Office of Coast Survey
Coast Survey Development Laboratory
Coastal & Marine Modeling Branch
Storm Surge Modeling Team

National Ocean Service
National Oceanic and Atmospheric Administration
U.S. Department of Commerce

Role of Storm Surge in COASTAL Act; Storm Surge Model Development at NOS

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Hurricane Forecast Improvement Program Annual Review Meeting
November 9 2017
Miami, FL

Background

- On July 6, 2012, the President signed the Federal highway conference bill, which included legislation known as the **Consumer Option for an Alternative System to Allocate Losses (COASTAL) Act.**
- Intended to lower costs to the National Flood Insurance Program (NFIP) – managed by FEMA – by improving the determination of wind vs. water damage in cases of "indeterminate losses" (or "slab cases").
- A loss is indeterminate when little tangible evidence beyond a building's foundation remains for the proper adjustment of insurance claims for homes totally destroyed by a tropical system (water damage is covered by NFIP; wind damage is covered by private insurers).
- This will enable a more timely claims adjustment process, which has frequently faced excessive delays due to litigation between the Federal government and private insurers.

Background

- The COASTAL Act requires NOAA to produce detailed “post-storm assessments” following certain named tropical systems that impact the U.S. and its territories.
  - The assessments will be produced using a new NOAA hindcast model that indicates the strength and timing of damaging winds and water at a given location in the impact area.
  - The assessments must be submitted to FEMA within 90 days after DHS and NOAA deem a storm “reasonably constitutes a threat.”
  - NOAA is required to make post-storm assessment results and obs from the storm available to the public via a new online database.
- The post-storm assessment output (assuming it meets 90% accuracy at the location in question) will then be incorporated in the COASTAL Formula (managed by FEMA). The formula will consider other non-geophysical data (e.g. structure data) to determine the extent to which water vs. wind contributed to the destruction (thereby determining the cost responsibility between NFIP and private home insurers).

Agency Responsibilities

- NOAA Deliverables:
  - Data collection plan (the *COASTAL Act Capabilities Development Plan* or CACDP)
  - Data collection protocol
  - Coastal Wind and Water Event Database (CWWED)
  - Named Storm Event Model (NSEM)
- GAO must audit NOAA's data collection efforts, including the cost-effectiveness of the approach
- FEMA must develop the COASTAL Formula and NAS will evaluate the formula's effectiveness.

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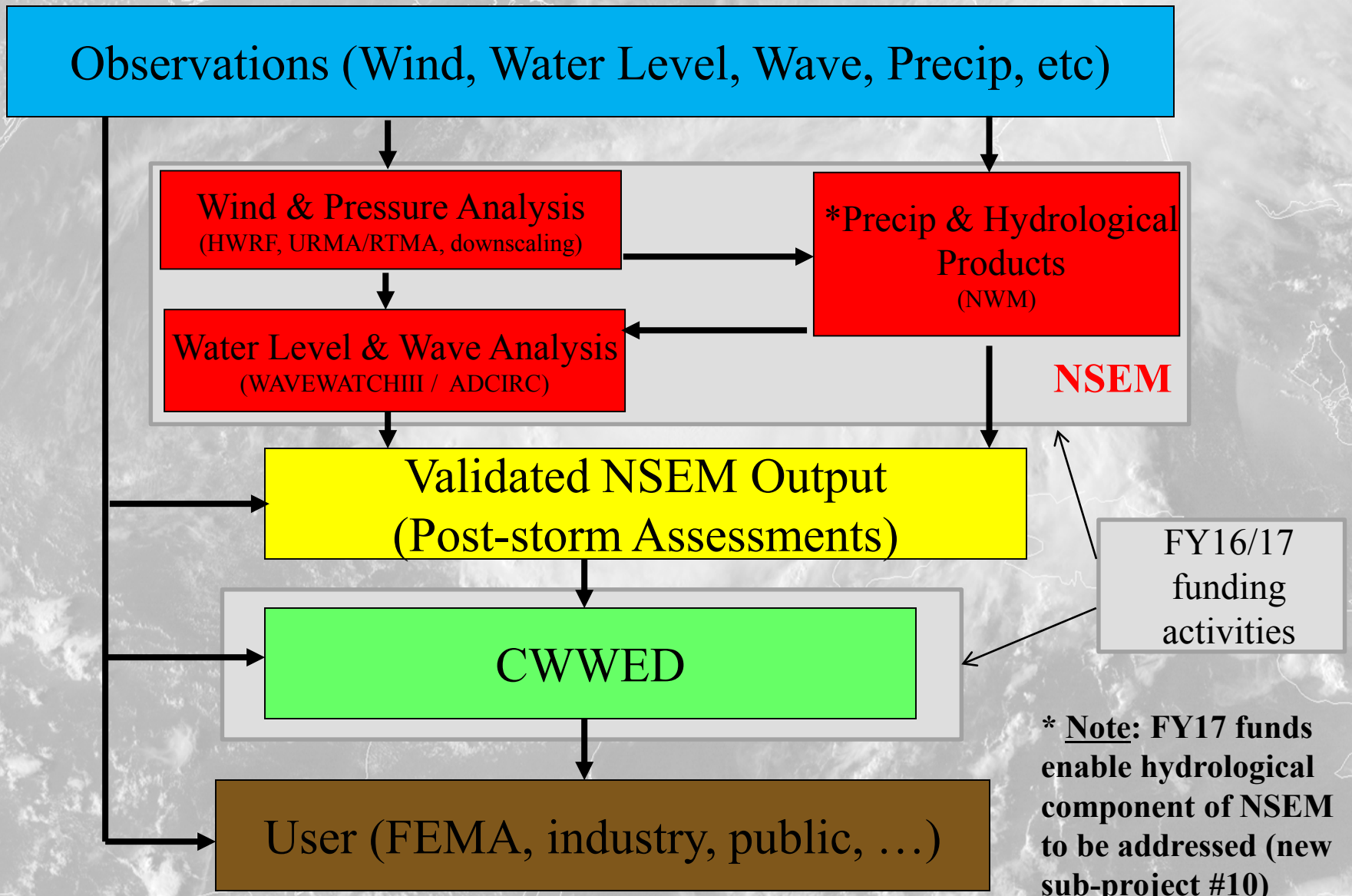
Predecisional information not releasable outside of US Government

COASTAL Act Process



*** Note: FY17 funds enable hydrological component of NSEM to be addressed (new sub-project #10)**

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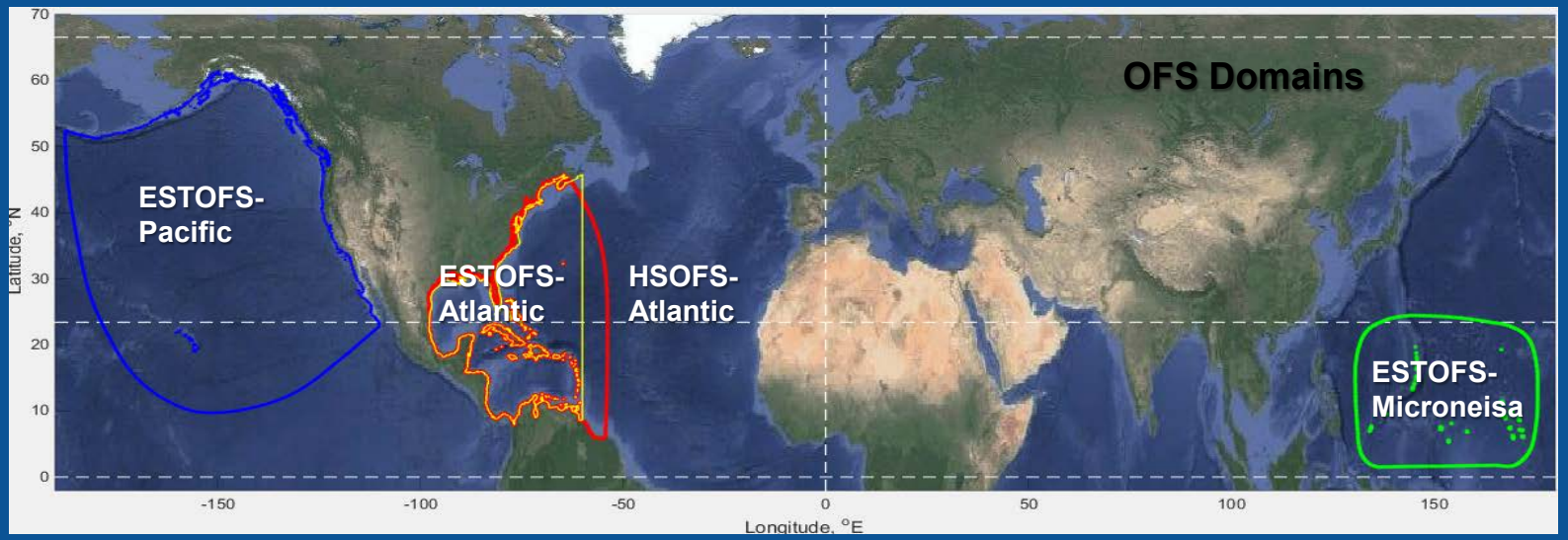
Summary

- Towards Integral Water Level Prediction
- Surge/Wave Coupling
  - NUOPC Layer
  - NEMS Infrastructure
  - ADCIRC modifications
  - COASTAL Act experiments
- Compound Flooding
- Assimilation of Coastal Water Levels
- Operational Forecast and Hindcast Model Skill Assessment

NOS Storm Surge Operational Forecast Systems

Storm Surge Model Guidance Systems

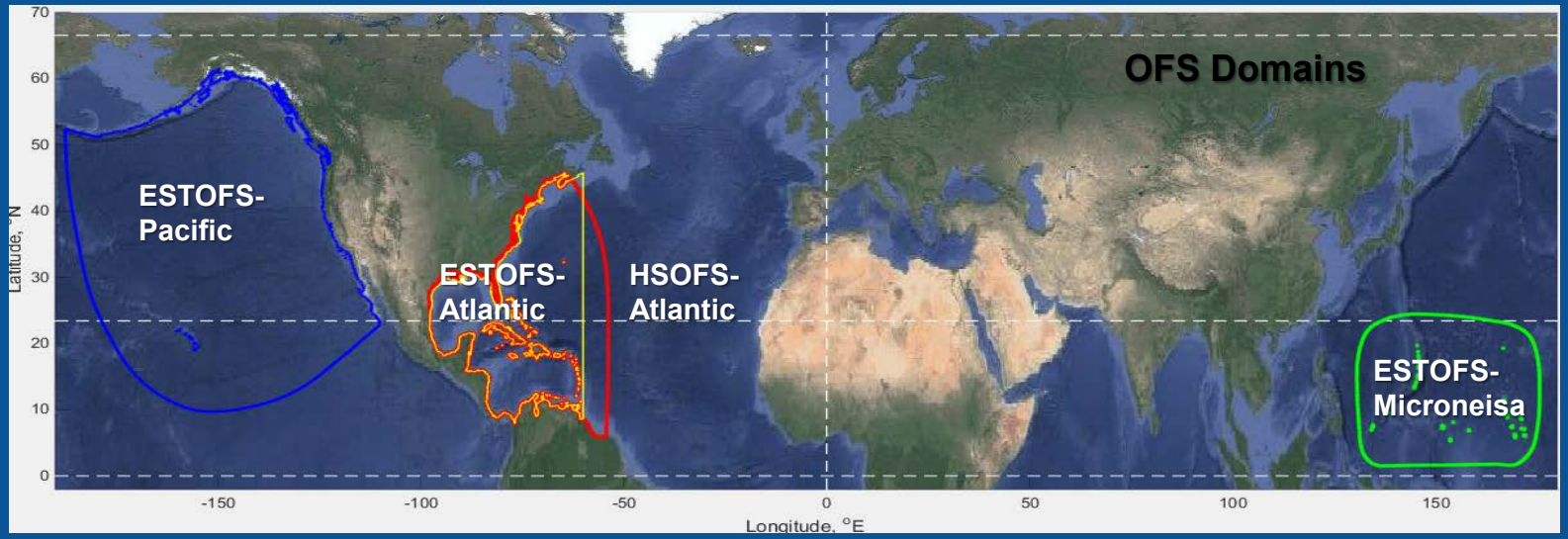


Requirements identified in NOAA's Storm Surge Roadmap to provide coastal inundation model guidance for US Territories

