 Team Overview

- **University of Miami Group**
  - Roland Romeiser (PI) – professor, remote sensing scientist
  - Hans Graber (Co-PI) – professor, director of CSTARS
  - Michael Caruso (Co-PI) – satellite data analysis expert at CSTARS
  - Victoria Pizzini – PhD student, Atmospheric Sciences
  - Industry partner: Airbus Defence & Space
- **University of Massachusetts Group** (Subcontractor)
  - Stephen Frasier (PI) – professor, director of MIRSL, radar engineer
  - Steven Beninati – PhD student
  - Industry partner: Capella Space

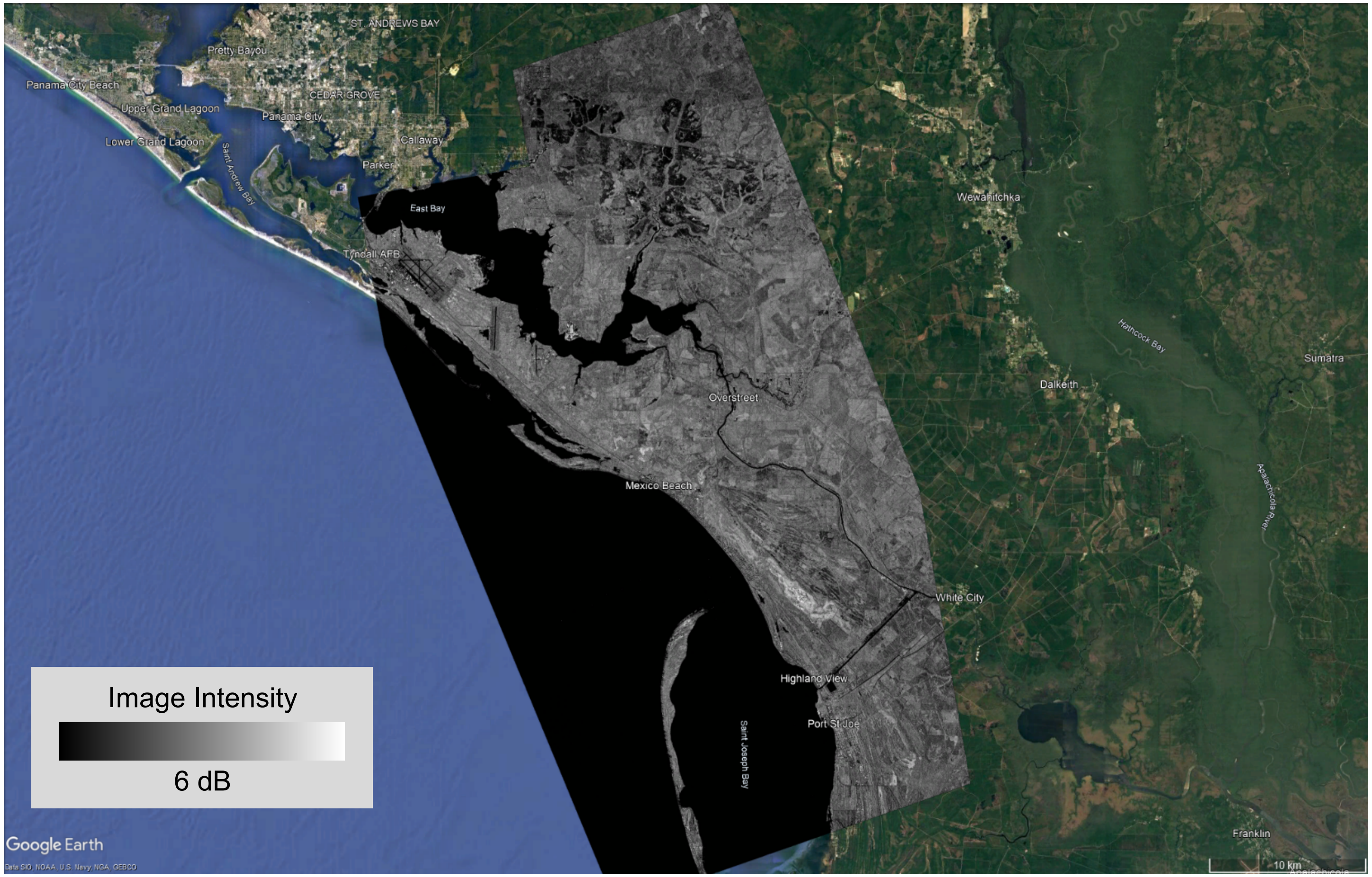
University of Miami Task 2 Team Objectives

- **Development of Advanced Satellite Data Products**
  - SAR-based wind and wave fields over the ocean
  - Coastal bathymetry and currents
  - Coastlines, flooded areas, changes on land
  - Land topography and surface types
  - High-resolution land surface characterization based on synergistic analysis of SAR-based products and optical imagery
- **Dedicated Image Acquisitions for Each Hurricane of Interest**
- **Timely Data Delivery to Other Teams**

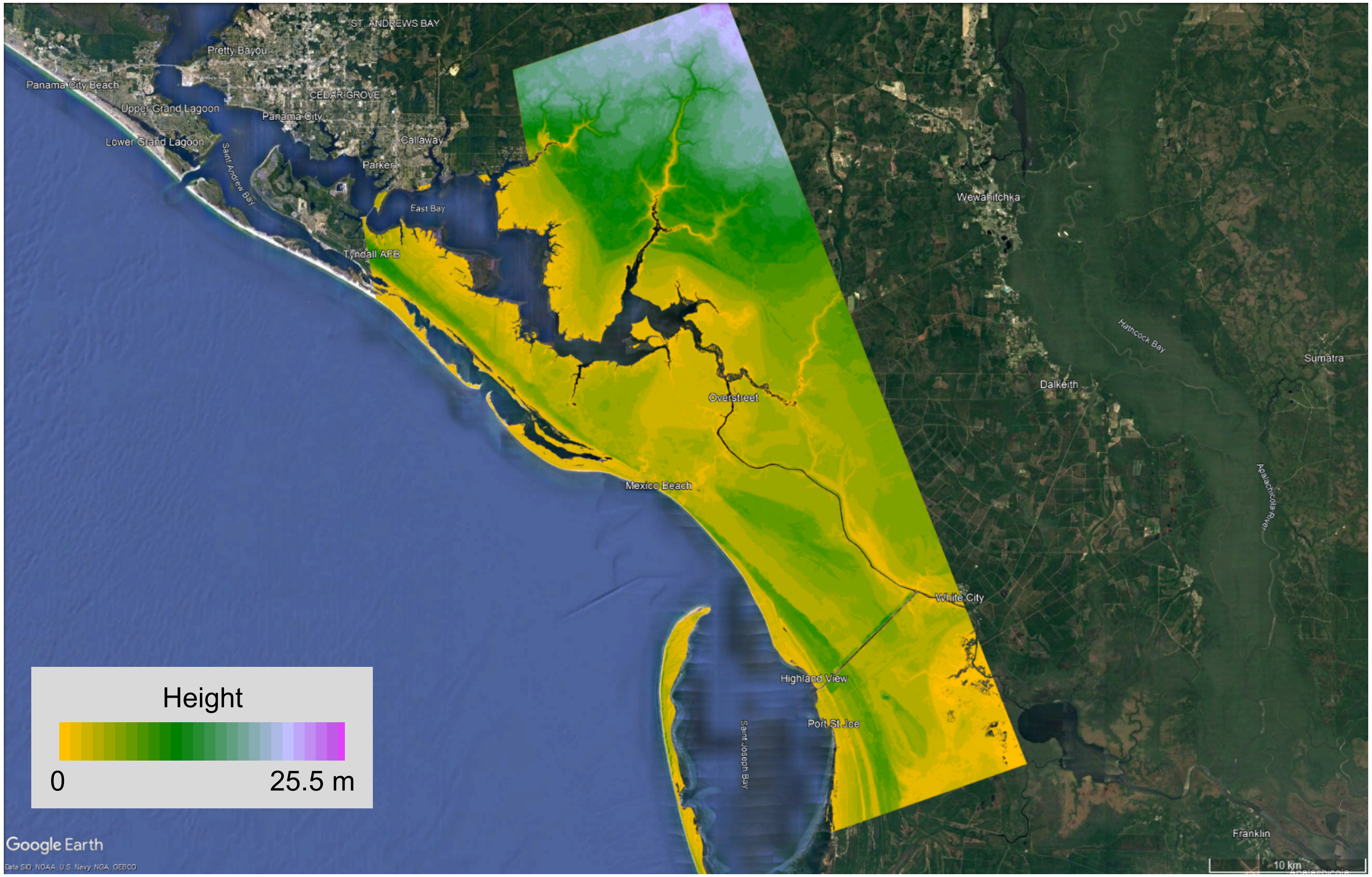
Hurricane Michael Test Area



PAZ SAR Intensity Image, 2021-08-26 23:40 UTC



Reference Topography (CUDEM)



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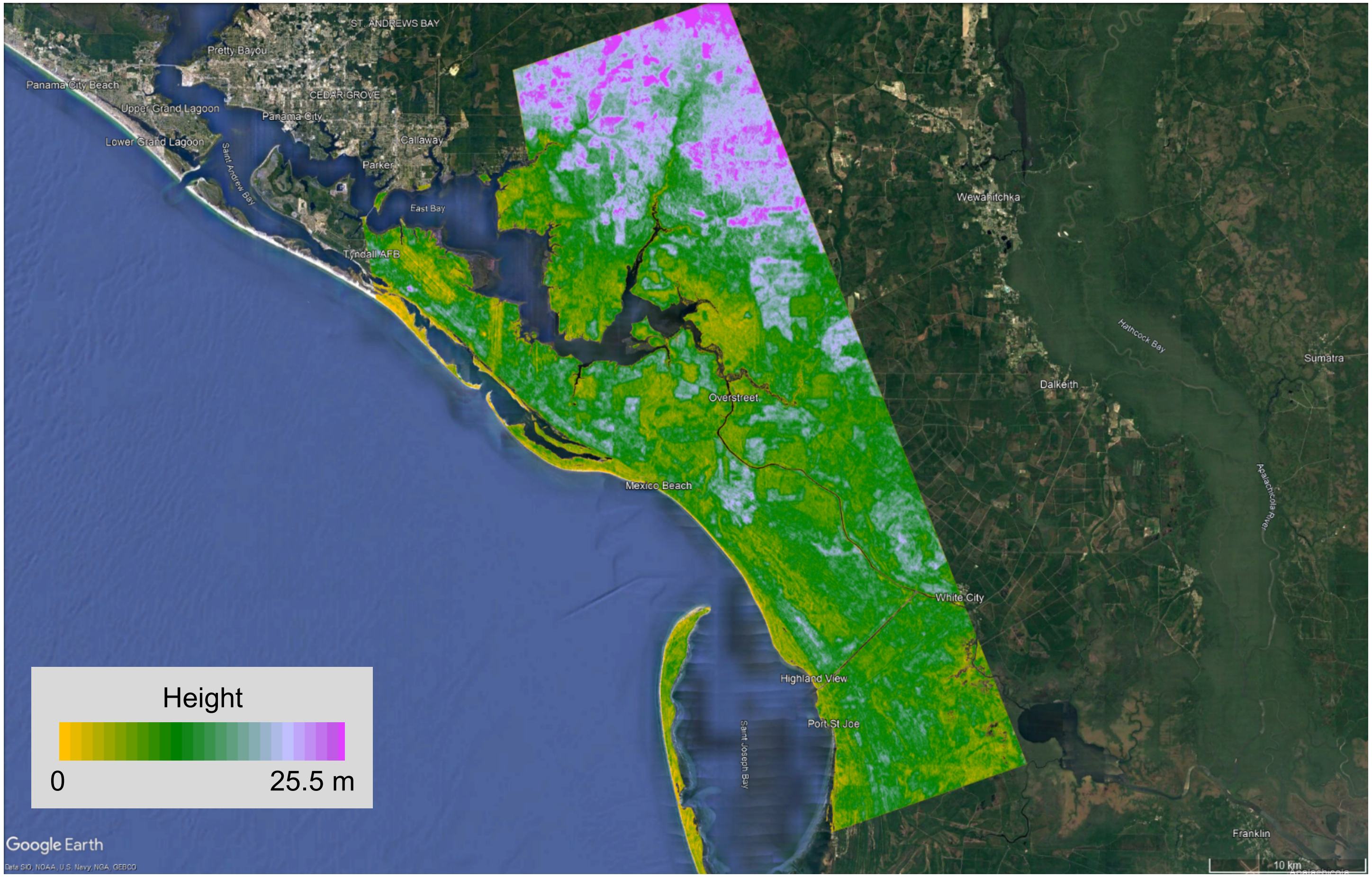
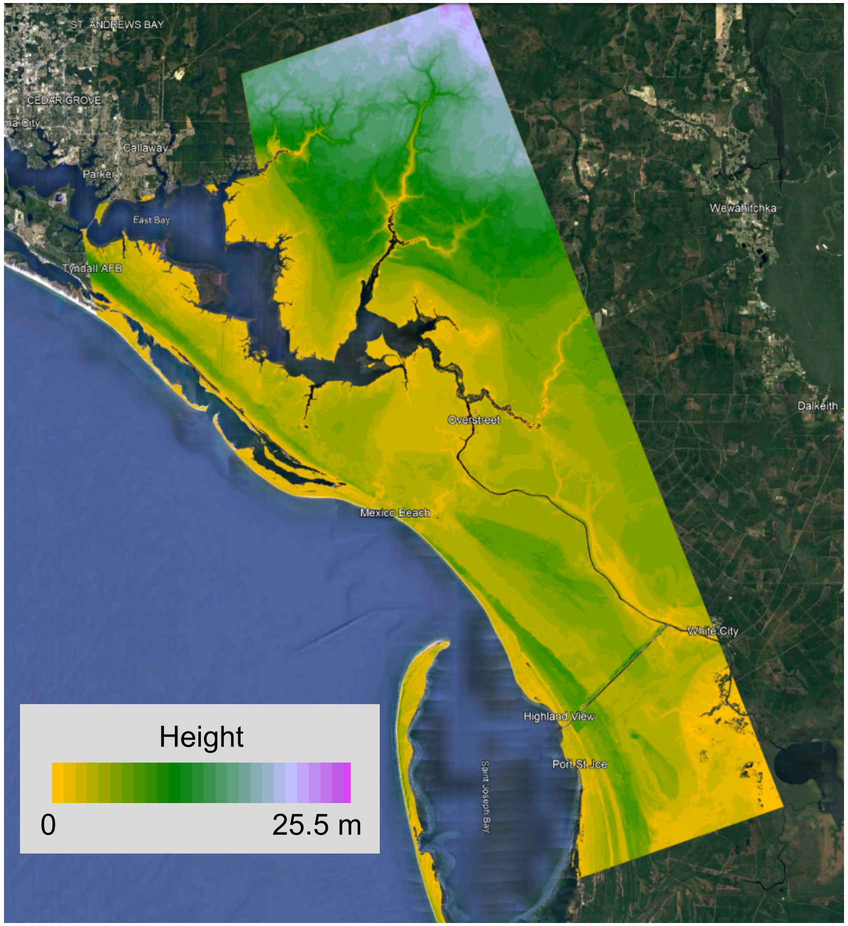
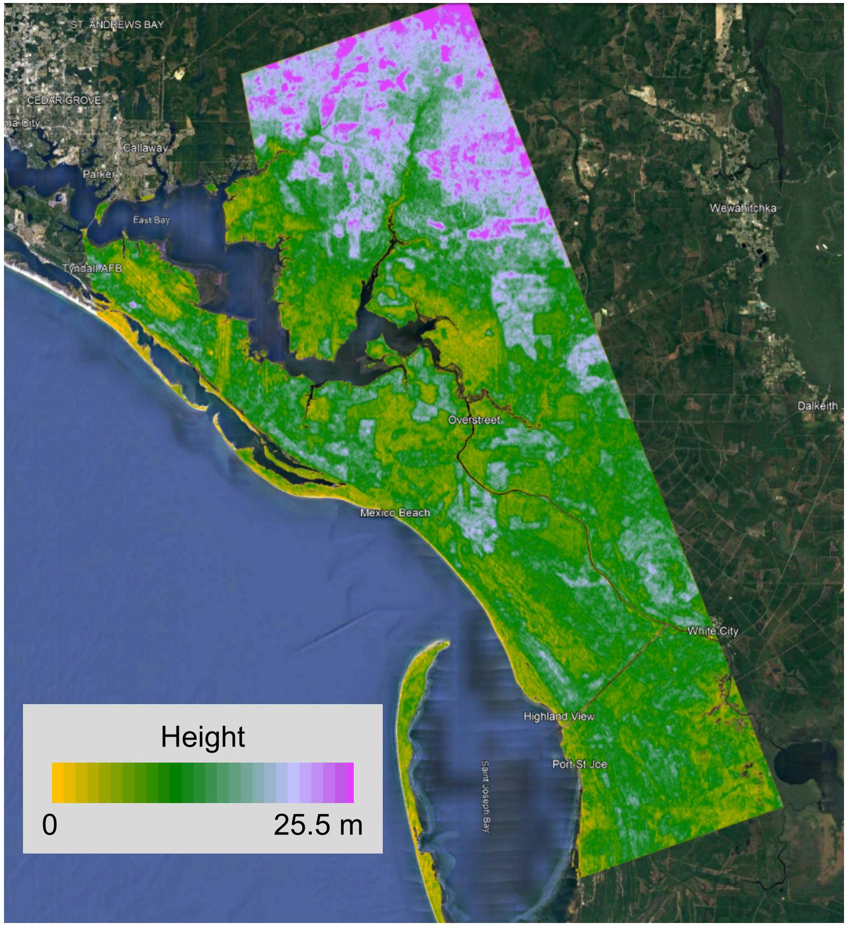
Initial Radargrammetry Height (Airbus)

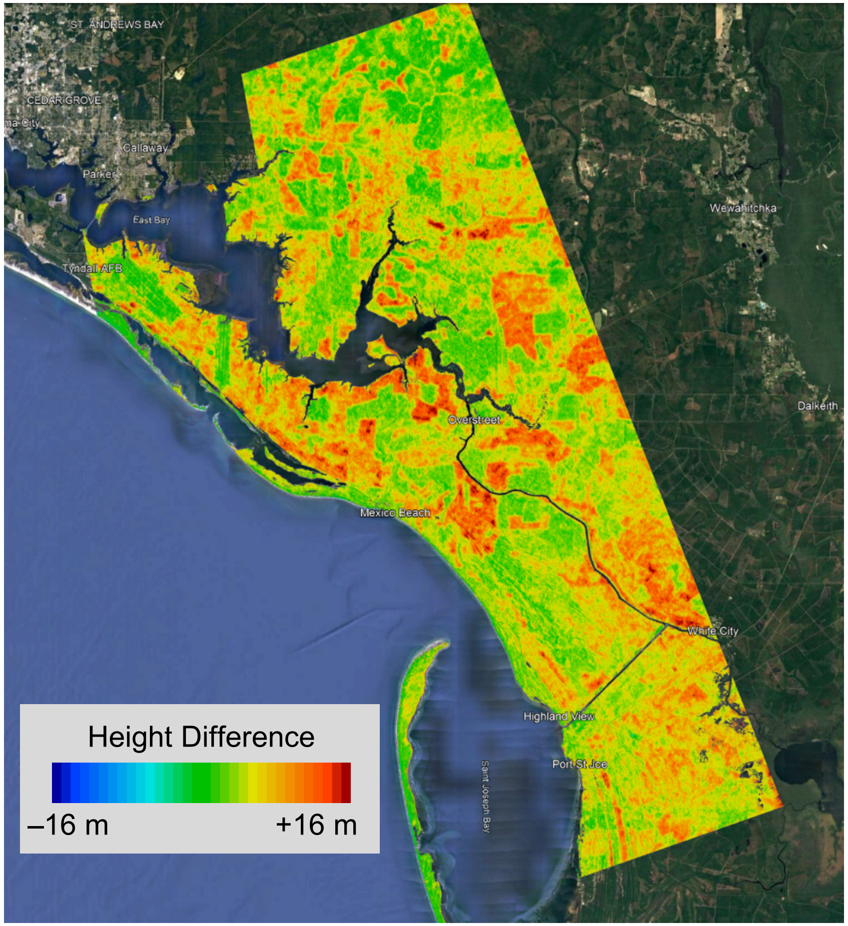


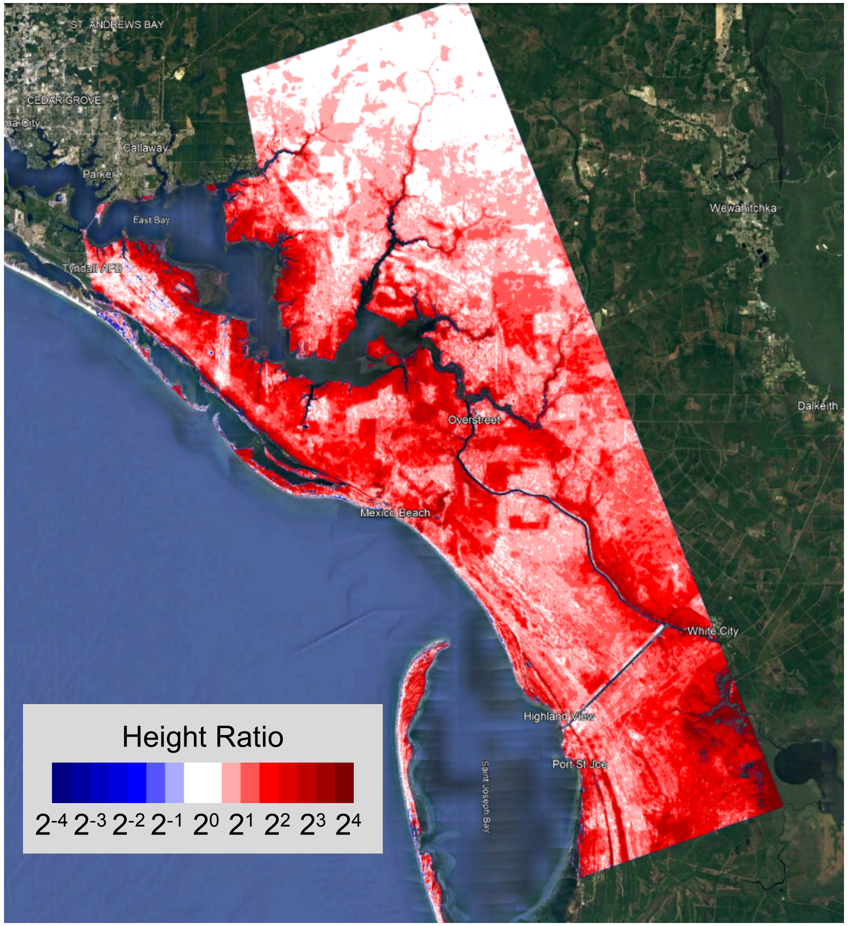
Initial Radargrammetry Height (Right) vs. CUDEM Height (Left)



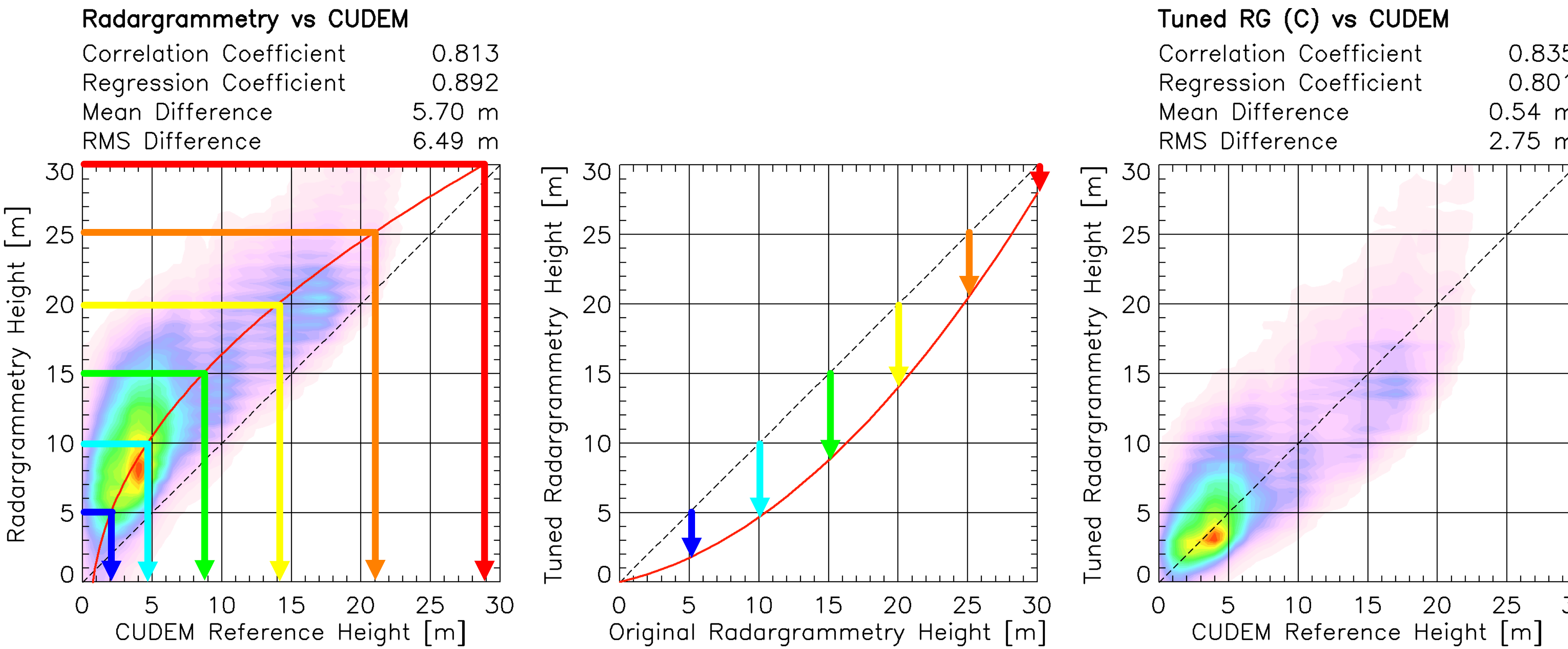


Initial Radargrammetry Height vs. CUDEM Height



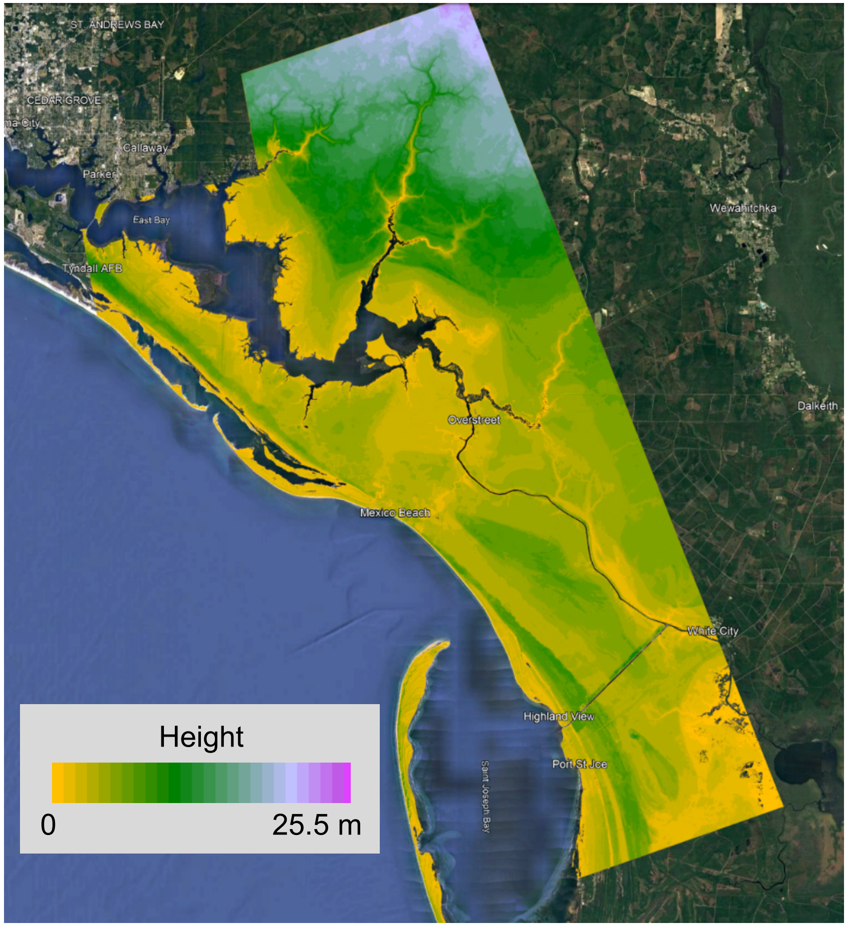


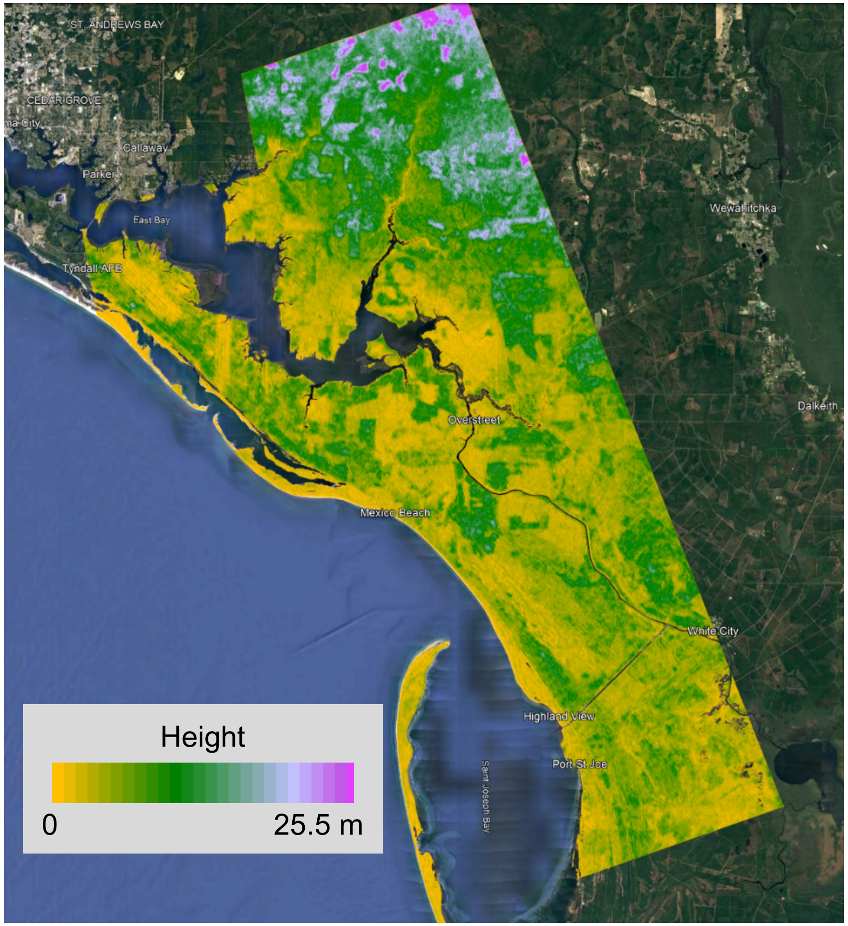
Radargrammetry Height vs. CUDEM Height



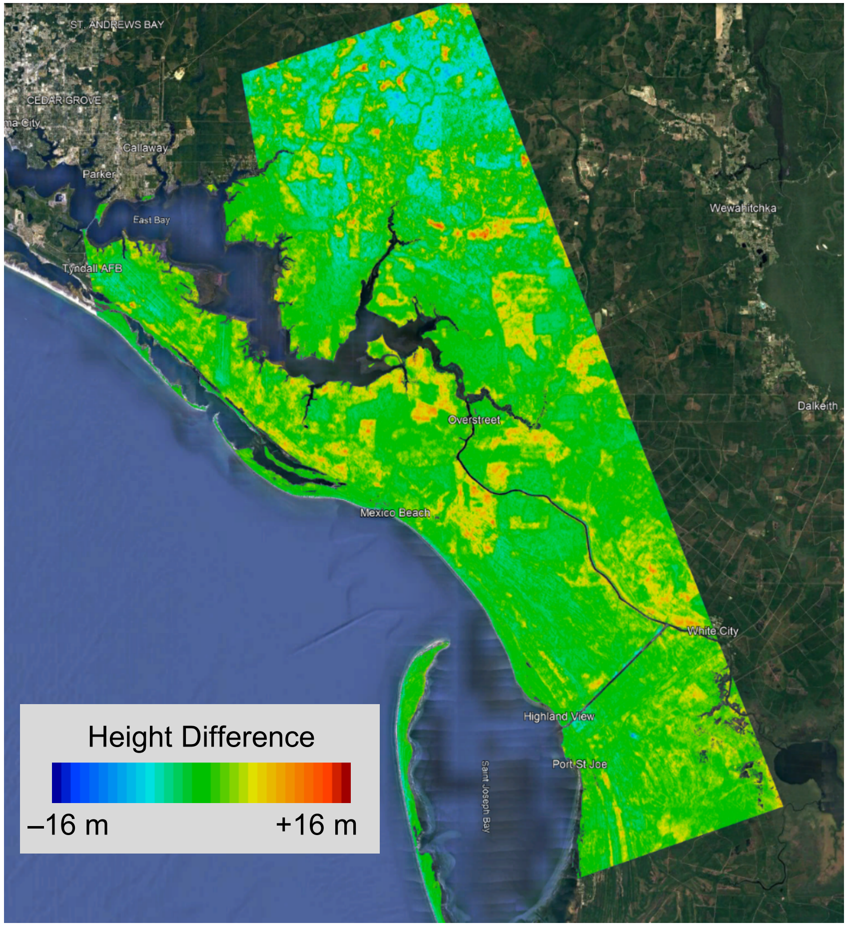
Red curve is fitted 2nd-order polynomial $H_{CUDEM} = f(H_{RGram})$

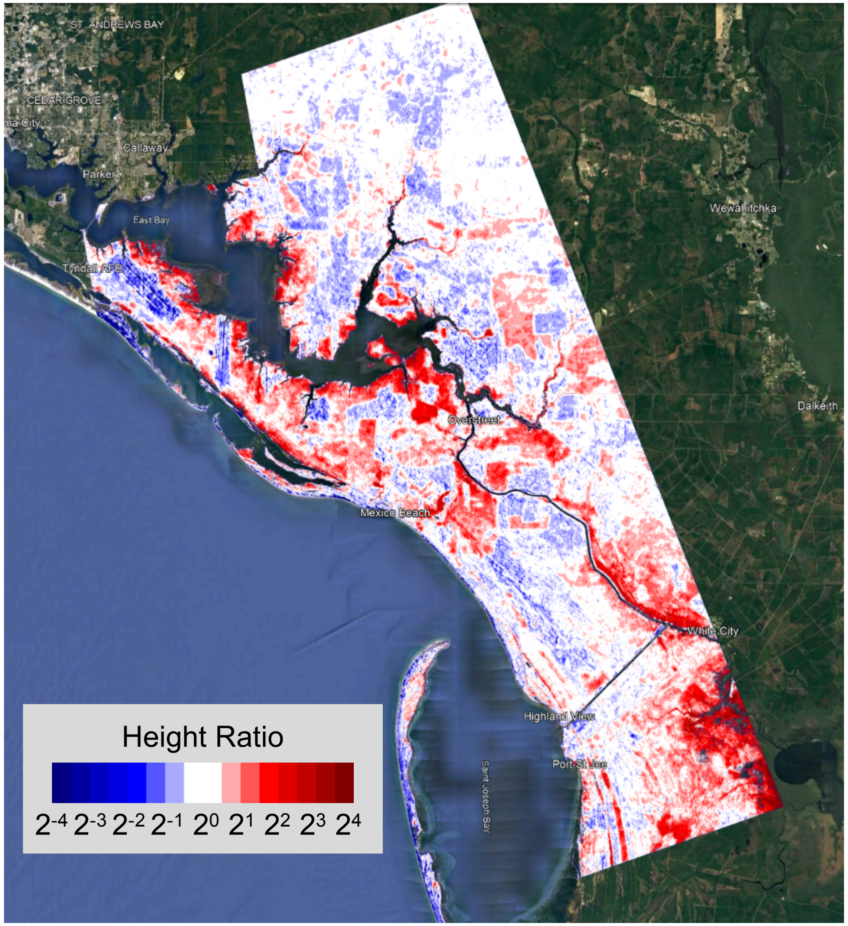
Tuned Radargrammetry Height (Right) vs. CUDEM Height (Left)