- ESTOFS - Extra-Tropical : continuous forecasts
- HSOFS - Hurricane (Tropical) : on-demand ensemble forecasts, post-event hindcasts

NOS Storm Surge Operational Forecast Systems

Storm Surge Model Guidance Systems



Component	ESTOFS-ATL	ESTOFS-PAC	ESTOFS-MIC	HSOFS-ATL
Grid resolution	160+ m (V2)	2+ km	500+ m	160+ m
Forcing	GFS	GFS	GFS	TRACK
Ensembles	1	1	1	5
Forecast frequency/ Forecast horizon	4/day 180 hrs	4/day 180 hrs	4/day 180 hrs	On demand
Inland flooding	Yes (V2)	No	Yes	Yes

ESTOFS – Atlantic

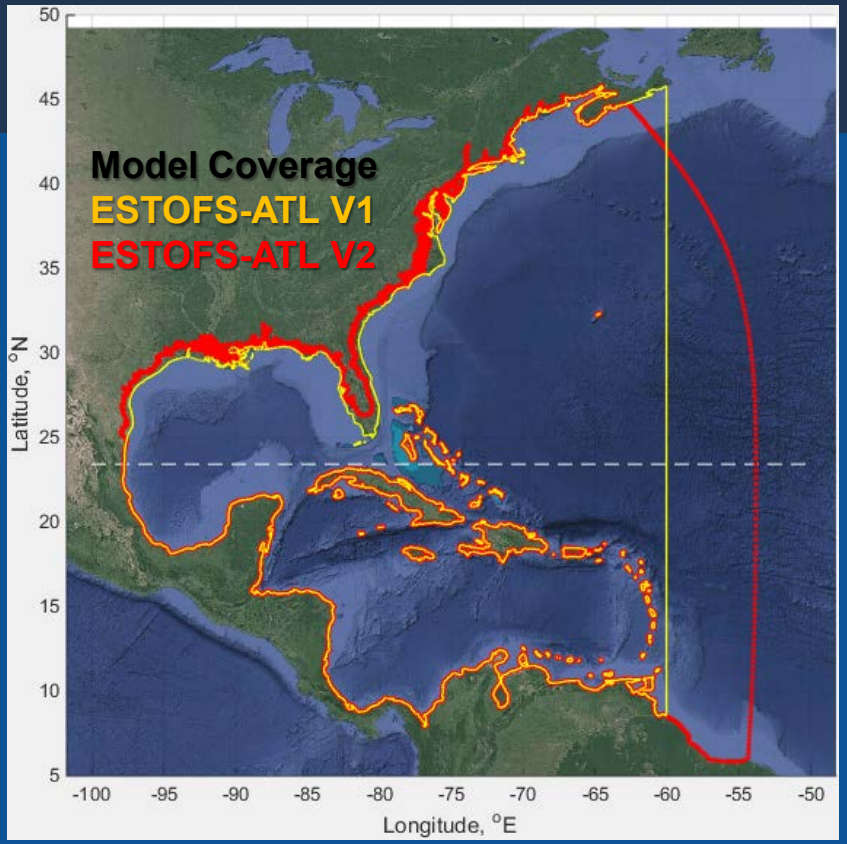
In operation since 2012

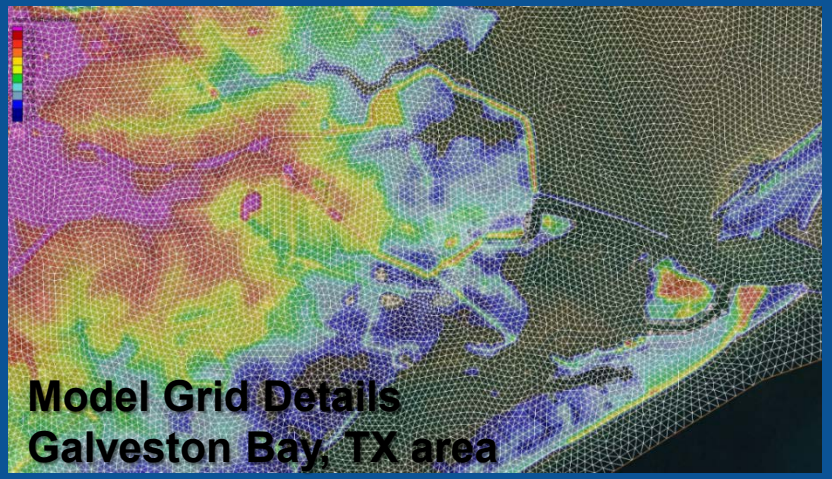
Major Upgrade (April 24 2017)

- Covers US East and Gulf Coast + Caribbean
- HSOFS grid + inland flooding
- 200 m coastal resolution
- 1.8M nodes
- GFS 13-km forcing

Cycles 00z, 06z, 12z and 18z
6-hr nowcast + 180-hr forecast

- Provides live boundary conditions for **Nearshore Wave Prediction System (NWPS)**
- 6-min water levels at 128 coastal tide gauges
- Hourly water levels for the whole domain





ESTOFS – Pacific

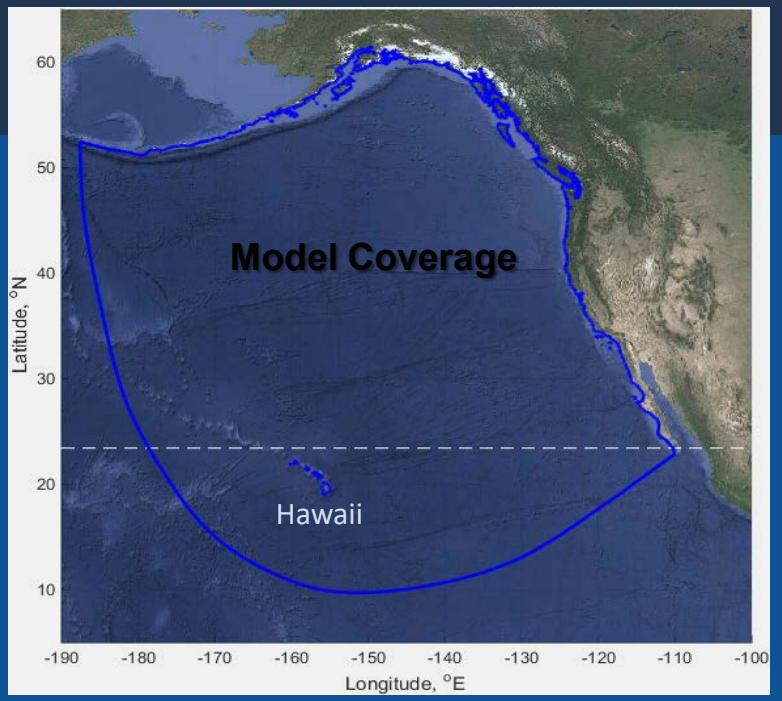
In operation since 2014

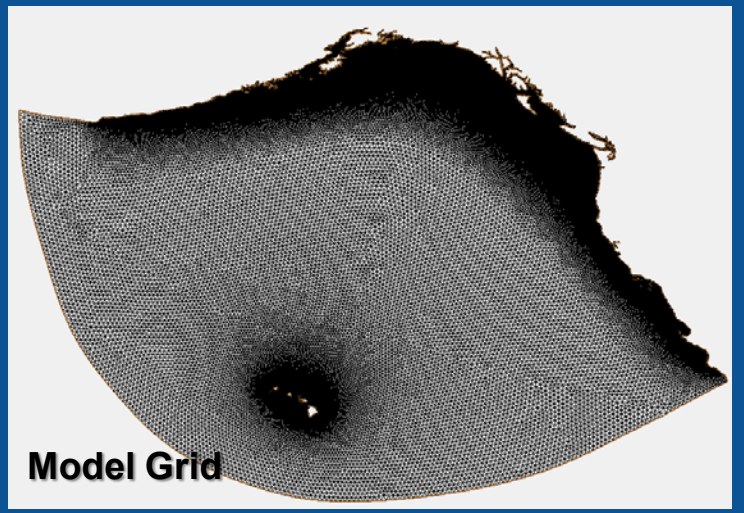
- Covers US West Coast + Hawaii
- 1-3 km coastal resolution
- 132K nodes
- No inland flooding
- GFS 55-km forcing

Cycles 00z, 06z, 12z and 18z
6-hr nowcast + 180-hr forecast

- Provides live boundary conditions for **Nearshore Wave Prediction System (NWPS)**
- 6-min water levels at 71 coastal tide gauges
- Hourly water levels for the whole domain

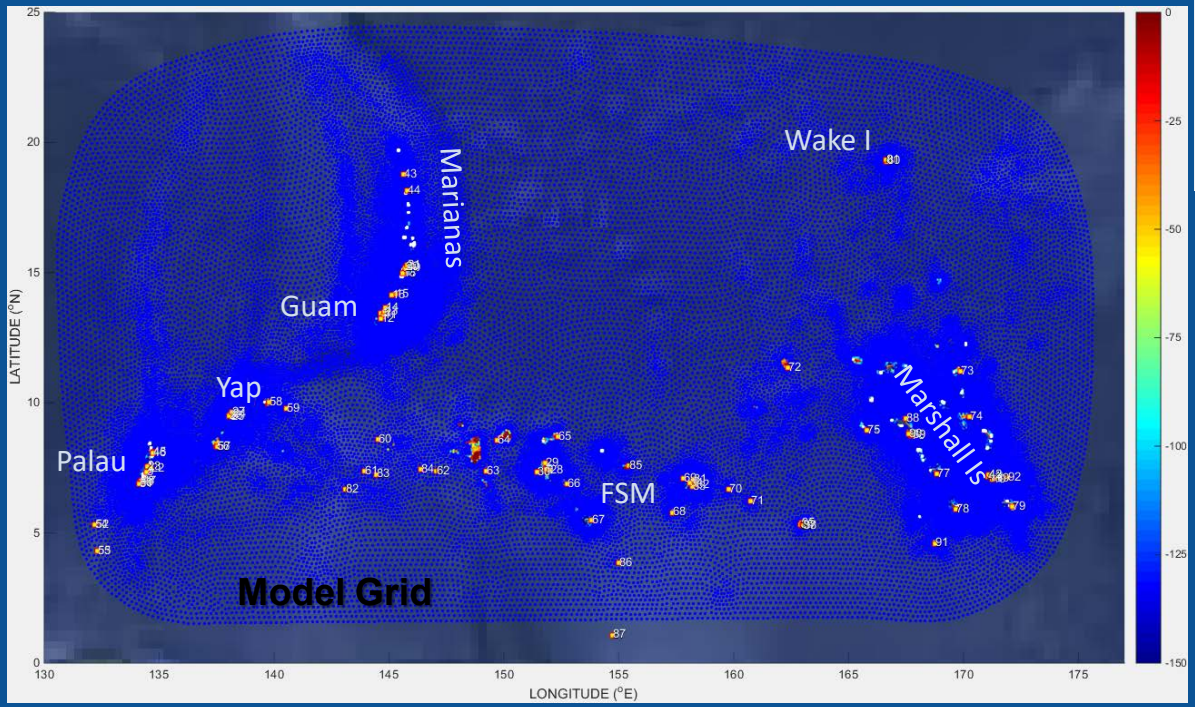
Future upgrades will include
- Increase forcing resolution to 13km
- Update model grid

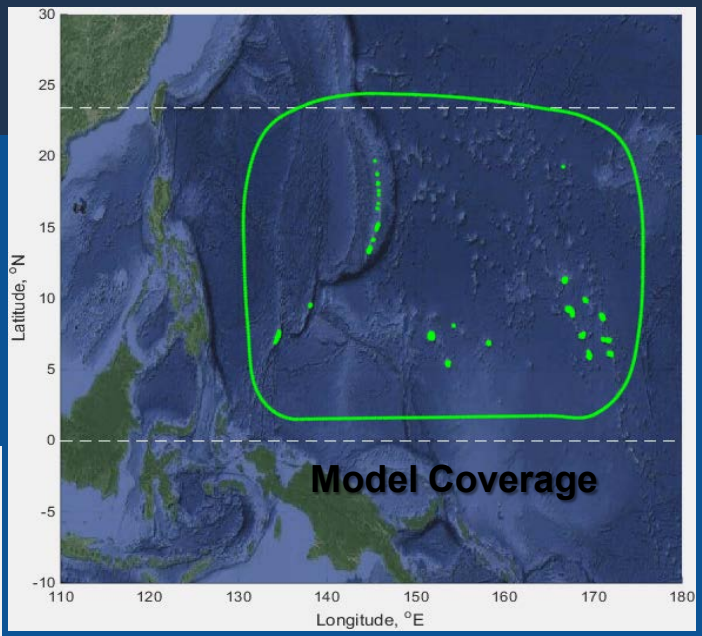




ESTOFS – Micronesia

- Covers Palau, Mariana Islands, Fed State of Micronesia, Marshall Islands, Wake Island
- Up to 200 m coastal resolution
- Overland up to 10m elevation
- Implementation planned for September 2017





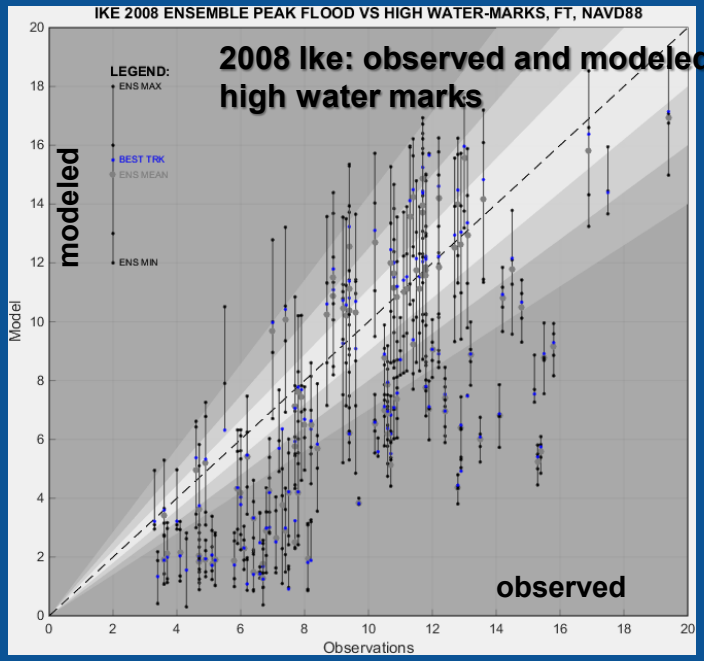
- GFS 13-km forcing
- 24-hr nowcast + 180-hr forecast
- Will provide live boundary conditions for regional wave models
- Water levels at 4 CO-OPS tide gauges and 40+ populated islands and warning points

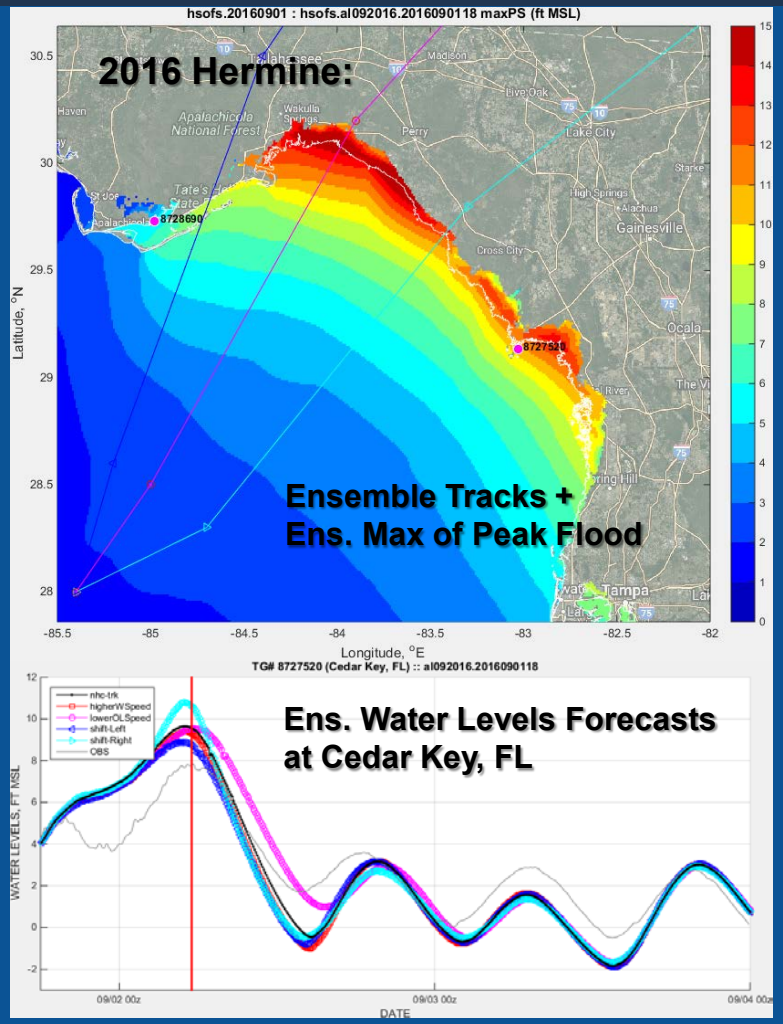
Hurricane Surge On-Demand Forecasting System (HSOFS)

- Implemented for ESTOFS-ATL domain
- 2-year testing phase with NWS National Hurricane Center
- Augments existing SLOSH/P-Surge capabilities with a high-fidelity estimates near landfall, or in post-event hindcasts
- Provides uncertainty estimates of NHC Best Track product

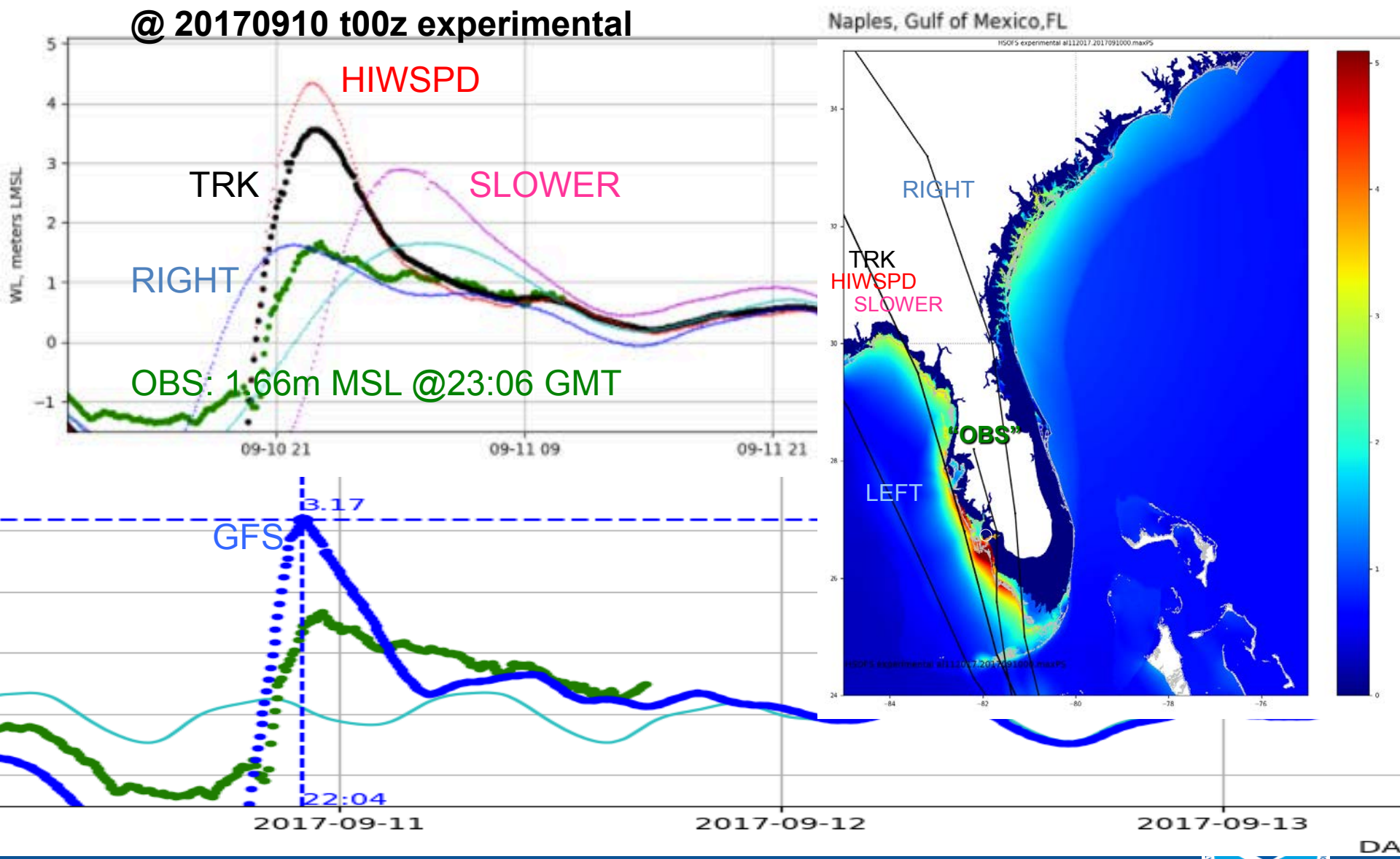
5 ensemble members

- NHC Track + 20% Higher Max Wind Speed + 20% Lower Overland Speed + 100% Shift Left of the Uncertainty Cone + 100% Shift Right of the Uncertainty Cone.