Tuned Radargrammetry Height vs. CUDEM Height

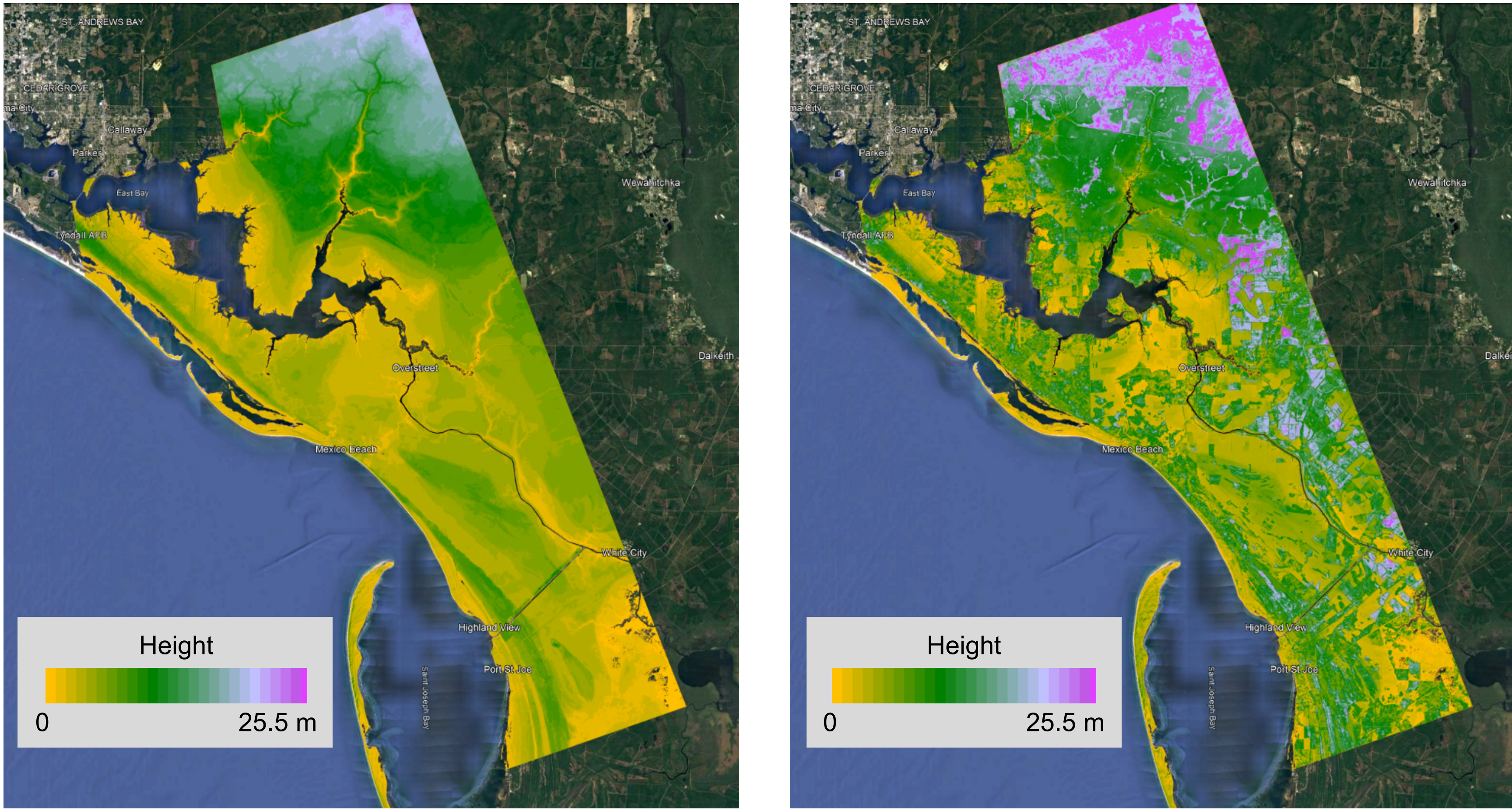




NOPP National Oceanographic Partnership Program

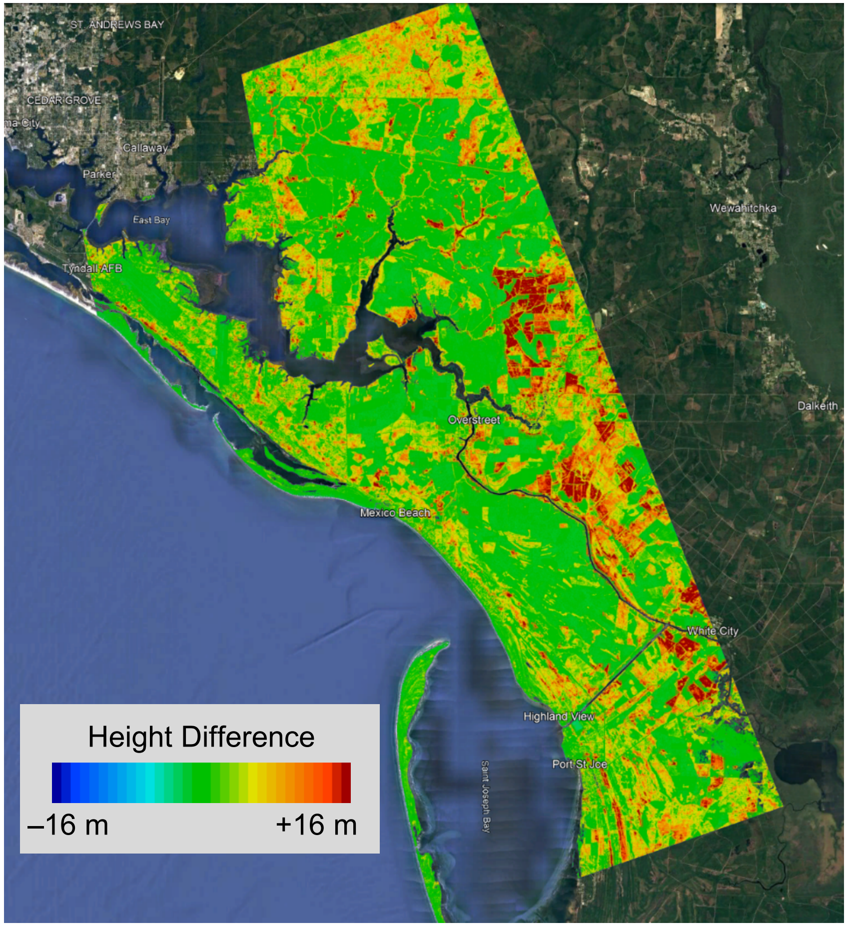
CSTARS

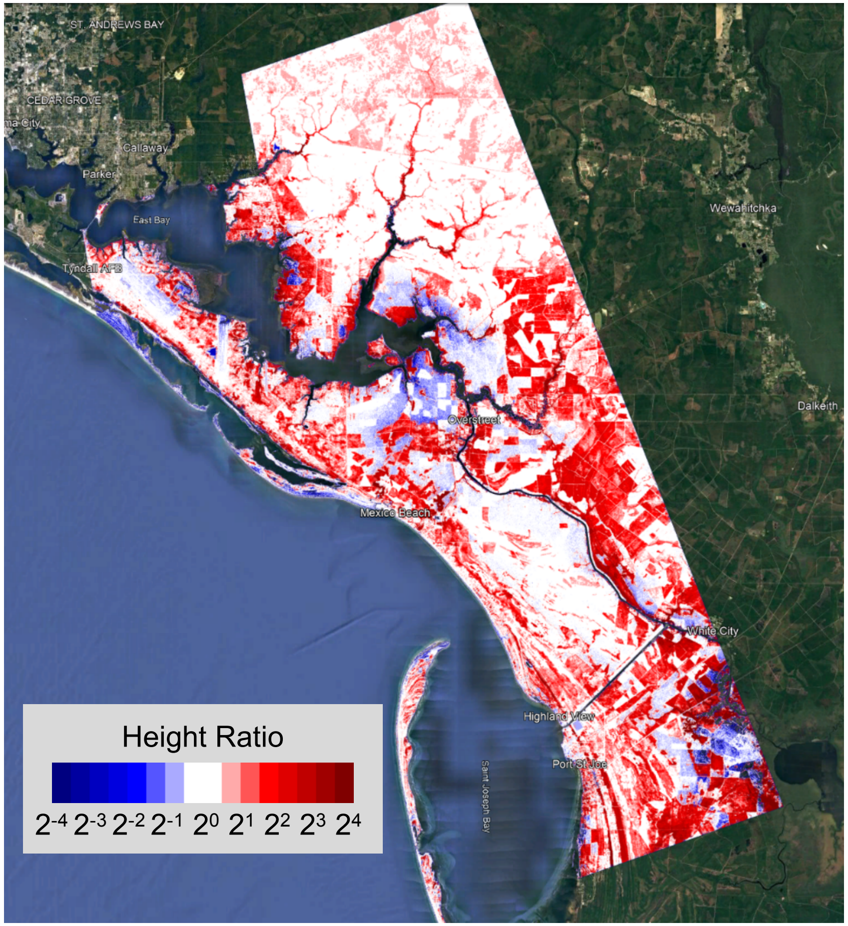
WorldDEM-Neo Height (Right) vs. CUDEM Height (Left)



NOPP National Oceanographic Partnership Program
CSTARS

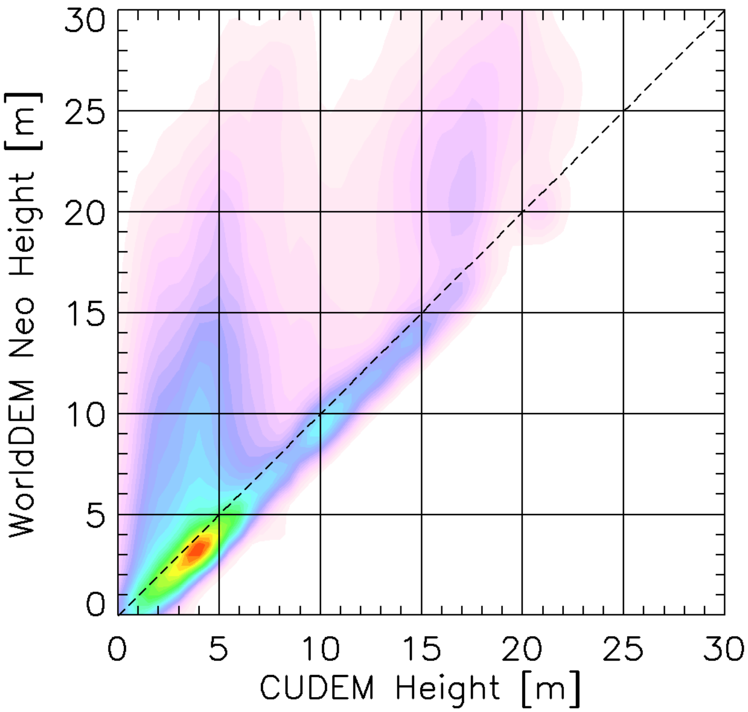
WorldDEM-Neo Height vs. CUDEM Height



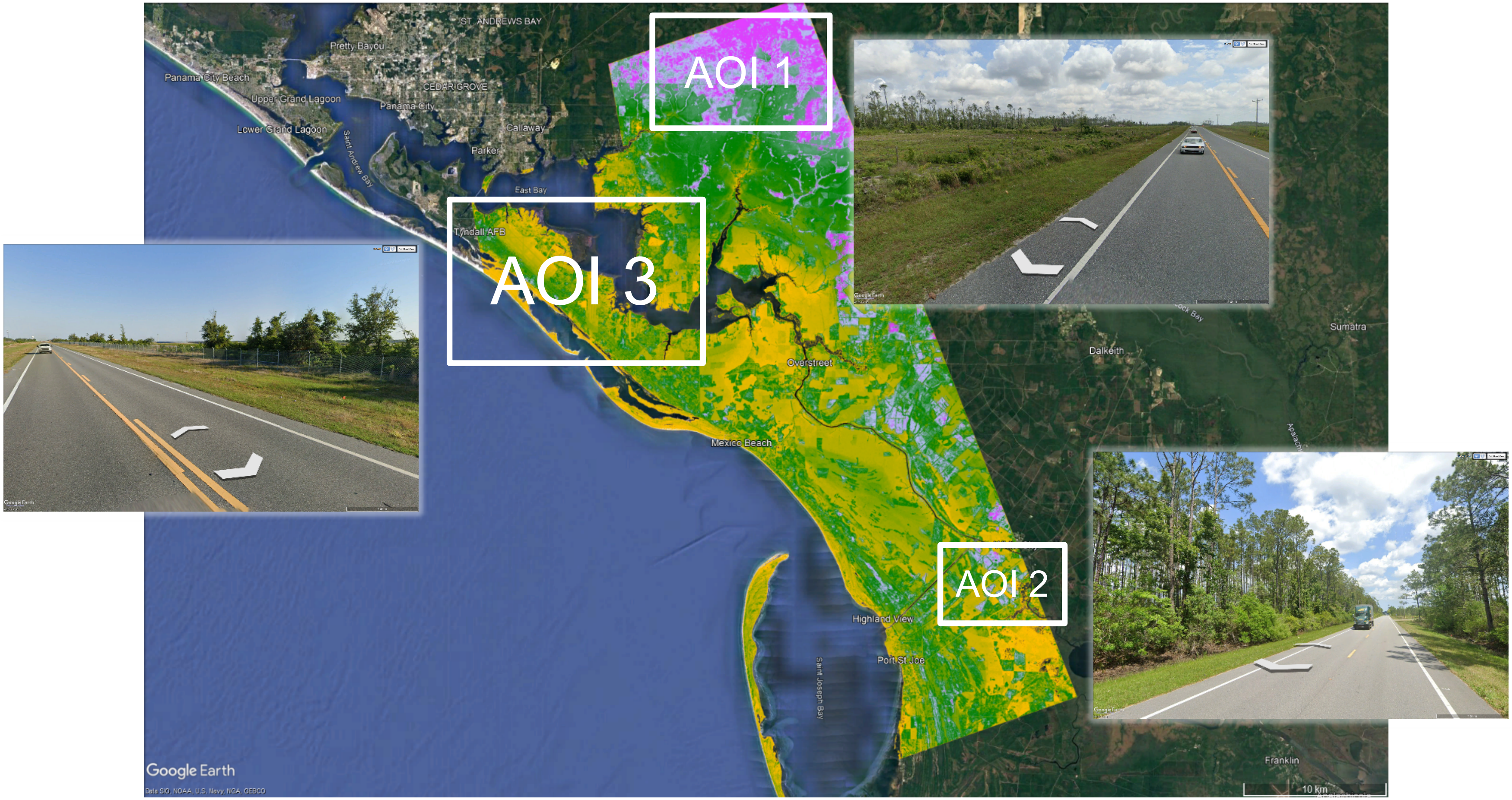


WorldDEM-Neo vs. CUDEM

Correlation Coefficient	0.721
Regression Coefficient	1.011
Mean Difference	3.05 m
RMS Difference	5.56 m

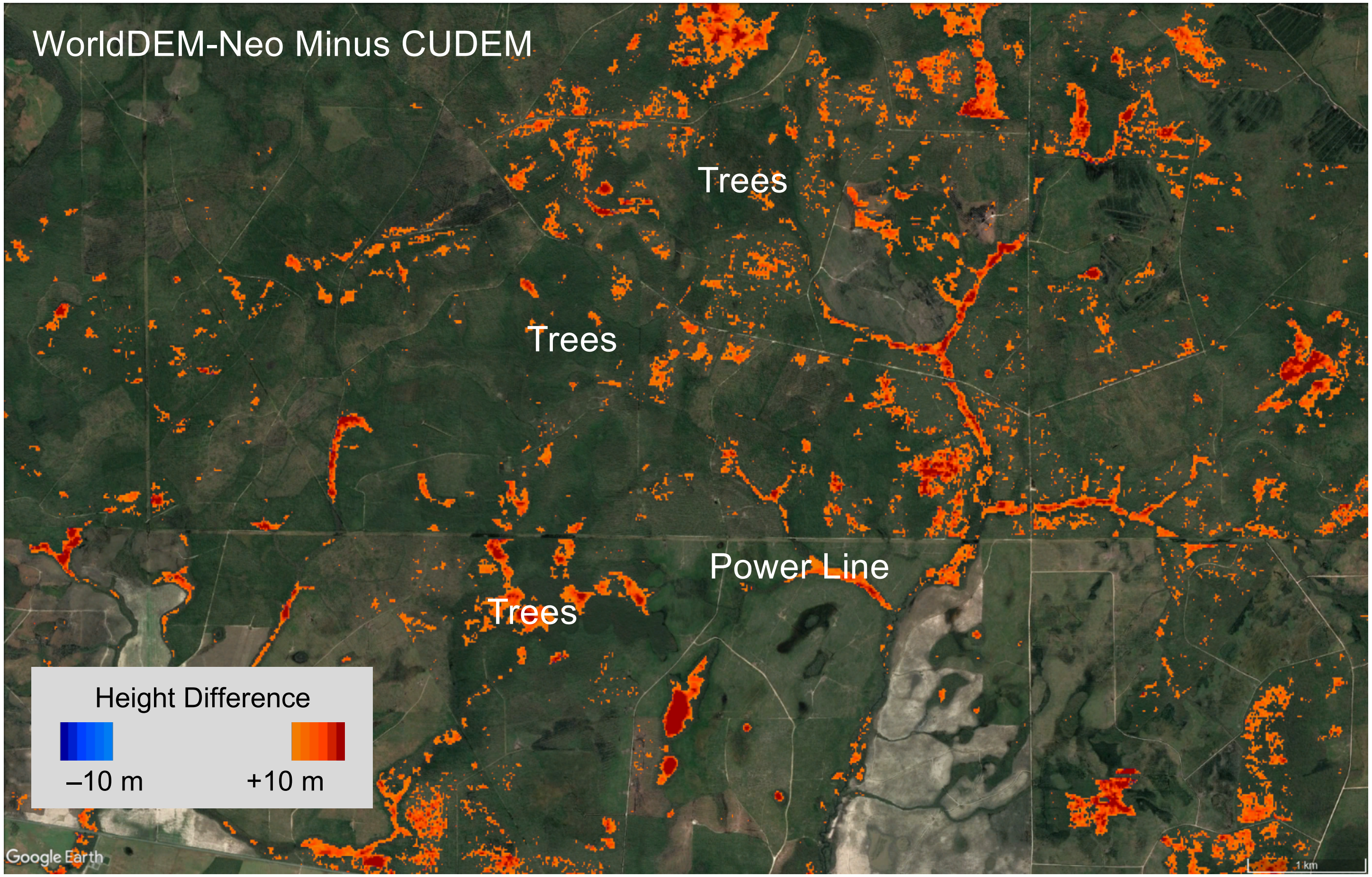


WorldDEM-Neo vs. CUDEM – Areas of Interest

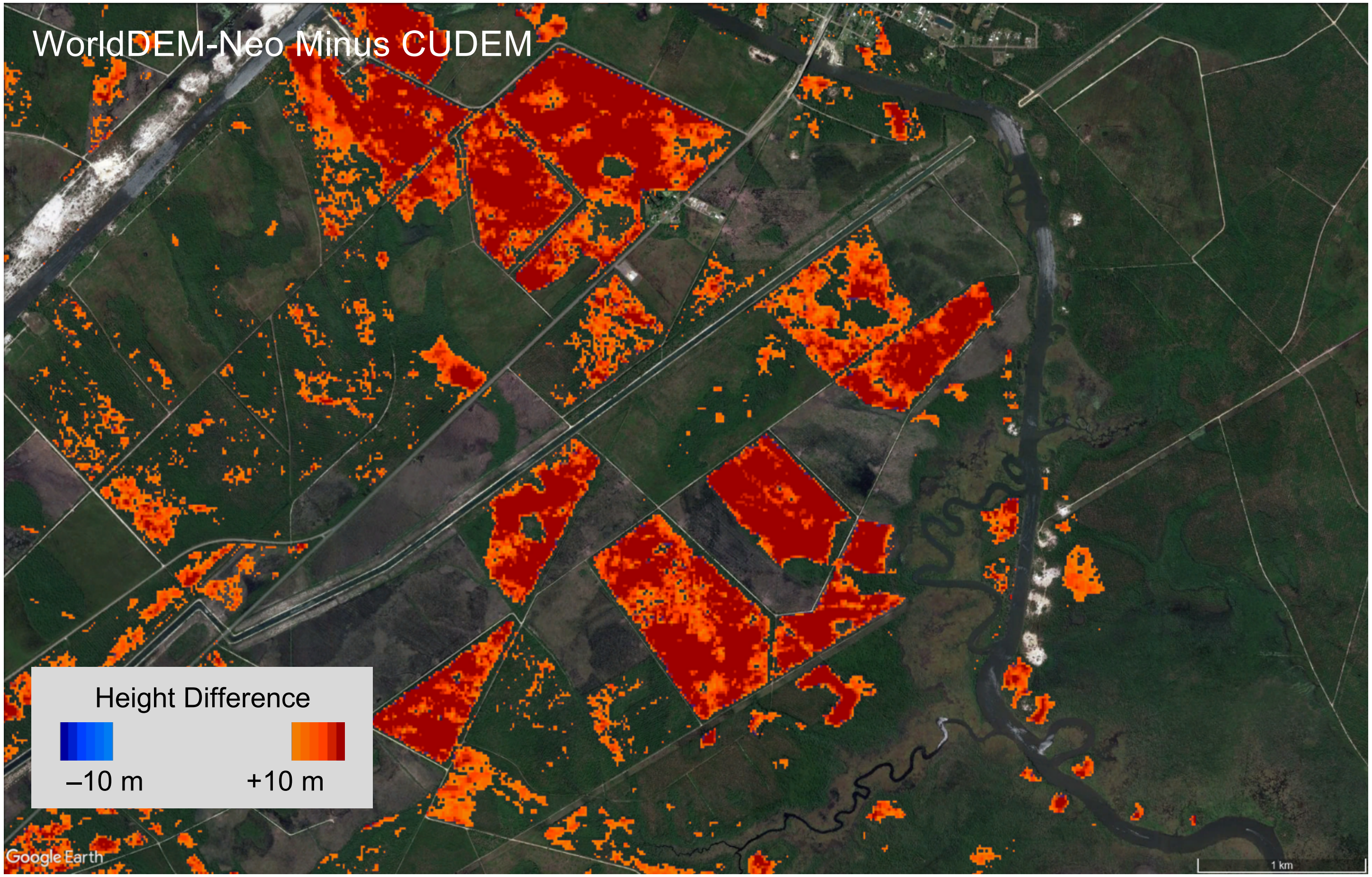


NOPP National Oceanographic Partnership Program
CSTARS

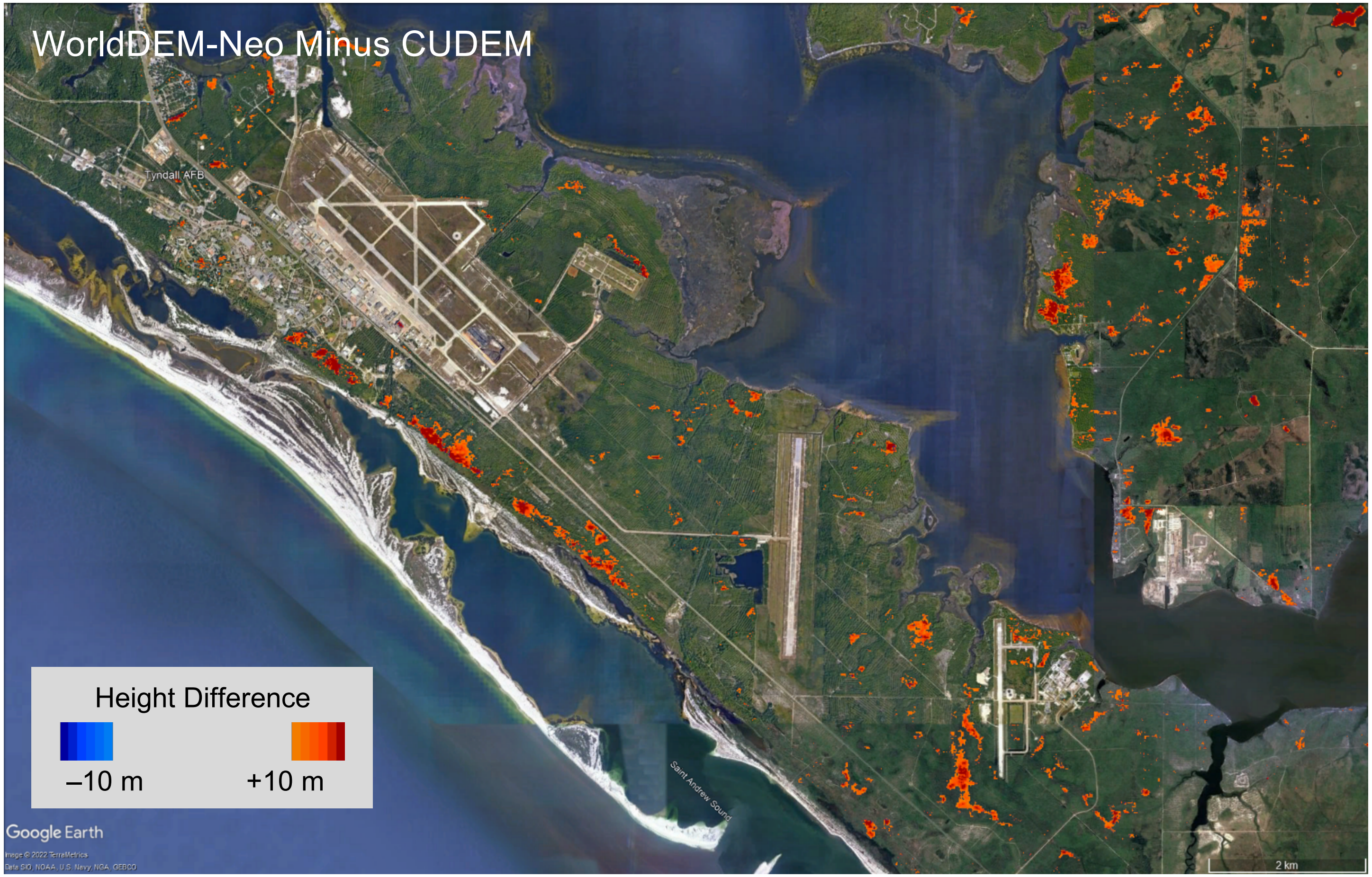
WorldDEM-Neo vs. CUDEM – Area of Interest 1



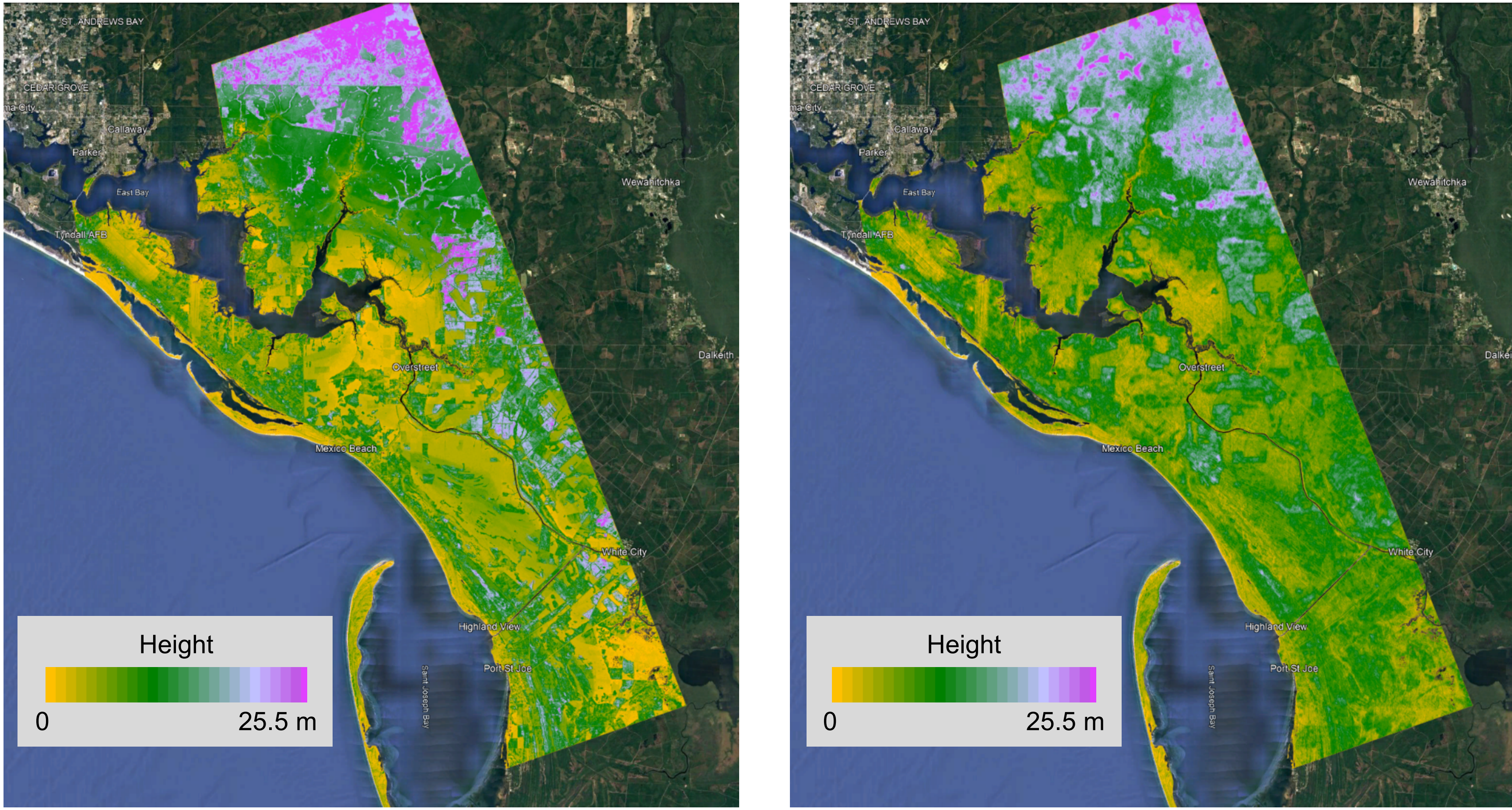
WorldDEM-Neo vs. CUDEM – Area of Interest 2



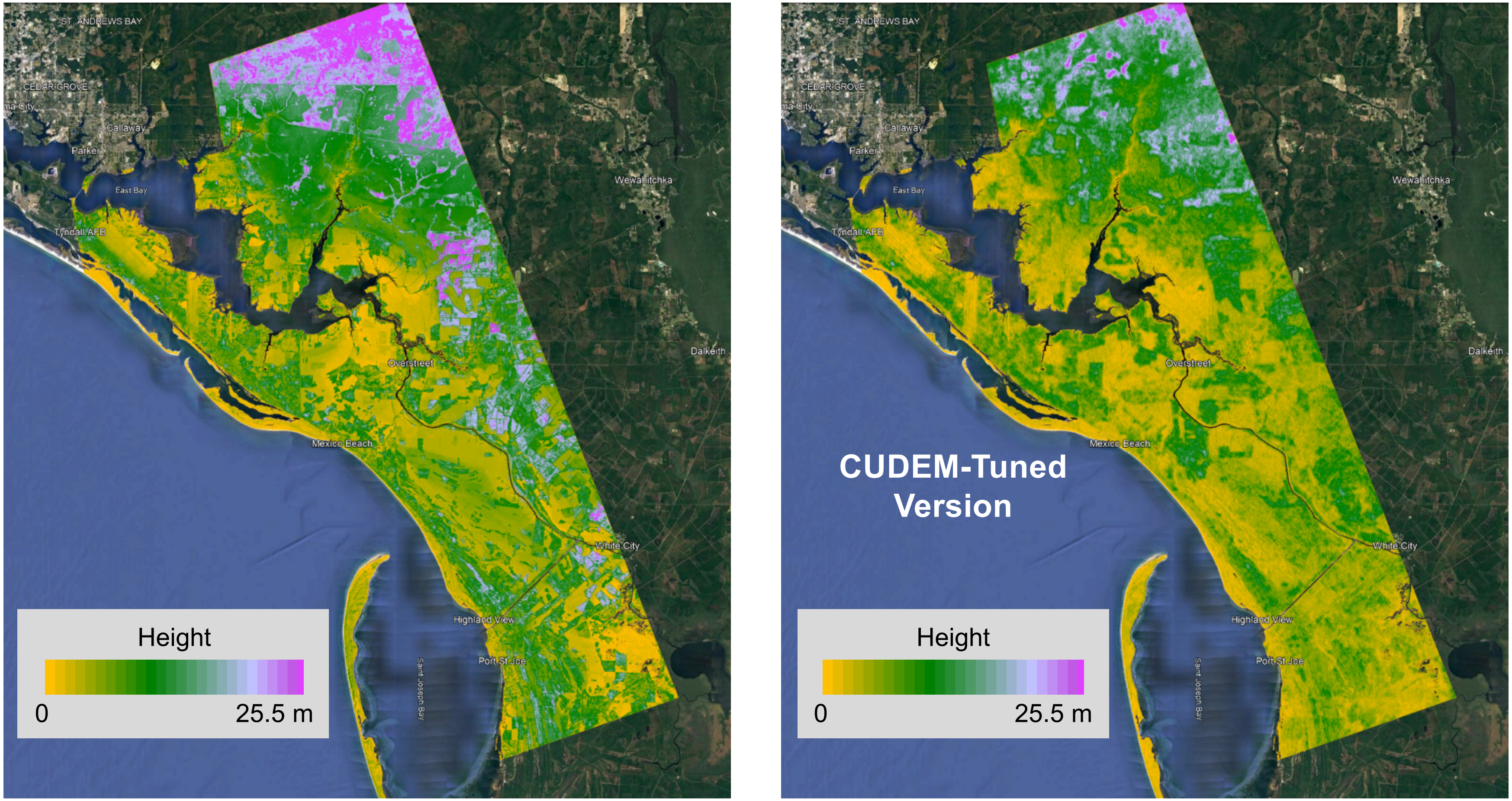
WorldDEM-Neo vs. CUDEM – Area of Interest 3



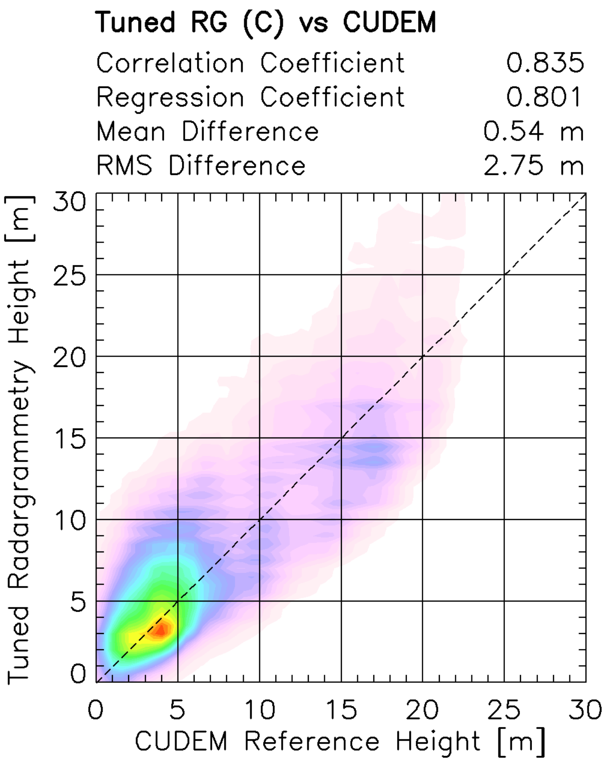
Tuned Radargrammetry Height (Right) vs. WorldDEM-Neo Height (Left)