On-Demand Ensemble Modeling



Integral Water Level Prediction

TOTAL WATER LEVEL =	
Tides +	
Waves +	wave setup, wave runup, wave breaking
Storm Surge +	wind-driven, pressure-driven setup
Freshwater Input +	river inflow, controlled release, precip, …
Steric Setup +	local + remote seasonal density variations
Ocean Circulation +	mesoscale eddy intrusion, coastal jets
Sea Level Rise	historical change in vertical datum

- *Non-linear interactions between all major components*
- *Dynamical coupling required*
- *Model errors due to missing physics*
- *Model errors can be minimized by data assimilation*

Surge/Wave Coupling

Framework

COASTAL (The Consumer Option for an Alternative System to Allocate Losses) Act
https://www.weather.gov/sti/coastalact

- Lower the cost to FEMA's National Flood Insurance Program (NFIP)
- Better distinguish between wind- and water damage
- For every named storm, provide the best possible reanalysis/hindcast

Technology:

In leu of NOAA's Unified Modeling Approach, utilize

- the National Unified Operational Prediction Capability (NUOPC)
- couple ADCIRC and WaveWatch III
- Flexible mechanism for adding/changing/upgrading the coupled models/modules
- Independent dev cycles for coupled components
- Allows easier transition of the coupled systems into operations in the future

COASTAL Act Modeling Partners:

Andre van der Westhuysen, Ali Abdolali, Jessica Meixner, Anil Kumar, Zaizong Ma, …

National Unified Operational Prediction Capability (NUOPC) Layer

NUOPC Layer interoperability rules are implemented using a set of generic components that represent the major structural pieces needed to build coupled models.

NUOPC Generic Components

Driver	Harness that initializes components according to an *Initialization Phase Definition*, and drives their Run() methods according to a customizable run sequence.
Connector	Implements field matching based on standard metadata and executes simple transforms (e.g. grid remapping, redistribution). It can be plugged into a generic Driver component to connect Models and/or Mediators.
Model	Wraps model code so it is suitable to be plugged into a generic Driver component.
Mediator	Wraps custom coupling code (flux calculations, averaging, etc.) so it is suitable to be plugged into a generic Driver component.

Theurich et al. 2016

NOAA Environmental Modeling System (NEMS) Infrastructure

ATM	atmosphere	GSM (Global Spectral Model), NMMB (Non-hydrostatic multiscale model on the B-grid)
OCN	ocean	MOM5 (Modular Ocean Model), HYCOM (Hybrid Coordinate Ocean Model
WAV	wave	WWIII (WAVEWATCH III)
ICE	sea ice	CICE (Los Alamos Sea Ice Model) KISS (Keeping Ice's Simplicity)
HYD	hydrology	WRF-Hydro (Weather Research and Forecast Model Hydrology)
LND	land	LIS (Land Information System)
AER	aerosol or chemistry	GOCART (Goddard Chemistry Aerosol Radiation and Transport)
IPM	ionosphere plasmasphere	IPE (Ionosphere-Plasmasphere Electrodynamics Model)
CST	coast	ADCIRC (Advanced Circulation)

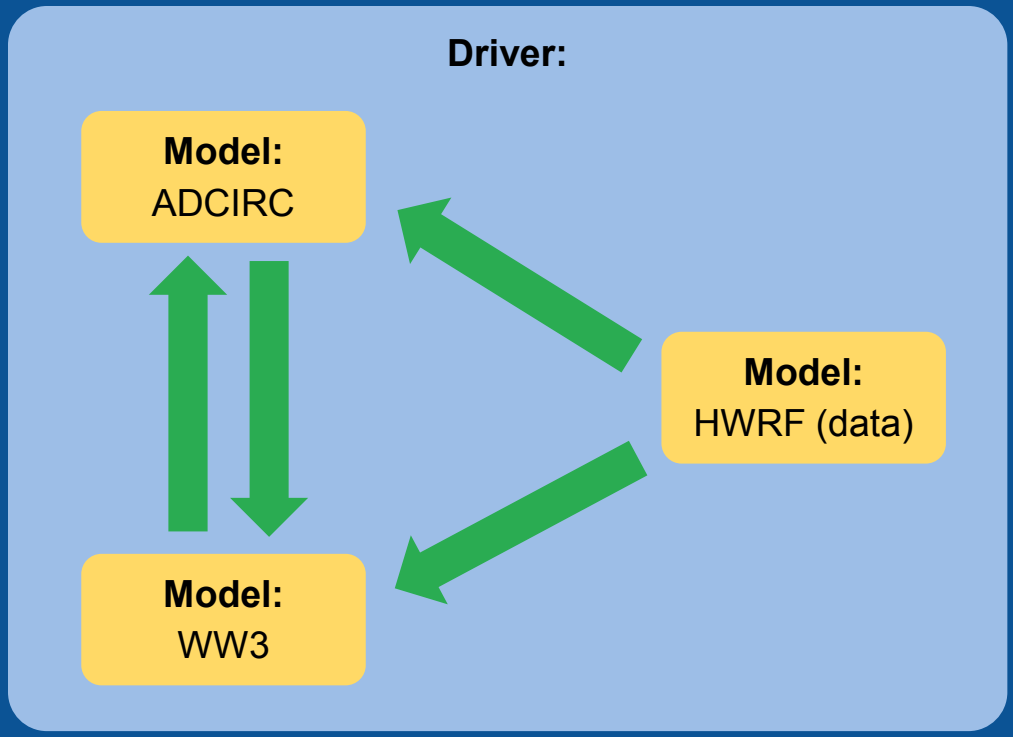
NEMS (NUOPC/ESMF) Applications

Application	ATM	OCN	WAV	ICE	HYD	LND	AER	IPM	CST
CMAQ Air Quality	NMMB						PM2.5		
Coastal			WWIII						ADCIRC
HYCOM-GSM-CICE	GSM	HYCOM		CICE					
Regional Hydro	GSM	MOM5		CICE	WRF-Hydro	LIS-Noah			
Regional Nest	NMMB	HYCOM							
UGCS-Seasonal	GSM	MOM5		CICE					
UGCS-Weather									
WAM-IPE	GSM							IPE	
Wave	GSM		WWIII						

NSEModel Application

Model components

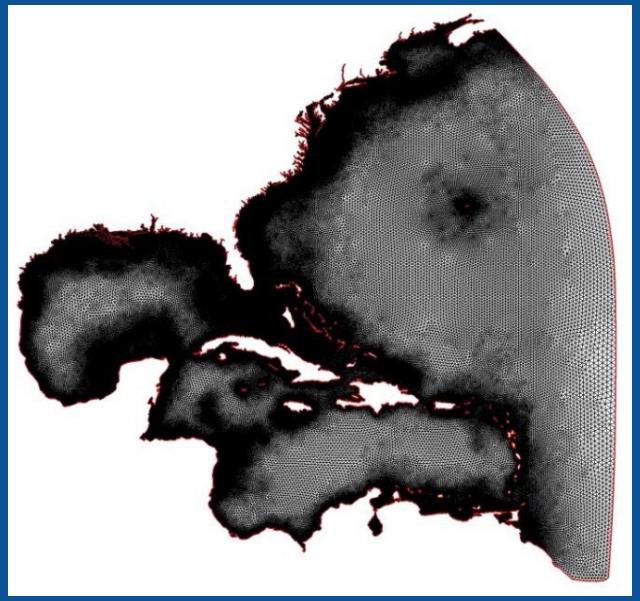
- HWRF-HYCOM-DA
- ADCIRC
- WW3



NUOPC components

ADCIRC Modifications

```
1  ##############################################
2  ####  NEMS Run-Time Configuration File  #####
3  ##############################################
4  # EARTH #
5  EARTH_component_list: ATM OCN WAV
6  EARTH_attributes::
7    Verbosity = max
8  ::
9  # ATM #
10 ATM_model:                      hwrfdata
11 ATM_petlist_bounds:             0 0
12 ATM_attributes::
13   Verbosity = max
14 ::
15 # OCN #
16 OCN_model:                      adcirc
17 OCN_petlist_bounds:             1 4
18 OCN_attributes::
19   Verbosity = max
20 ::
21 # WAV #
22 WAV_model:                      ww3data
23 WAV_petlist_bounds:             5 5
24 WAV_attributes::
25   Verbosity = max
26 ::
27 # Run Sequence #
28 runSeq::
29   @3600.0
30     ATM -> OCN
31     WAV -> OCN
32     ATM
33     WAV
34     OCN
35   @
36 ::
```



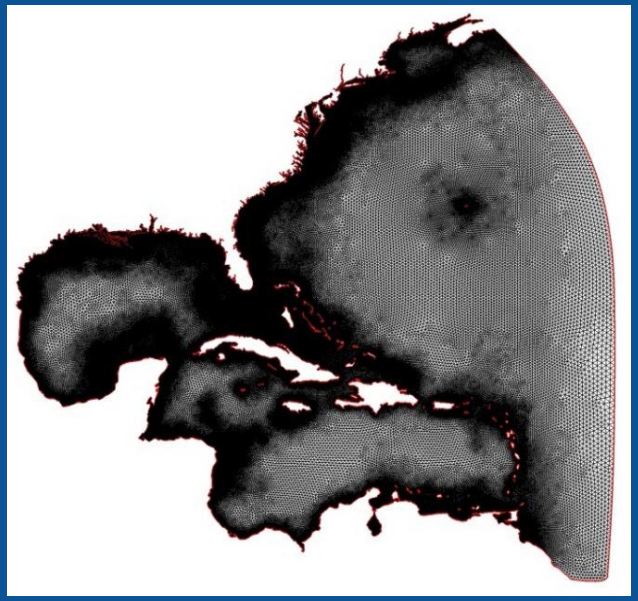
Hurricane Surge On-Demand Forecast System (HSOFS) grid coverage

New fort.15 variables:

- HWRF coupling: NWS=17
- WW3 coupling: NRS=5

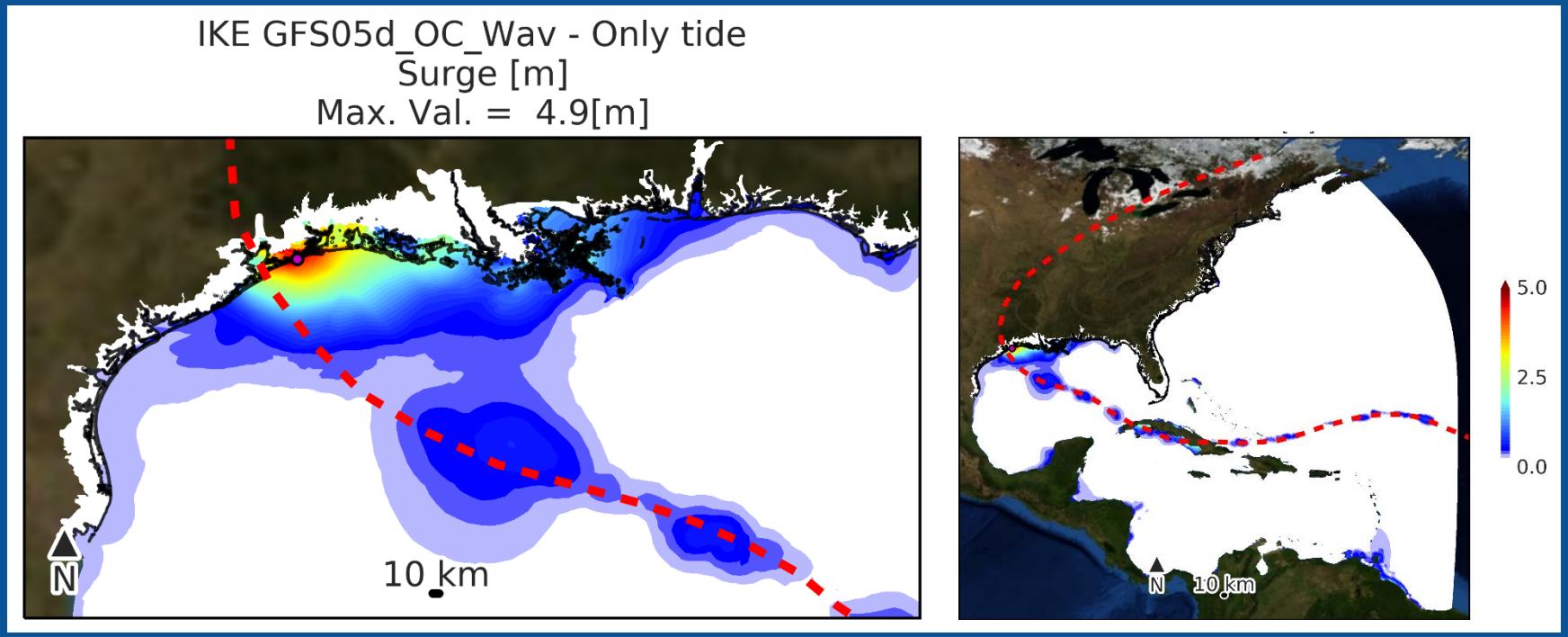
- IKE_HWRF_GFS05d_HSOFS
- IKE_HWRF_GFS05d_OC_DA_HSOFS
- IKE_HWRF_GFS05d_OC_HSOFS
- IKE_HWRF_GFS1d_HSOFS
- IKE_HWRF_GFS25d_HSOFS

- Downscaling

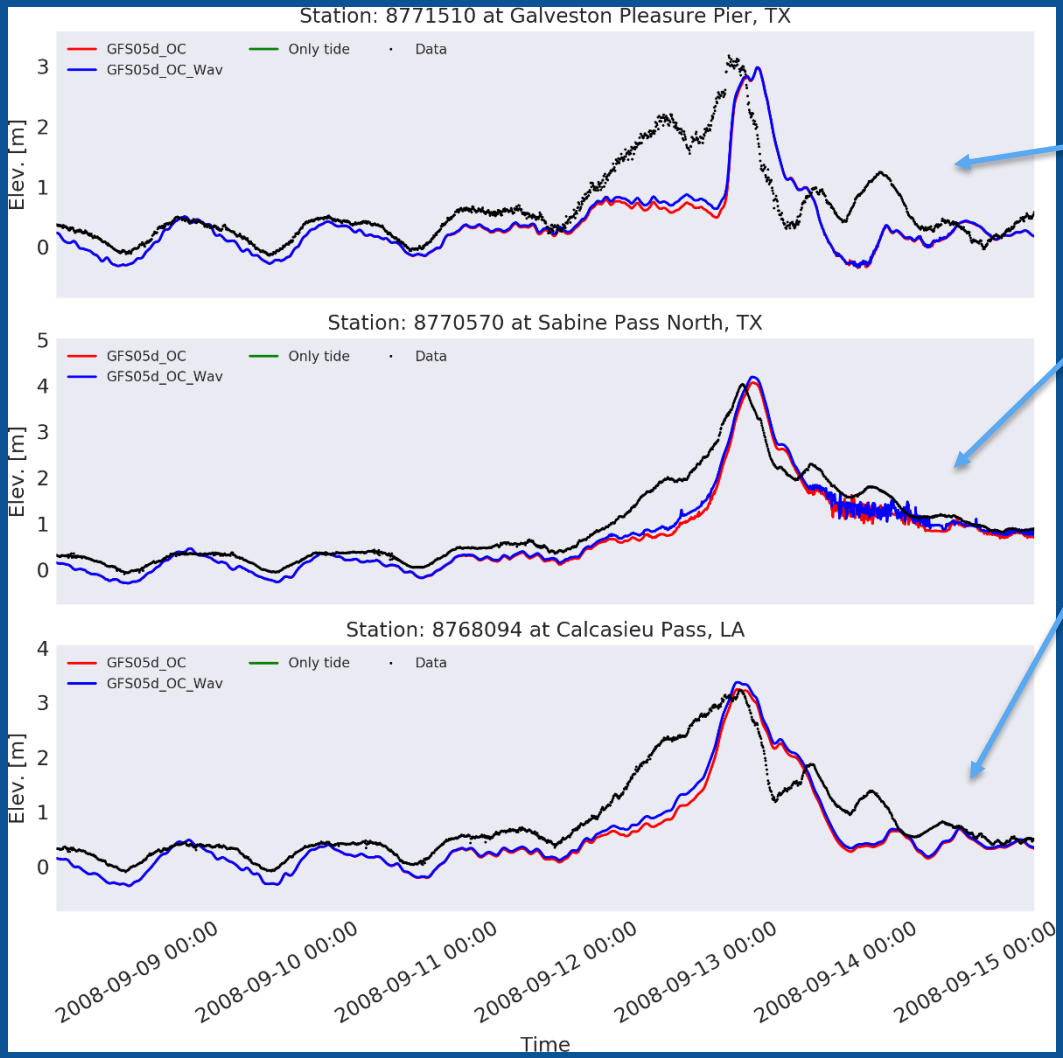


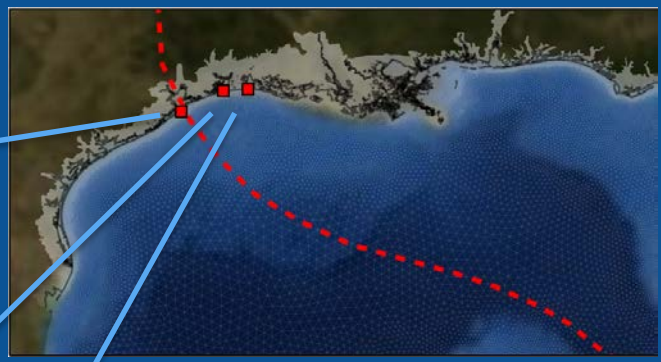
Hurricane 2008 Ike

Total surge + wave setup (detided)