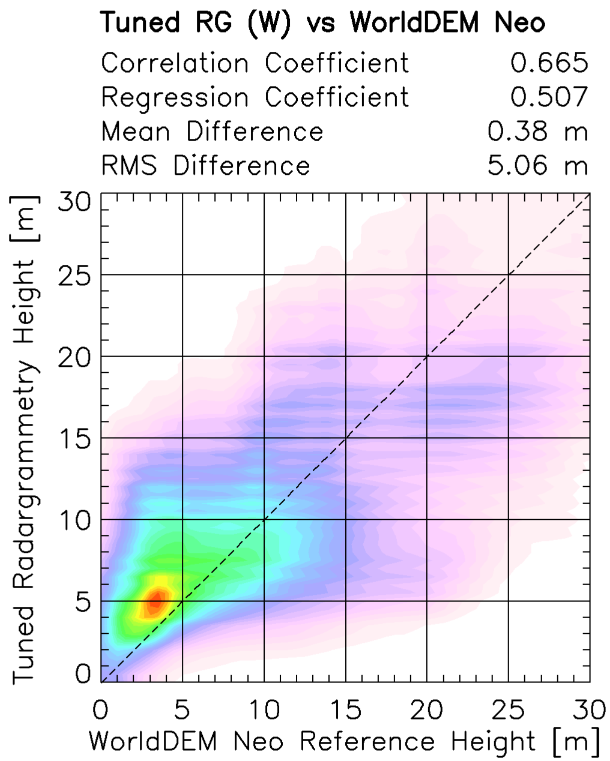
Tuned Radargrammetry Height (Right) vs. WorldDEM-Neo Height (Left)



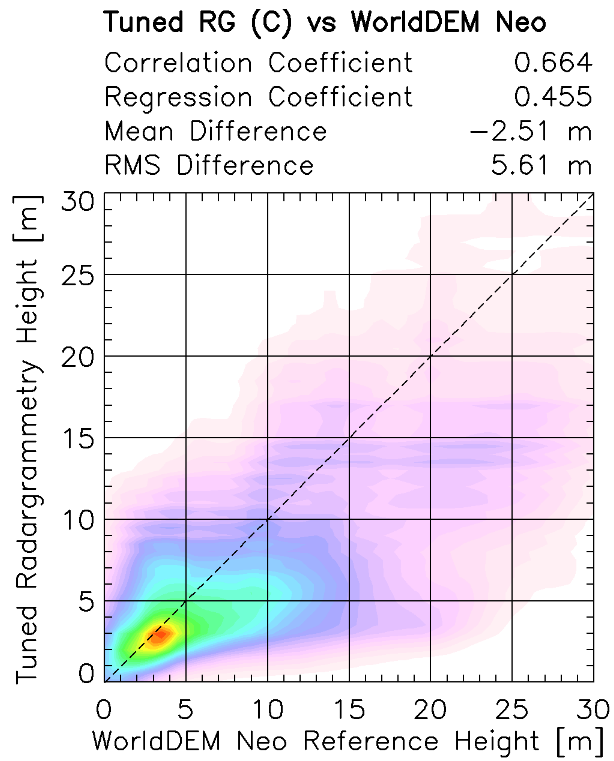
Tuned Radargrammetry Height vs. CUDEM and WorldDEM-Neo



Tuned against CUDEM, compared to CUDEM

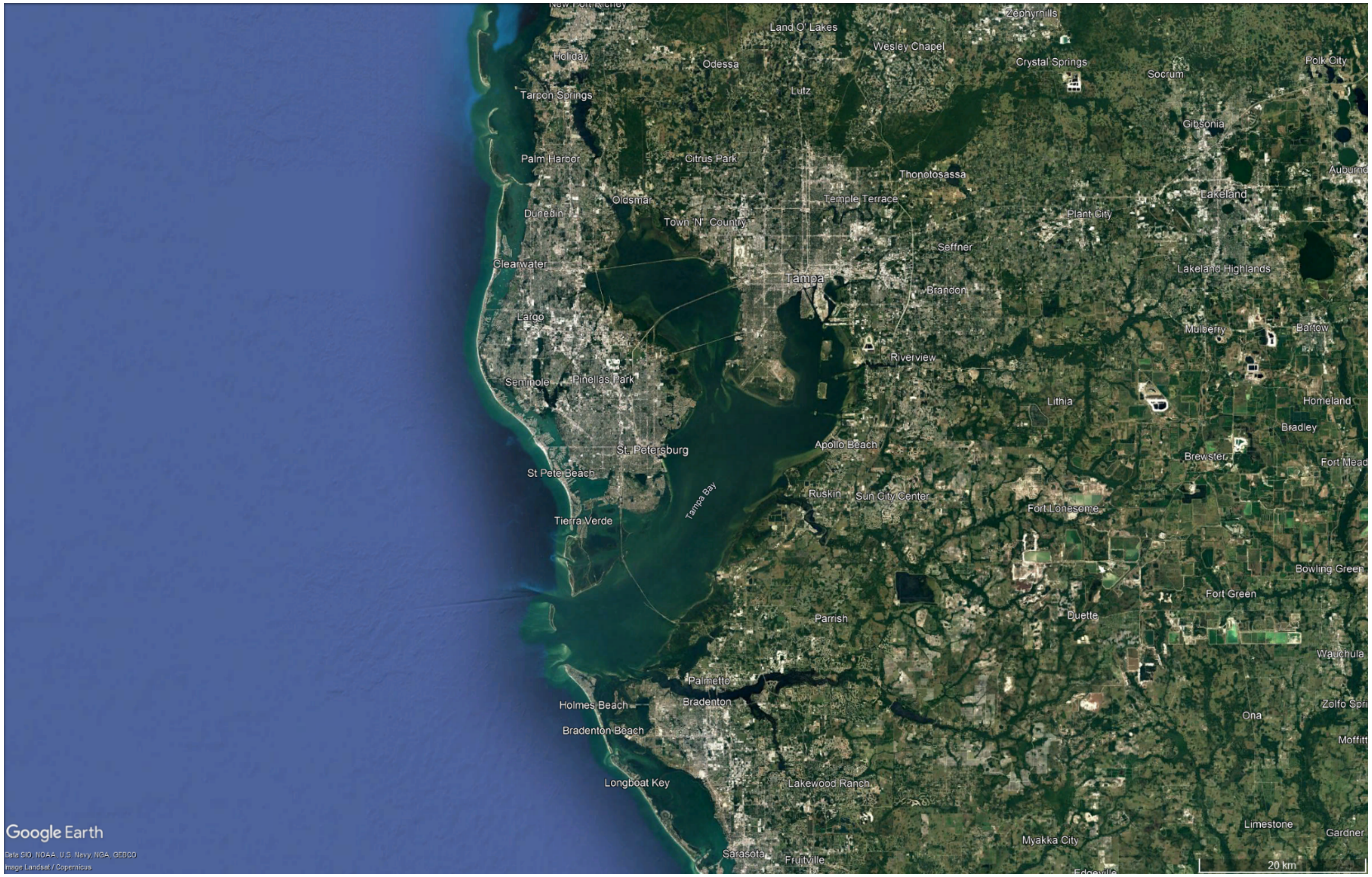


Tuned against WorldDEM-Neo, compared to WorldDEM-Neo

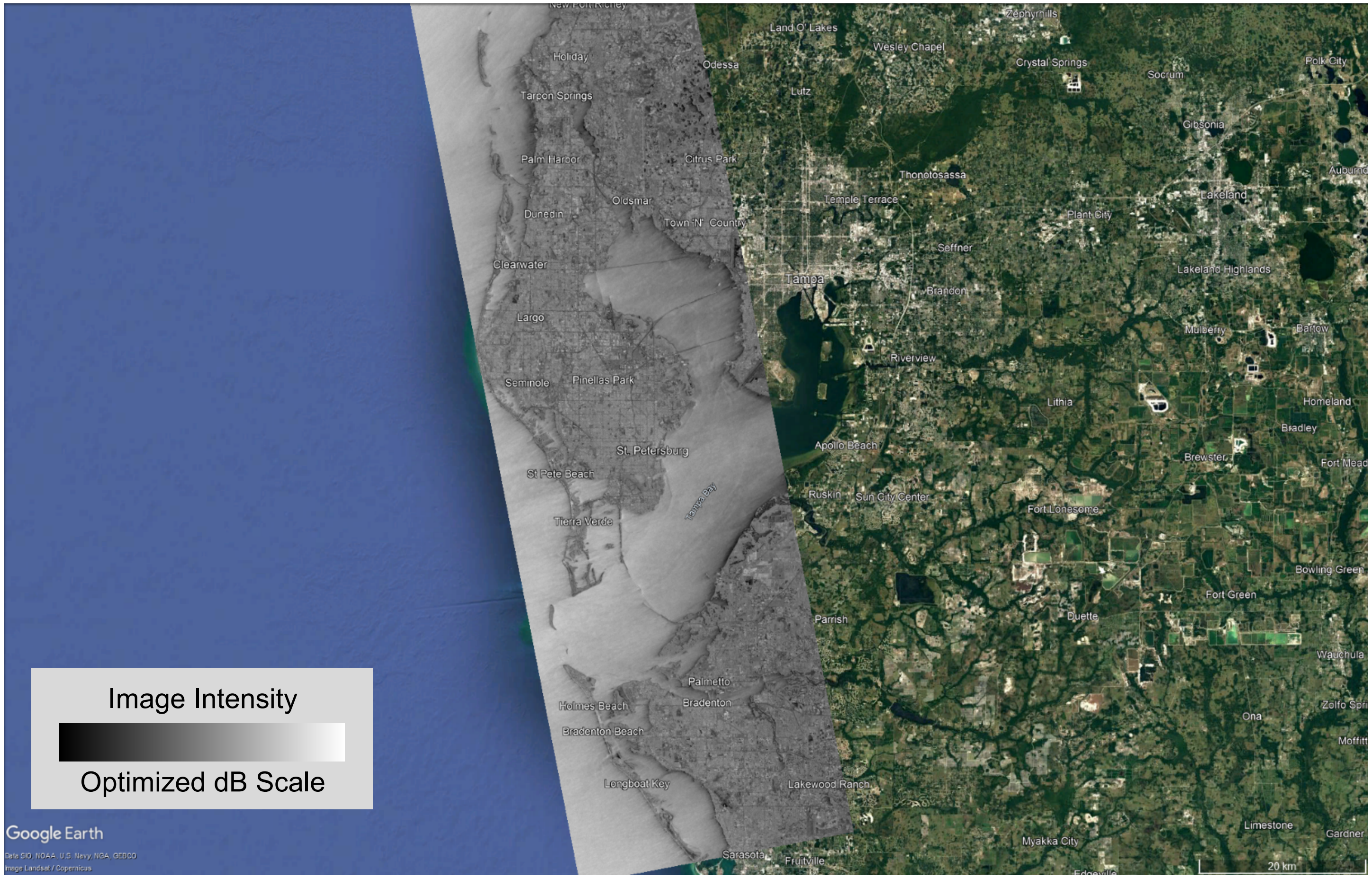


Tuned against CUDEM, compared to WorldDEM-Neo

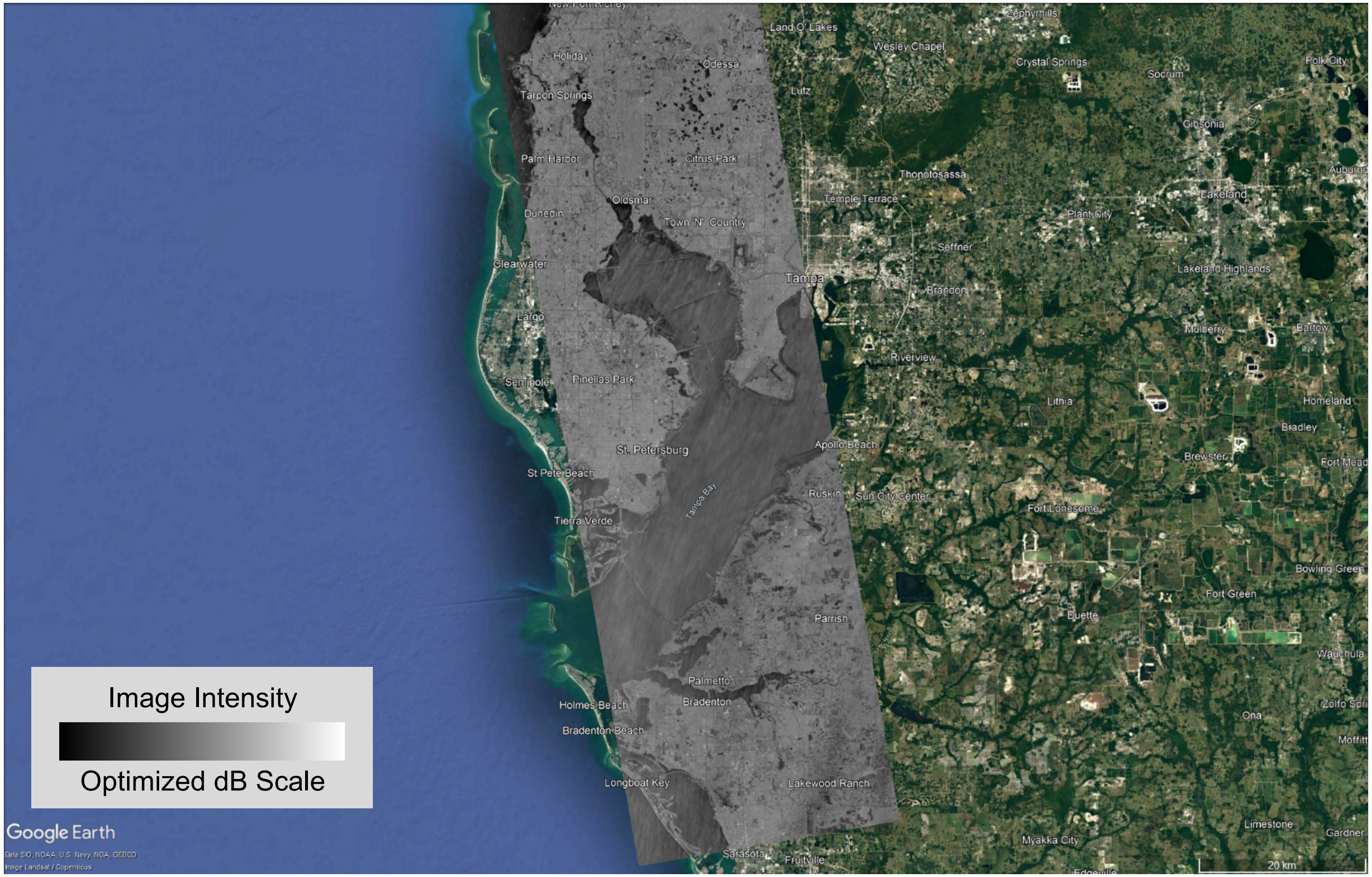
Hurricane Ian / Tampa Bay Test Area



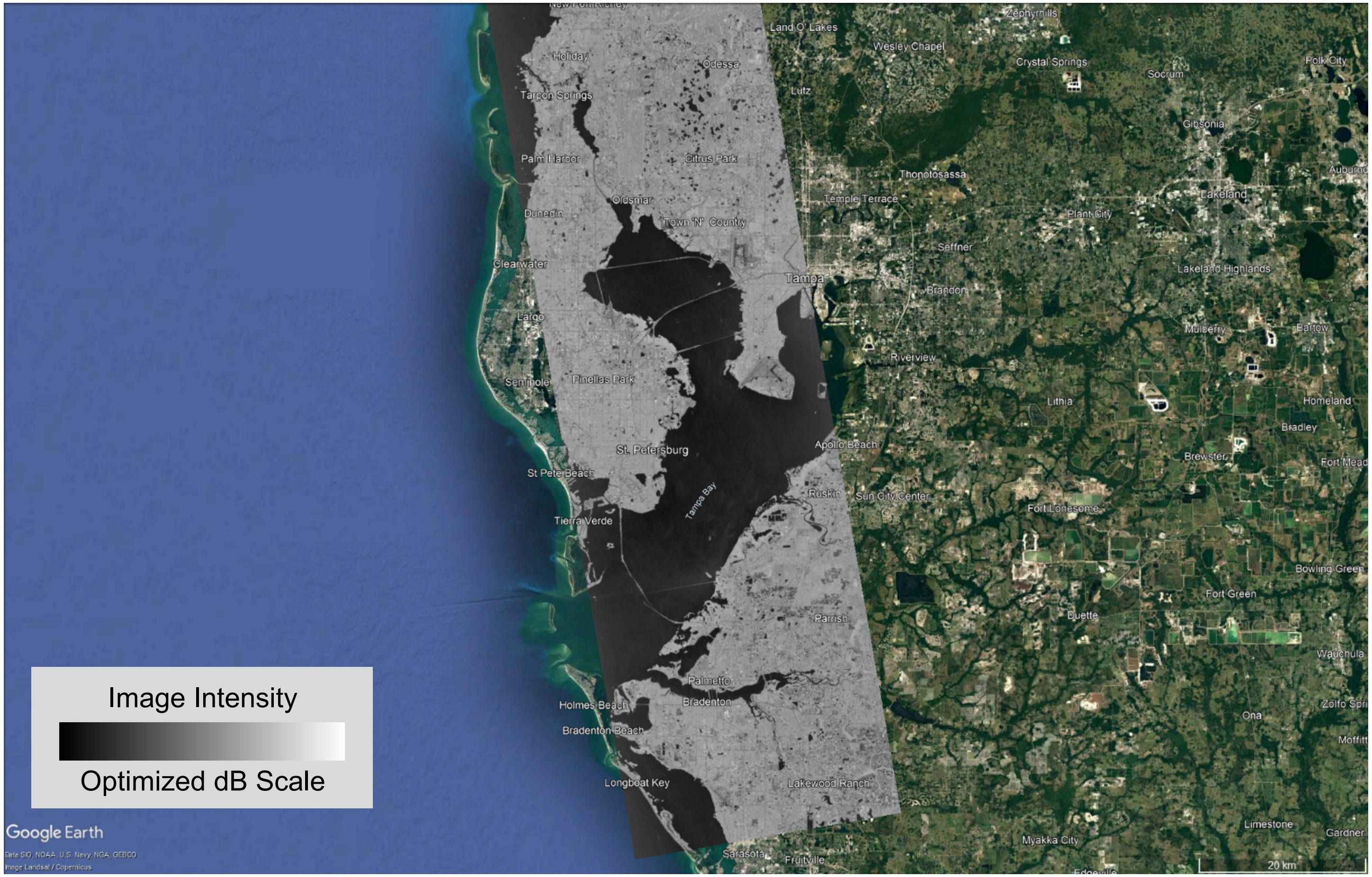
PAZ SAR Image, 2022-09-27 23:23 UTC (Image 1 of Pair 1, 21°)



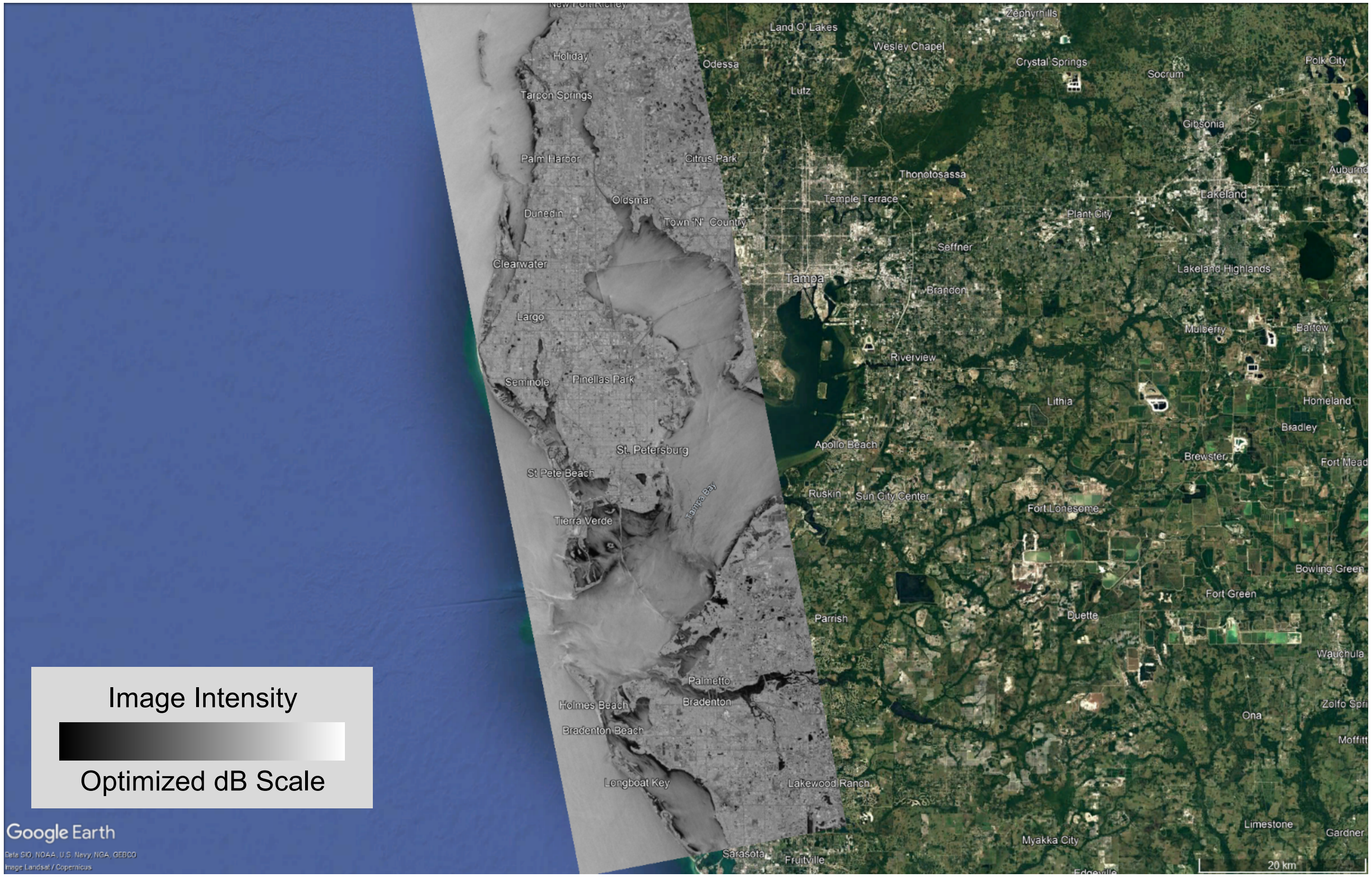
TDX SAR Image, 2022-09-28 23:32 UTC (Image 2 of Pair 1, 41°)



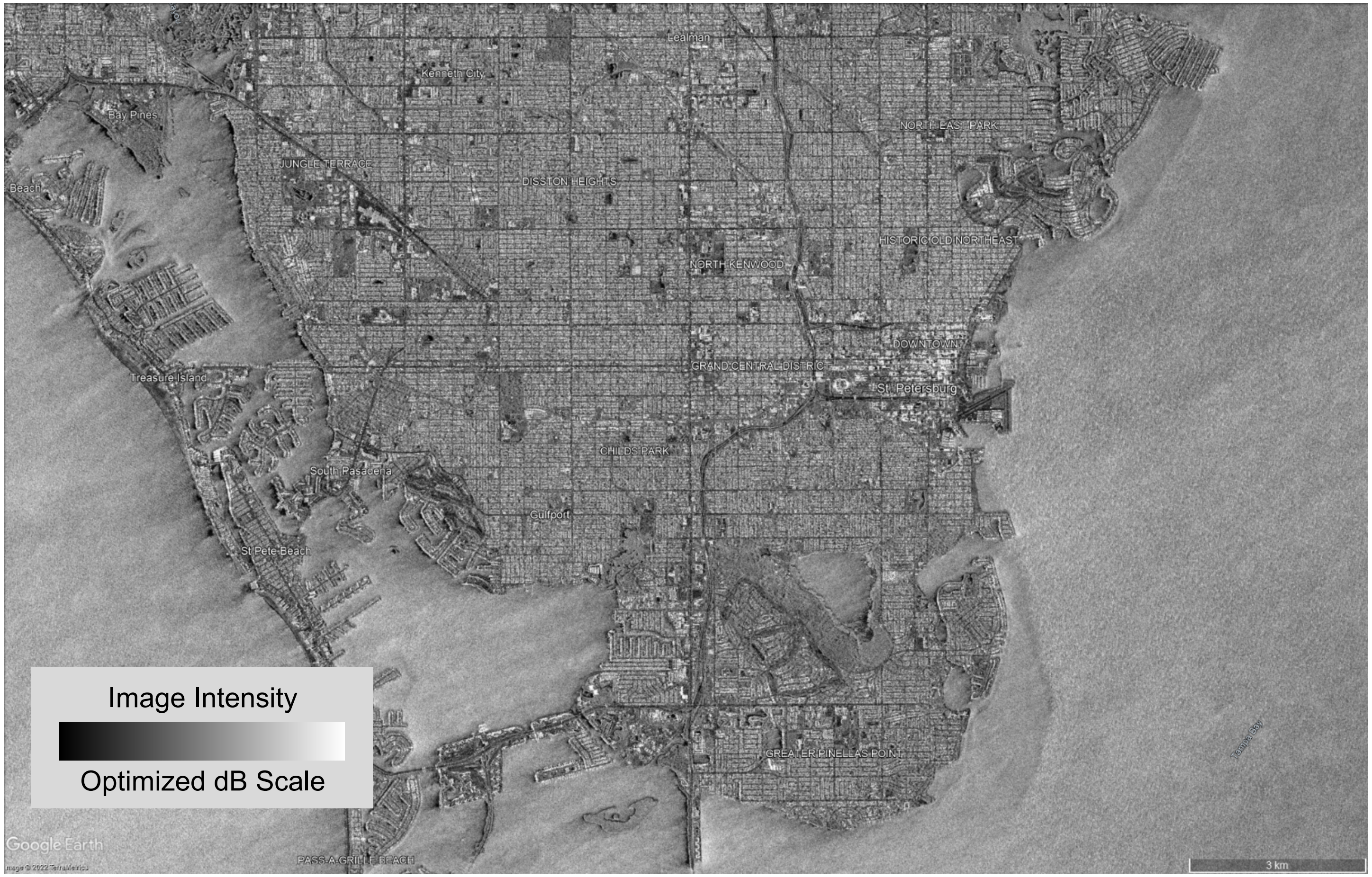
PAZ SAR Image, 2022-10-02 23:31 UTC (Image 1 of Pair 2, 41°)



TDX SAR Image, 2022-10-04 23:24 UTC (Image 2 of Pair 2, 21°)

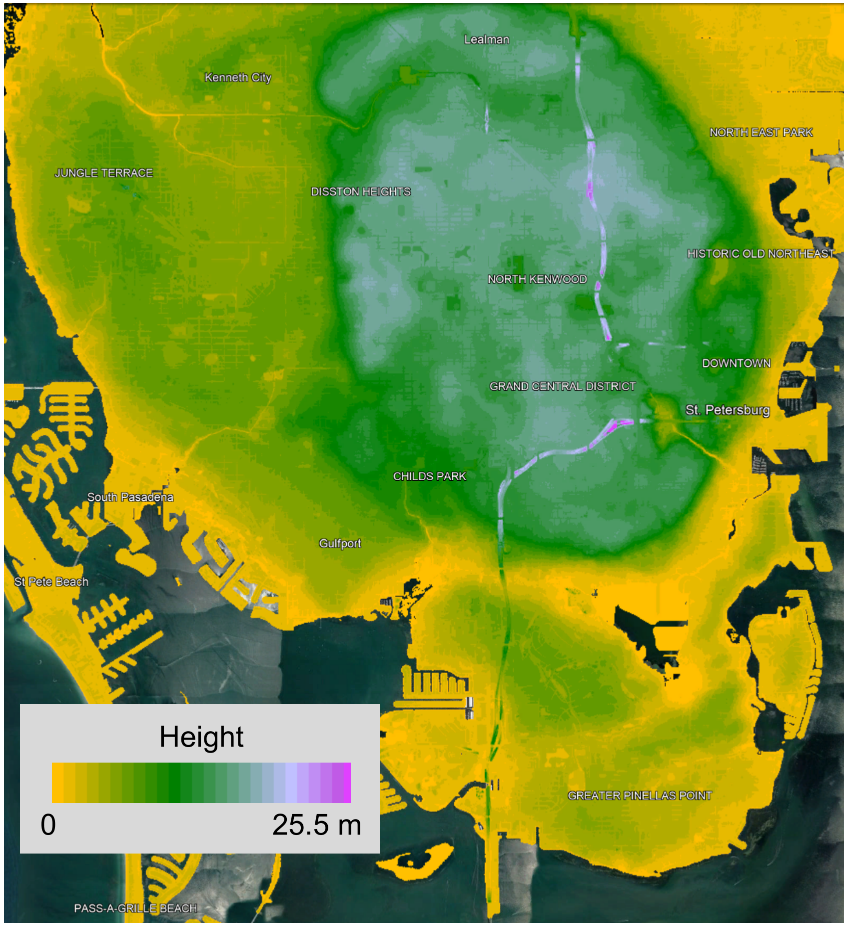


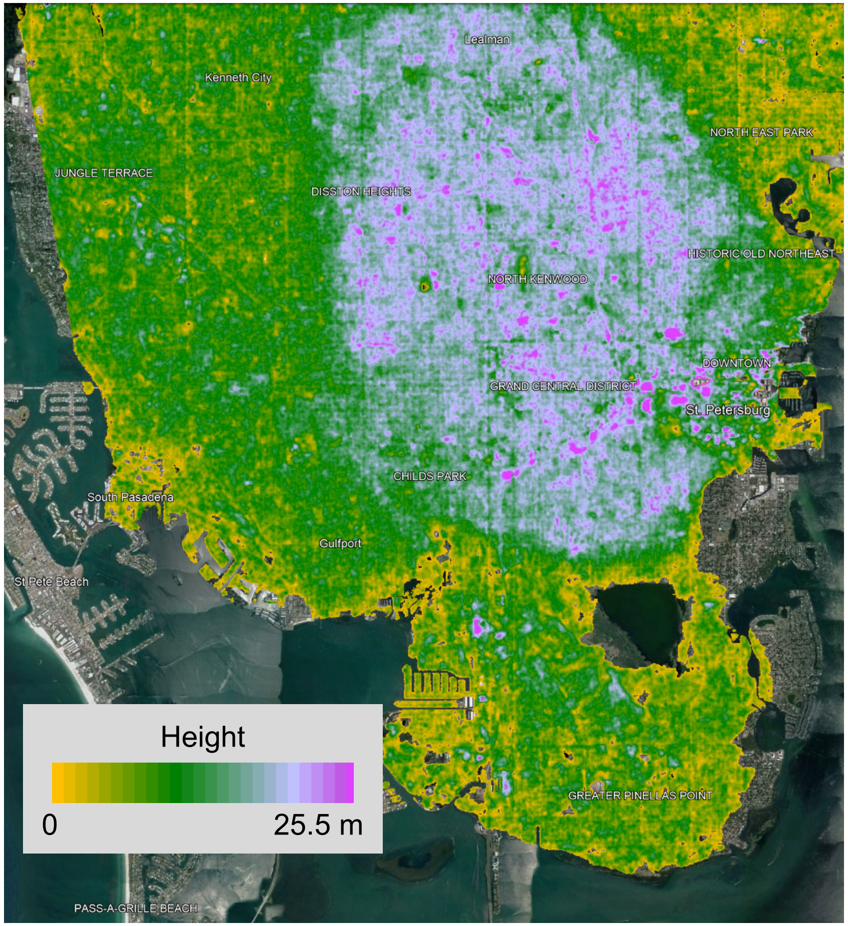
PAZ SAR Image, 2022-09-27 23:23 UTC (Image 1 of Pair 1, 21°)



TDX SAR Image, 2022-09-28 23:32 UTC (Image 2 of Pair 1, 41°)

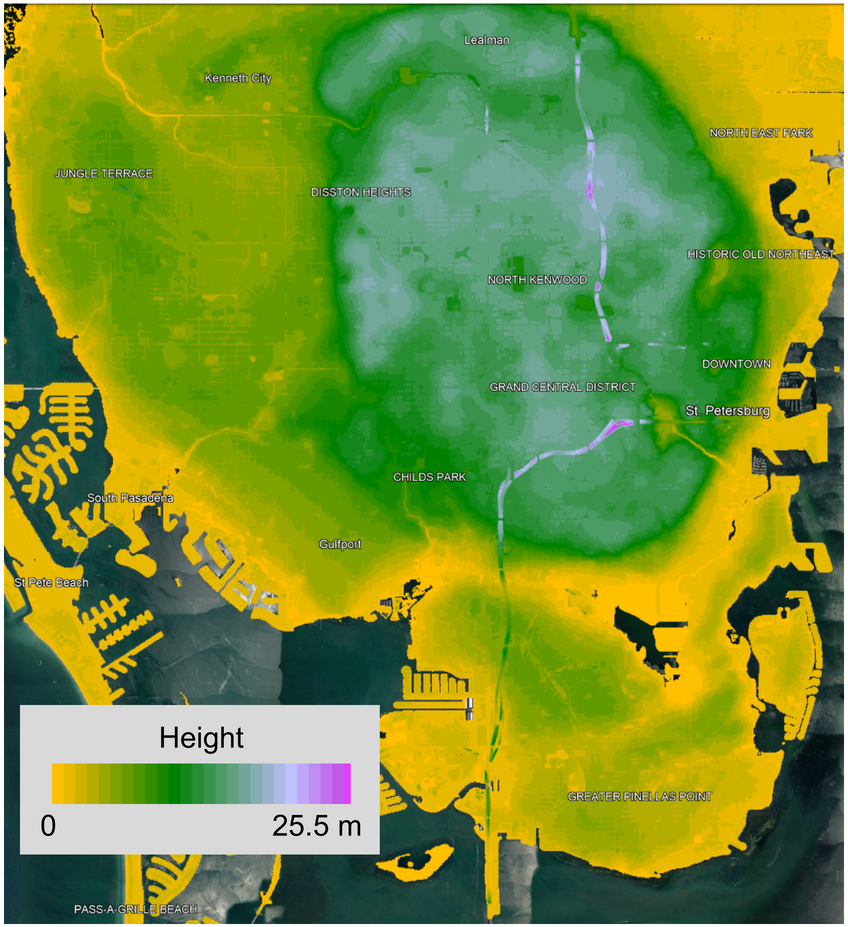
Initial Radargrammetry Height (Pair 1, Right) vs. CUDEM Height (Left)

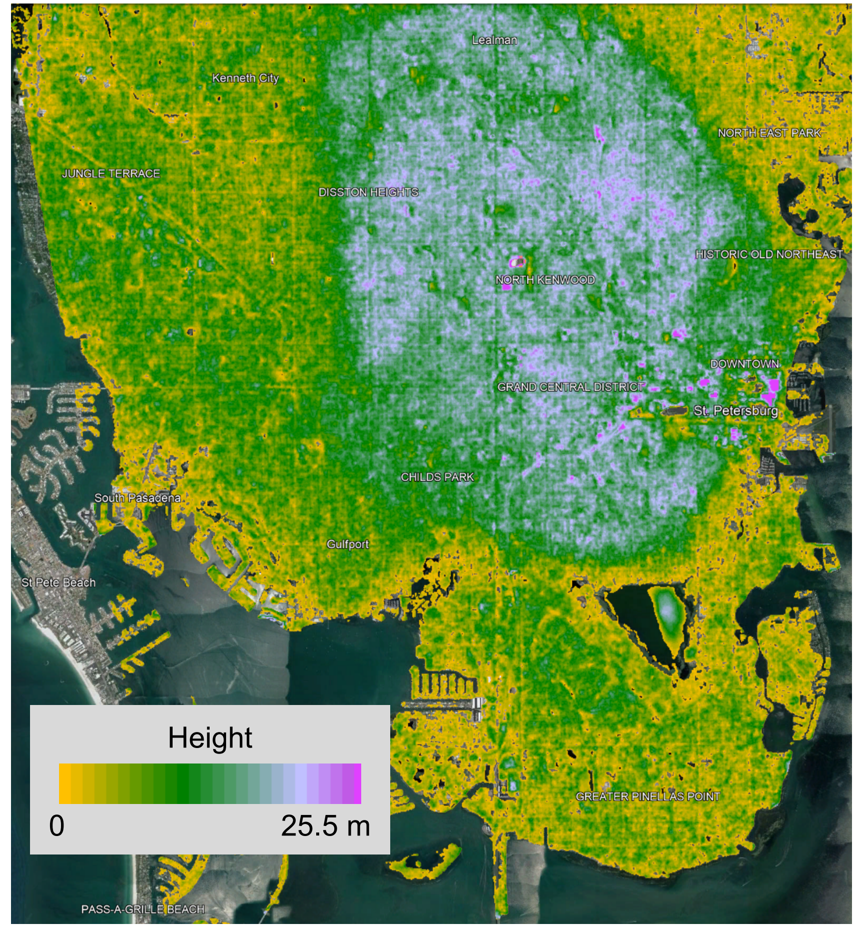




National Oceanographic Partnership Program

Initial Radargrammetry Height (Pair 2, Right) vs. CUDEM Height (Left)





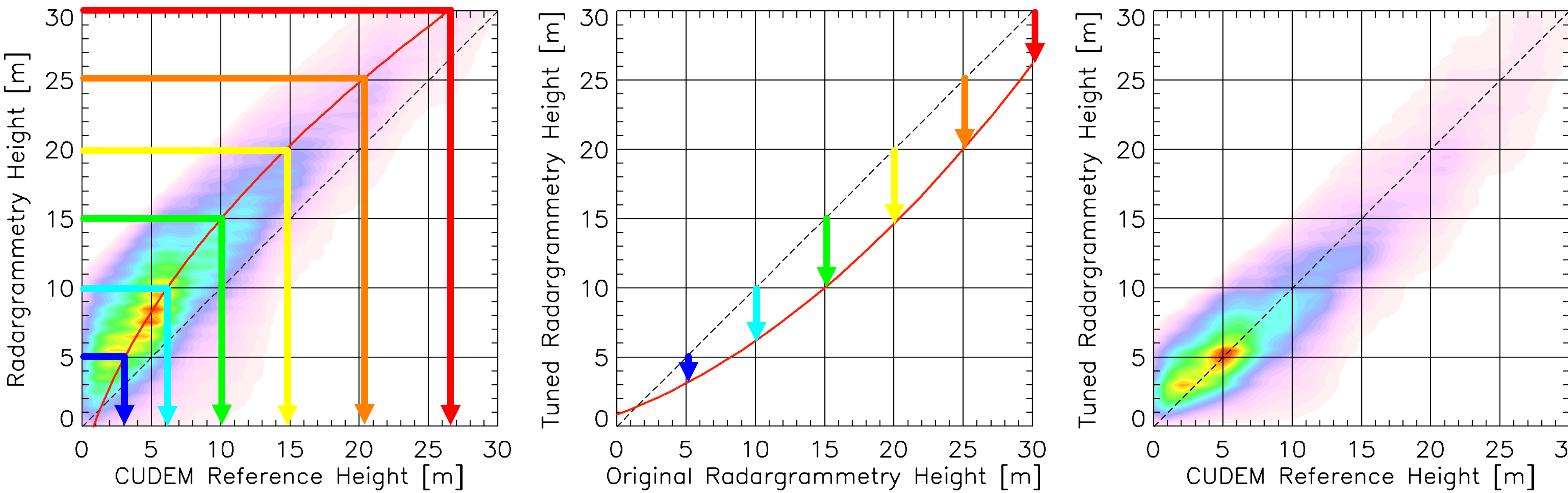
Radargrammetry Height (Pair 1) vs. CUDEM Height

RG–DEM vs CUDEM, Sep 27–28

Correlation Coefficient	0.880
Regression Coefficient	0.973
Mean Difference	3.49 m
RMS Difference	4.36 m

Tuned RG vs CUDEM, Sep 27–28

Correlation Coefficient	0.892
Regression Coefficient	0.790
Mean Difference	0.03 m
RMS Difference	2.25 m



Red curve is fitted 2nd-order polynomial $H_{CUDEM} = f(H_{RGram})$

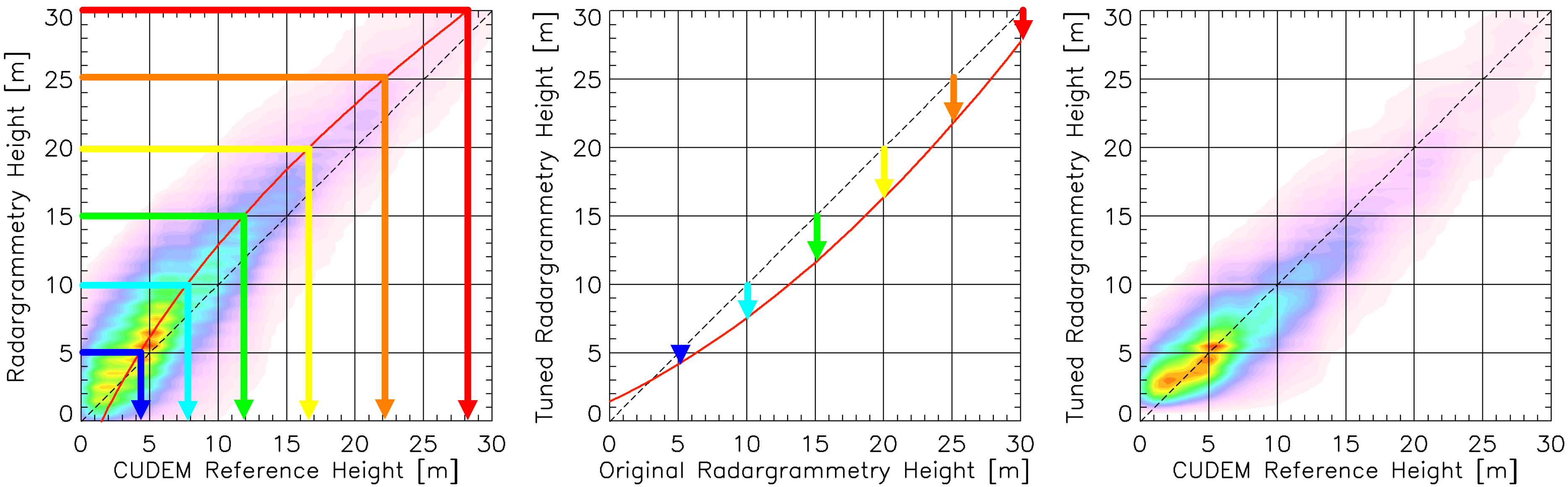
Radargrammetry Height (Pair 2) vs. CUDEM Height

RG–DEM vs CUDEM, Oct 02–04

Correlation Coefficient	0.882
Regression Coefficient	0.975
Mean Difference	1.45 m
RMS Difference	2.98 m

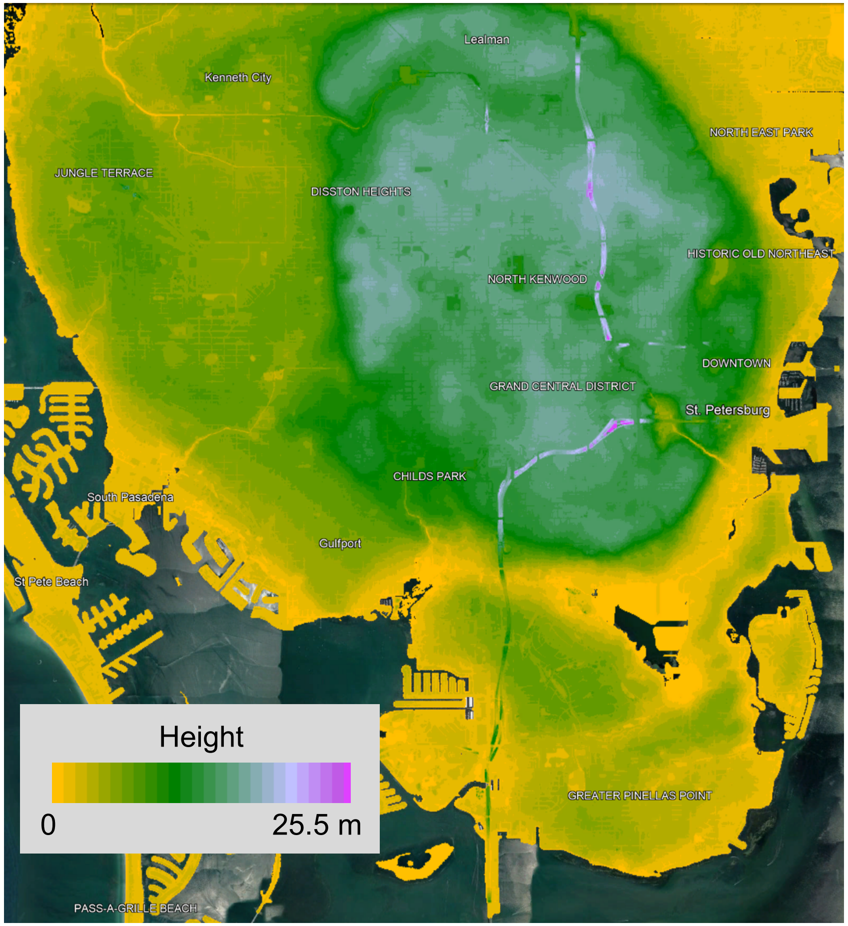
Tuned RG vs CUDEM, Oct 02–04

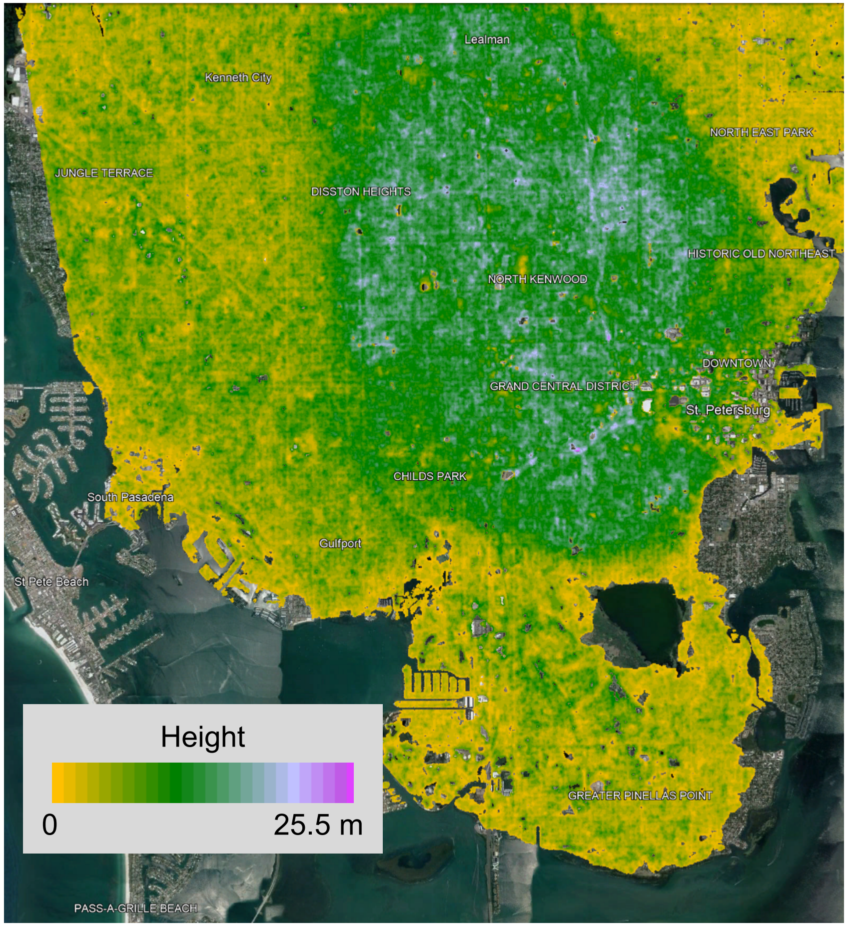
Correlation Coefficient	0.890
Regression Coefficient	0.781
Mean Difference	−0.12 m
RMS Difference	2.28 m



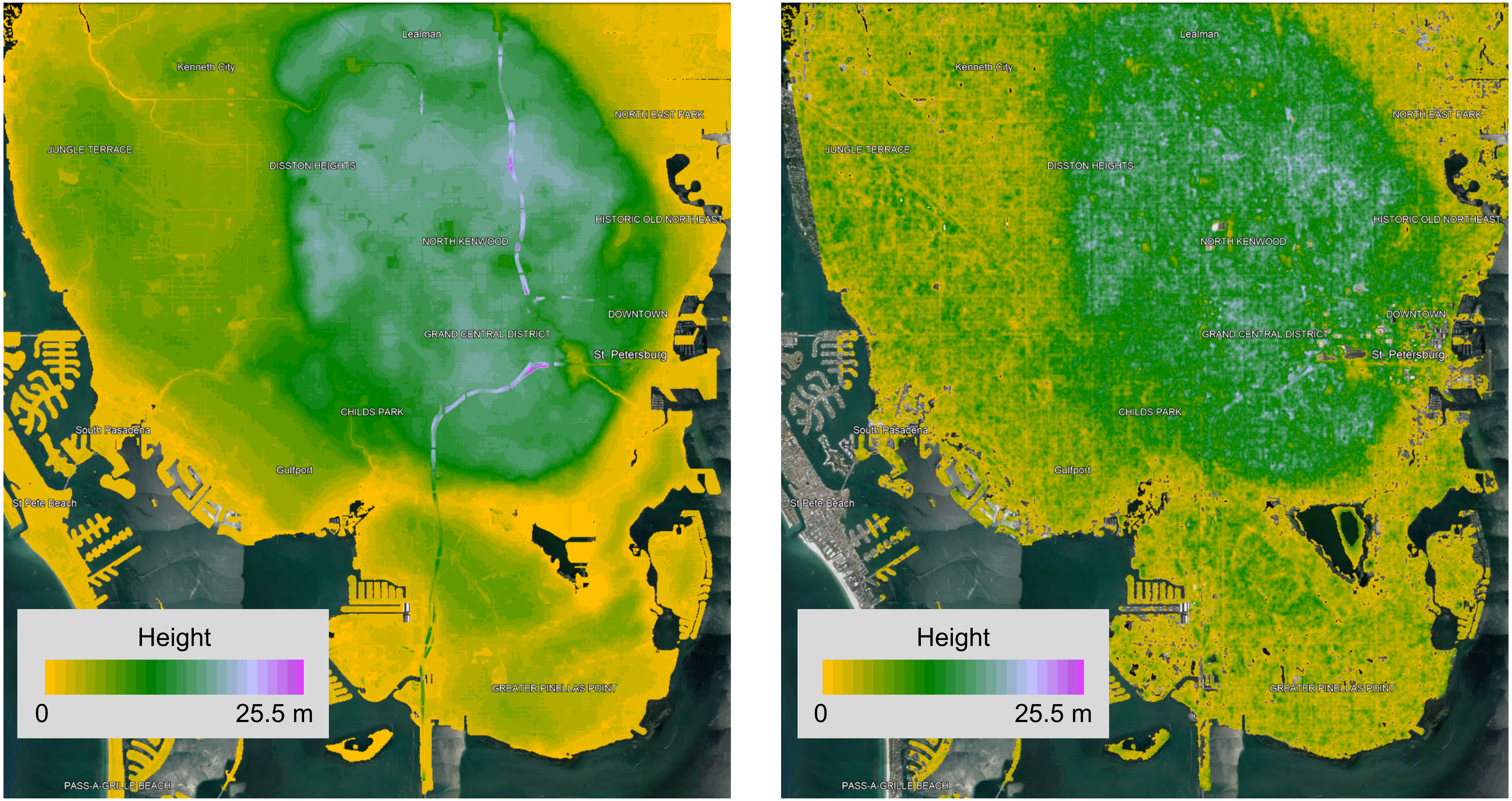
Red curve is fitted 2nd-order polynomial $H_{CUDEM} = f(H_{RGram})$

Tuned Radargrammetry Height (Pair 1, Right) vs. CUDEM Height (Left)

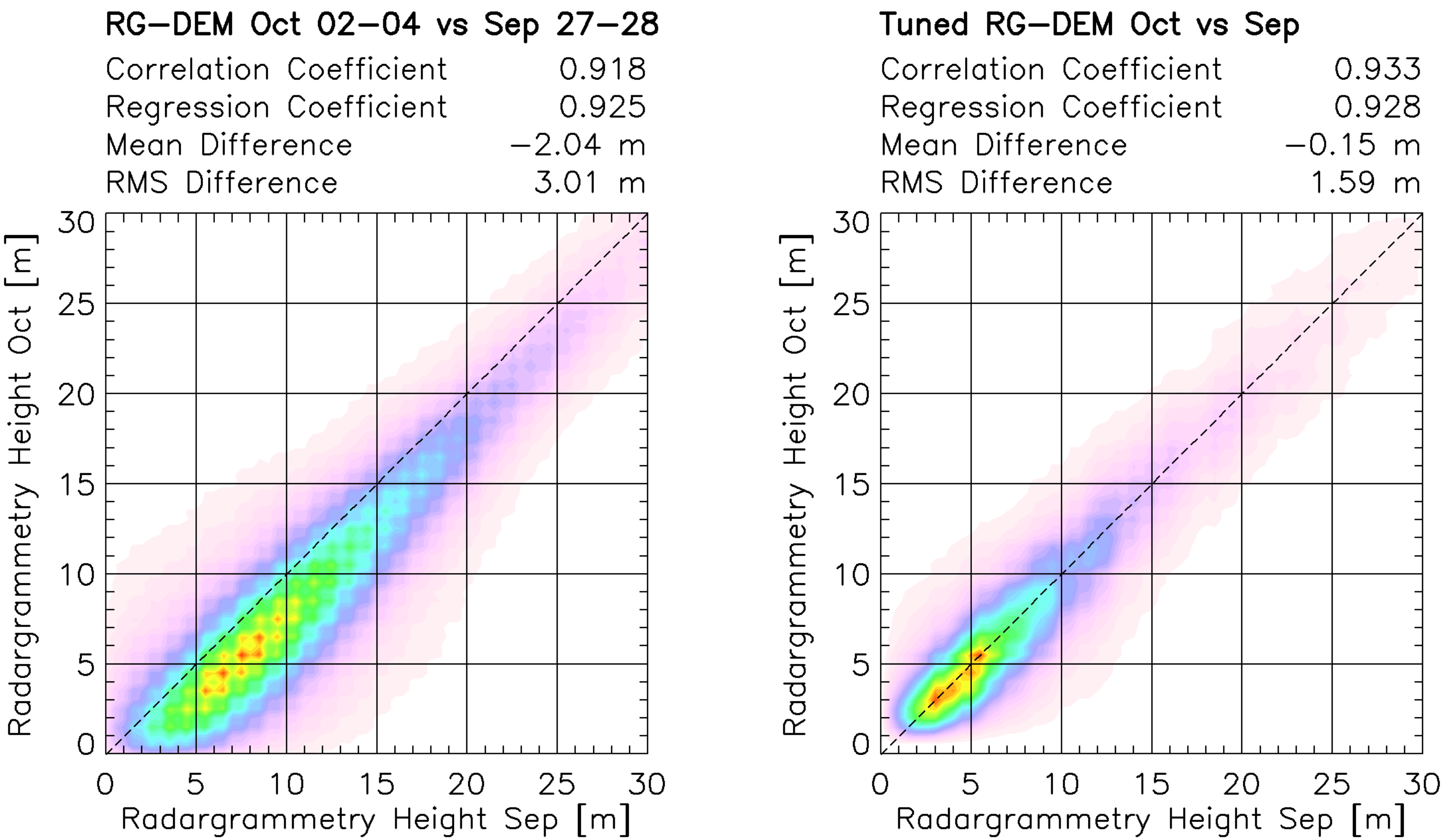




Tuned Radargrammetry Height (Pair 2, Right) vs. CUDEM Height (Left)



Radargrammetry Height, Pair 2 vs. Pair 1, Before and After Tuning



Conclusions and Outlook

- TerraSAR-X radargrammetry DEMs agree well with CUDEM after simple filtering and tuning
- Available WorldDEM-Neo data (InSAR) more affected by trees etc.
- In general, DEM / DSM differences need to be taken into account
- Working on our own radargrammetry algorithm to skip processing by Airbus, save time and money
- Alternative approach: Detect changes between SAR intensity images, combine with CUDEM or WorldDEM-Neo – to be tested
- No good examples with significant changes over land from the 2022 hurricane season!
- Need to discuss what products have highest priority for modelers

National Oceanographic Partnership Program

Air-deployed wave buoys for hurricane forecast improvements

Jim Thomson, Jake Davis (APL-UW)
Isabel Houghton, Pieter Smit (Sofar Ocean)
Elizabeth Thompson, Chris Fairall (NOAA PSL)
Gijs de Boer (U Colorado / NOAA PSL)

NOPP National Oceanographic Partnership Program

T3 Objectives and Performance

Provide real-time observations of hurricane waves and wave forcing that can be ingested by modelling groups to improve forecasts.

Specifically:

- Deploy arrays of Spotter and micro-SWIFT wave buoys from aircraft 12-48 hours ahead of hurricanes.
- Describe the wave field surrounding hurricanes.
- Compare buoy observations to NOAA WP3D aircraft estimates (WSRA, SFMR)
- Optimize buoy array design for analysis and assimilation.

2022 Planning/coordination:

- Established P-3 support with NRL
- Developed rapid response workflow and air-drop methods

2022 Deployments:

- May 2022 Cessna tests (Seattle)
- July 2022 Helicopter tests (Gulf of Mexico)
- Aug 2022 NRL P-3 tests (mid-Atlantic, offshore)
- Sep 2022 NRL P-3 rapid response (Florida, Hurricane Ian)
- Oct 2022 NRL P-3 tests (mid-Atlantic, shelf)

2022 Results:

- Buoy inter-comparisons
- Wave slopes (understanding air-sea interactions under extreme conditions)
- Model-data comparisons

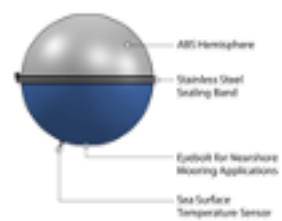
National Oceanographic Partnership Program

Rapid-response deployment for Hurricane Ian

Buoy deployment from NRL P3 airplane in front of Hurricane Ian, September 2022.

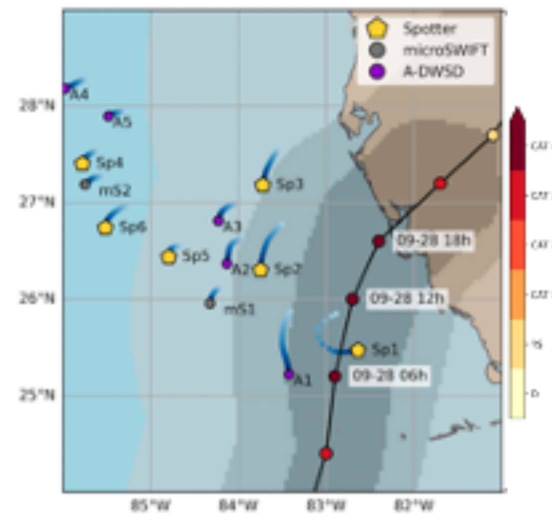
Three directional wave buoy types (microSWIFT, Spotter, DWSD)

Spotter



DWSD (UCSD-SIO)

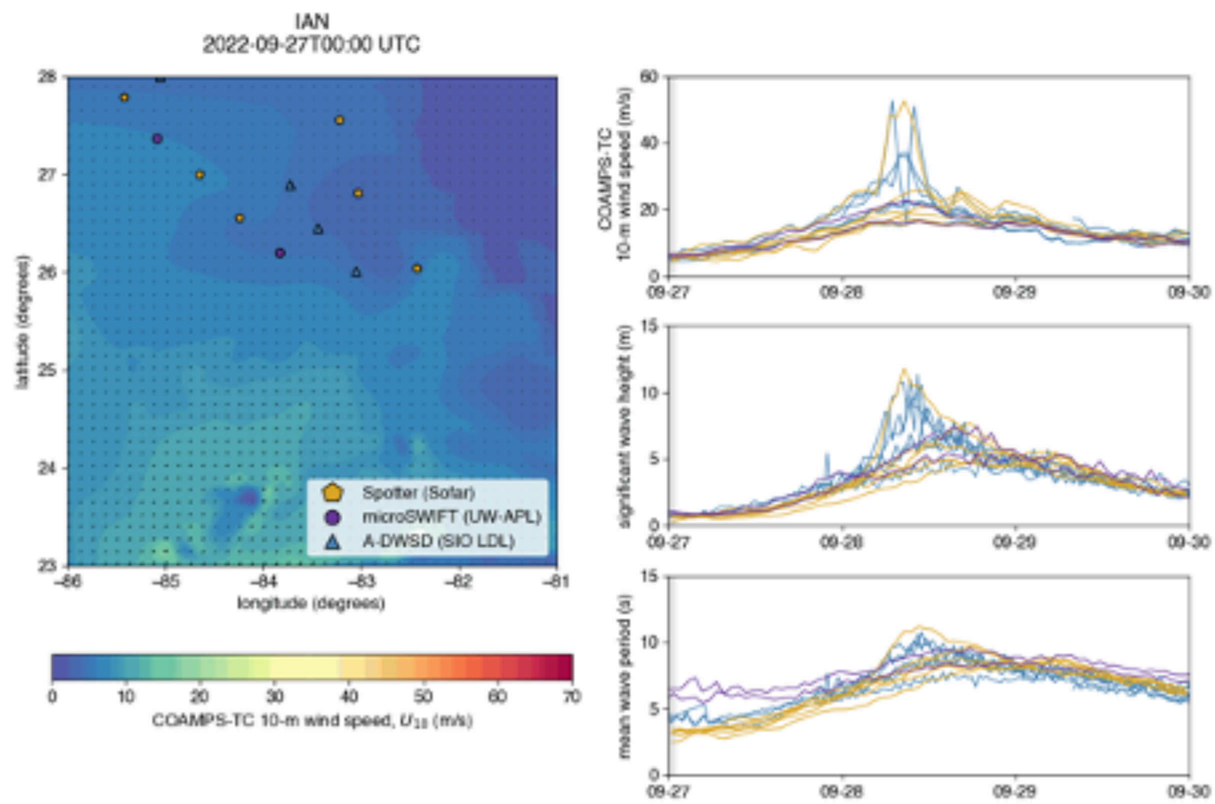
Buoy locations relative to Hurricane Ian



National Oceanographic Partnership Program

Real-time observations of the air-sea interface during Ian

- Extreme wave conditions in excess of 10 m observed prior to landfall
- High resolution wave frequency and direction information provided by buoys - critical to correctly representing the wave field and coastal impacts
- Dataset for model hindcast validation and improvement (see Task 4 intercomparisons)



Task 3B:
Real-time and Observed Measurements of Hurricane-Induced Hydrodynamics and Flooding

NOPP National Oceanographic Partnership Program

Shore-based Deployments

USGS science for a changing world

Jenna Brown
Robert Mason
Athena Clark
John Warner
Bryce McClenney
Laura LaPolice
Chris Lewis

Nearshore Deployments

SOFAR

Tim Janssen
Pieter Smit
Isabel Houghton

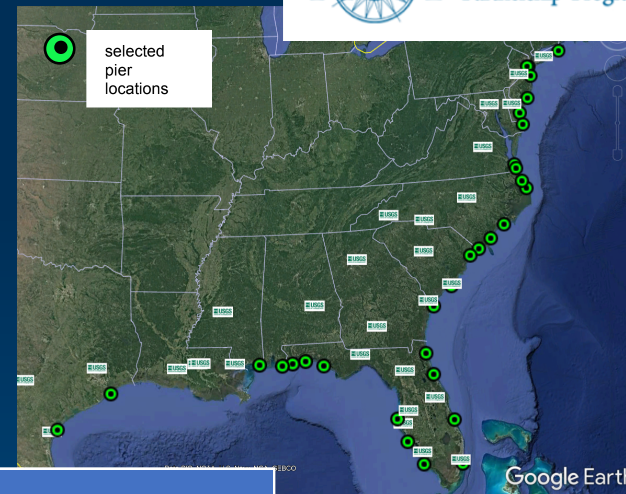
Deployment Support

NOAA National Oceanic and Atmospheric Administration U.S. Department of Commerce

National Weather Service

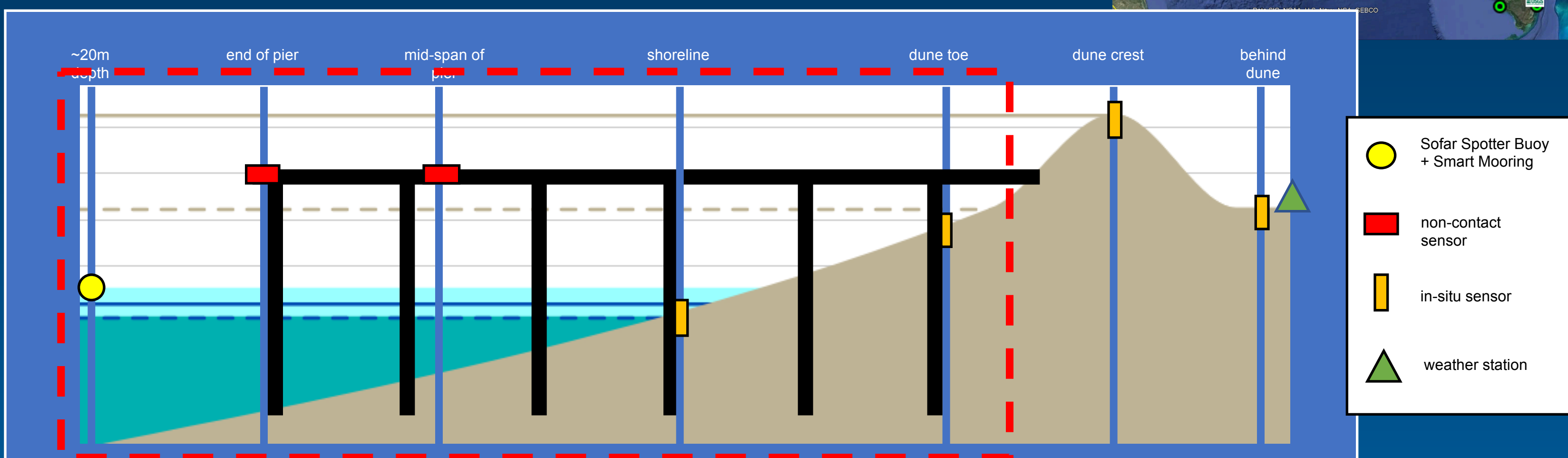
Ali Abdolali
Josh Alland

Objectives & Approach



<u>Provide measurements of water levels and waves spanning the nearshore region, beach/dune, and inland flooding extent.</u>

- deploy instruments in 2 <u>cross-shore transects</u> extending from offshore (~20 m), across the nearshore and beach/dune, inland
    - on each side of projected hurricane landfall, 2-3 days prior to landfall
- on land, utilize existing infrastructure (e.g., piers)
- offshore, opportunistically deploy Sofar Spotter Buoy+Smart Mooring



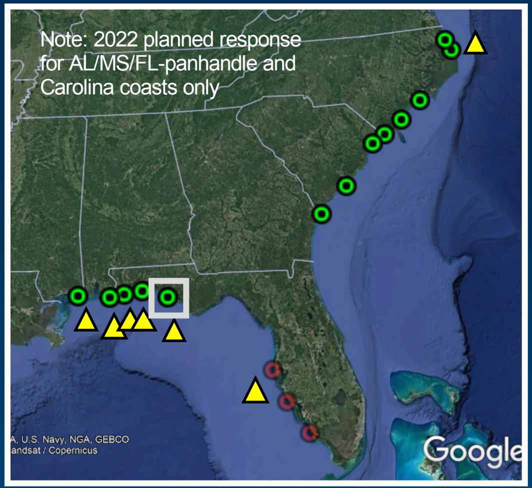
Results – Hurricane Ian

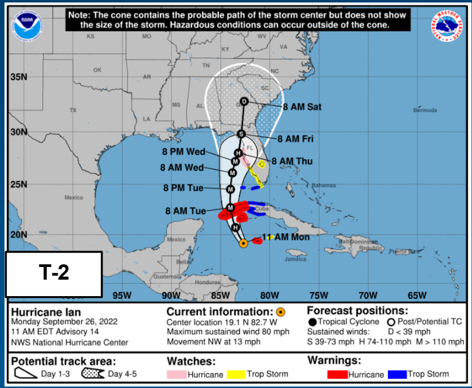
- On land
  - 2-person team deployed 2 cross-shore transects, 2 days in advance of landfall

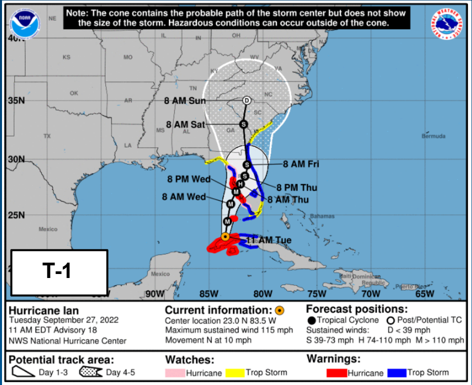
    Mon, Sep 26 installed 8 sensors at Clearwater Beach, FL

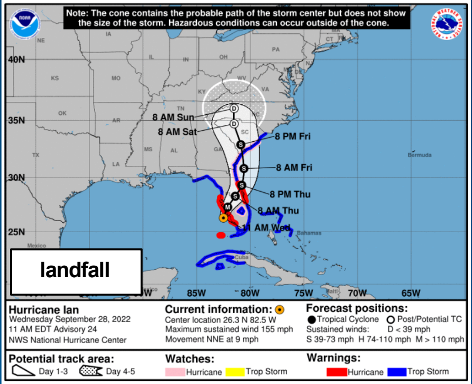
    Tue, Sep 27 installed 3 sensors at Panama City Beach, FL

    Wed, Sep 28 landfall
  - real-time data from end of piers and weather station available online
- Offshore
  - pre-emptively deployed moored buoys aligned with piers
  - real-time data available online

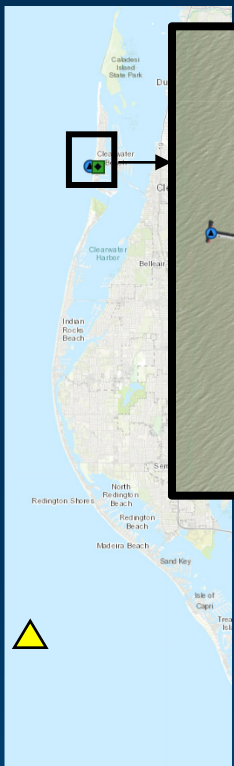


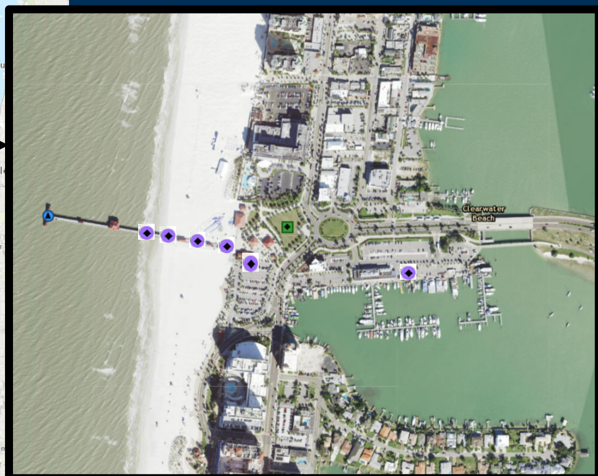






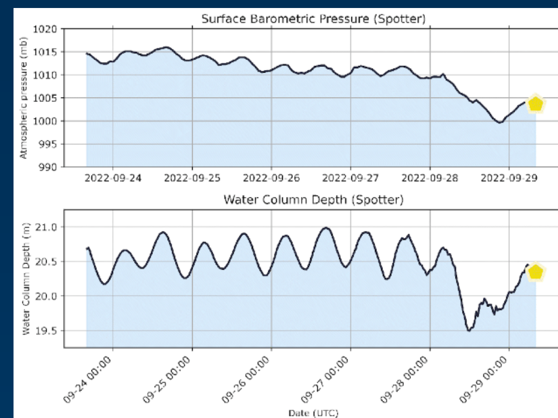
Results – Hurricane Ian: Clearwater Beach, FL