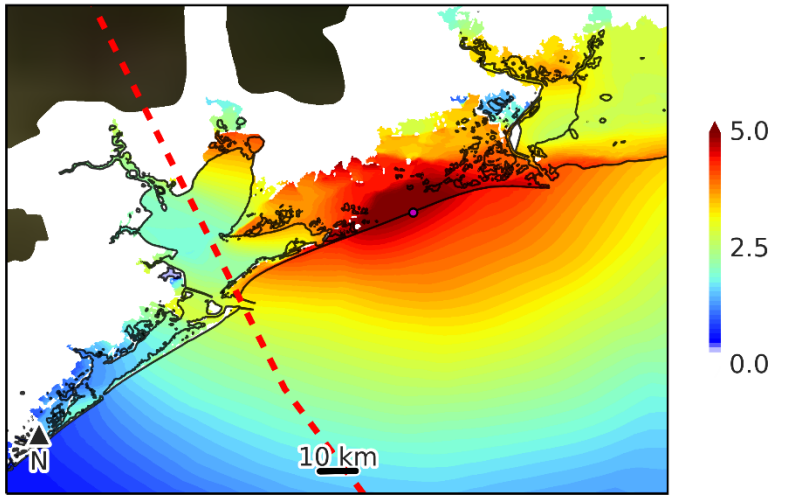
Hurricane 2008 Ike



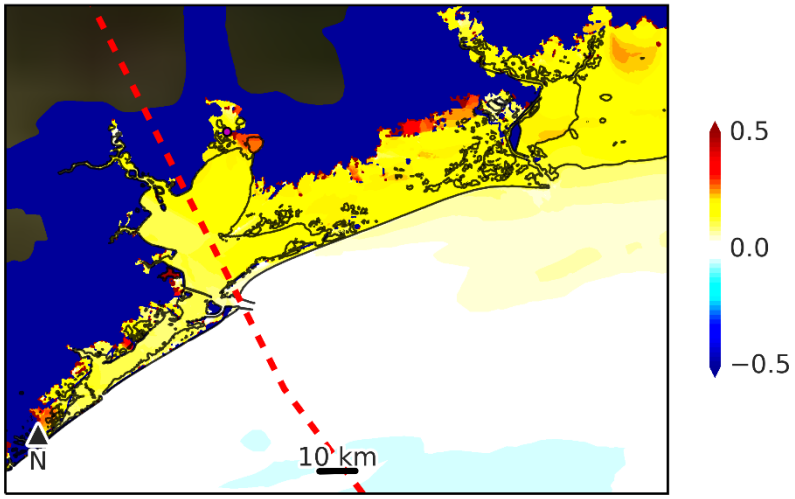


Hurricane 2008 Ike

Total surge

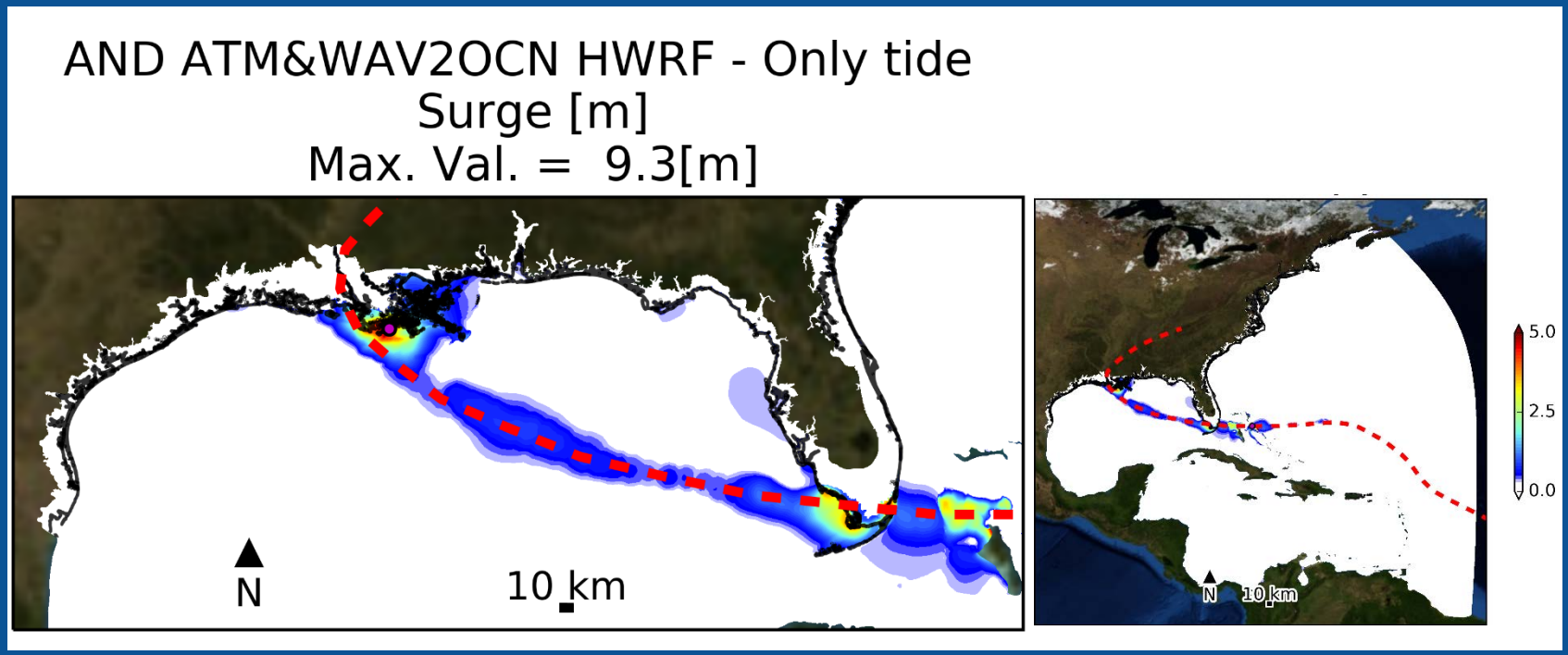


Wave-setup



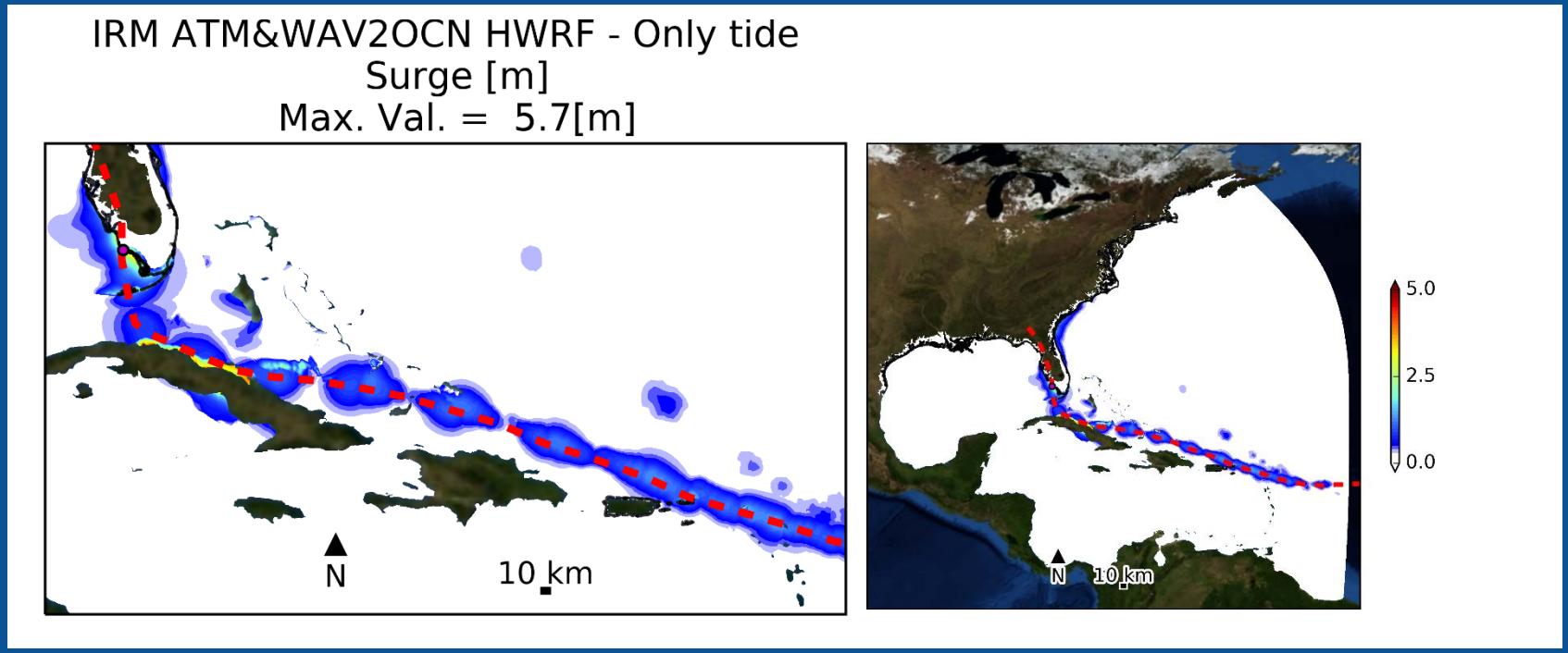
Hurricane 1992 Andrew

Total surge and wave setup (detided)

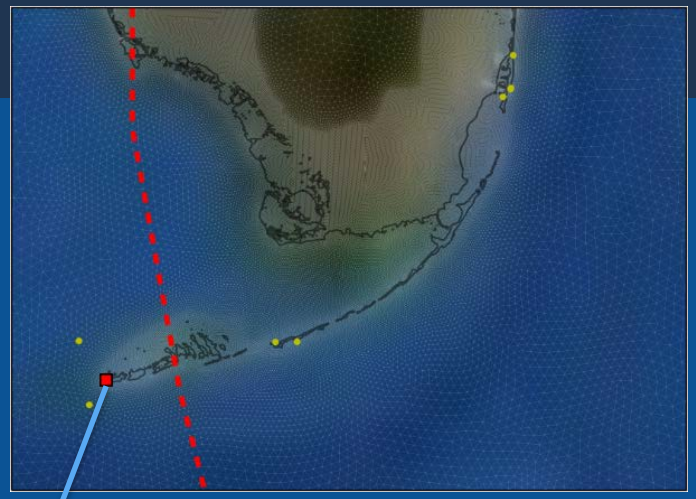


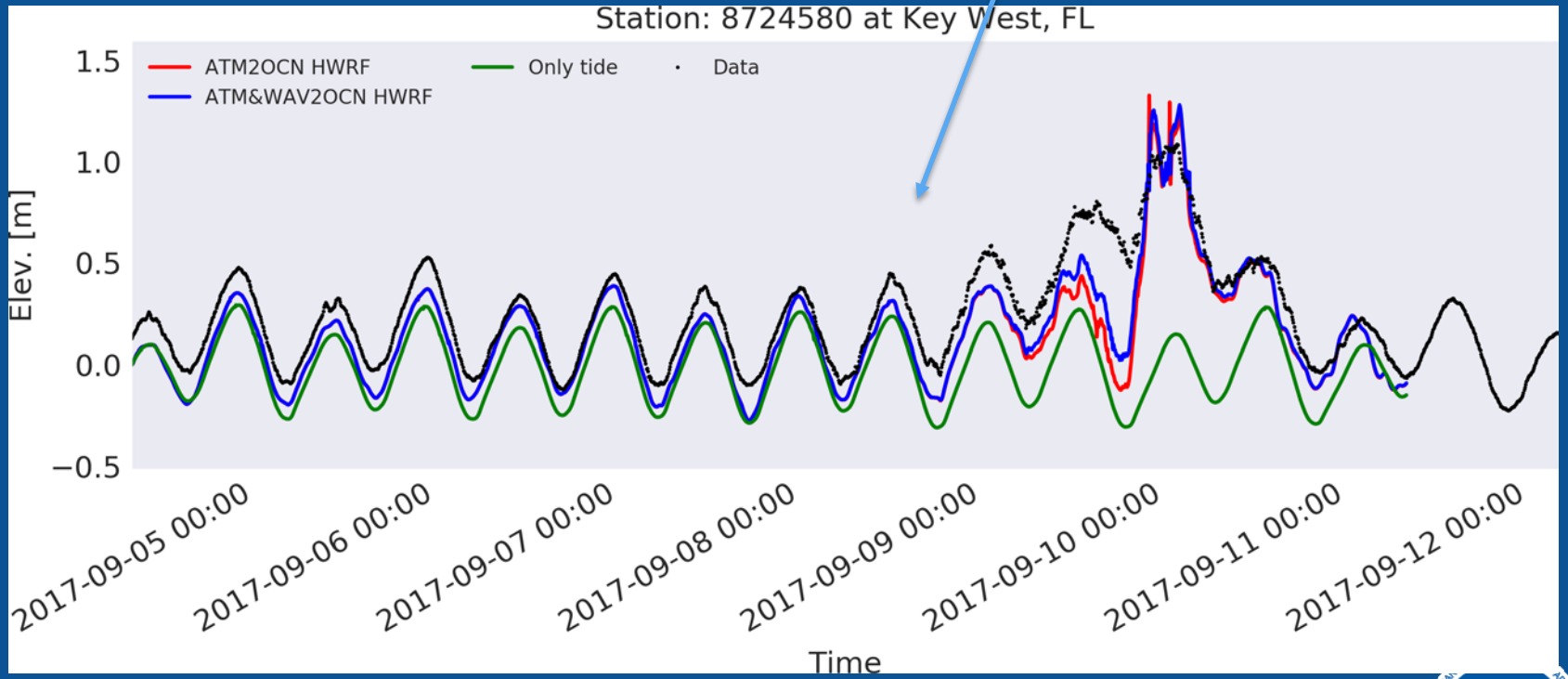
Hurricane 2017 Irma

Total surge and wave setup (detided)