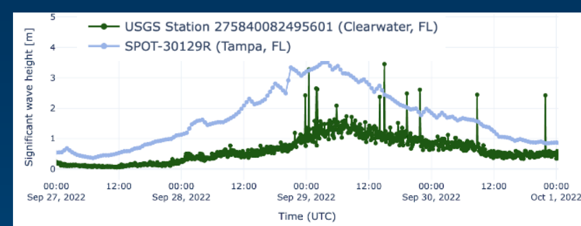




- (1) Sofar Smart Mooring
- (1) radar / RDG
- (6) pressure sensors / wave height sensor (8 Hz)
- (1) weather station / met sensor

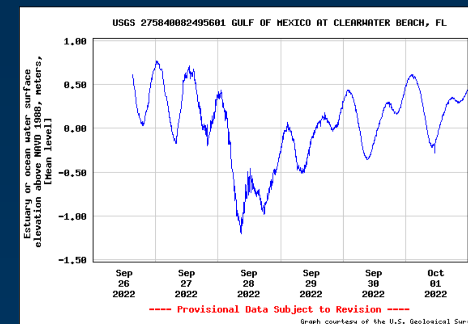
~20m depth:
Sofar Smart Mooring (USGS, Buckley)

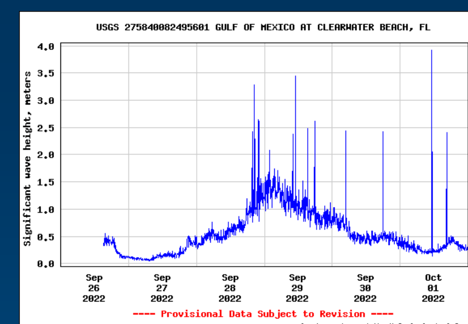




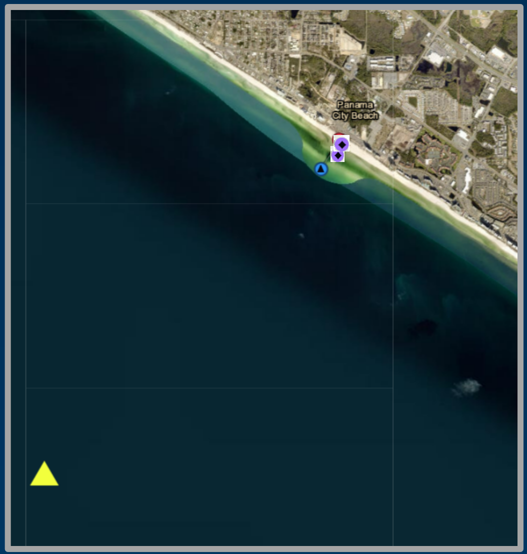
*located offshore Madeira Beach, pre-emptively deployed

End of Pier:
Radar (real-time data)





Results – Hurricane Ian: Panama City Beach, FL

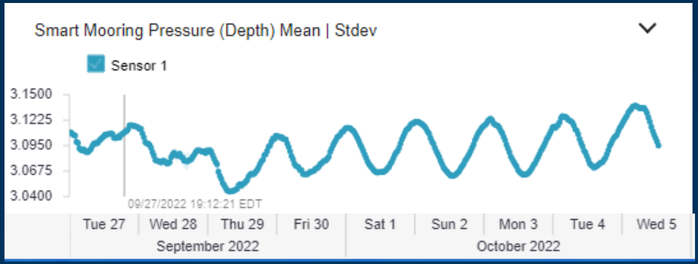


(1) Sofar Smart Mooring

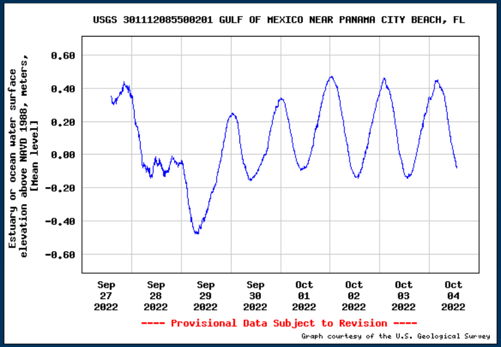
(1) radar / RDG

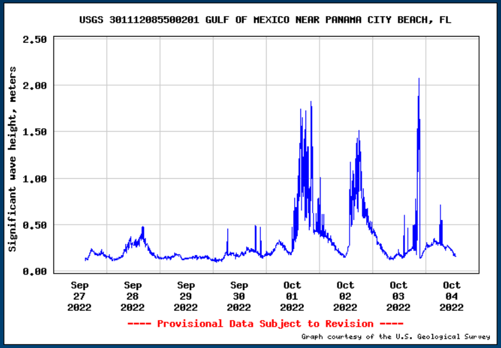
(6) pressure sensors / wave height sensor (8 Hz)

~20m depth:
Sofar Smart Mooring



End of Pier:
Radar (real-time data)



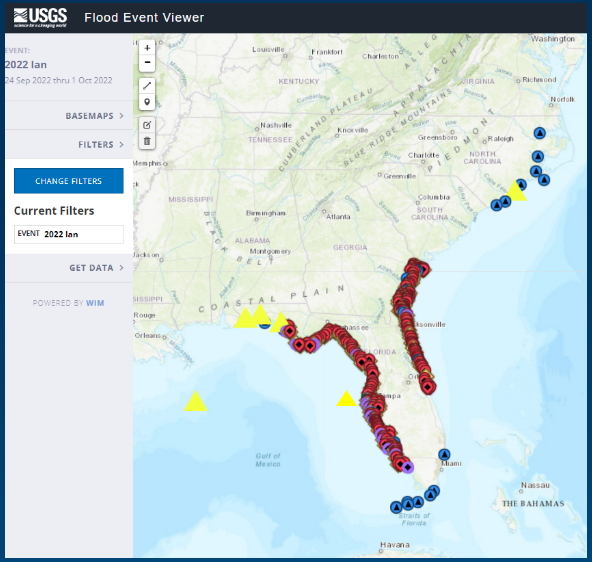


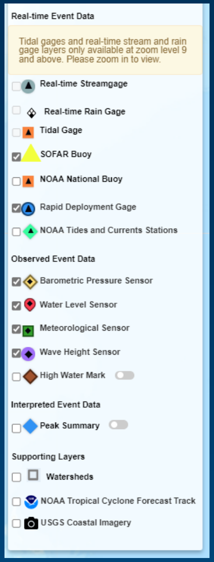
Results – Hurricane Ian

Project support by other USGS efforts:

<u>USGS Coastal Storm Team / Water Mission Area</u>

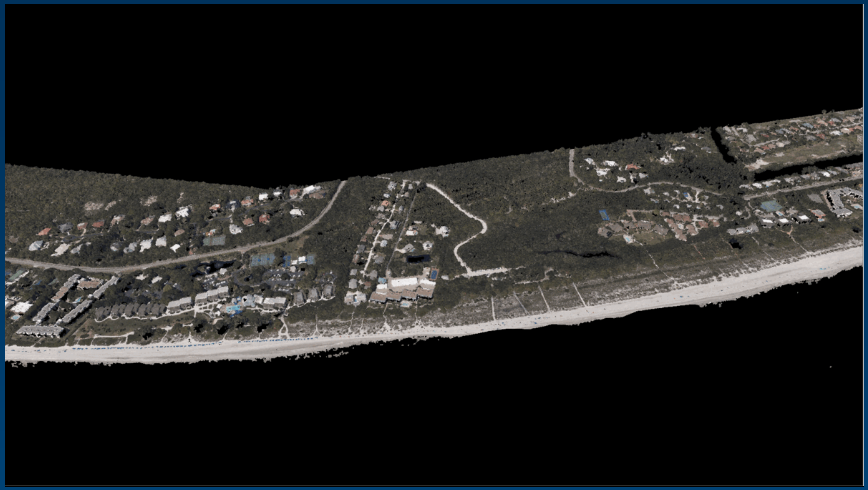
- funded by FEMA Mission Assignments
- over 250 sensors deployed
- hundreds of HWMs measured





<u>USGS Remote Sensing Coastal Change Project</u>

- funded by USGS Coastal/Marine Hazards & Resources Program
- aerial imagery collected and processed with Structure-from-Motion
- high-resolution topographic orthophotos and digital surface models



Deltares USA

FHICS – Forecasting Hurricane Impacts on CoastS

Kees Nederhoff, Ap van Dongeren PIs

28 november 2019

FHICS – Forecasting Hurricane Impacts on CoastS

Single daily forecast of the nearshore wave, storm surge, currents, sediment transport, morphological change, breaches, flooding and damages.

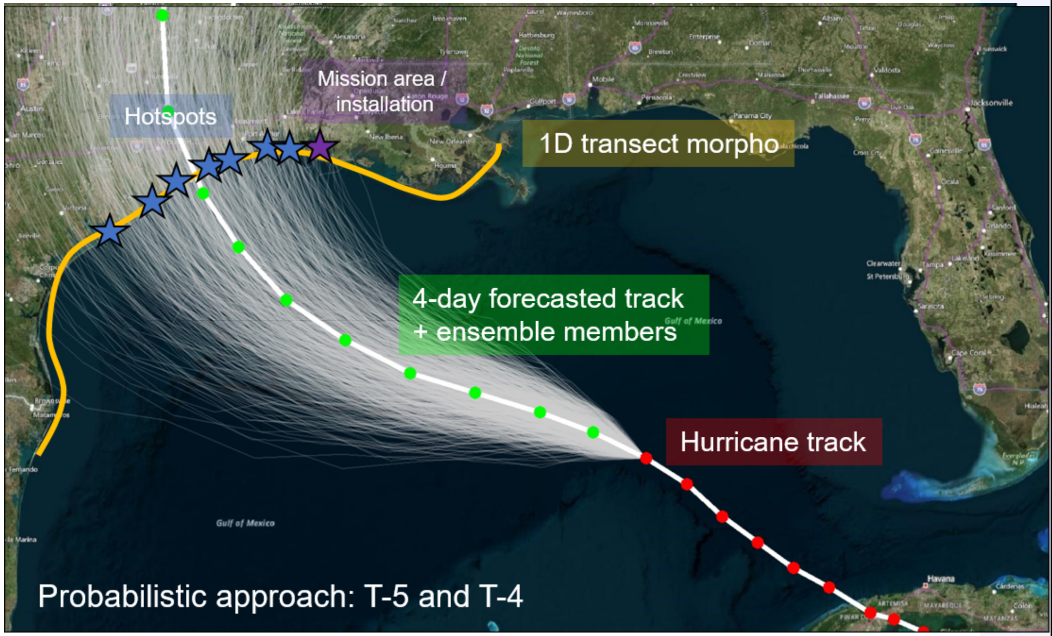
Using:

- best-track COAMPS meteo forcing for events
- GFS for non-events

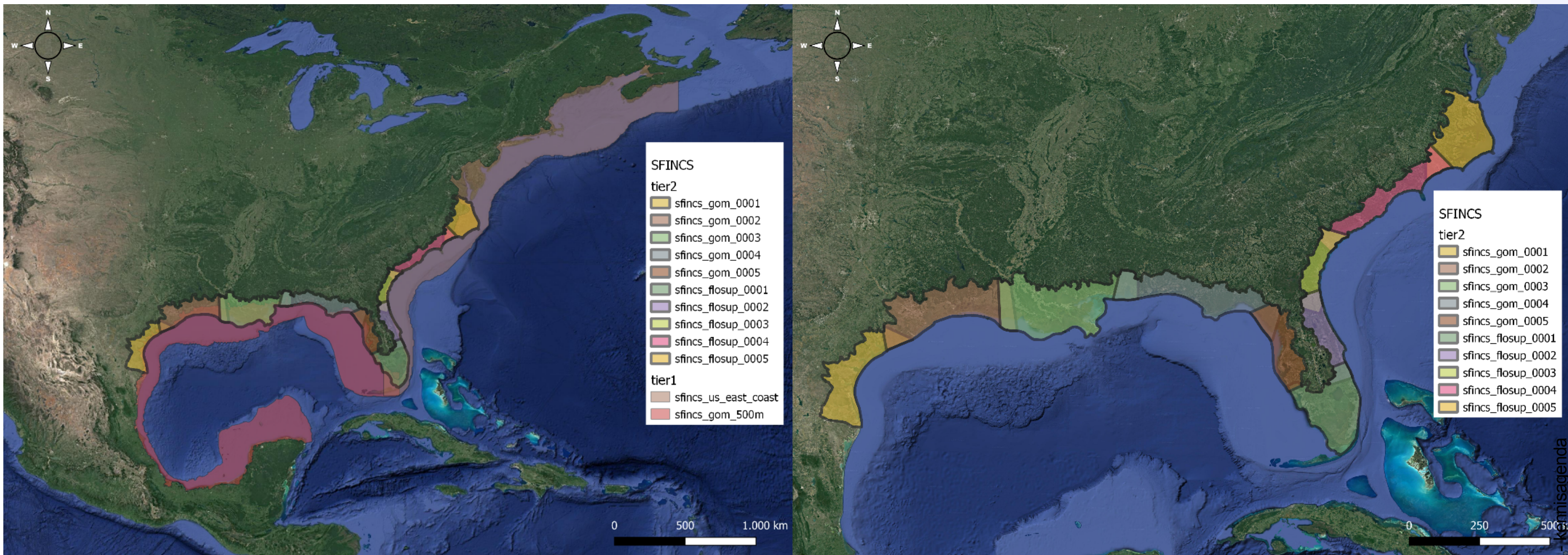
- large-scale surge and wave models (Delft3D-FM/SWAN+ Delft-SFINCS/Hurrywave)

- Large-scale flooding (Delft-SFINCS)

- Hotspot morphodynamics (2D XBeach)



Delft3D and Delft-SFINCS surge and overland flow models

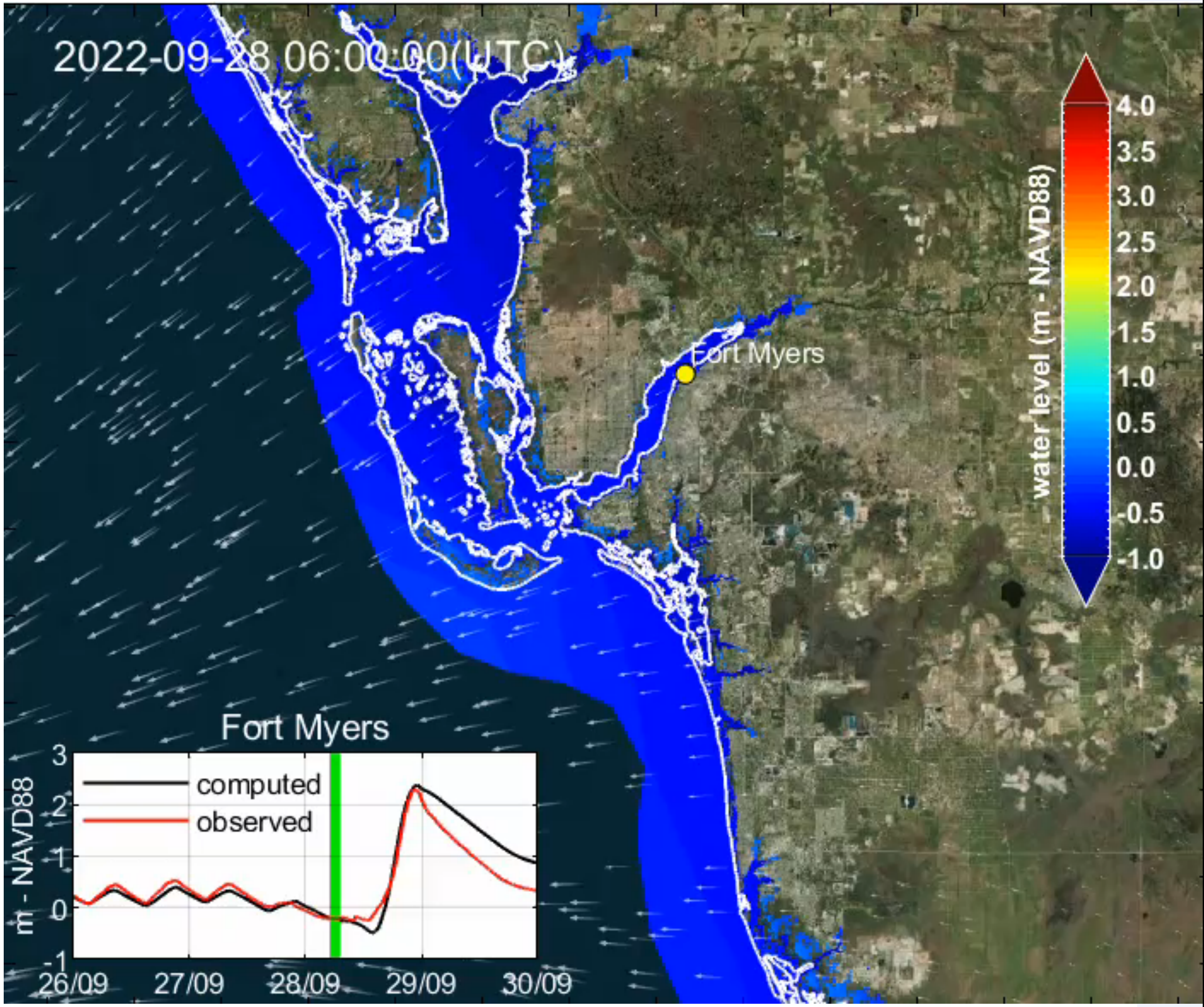


XBeach morphodynamical models on sandy coasts

Using default settings derived for Dutch gov't

Hurricane Ian

- Surge and flooding response using Delft-SFINCS
- forced by COAMPS forecasts of wind and atmospheric pressure
- Including Tides from Topex/Poseidon
- Including wave setup
- No rain! (to show surge)
- Good agreement at Ft. Meyers gauge



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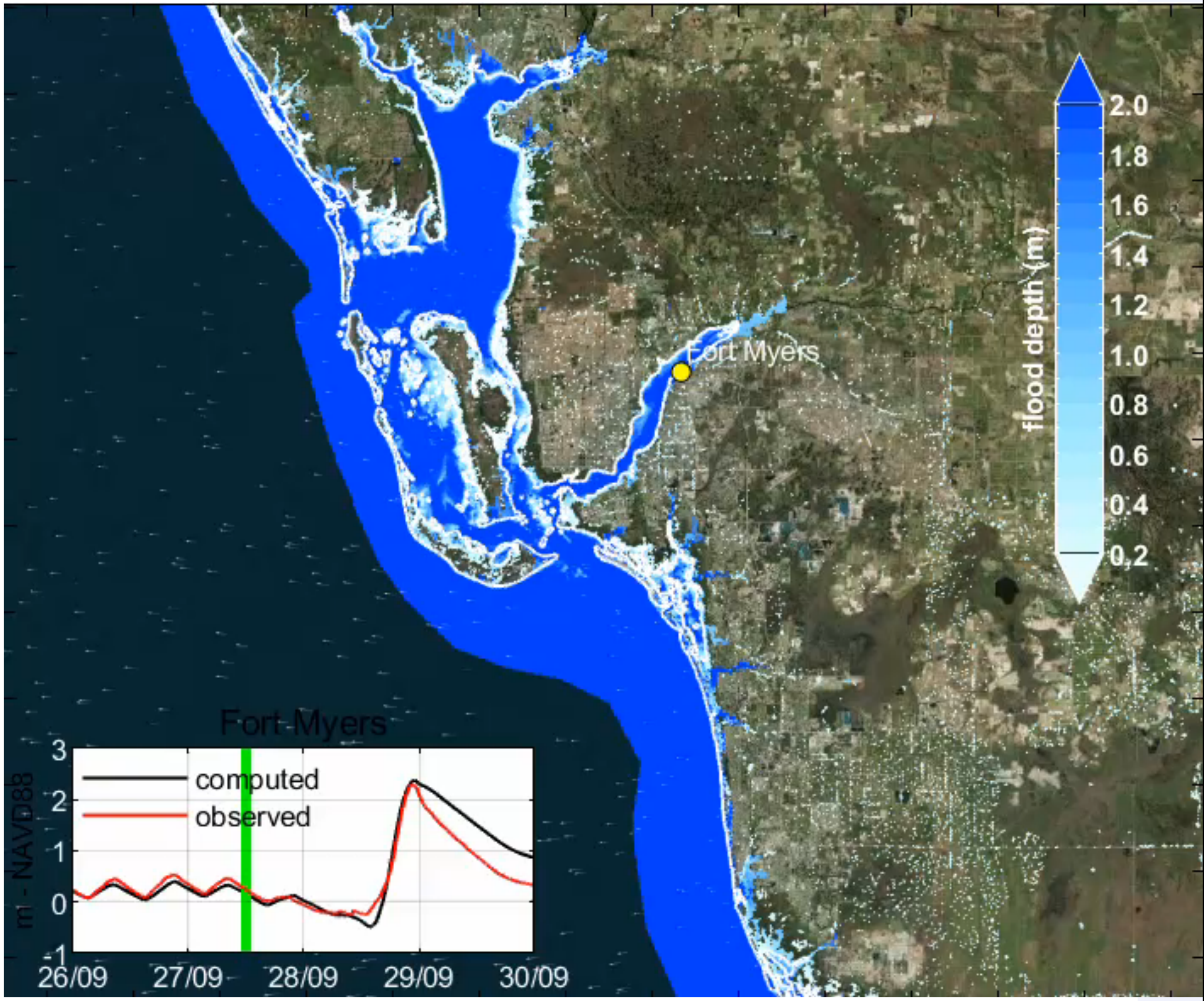
Hurricane Ian

- Flood depth using Delft-SFINCS
- With rain
- Forced by COAMPS forecasts of wind and atmospheric pressure
- Including Tides from Topex/Poseidon
- Including wave setup
- Good agreement at Ft. Meyers gauge



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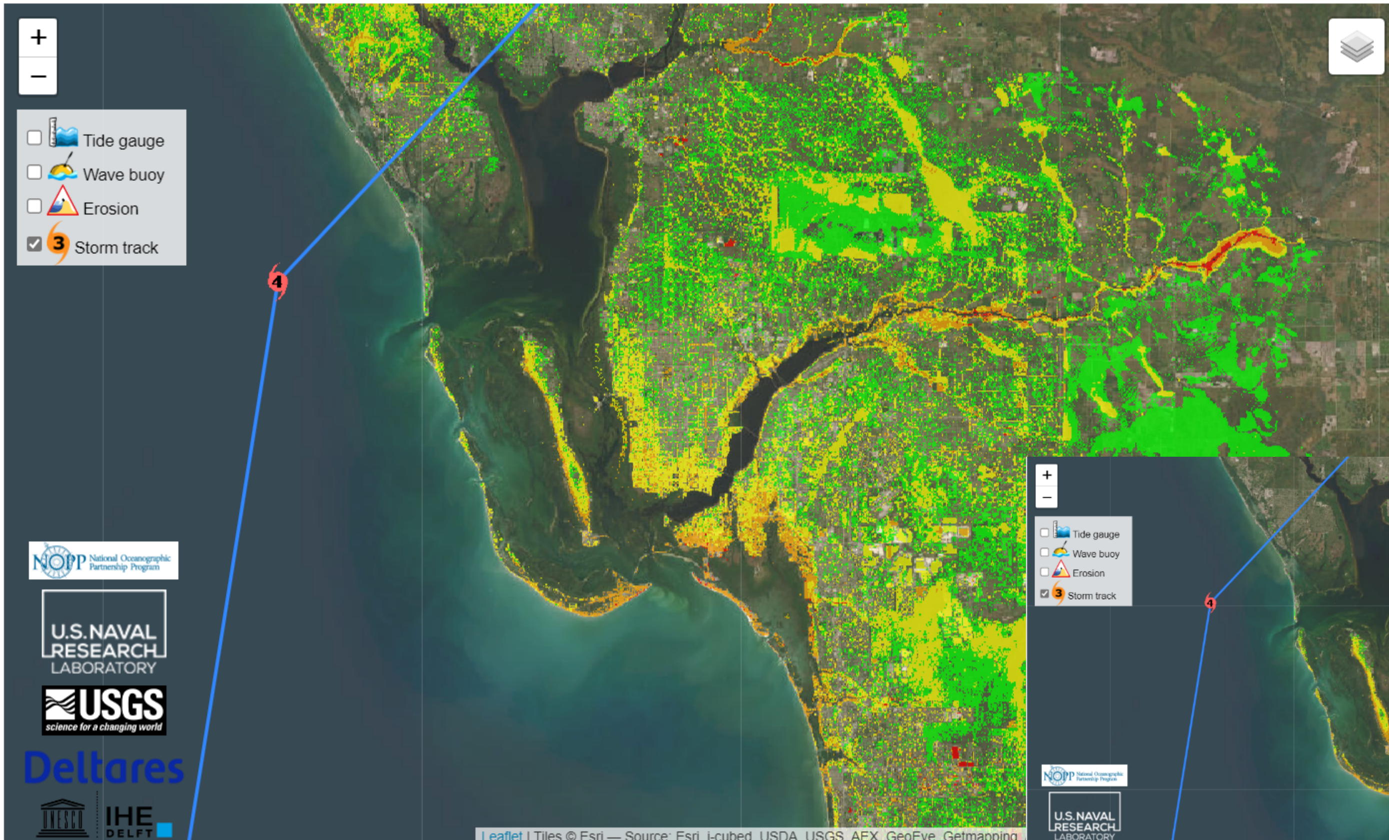
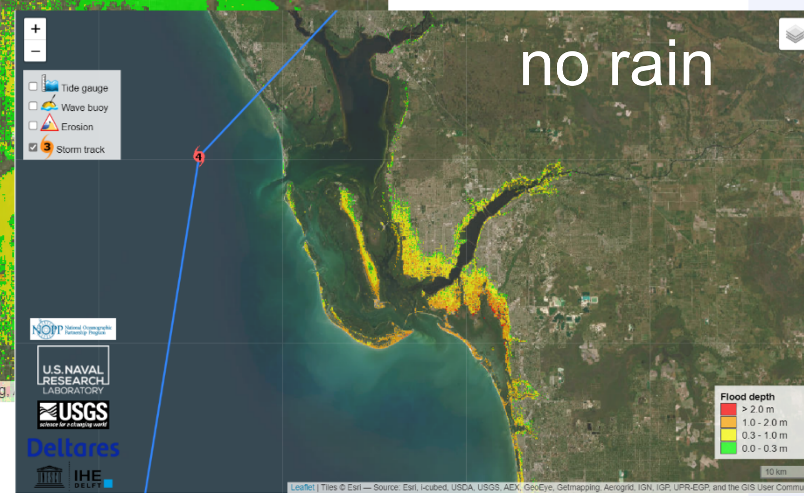
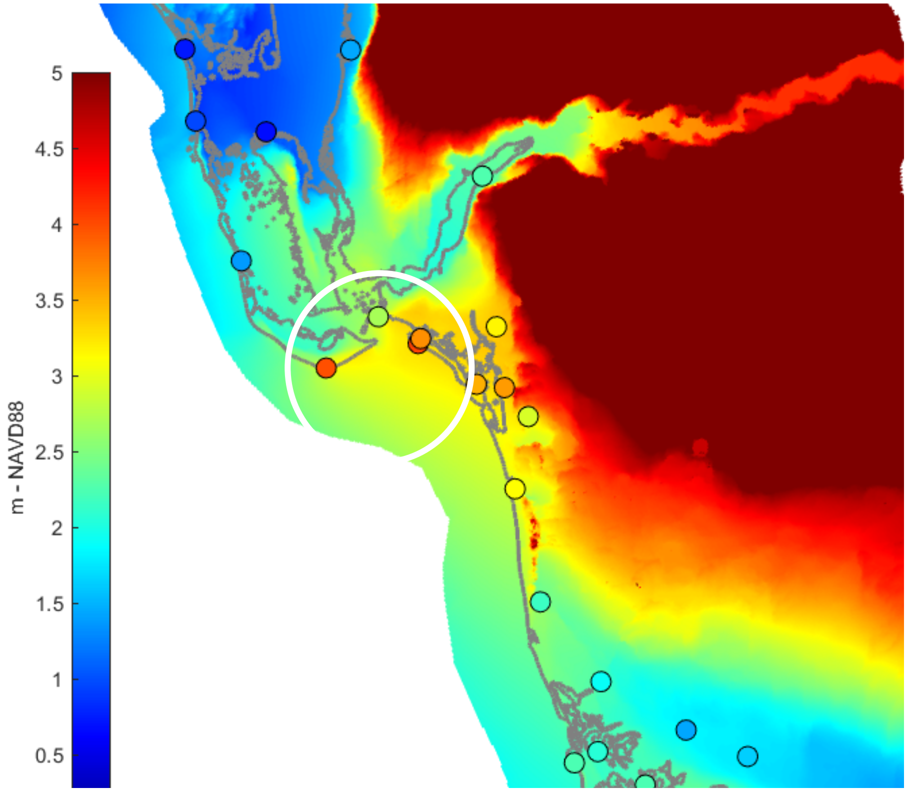
Predicted flood depths

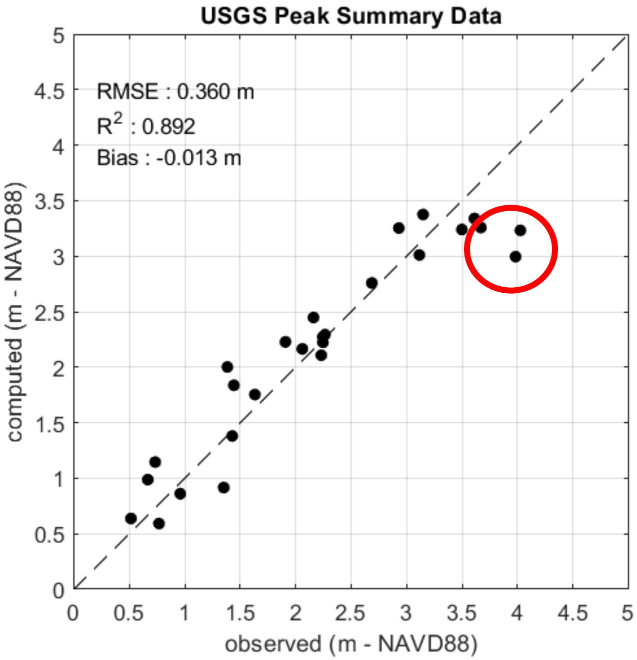


Essential to **include rain** for accurate flood predictions



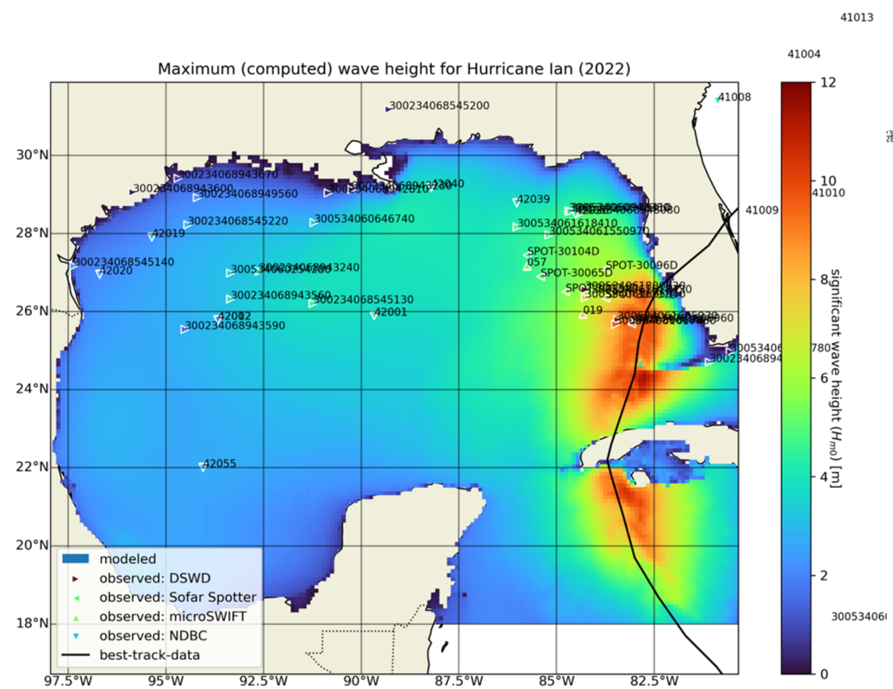
Validation Peak Water Levels

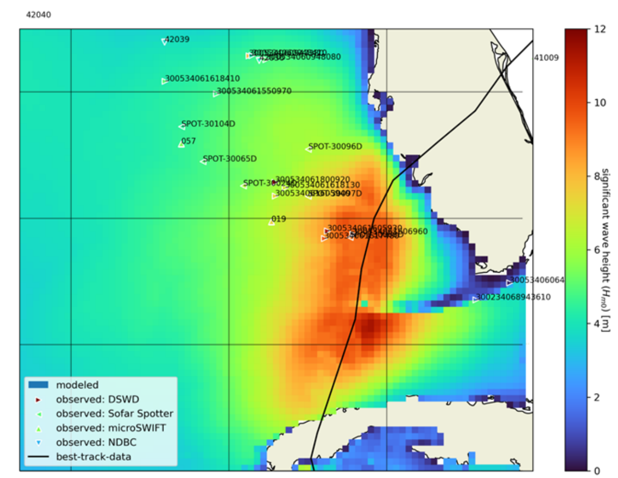




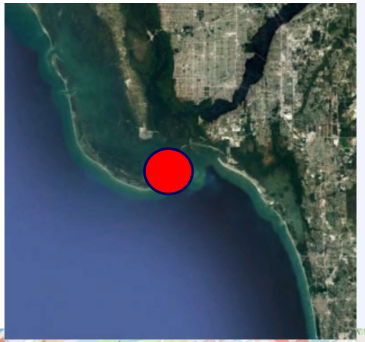
High water marks at Sanibel Island underpredicted because forecasted track was too far North

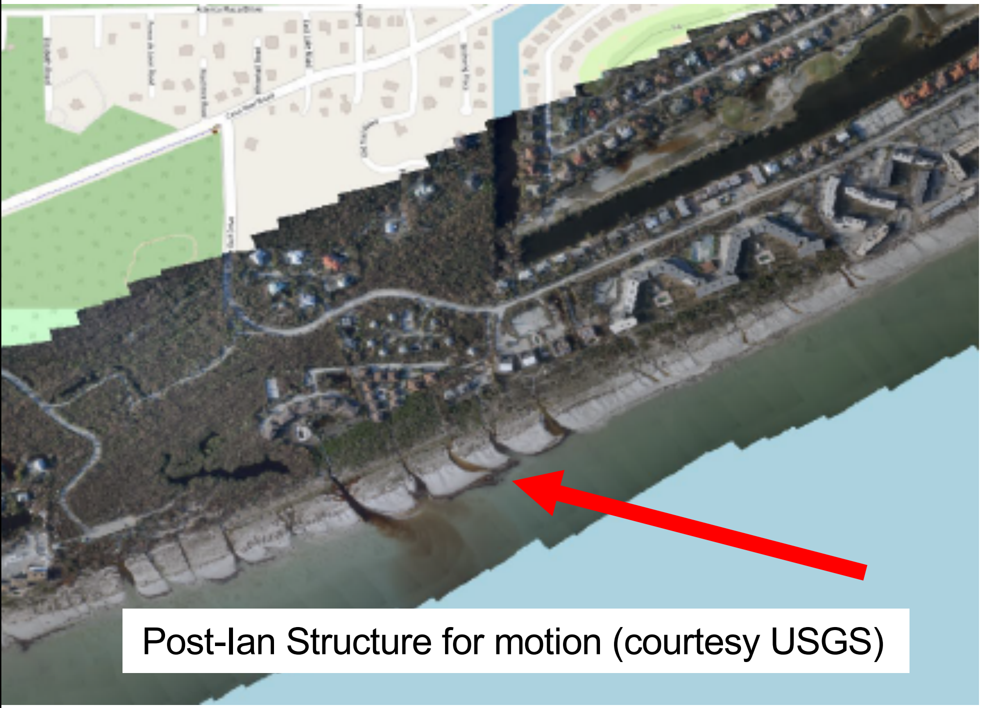
Delft-HurryWave model maximum computed wave height compared to all observational data available



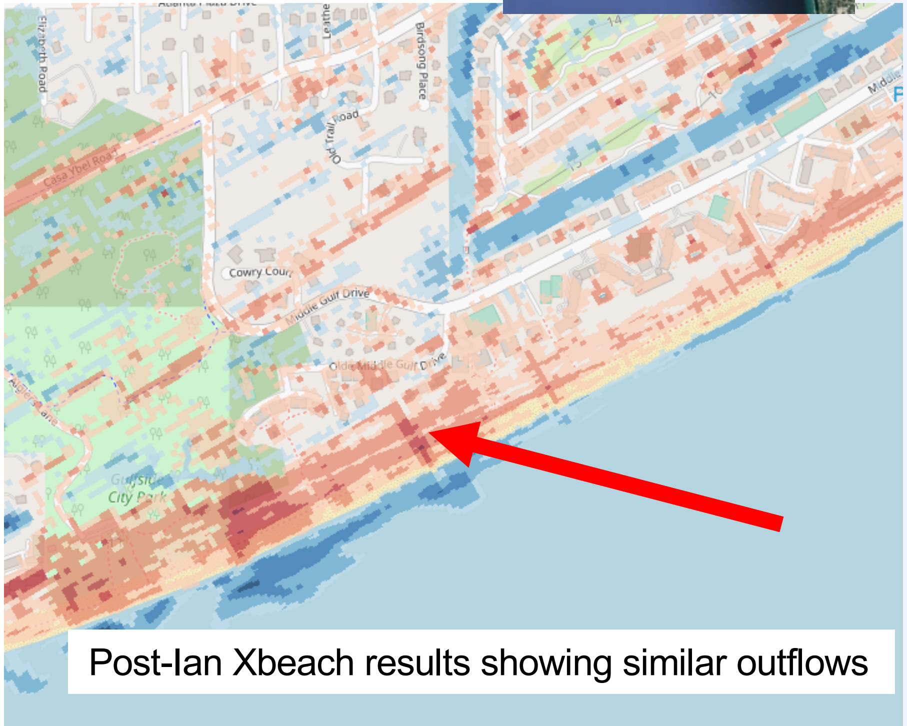


Sanibel Island morphological response





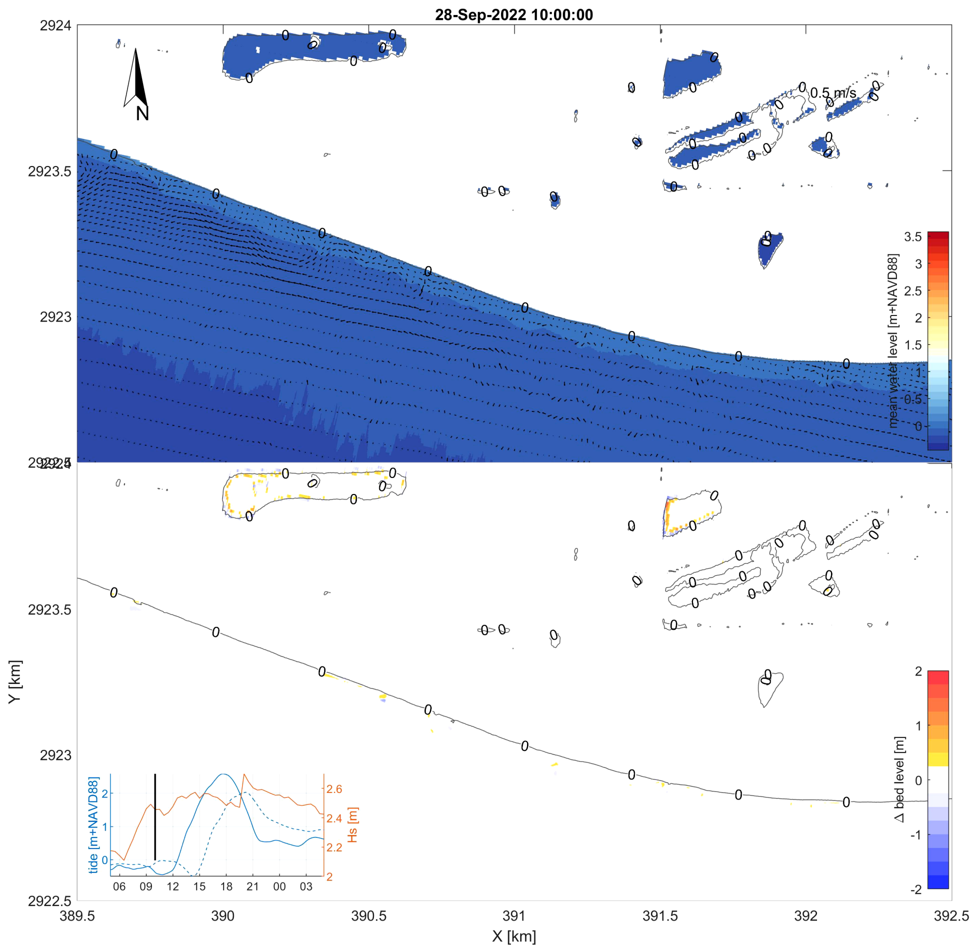
Post-Ian Structure for motion (courtesy USGS)



Post-Ian Xbeach results showing similar outflows

Sanibel Island beach drains

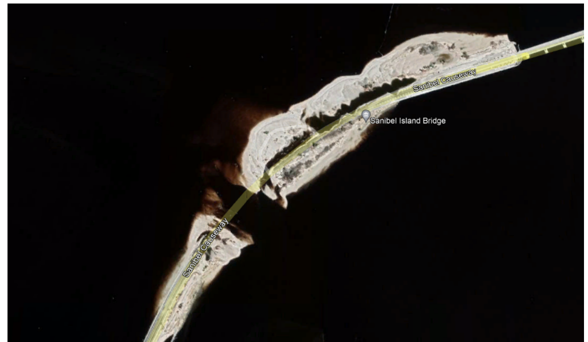
- Top: flow velocities
- Bottom: morphological change
- Showing development of channels draining the water off the beach



Deltares USA

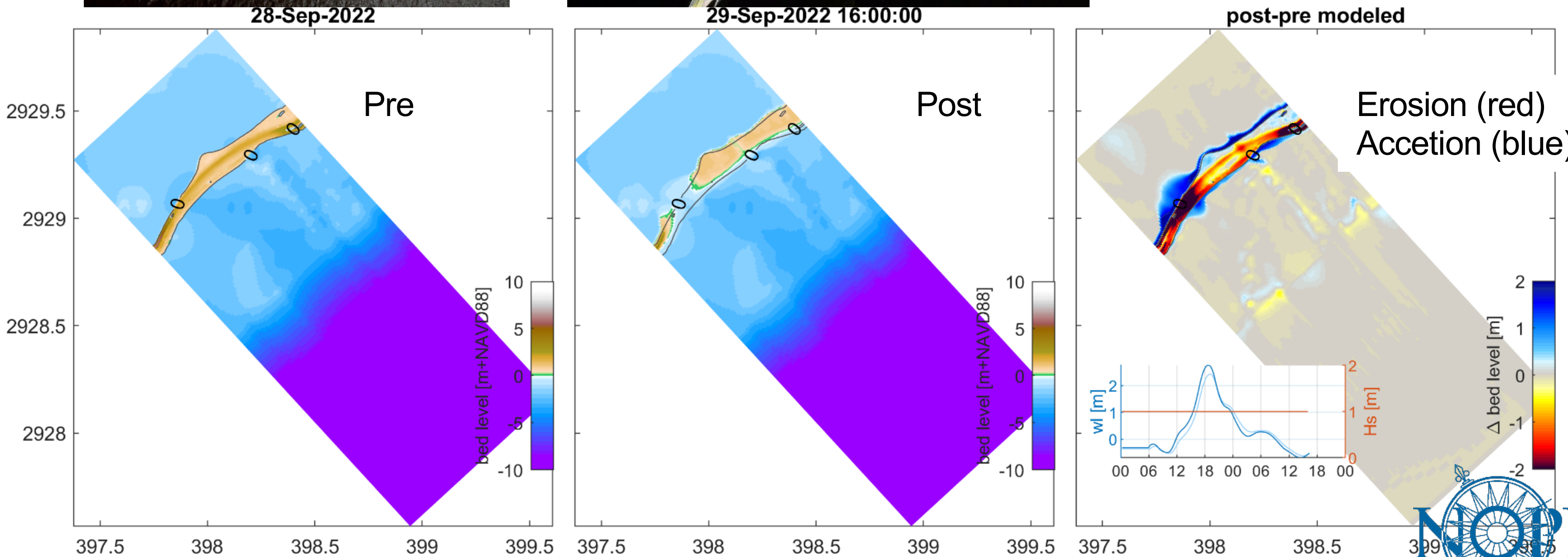
Voettekst van de presentatie

Breaching of Sanibel Island causeway islands



Island breaches on the flood surge

Scours out during the ebb surge



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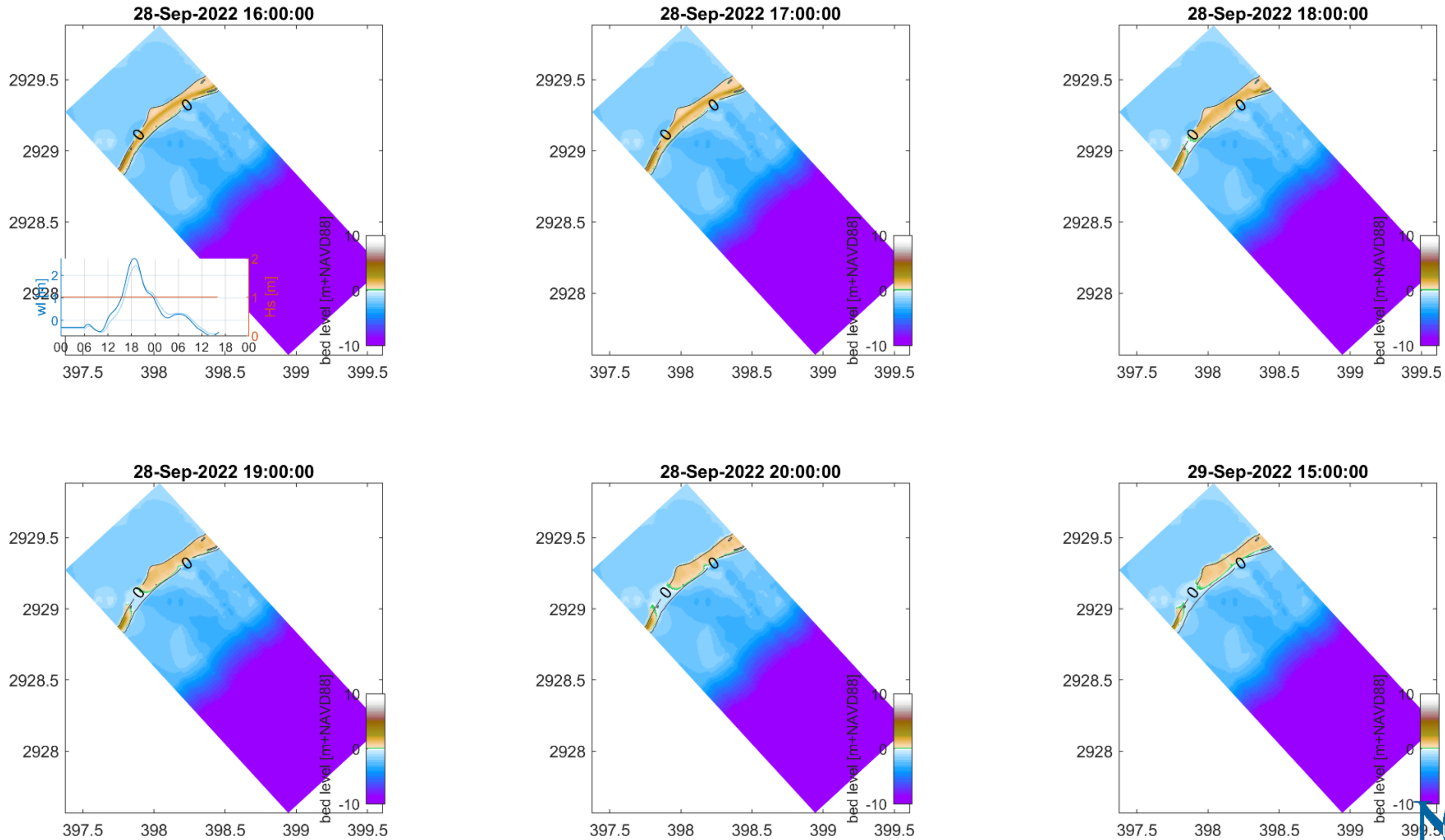
Development in time: breaching on the flood surge,



Findings, strengths, weaknesses, next steps

- Findings
  - **Surge response is very sensitive** to track. COAMPS did well, but surge was still underpredicted
  - **Rain is essential** to predict flooding accurately.
  - Delft SFINCS model results **compare well** with Delft3D-FM and Adcirc (Team4c)
  - Delft-SFINCS model is very **fast, opens door to ensemble modelling** to capture hurricane track/speed/intensity uncertainty
  - Xbeach morphodynamical **model predicts breaches and beach erosion** where observed
  - **Sanibel Causeway island breach** predicted well.
- Strengths
  - **System ran continuously**, even when no hurricane – learned a lot about robustness
  - **Good cooperation** between Teams on model setting, tool and data sharing.
- Weaknesses
  - Model chain finishes just in time for 12 hr forecast -> **moving to the cloud in 2023**!
- Next steps
  - Complete all model domains up the Eastern Seaboard
  - Include heat maps of building damage

NOPP Hurricane Coastal Impacts All Hands Meeting

Team 4a Luettich

Rick Luettich, Brian Blanton, Shintaro Bunya, John Ratcliff* – UNC Chapel Hill, RENCI, CRC

Matt Bilskie, Nashid Mumtaz* – U Georgia

Zach Cobell – Water Institute of the Gulf

Dan Cox, Jaimlyn Sypniewski* - Oregon State

Casey Dietrich, Jessica Gorski* - North Carolina State

Isaac Ginis, Tetsu Hara, Angelos Papandreou*, Mansur Ali Jisan*, Josh Port* - U Rhode Island

*students

02/27/2023

revised 03/02/2023

Primary Accomplishments: Years 0 – 1.5

Hurricane Ian forecasts

- Forecast run summary
- Experience with COAMPS-TC met forecasts
- Results
  - water levels – ADCIRC+SWAN
  - waves - ADCIRC+SWAN & ADCIRC+WWIII
  - morphology change - XBeach 1D
  - damage – FEMA HAZUS software

Hurricane Michael hindcast

- Assess COAMPS-TC reanalysis and other meteorological products
- Created OWI scaled v6 “reanalysis” winds/pressures
- Results – water levels, momentum balance, XBeach 1D, damage
- Next steps – manuscript on hydrodynamics in prep

Hurricane Nicole

MetGet

- Standardized access to COAMPS-TC fields including ability to skip time snaps near the initialization time

Hurricane Ian

COAMPS-TC forced model forecasts

- ADCIRC+SWAN – water level, inundation, waves
  - Matt Bilskie, Brian Blanton, Shintaro Bunya, Zach Cobell
  - HSOFS grid 0923 06Z - 0930 06Z – 28 runs
  - EGOM grid (enhanced w FL coast) 0927 12Z - 0928 18Z – 6 runs
  - NCSC_SAB (enhanced GA – NC coast) 0923 18Z – 0930 06Z - 26 runs

- XBeach 1D – nearshore hydrodynamics, morphology
  - Jessica Gorski, Casey Dietrich 0923 12Z, 0924 06Z, 0925 12Z, 0926 06Z, 0926 12Z, 0927 12Z
- Hazus - level 1 damage
  - Jaimlyn Sypniewski, Dan Cox 0928 12Z

Surge results: slides 5-7

- As storm track gradually shifted toward the south and the forecast storm strength increased, the surge magnitude and extent adjusted accordingly.
- The storm surge driven by the 0928 12Z COAMPS-TC was quite accurate along the coast. Morphology and damage estimates use this forecast.
- Analysis of COAMPS-TC winds indicated skipping the first 4 hours (0-3) in each forecast cycle eliminated artifacts associated with the COAMPS-TC initialization and provided highly accurate surge results.
- Animations: note, in ppt “show” mode these will all sync properly in time
  - Upper left hand – larger scale, draw down around Tampa Bay as well as the large surge in the Ft. Meyers Beach area are captured well compared to NOAA gauges
  - Upper right hand, lower left hand, lower right hand – zoom ins north of, centered on and south of Ft. Meyers Beach area. Results compare quite favorably to USGS rapid gauges, even in areas that are well inland.
- Peak simulations vs high water marks are also quite good

Maximum Water Elevation – NAVD88 from 6 COAMPS-TC forecasts

0927 12Z

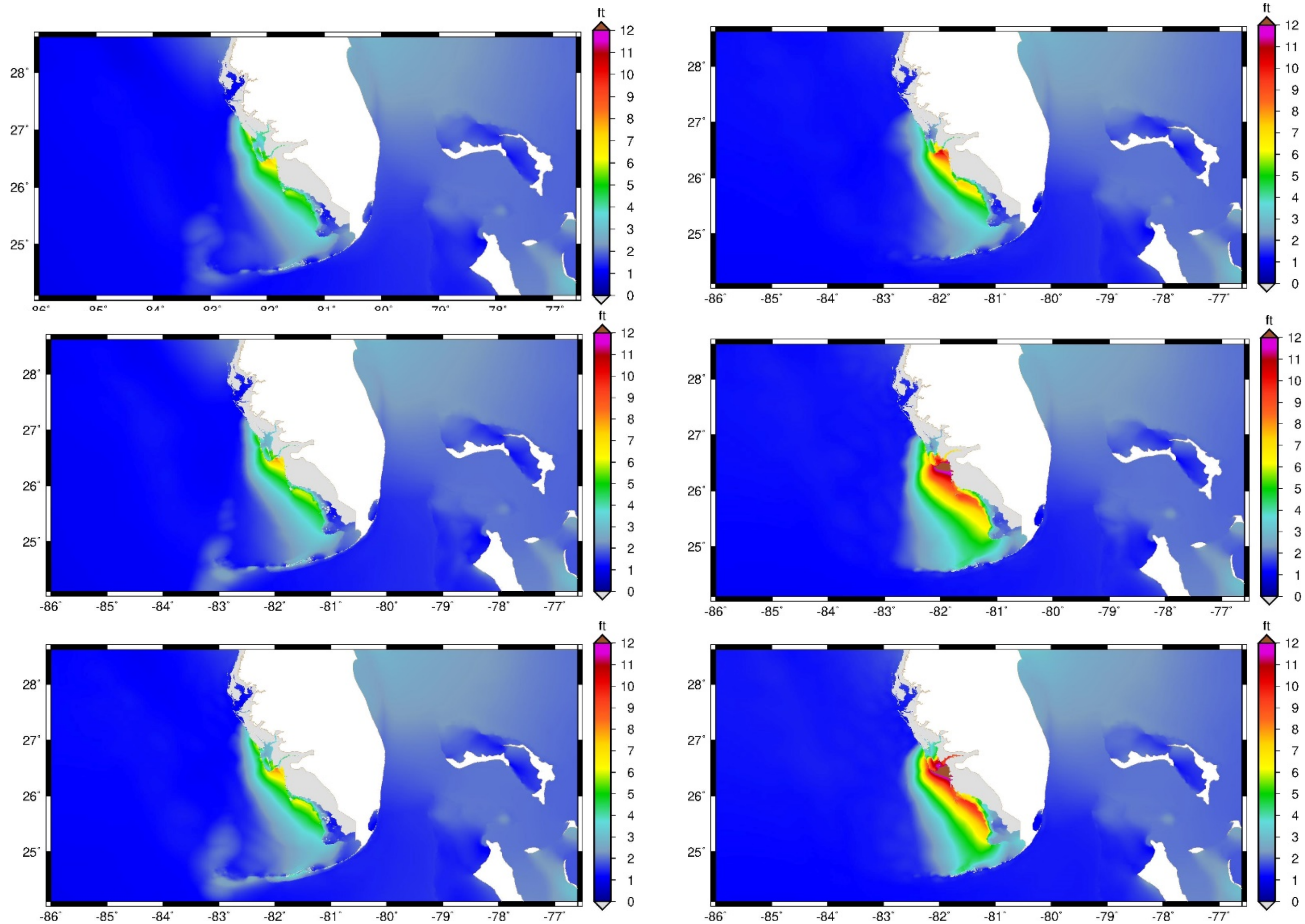
0928 06Z

0927 18Z

0928 12Z

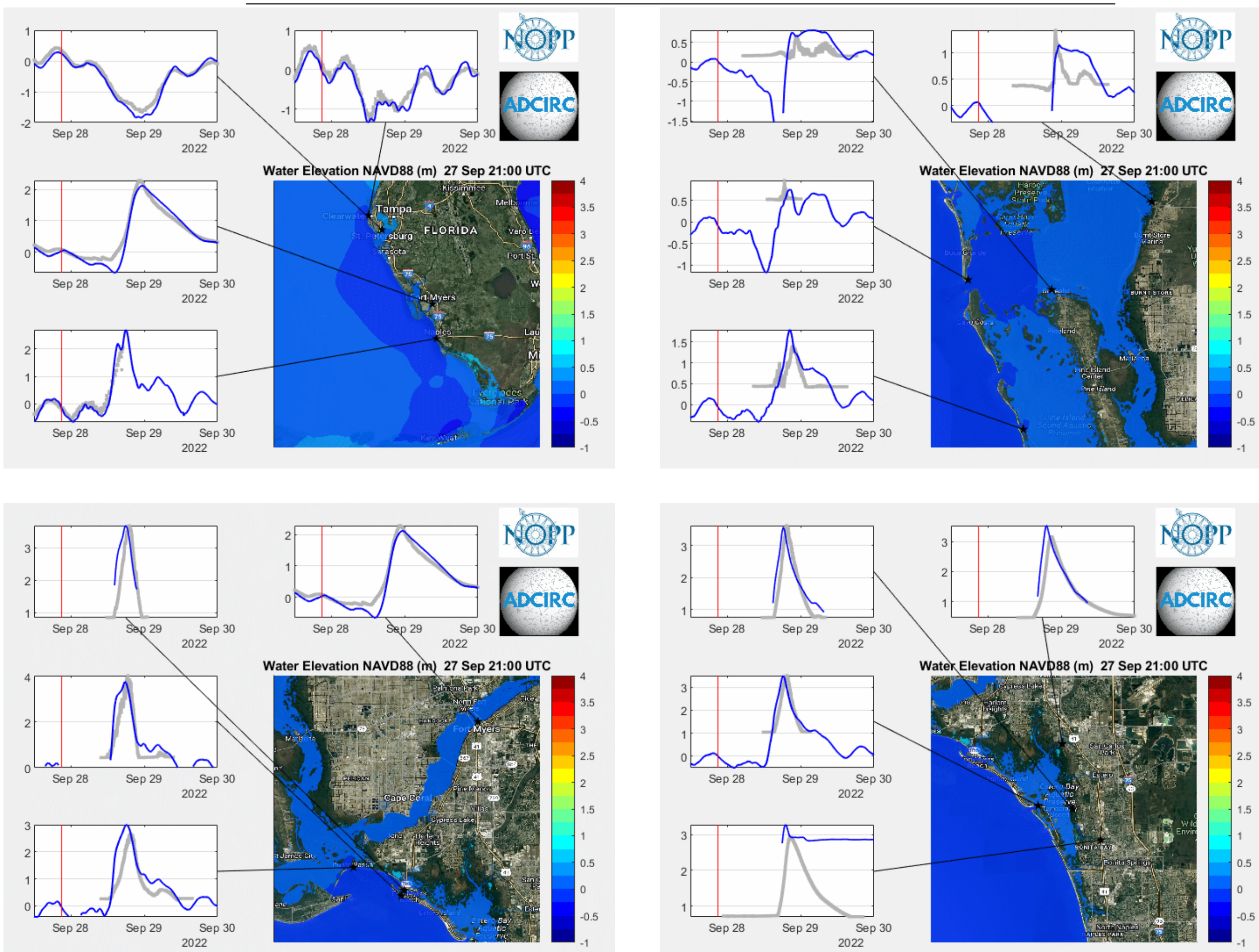
0928 00Z

0928 18Z near landfall



NOPP

Simulated & Observed Water Levels, Hurricane Ian
September 27 – September 29, 2022



White line: COAMPS-TC storm track

Grey line: NHC storm track

THE UNIVERSITY of NORTH CAROLINA at CHAPEL HILL

UNIVERSITY OF GEORGIA
Coastal Ocean Analysis and Simulation Team

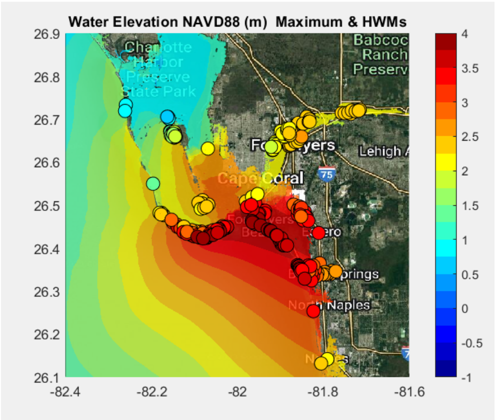
THE WATER INSTITUTE OF THE GULF™

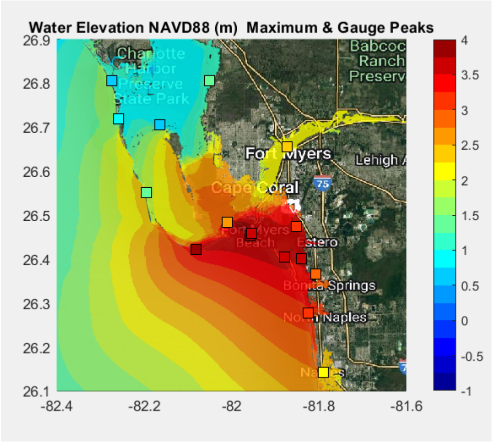
NC STATE UNIVERSITY

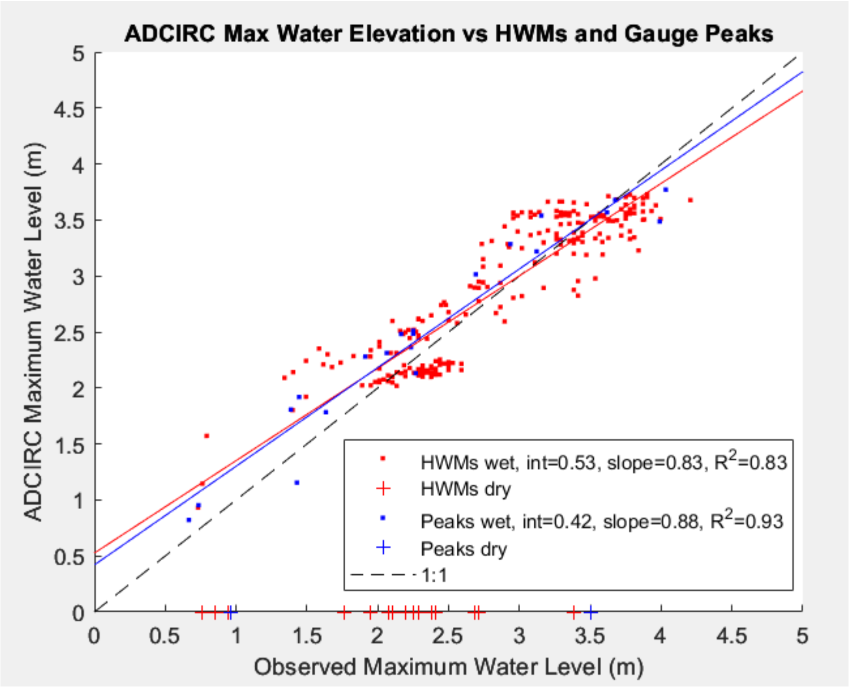
THE UNIVERSITY OF RHODE ISLAND

Oregon State University

ADCIRC Maximum Water Levels vs Observed High Water Marks & Gauge Peaks



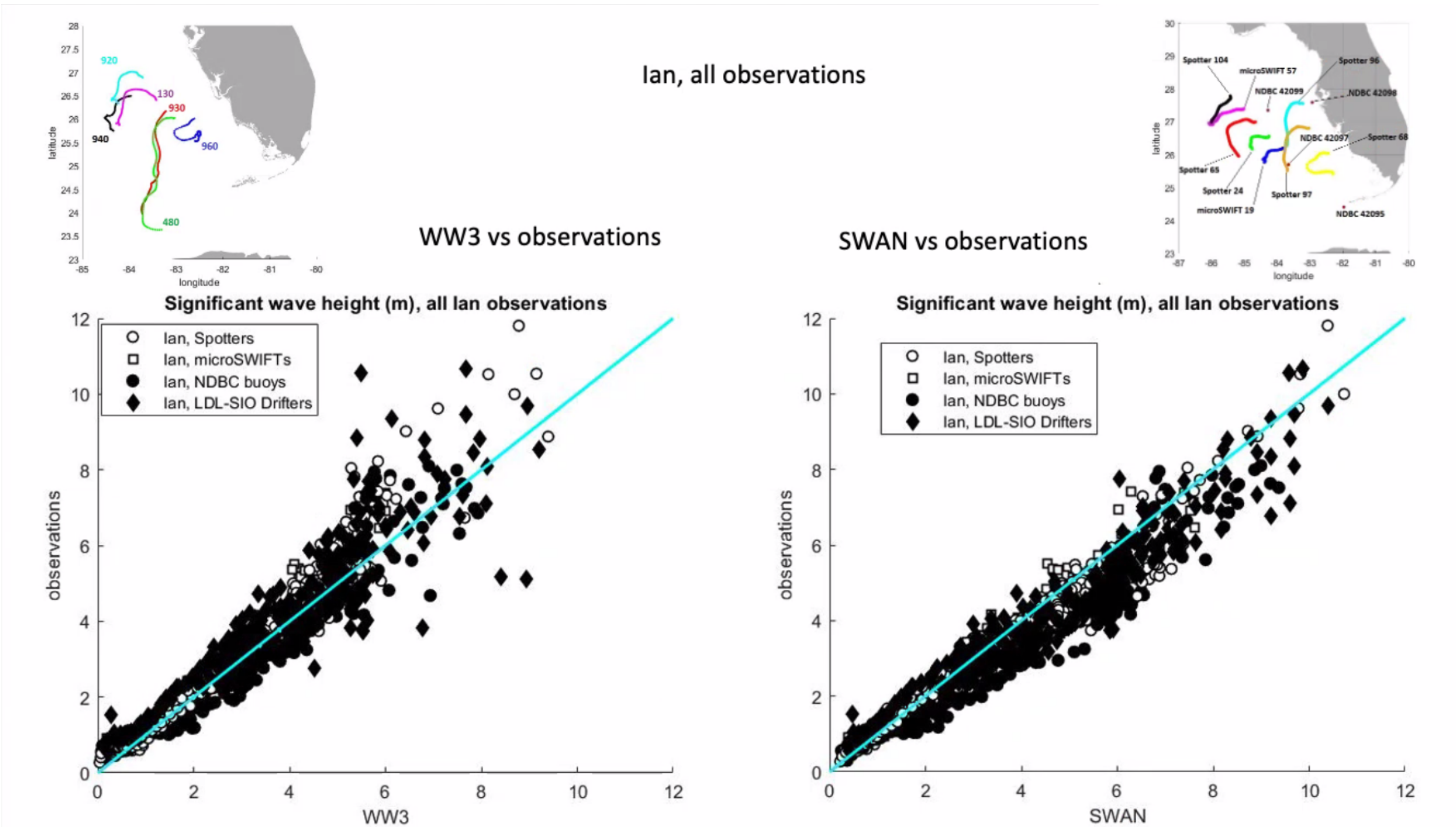




Wave results: slide 9

- Comparing ADCIRC+SWAN and ADCIRC+WaveWatch3 (WW3)
- Analysis of bulk wave properties, e.g., significant wave height, between models and all available wave observations (fixed buoys and project drifters)
  - Both SWAN & WW3 represent low to moderate waves reasonably well
  - NOAA's WaveWatch3 generally underpredicts and has larger variance at high waves
  - SWAN may slightly overpredict higher wave heights, but generally represents the observations well
- More detailed of spectra and moments is ongoing
  - preliminary results suggest SWAN also better represents spectra

ADCIRC+SWAN vs ADCIRC+WaveWatch3



Morphology Results: slides 11-12

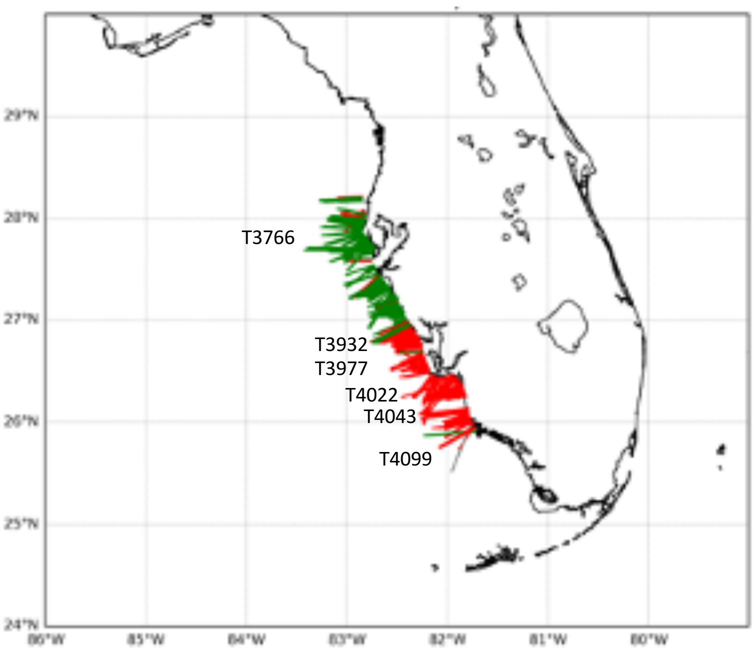
- Collision(green): water does not reach the dune crest
- Overwash/inundation(red): water reaches and/or passes the dune crest
- Dune transect changes
- Ongoing work to validate versus observations

Website:https://sites.google.com/ncsu.edu/ncsu-xbeach-forecasts

Hurricane Ian

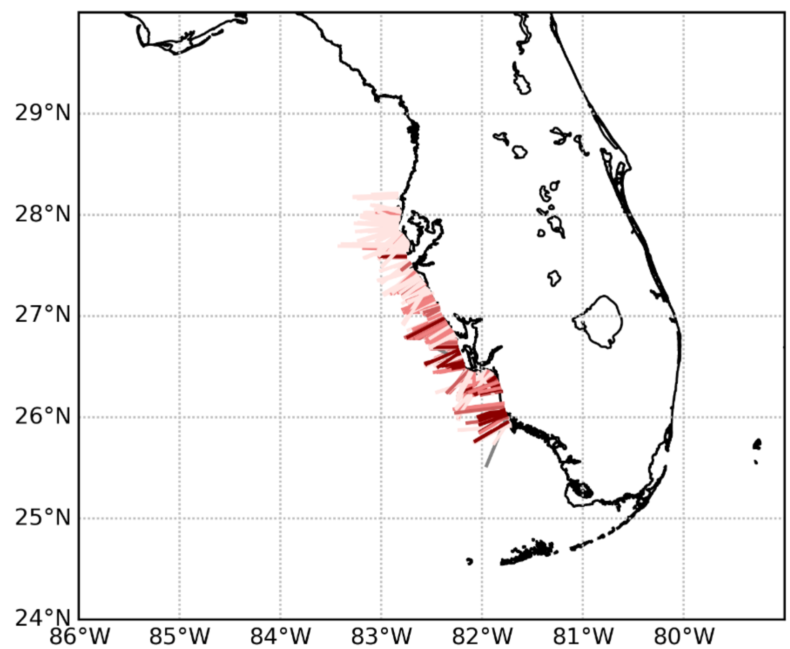
Morphology results – 0928 12Z forecast

Overtopping: green – no; red – yes

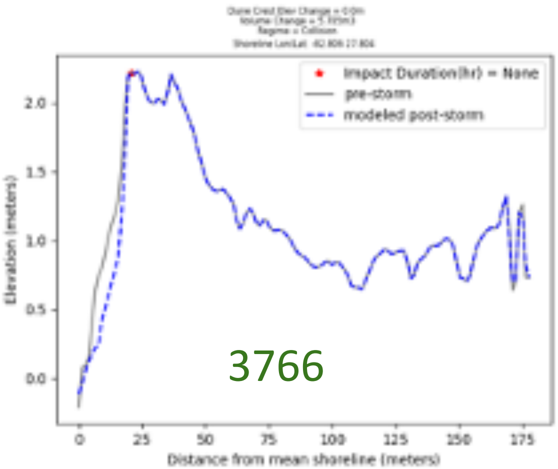


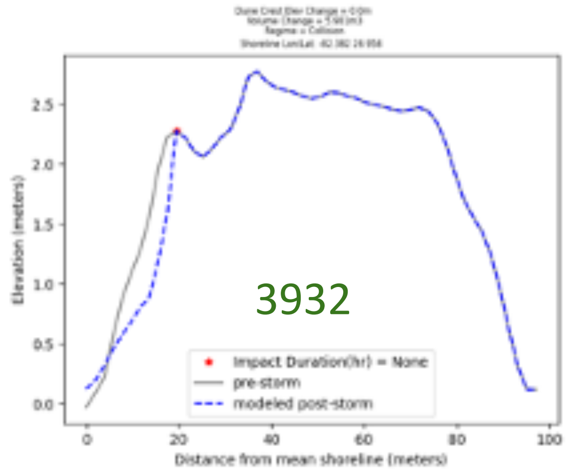
ADCIRC EGOM mesh: high resolution west FL coast