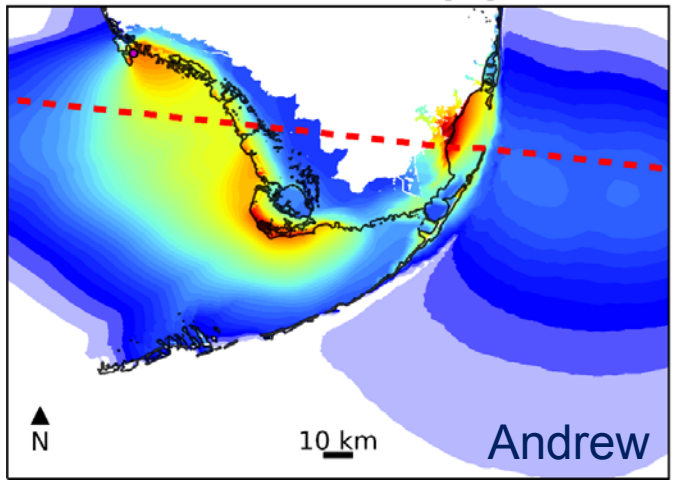
Hurricane 2017 Irma

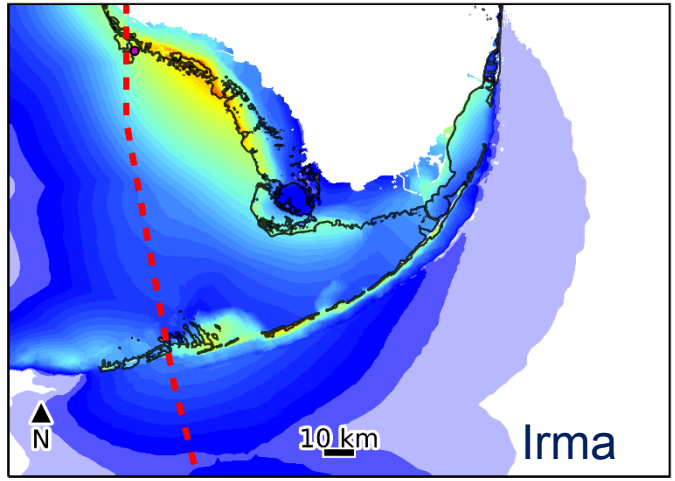


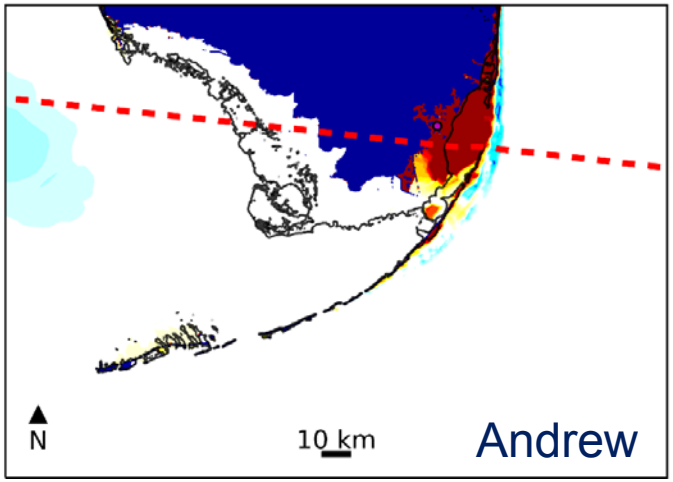


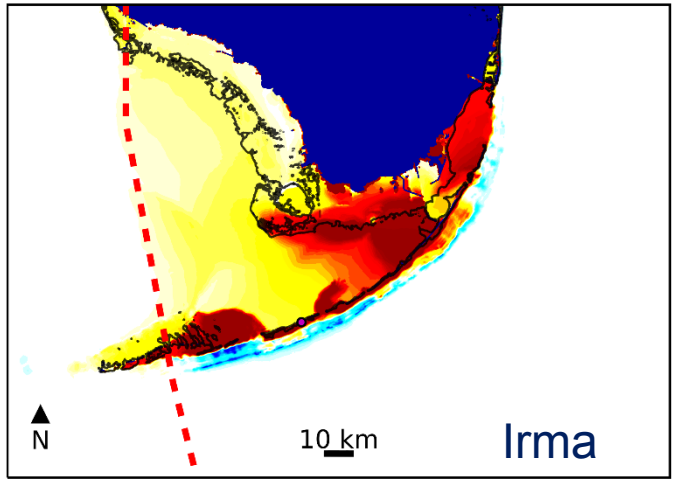
Total surge

Wave-setup









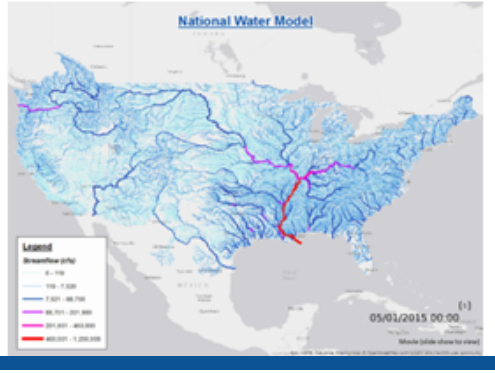
Compound Flooding

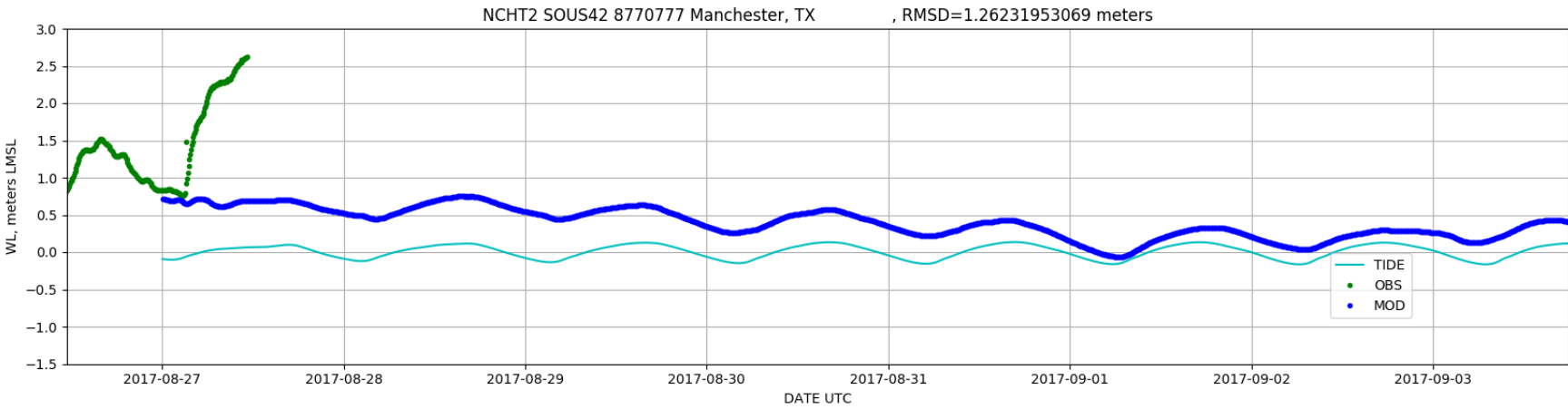
2017 Harvey:
- Freshwater flooding

Current River Forecast Points (~3,600)

+

NWM Streamflow Output Points (~2.7 mil)



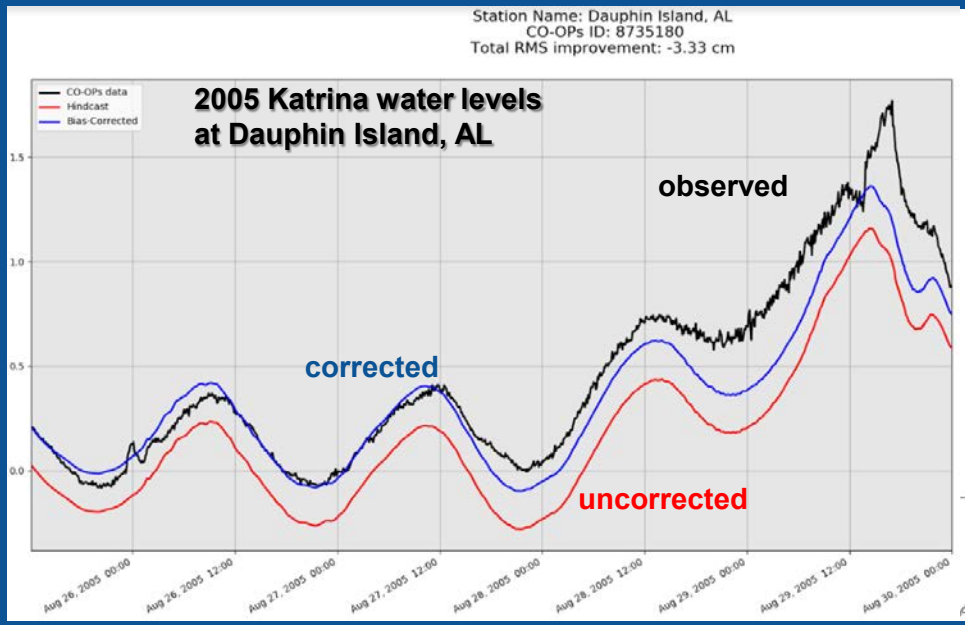


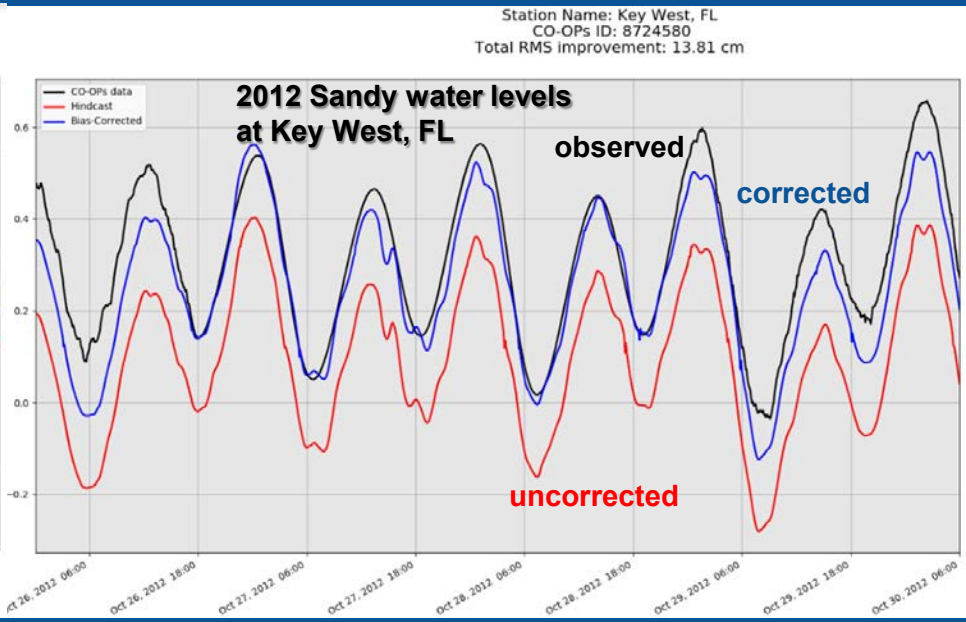
- Integrate with National Water Model to provide two-way coupling
- Precipitation + river inflow + surge upstream propagation
- Office of Water Prediction coordinating the effort
- Several solutions exist, need a feasibility study, e.g. model testbed