Percent Volume change 0 – 100%



XBeach: ~1,800 1D transects


Impact Duration(hr) = None
pre-storm
modeled post-storm
Elevation (meters)
Distance from mean shoreline (meters)
3766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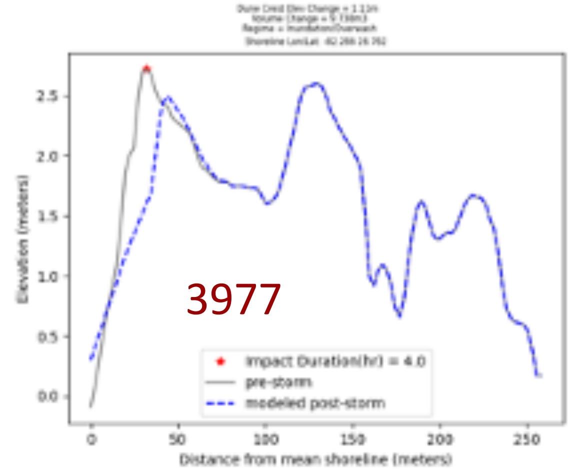
pre-storm
modeled post-storm
Elevation (meters)
Distance from mean shoreline (meters)
3932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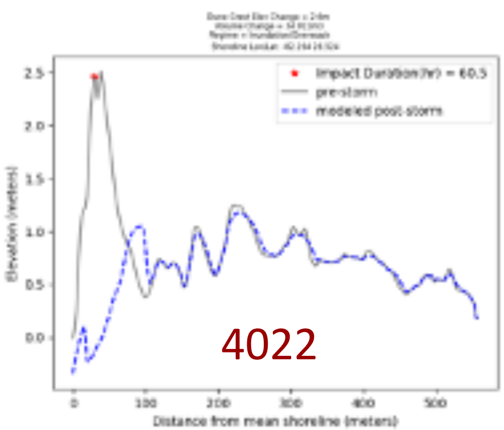
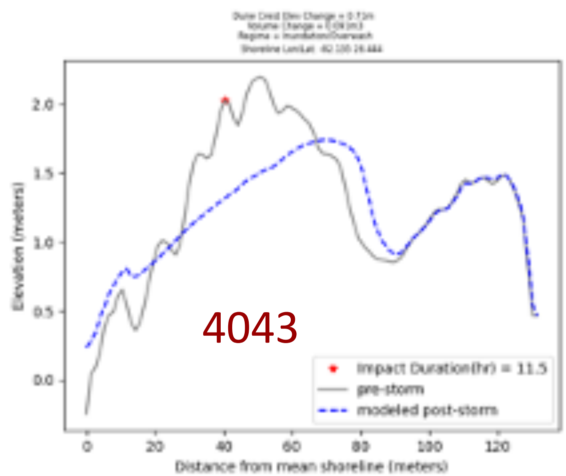
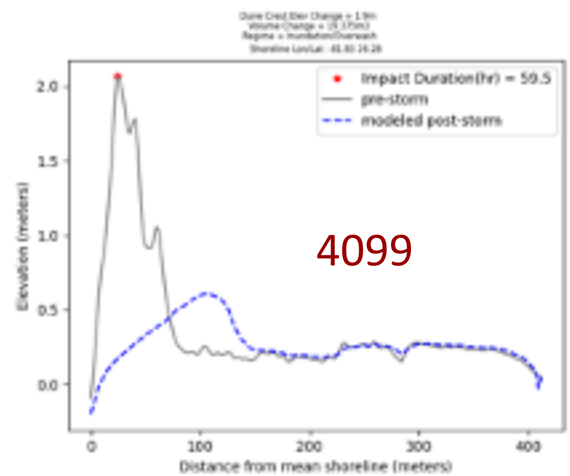
pre-storm
modeled post-storm
Elevation (meters)
Distance from mean shoreline (meters)
3977


Impact Duration(hr) = 60.5
pre-storm
modeled post-storm
Elevation (meters)
Distance from mean shoreline (meters)
4022


Impact Duration(hr) = 11.5
pre-storm
modeled post-storm
Elevation (meters)
Distance from mean shoreline (meters)
4043

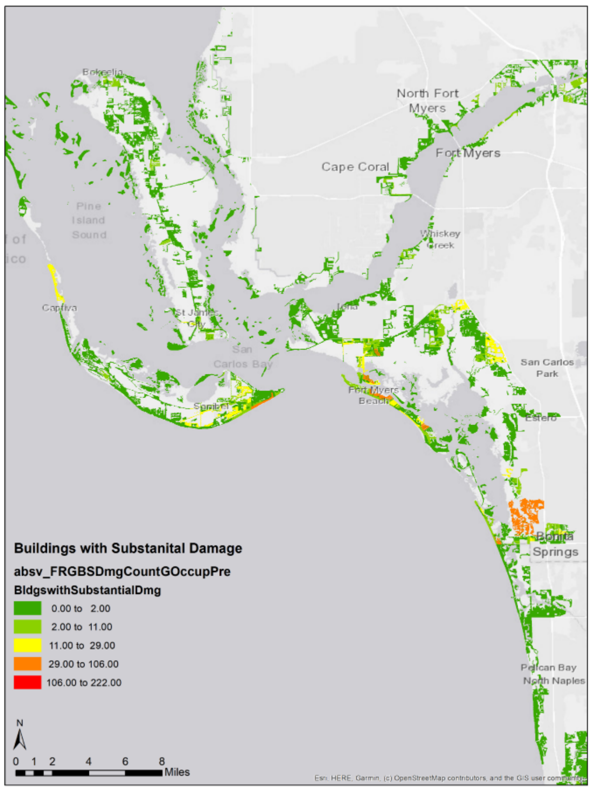

Impact Duration(hr) = 59.5
pre-storm
modeled post-storm
Elevation (meters)
Distance from mean shoreline (meters)
4099

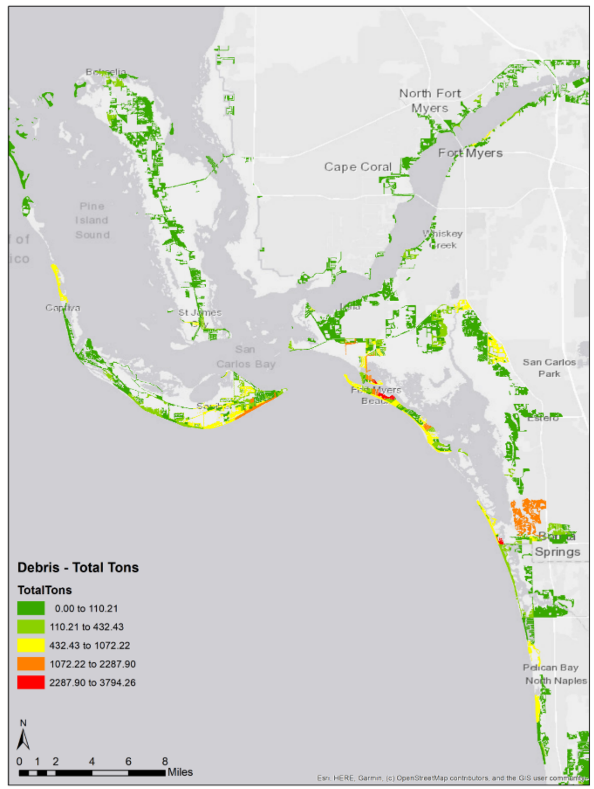
Damage results: slides 14-15

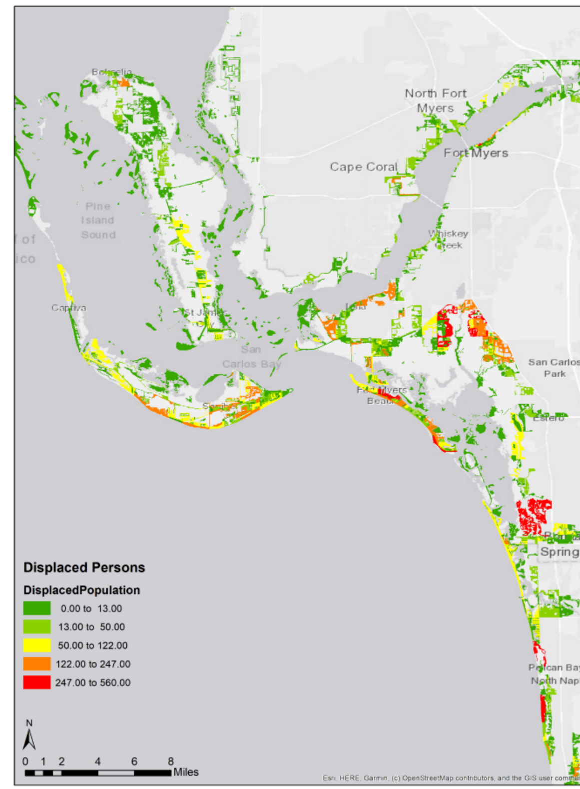
- Flood driven damages (exclusive of direct wind damage) computed by our team using FEMA's HAZUS damage assessment software. Flood damage based on depth – damage curves that do not explicitly include the effect of waves.
- In general damage estimates were 10-20% of the damage estimates reported in the media.

Hurricane Ian

HAZUS level 1 Damage Assessment - 0928 12Z forecast







Hurricane Ian

HAZUS level 1 Damage Assessment - 0928 12Z forecast

HAZUS EARTHQUAKE · WIND · FLOOD · TSUNAMI

FEMA

Quick Assessment Report

RiskMAP Increasing Resilience Together

September 28, 2022

Study Region :	Ian928_Expanded
Scenario :	Ian928
Return Period:	Mix0
Analysis Option:	0

Regional Statistics

Area (Square Miles)	7,288
Number of Census Blocks	101,668
Number of Buildings	
Residential	1,580,011
Total	1,723,096
Number of People in the Region (x 1000)	4,021
Building Exposure ($ Millions)	
Residential	391,818
Total	495,809

Scenario Results

Shelter Requirements

Displaced Population (# Households)	16,340
Short Term Shelter (# People)	15,852

Economic Loss

Residential Property (Capital Stock) Losses ($ Millions)	2,362
Total Property (Capital Stock) Losses ($ Millions)	2,909
Business Interruption (Income) Losses ($ Millions)	2,246

Disclaimer:

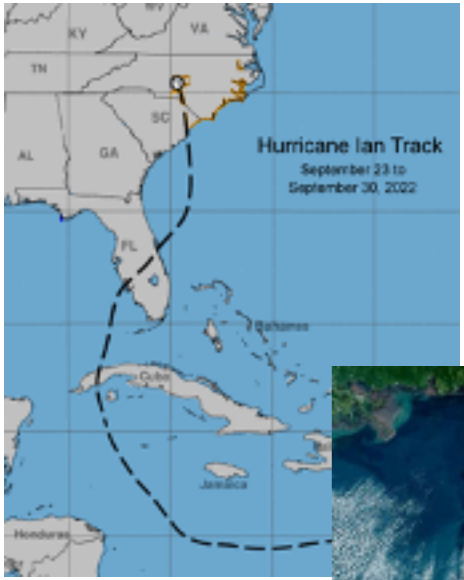
Totals only reflect data for those census tracts/blocks included in the user's study region.

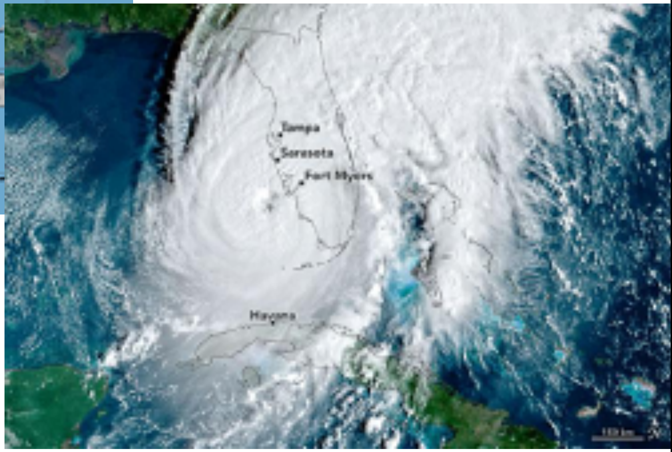
The estimates of social and economic impacts contained in this report were produced using Hazus loss estimation methodology software which is based on current scientific and engineering knowledge. There are uncertainties inherent in any loss estimation technique. Therefore, there may be significant differences between the modeled results contained in this report and the actual social and economic losses following a specific flood. These results can be improved by using enhanced inventory data and flood hazard information.

National Oceanographic Partnership Program

Task 4.
Forecasting TC impacts with the COAWST modeling system

Hurricane Ian 2022





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Maitane Olabarrieta

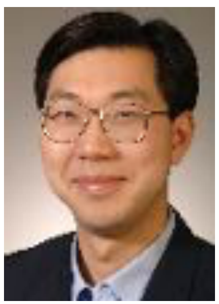

John C. Warner


Joseph Zambon


Z. George Xue


Arthriya Subgranon


Steven Klepac


Ruoying He


Chris R. Sherwood


Yanda Ou


Elias Hunter


Jennifer Warrillow


Daoyang Bao

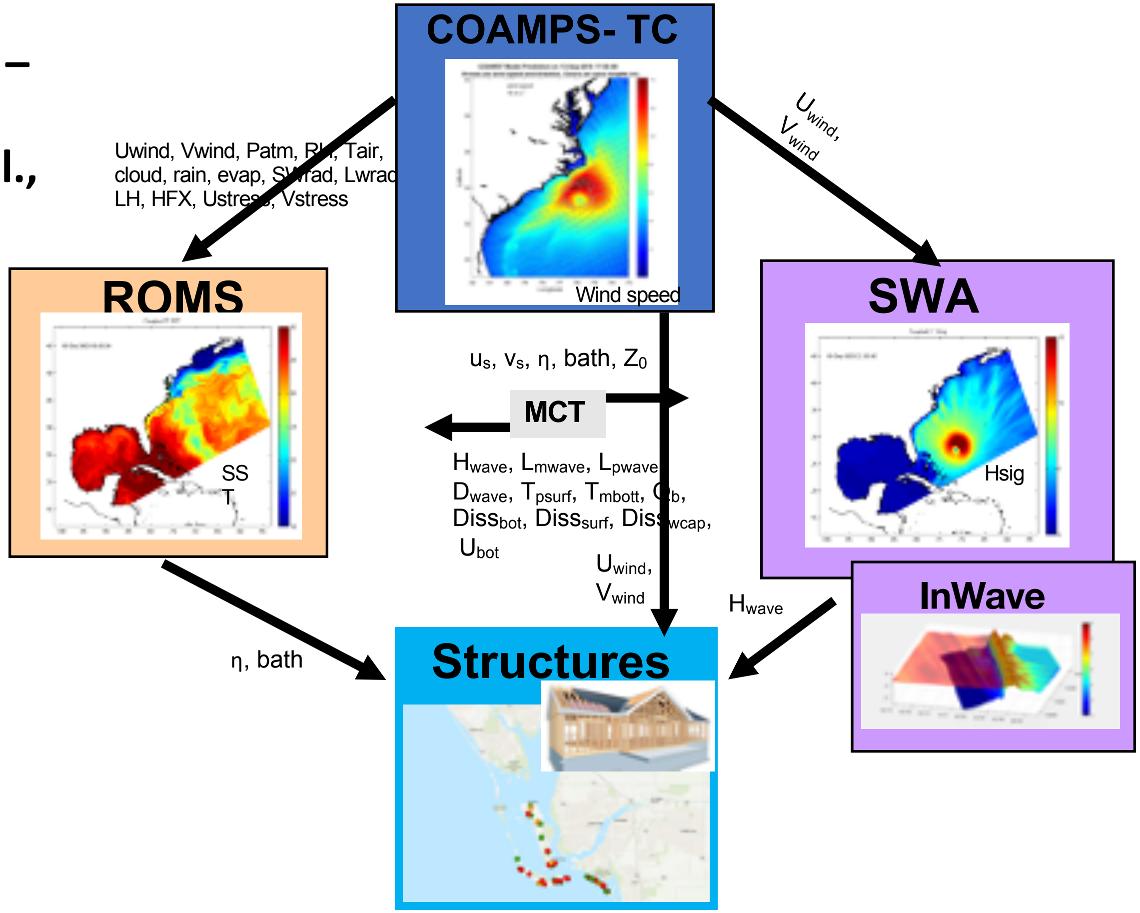

Jin-Si R Over


Jose Maria Gonzalez


Mark Carson

COAWST APPLICATION TO IAN (2022)

Coupled Ocean – Atmosphere – Wave – Sediment Transport Modeling System (Warner et al., 2010)



Main differences from the other forecasting approaches:

- Solves baroclinic structure
- Solves 4-dimensional flows
- Solves 3D wave-current interaction
- Several wave-dependent ocean roughness parameterizations
- Machine learning based infrastructure damage model

NUMERICAL GRIDS USED IN IAN (2022)

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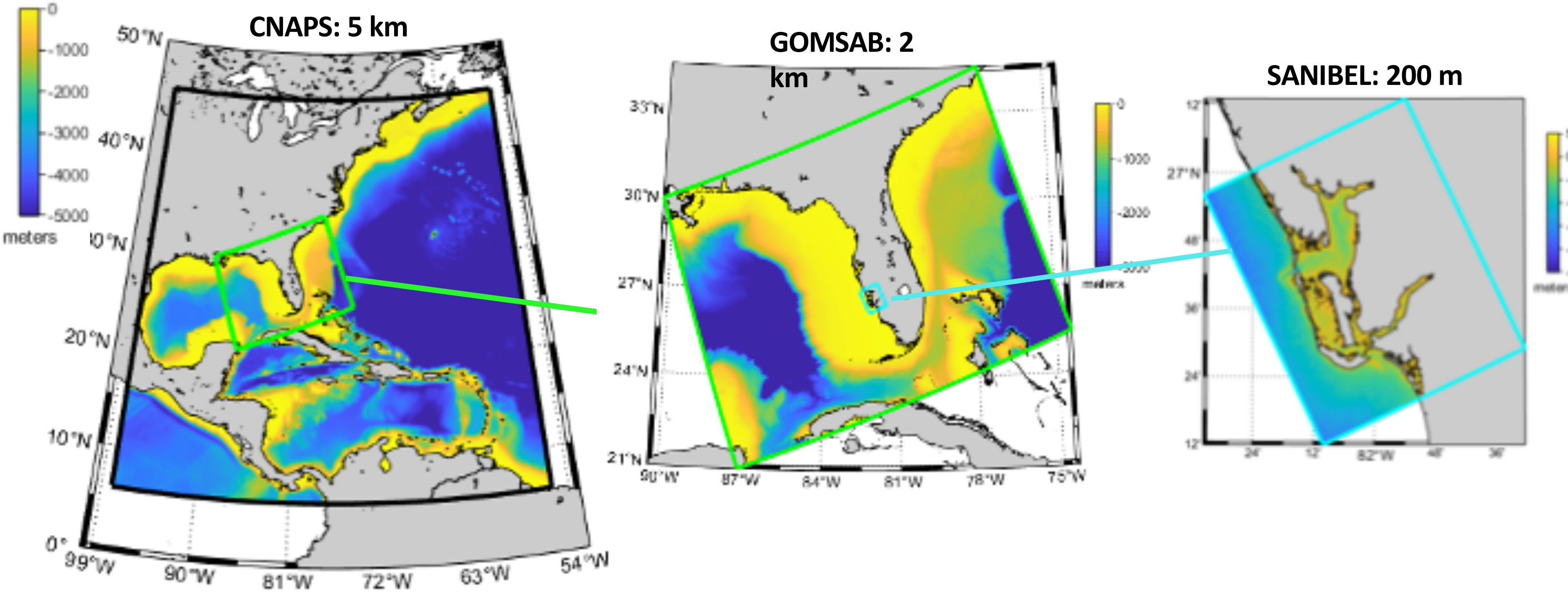
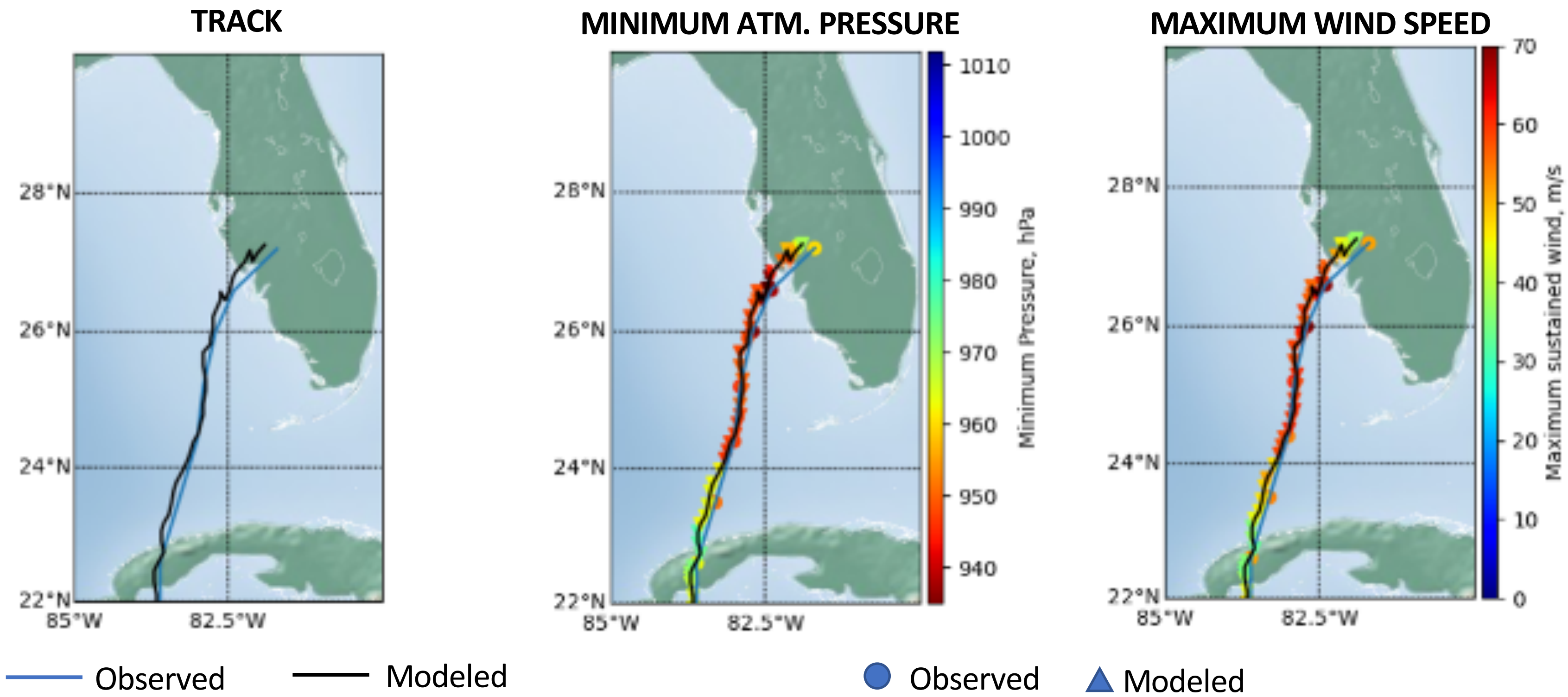


ATMOSPHERIC FORCING

Observed vs best available COAMPS-TC atmospheric forcing

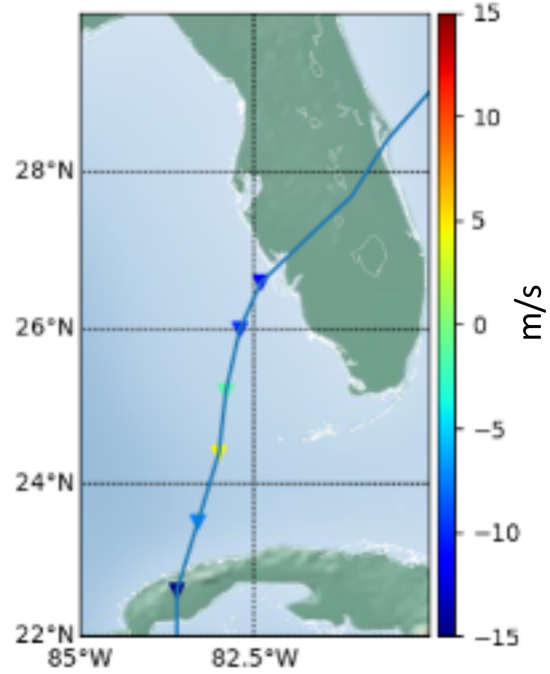


ATMOSPHERIC FORCING

Observed vs best available differences along the best-track

- Modeled track at landfall ~27 km to the north of the observed track
- Modeled minimum sea surface atmospheric pressure at landfall ~3.5 hPa overestimated
- Modeled maximum sustained wind at landfall ~13 m/s underestimated

MAXIMUM WIND SPEED DIFFERENCE (Modeled – Observed)



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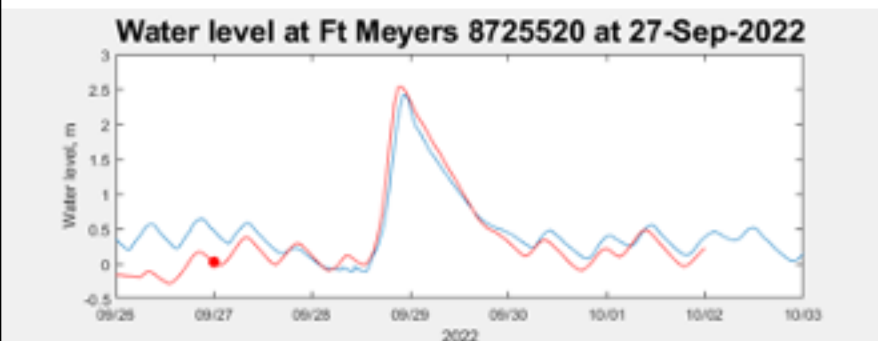
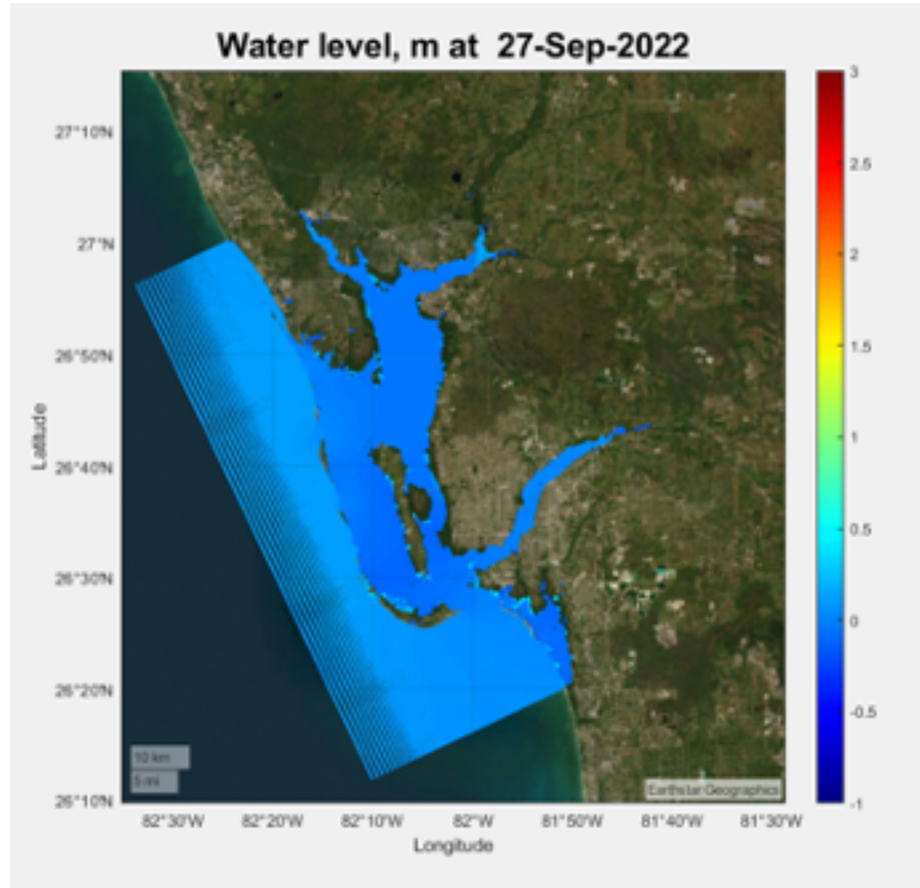
WATER LEVELS

Comparison to NOAA tide gauge observations



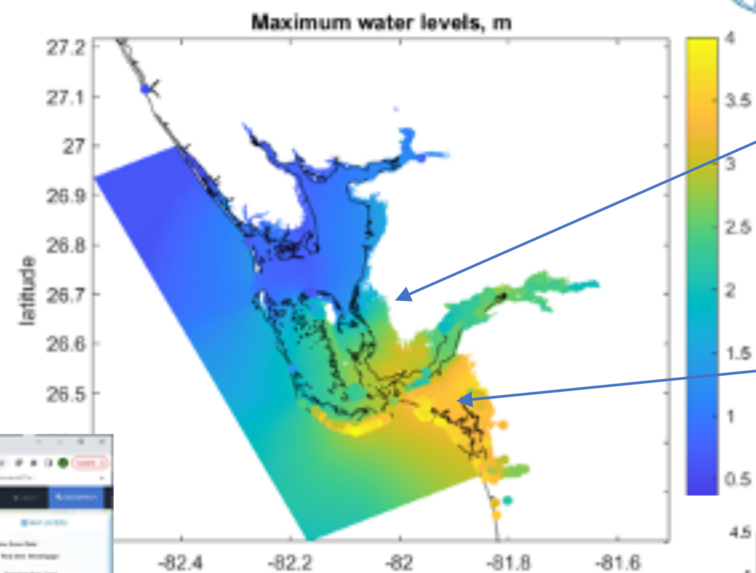
Observed water levels

Modeled water levels



WATER LEVELS

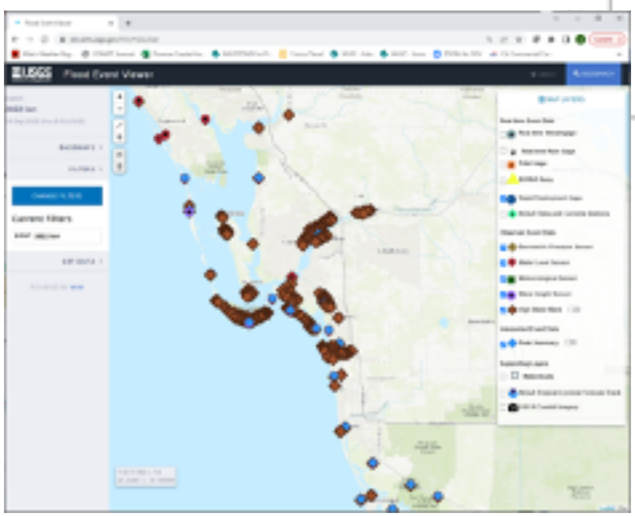
Comparison to FilteredHWMs and FilteredPeaks

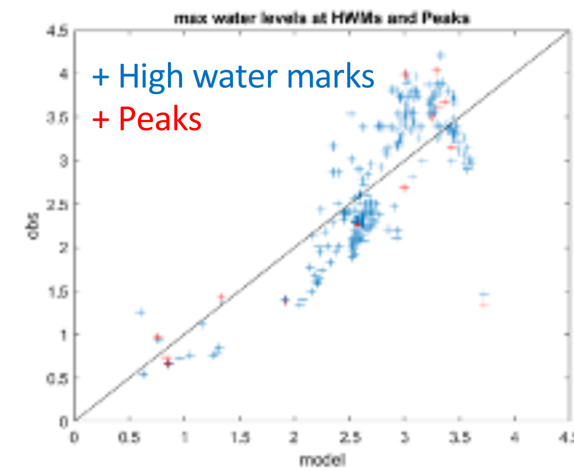


Model slightly too high

Model too low (bright yellow circles are obs)

USGS Flood Event Viewer





WAVE OBSERVATIONS

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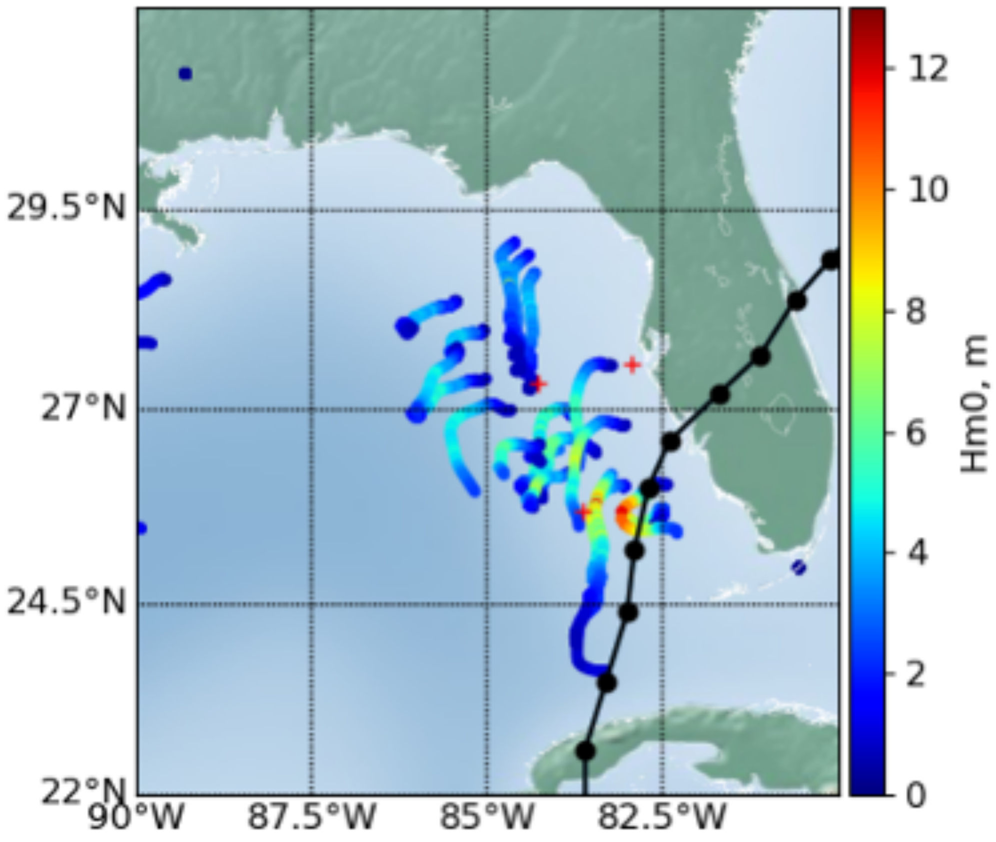

- **Eulerian:**
  - **3 NDBC buoys +**
- **Lagrangian:**
  - **2 MicroSwifts**
  - **6 Spotters**
  - **10 SIO buoys (in FL Western Shelf)**

WAVE OBSERVATIONS VS MODEL

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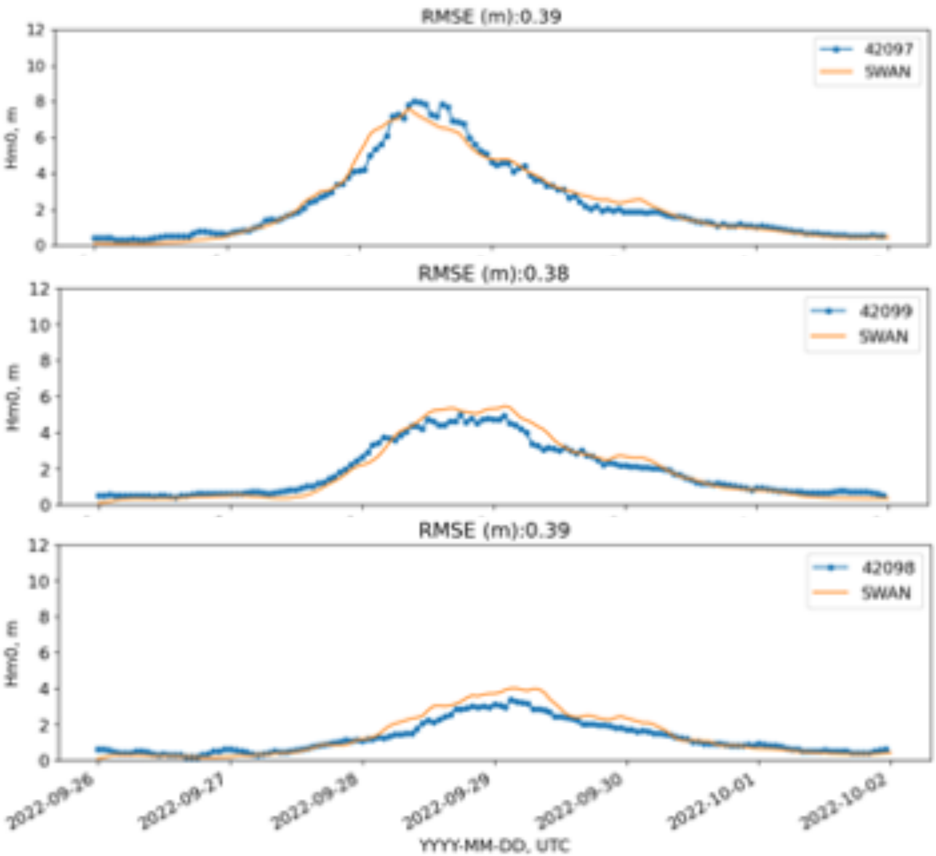
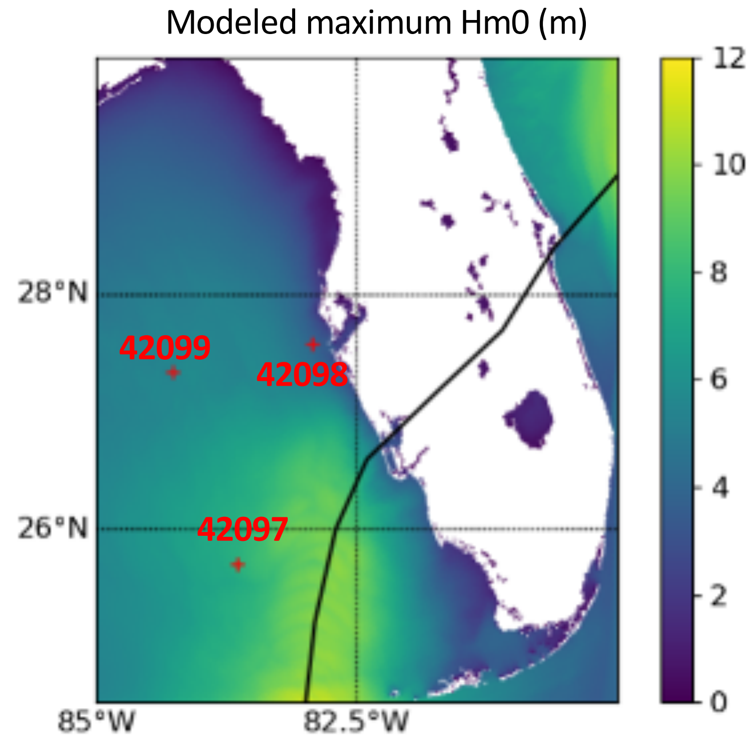
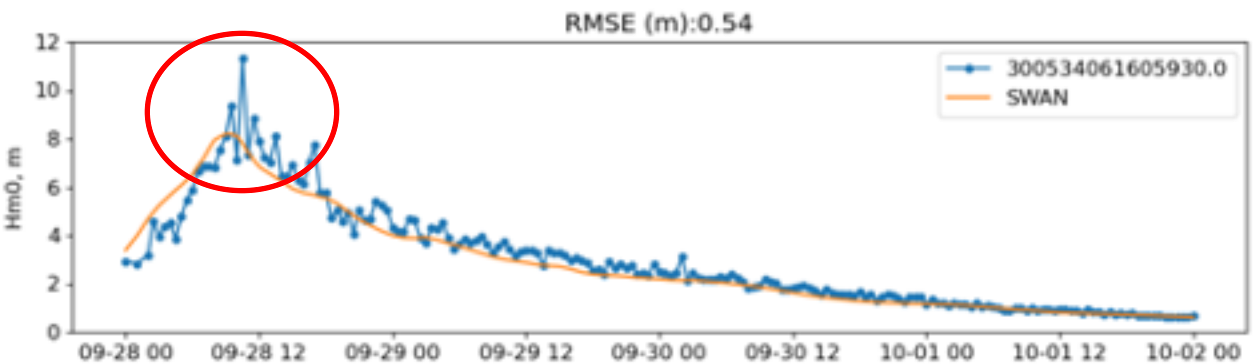
Hm0 time series (Eulerian)

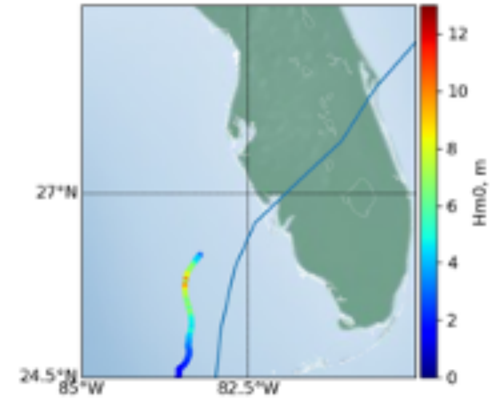


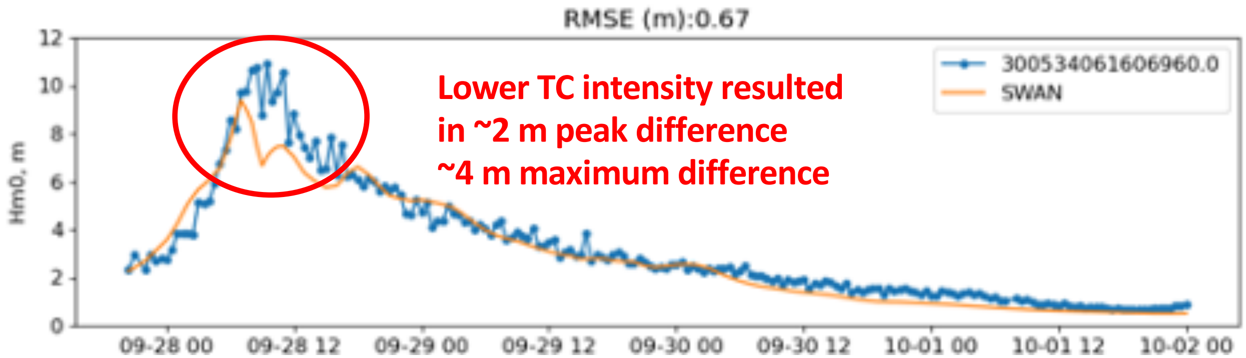


WAVE OBSERVATIONS VS MODEL

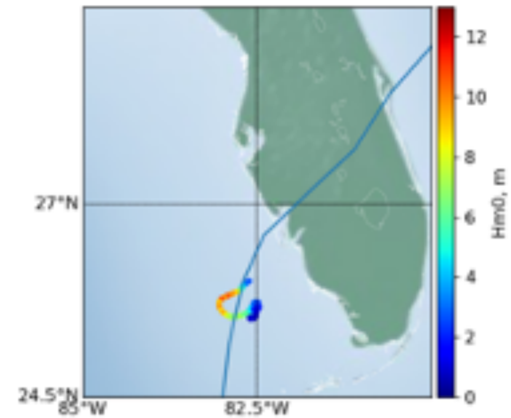
Hm0 time series (Lagrangian, SIO)





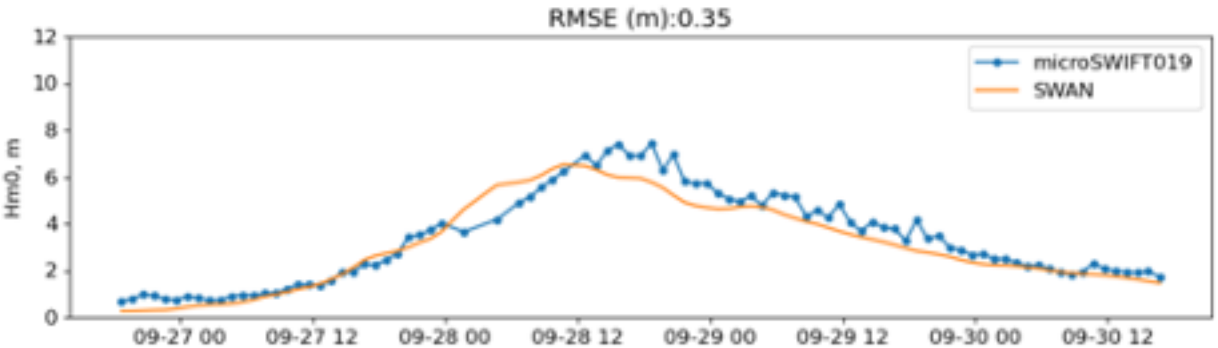


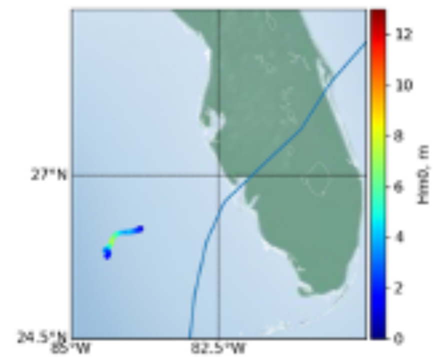
Lower TC intensity resulted in ~2 m peak difference
~4 m maximum difference

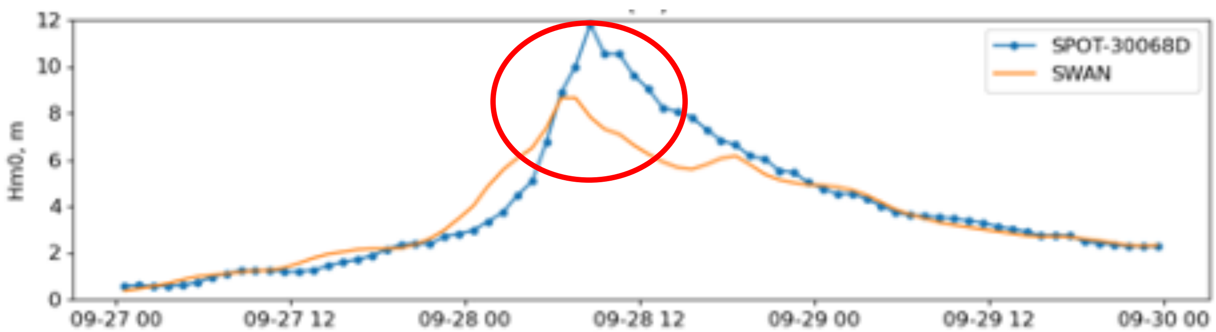


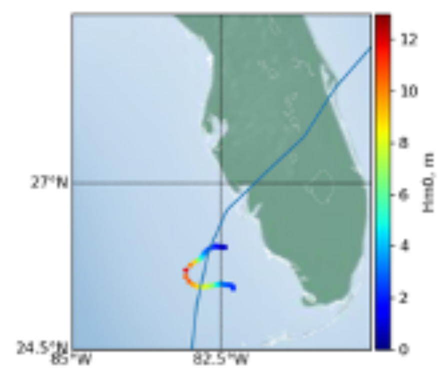
WAVE OBSERVATIONS VS MODEL

Hm0 time series (Spotter and MicroSwift)









WAVE OBSERVATIONS VS MODEL

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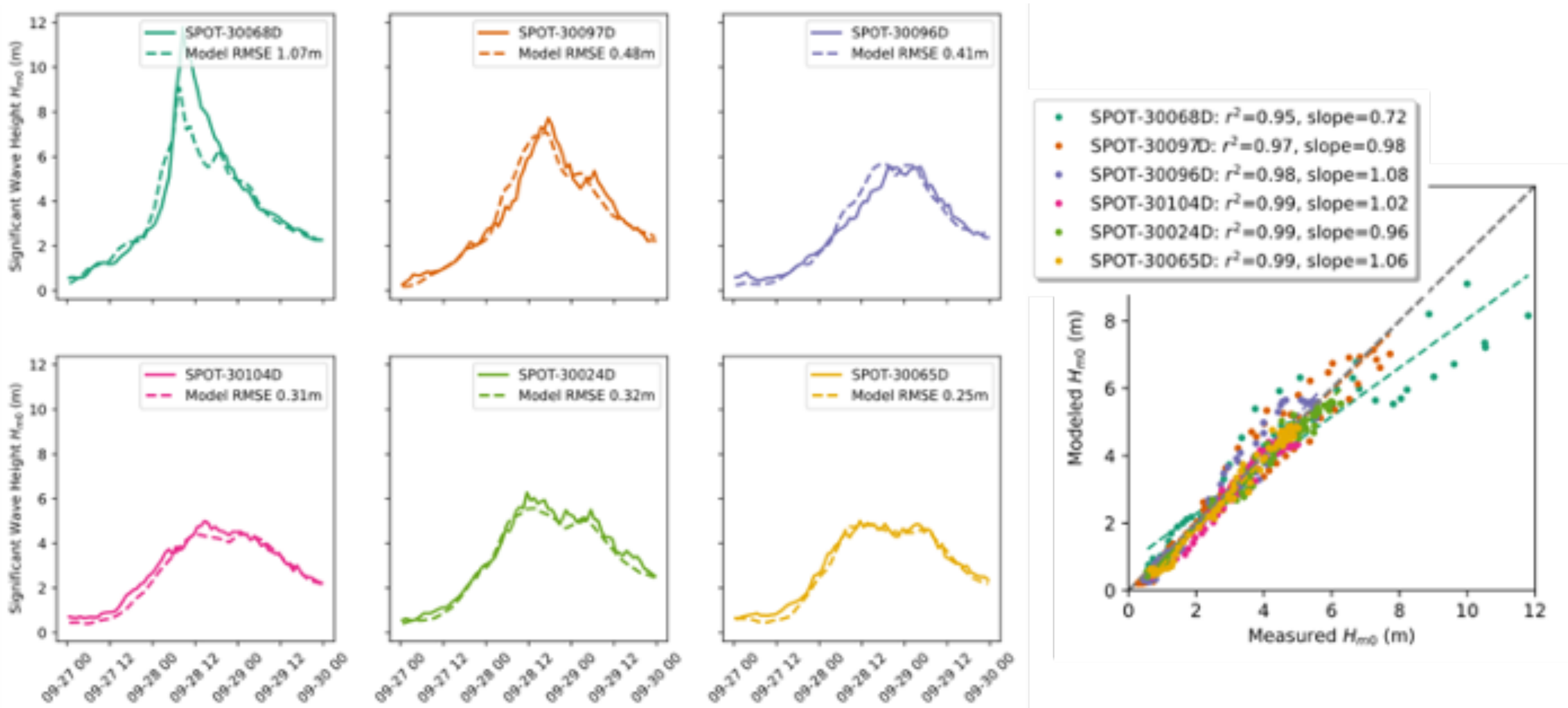

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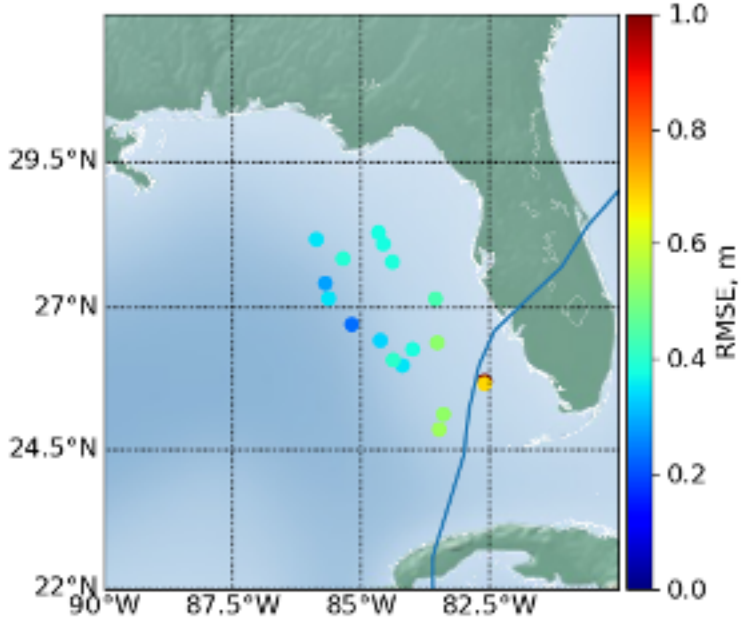
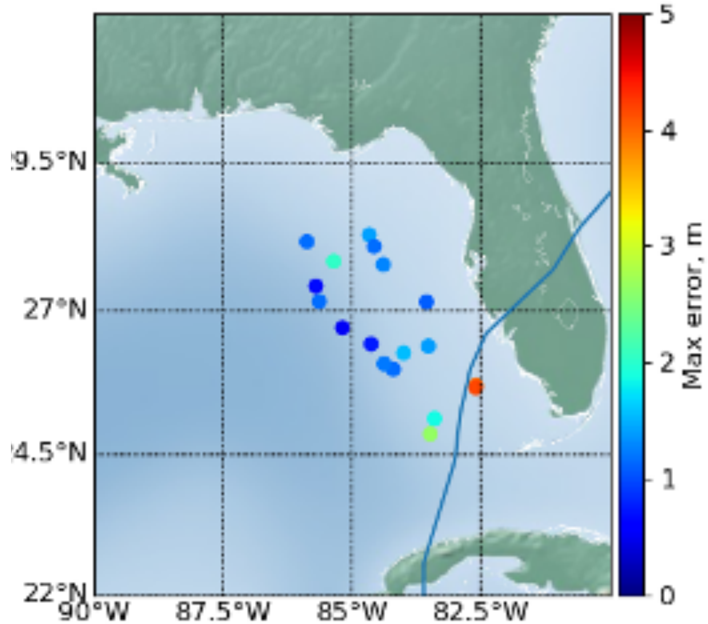
WAVE OBSERVATIONS VS MODEL

- **RMSE and Max Hm0 errors depicted in the mean location of the lagrangian buoys**
- **Max Hm0 errors close to the TC track**

Hm0 RMSE, m



Maximum Hm0 error, m



STRUCTURAL DAMAGE ML MODEL

Framework – Random Forest Algorithm

- Train model with features from Harvey, Irma, Michael and Laura
- Predict categorical damage states at building-level for residential structures
- Use model to forecast building damage as hurricanes approach

Damage State	Description	Extent of Damage to:			
		Roof/Wall Cover	Window/ Doors	Roof/Wall Substrate	Roof/Wall Structure
DS-0	No Damage	0%	None	None	None
DS-1	Non-Structural	> 0% and ≤ 50%	≥ 1 and ≤ larger of 3 and 20%	≤ 3 panels	None
DS-2	Structural	> 50%	> larger of 3 and 20%	> 3 panels or > 25%	Any

More Information on this work

- Link to our recent article →

Machine Learning (ML) Training Data

Building Features – StEER & GEER recon data

- DS (target), structural/cover/cladding types/materials, geometry, age

Hazard Features – NHC, NIST/ARA, FEMA

- Peak gust, sustained wind duration, inundation depth

Geospatial Features – MS Buildings, ArcGIS, NOAA

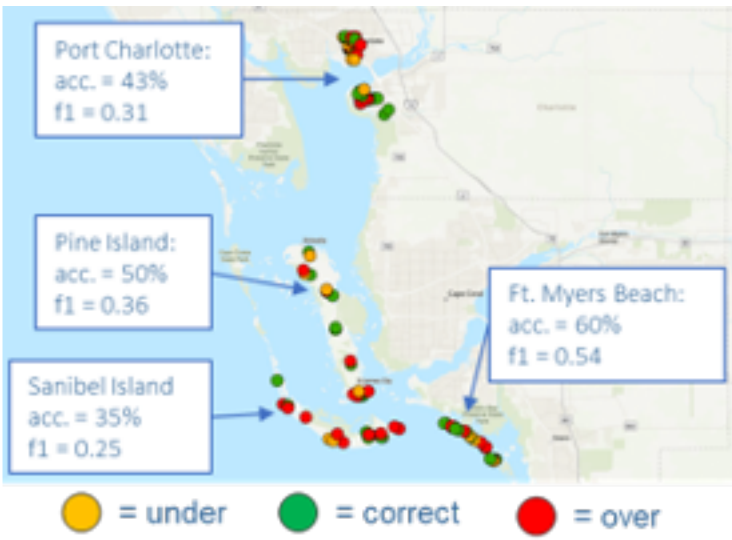
- Distance to coast, building density, shielding, elevation, land cover

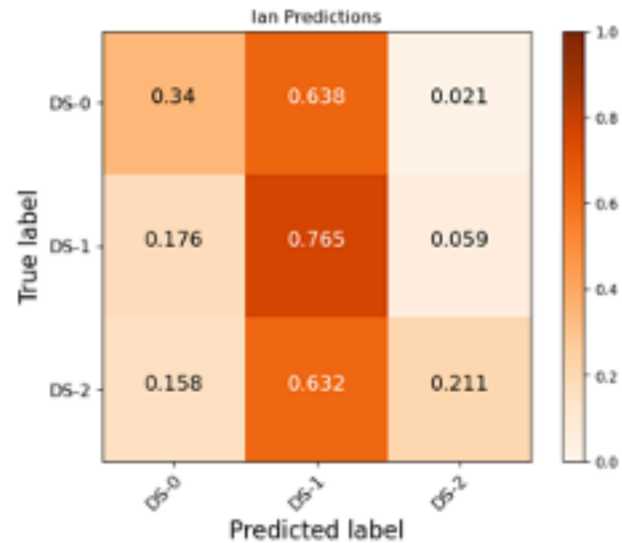
Socioeconomic Features – CDC, US Census

- Community Vulnerability Index, Community Resilience Estimates

Fragility Features – Hazus, USACE, Academic Research

PRELIMINARY APPLICATION TO HURRICANE IAN (2022)





- Overall accuracy: 46%
- Average f1-score: 0.42 (accounts for varying accuracy among DS)
- Over-prediction of DS-1, varies by region
- Vegetation effects are not accounted for (this might be relevant in this mangrove-dominated region)

Main advantages of this forecasting approach

- COAWST resolve:
  - Baroclinic structure of ocean
  - Meso-scale oceanic circulation (relevant for wave-current interaction and TC evolution)
- Good results for:
  - Water levels
  - Overall statistical wave-bulk parameters (although close to the eye Hm0 error are large, up to 4 m)

Main disadvantages of this forecasting approach

- Simulations are time-consuming
- Baroclinic contribution to water levels needs to be adjusted (this problem has been fixed in GOM but needs to be tested US East Coast)
- ML framework
  - The method is promising but training data is still limited (we need to train the ML method with more hurricanes including events with no damage)

Task 4.
Forecasting TC impact s with the COAWST modeling system

Hurricane Ian 2022

NOPP National Oceanographic Partnership Program

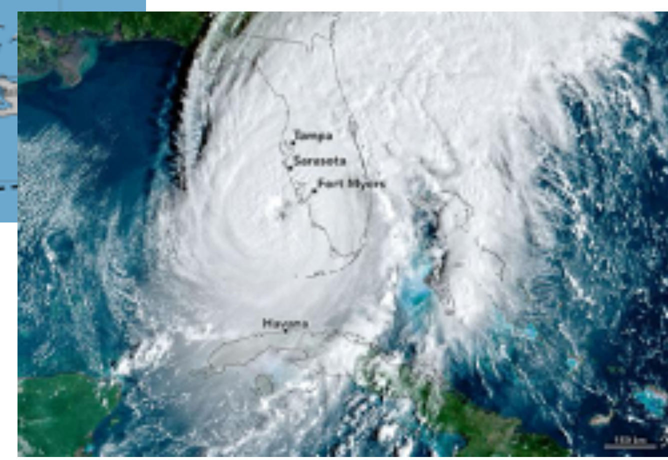
ONR Office of Naval Research Science & Technology

UF UNIVERSITY of FLORIDA

USGS

FATHOM SCIENCE

LSU



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Model physics

The ROMS model uses an orthogonal curvilinear grid in the horizontal and a stretched terrain-following vertical s-coordinate system. Here, simplified momentum balance components in Cartesian coordinates (x, y) are presented to identify the terms dependent on the Stokes drift and wave-current interaction. The

- x-component of momentum is,

$$\frac{\partial}{\partial t}\left(H_z^c u\right) + \frac{\partial}{\partial x}\left(H_z^c u^2\right) + \frac{\partial}{\partial y}\left(H_z^c uv\right) + u\frac{\partial}{\partial x}\left(H_z u^{St}\right) + u\frac{\partial}{\partial y}\left(H_z v^{St}\right)$$

$$+\frac{\partial}{\partial s}\left(w_s u\right) + u\frac{\partial w_s^{St}}{\partial s} = -H_z^c \frac{\partial \varphi^c}{\partial x}\bigg|_z + H_z^c fv + H_z^c fv^{St} + H_z^c v^{St}\left(\frac{\partial v}{\partial x} - \frac{\partial u}{\partial y}\right) - w_s^{St}\frac{\partial u}{\partial s} \qquad (2)$$

$$+H_z^c F^x + H_z^c F^{wx} + H_z^c D^x - \frac{\partial}{\partial s}\left(\overline{u'w'} - \frac{\nu}{H_z^c}\frac{\partial u}{\partial s}\right)$$

- y-component momentum,

$$\frac{\partial}{\partial t}\left(H_z^c v\right) + \frac{\partial}{\partial x}\left(H_z^c uv\right) + \frac{\partial}{\partial y}\left(H_z^c v^2\right) + v\frac{\partial}{\partial x}\left(H_z^c u^{St}\right) + v\frac{\partial}{\partial y}\left(H_z^c v^{St}\right)$$

$$+\frac{\partial}{\partial s}\left(w_s v\right) + v\frac{\partial w_s^{St}}{\partial s} = -H_z^c \frac{\partial \varphi^c}{\partial y}\bigg|_z - H_z^c fu - H_z^c fu^{St} - H_z^c u^{St}\left(\frac{\partial v}{\partial x} - \frac{\partial u}{\partial y}\right) - w_s^{St}\frac{\partial v}{\partial s} \qquad (3)$$

$$+H_z^c F^y + H_z^c F^{wy} + H_z^c D^y - \frac{\partial}{\partial s}\left(\overline{v'w'} - \frac{\nu}{H_z^c}\frac{\partial v}{\partial s}\right),$$

- and the continuity equation,

$$\frac{\partial H_z^c}{\partial t} + \frac{\partial}{\partial x}\left(H_z^c\left(u + u^{St}\right)\right) + \frac{\partial}{\partial y}\left(H_z^c\left(v + v^{St}\right)\right) + \frac{\partial}{\partial s}\left(w + w^{St}\right) = 0 \qquad (4)$$

Liu, G., Kumar, N., Harcourt, R., & Perrie, W. (2021). Bulk, spectral and deep water approximations for Stokes drift: Implications for coupled ocean circulation and surface wave models. Journal of Advances in Modeling Earth Systems, e2020MS002172. 13, https://doi.org/10.1029/2020MS002172

wave stokes transport physics terms (ST)

wave breaking physics terms (BK)

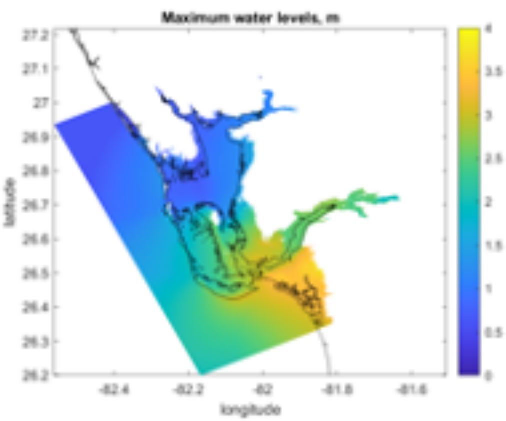
wave surface and bottom stresses contribution term (WS)

Ran several simulations but will compare:
Ian_yesST_yesBK_yesWS
to
Ian_noST_noBK_noWS

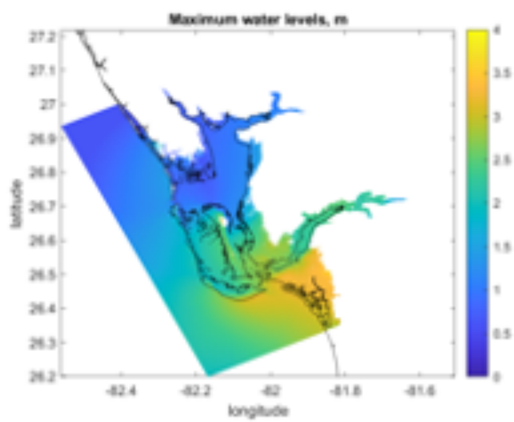
From this we can see what the waves do to water transport.

Difference in model physics results in different water volumes.

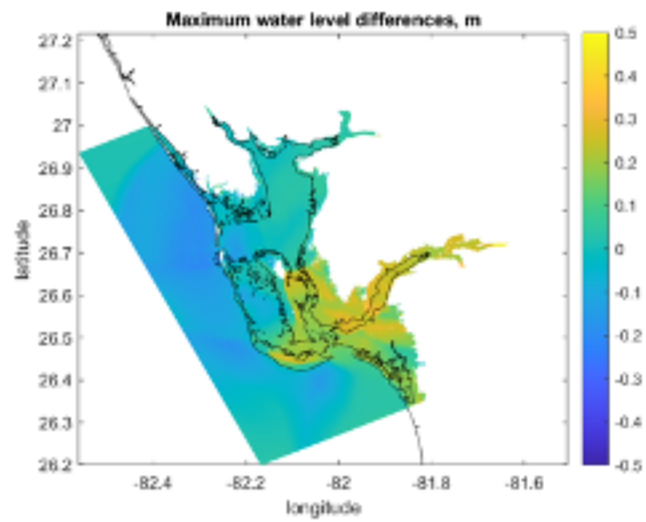
Ian_yesST_yesBK_yesWS
Max Water levels



Ian_noST_noBK_noWS
Max Water levels



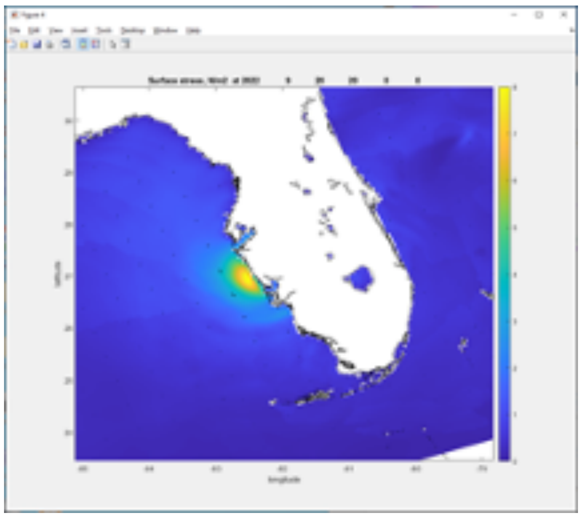
Difference of YES – NO

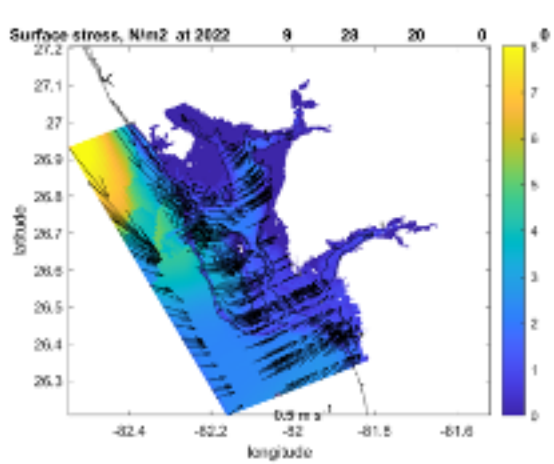


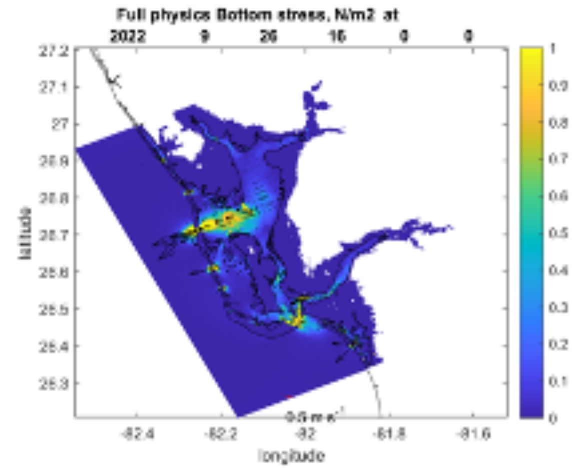
Removing waves from model physics can lead up to 0.5 m difference in water levels.

Physics that drive flow

Total volume of water is dependent upon surface stress (not just winds) and model physics.





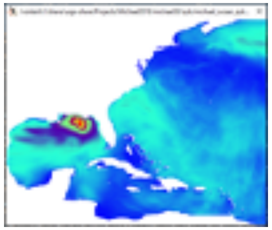


Because different modeling groups are using different physics, we could compare results by looking at other processes, such as surface stress, bottom stress, velocities, etc at certain moments in time.

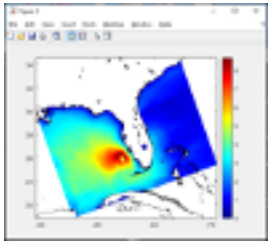
Model output

ROMS + SWAN coupled, Sept 26 hr 0000 – Oct 2 hr 0000, new tides
COAMPS forc:
https://icoast.rc.ufl.edu/thredds/catalog/coamps/catalog.html?dataset=coamps/Ian2022_forcing_regular.nc

ian1 = CNAPS grids, 5 km,
Hwave, Dwave, Pwave_top, zeta, ubar, vbar, u_sur, v_sur, temp_sur, salt_sur
http://geoport.whoi.edu/thredds/dodsC/vortexfs1/usgs/Projects/Ian2022/ian1/qck/ian_ocean_cnaps_qck.nc
u, v, salt, temp
http://geoport.whoi.edu/thredds/dodsC/vortexfs1/usgs/Projects/Ian2022/ian1/his/ian.ncml



ian4 = GOMSAB grids, 2km
Hwave, Dwave, Pwave_top, zeta, ubar, vbar, u_sur, v_sur, temp_sur, salt_sur
http://geoport.whoi.edu/thredds/dodsC/vortexfs1/usgs/Projects/Ian2022/ian4/qck/ian_ocean_sabgom_qck.nc
u, v, salt, temp
http://geoport.whoi.edu/thredds/dodsC/vortexfs1/usgs/Projects/Ian2022/ian4/his/ian.ncml



ian5 = SANIBEL grids, 200m
Hwave, Dwave, Pwave_top, zeta, ubar, vbar, u_sur, v_sur, temp_sur, salt_sur
http://geoport.whoi.edu/thredds/dodsC/vortexfs1/usgs/Projects/Ian2022/ian5/qck/ian_ocean_sanibel_qck.nc
u, v, salt, temp
http://geoport.whoi.edu/thredds/dodsC/vortexfs1/usgs/Projects/Ian2022/ian5/his/ian.ncml