Assimilation of Coastal Water Levels

Improving the Forecast – Linear biases and Data Assimilation

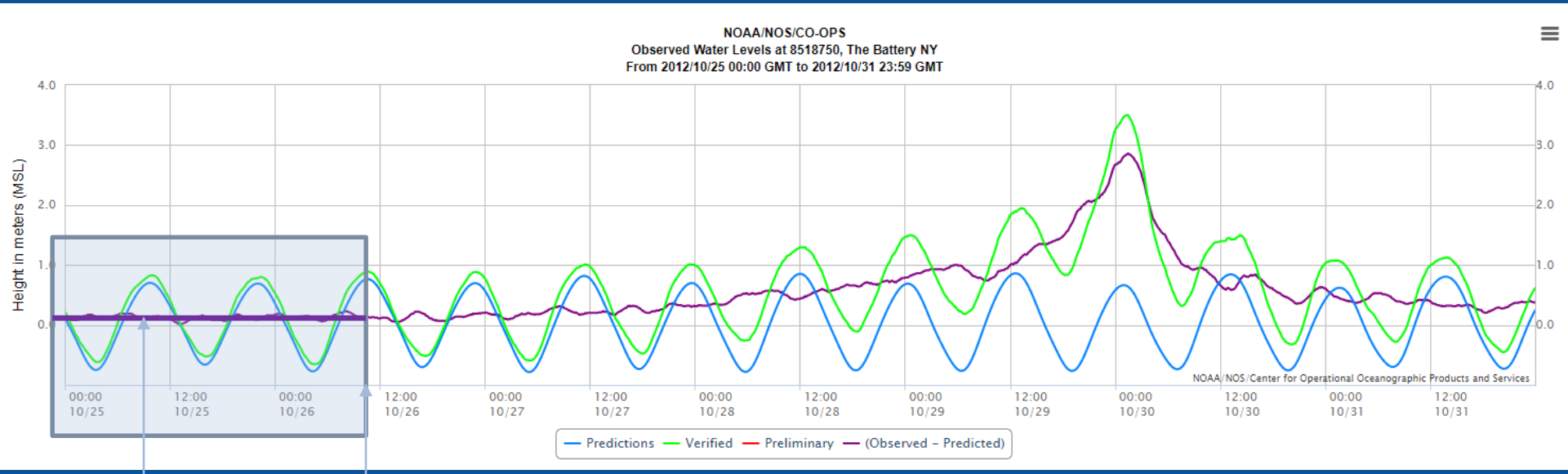
- Modeled water levels are biased w.r.t observations
- Unresolved physics include seasonal steric signal, wind setup, HF weather events…
- Post-corrections do not properly reflect changes in inland flooding
- Initial water level offsets for a dynamically-consistent correction can be computed from the coastal observations





Assimilation of Coastal Water Levels

Improving the Forecast – Linear biases and Data Assimilation

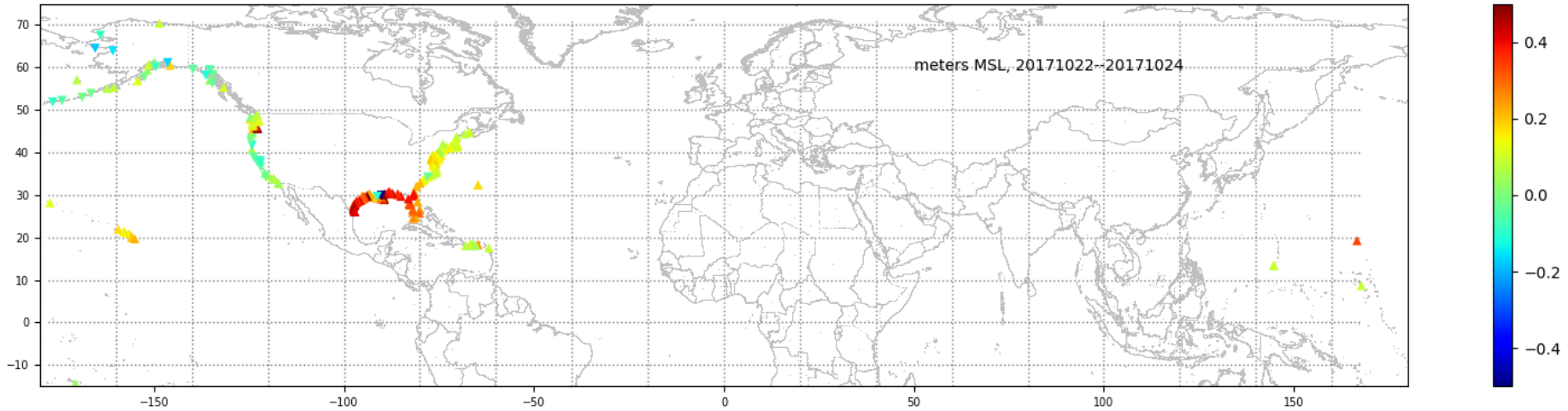


Start of the model hindcast/forecast

Time-mean setup = (WL OBS – Tides) = Initial correction wrt MSL

Assimilation of Coastal Water Levels

Improving the Forecast – Linear biases and Data Assimilation



Time mean WL setup at coastal tide gauges over the last 3 days.

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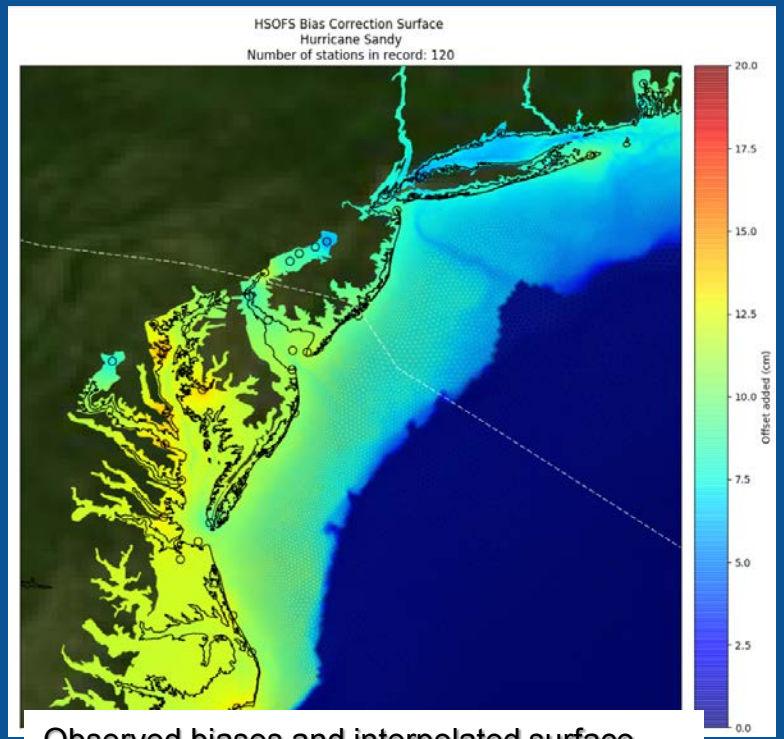

Observed biases and interpolated surface
Pre-2012 Sandy

- ADCIRC v52 can now introduce spatially-varying WL offsets that are persistent throughout the whole period of model run
- This option is implemented as an additional 'pseudo-pressure load' term
- Offsets can vary with time
- Offsets need to be specified at each grid node
- *User can manually add/remove/edit data points to improve the offset regionally*
- Sparse data interpolation to unstructured grid
- Tapering offshore values to zero ~f(depth)
- Tapering wrt data location
- Data assimilation of coastal WL observations
  - Can be applied to other kinds of data as well
- Will consider this option for all NOS OFS

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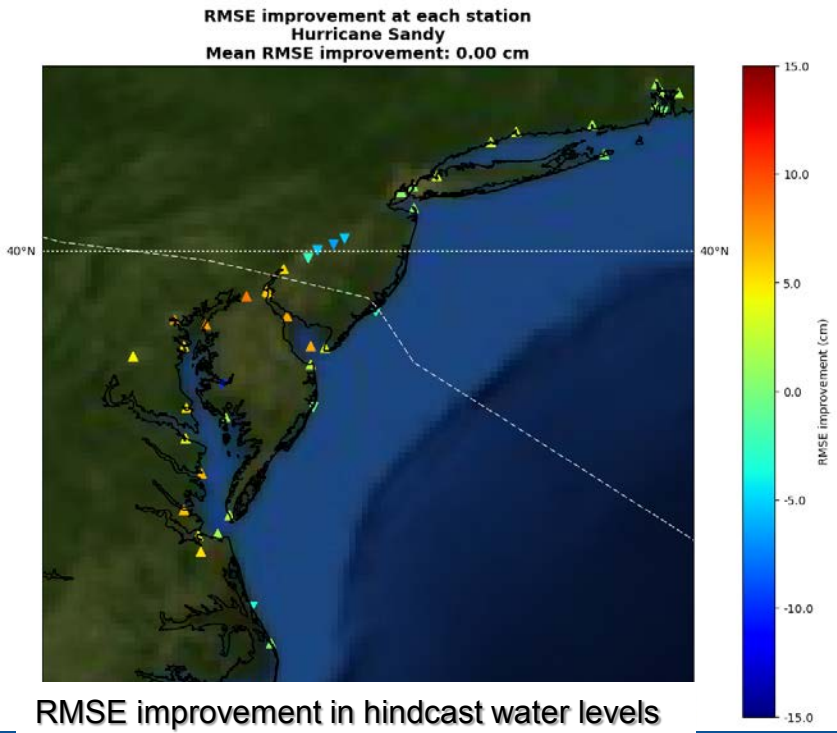
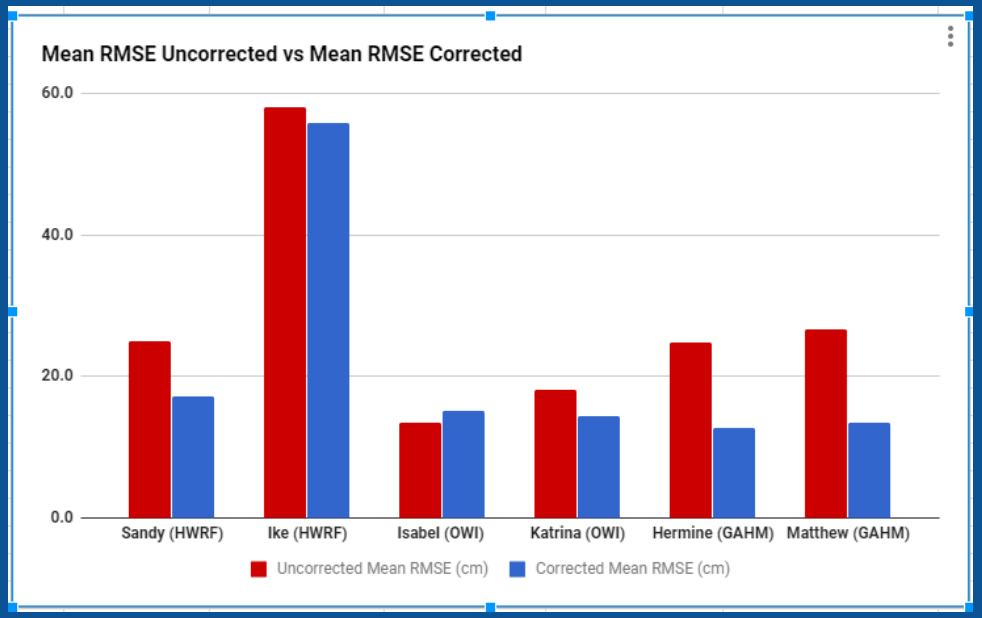
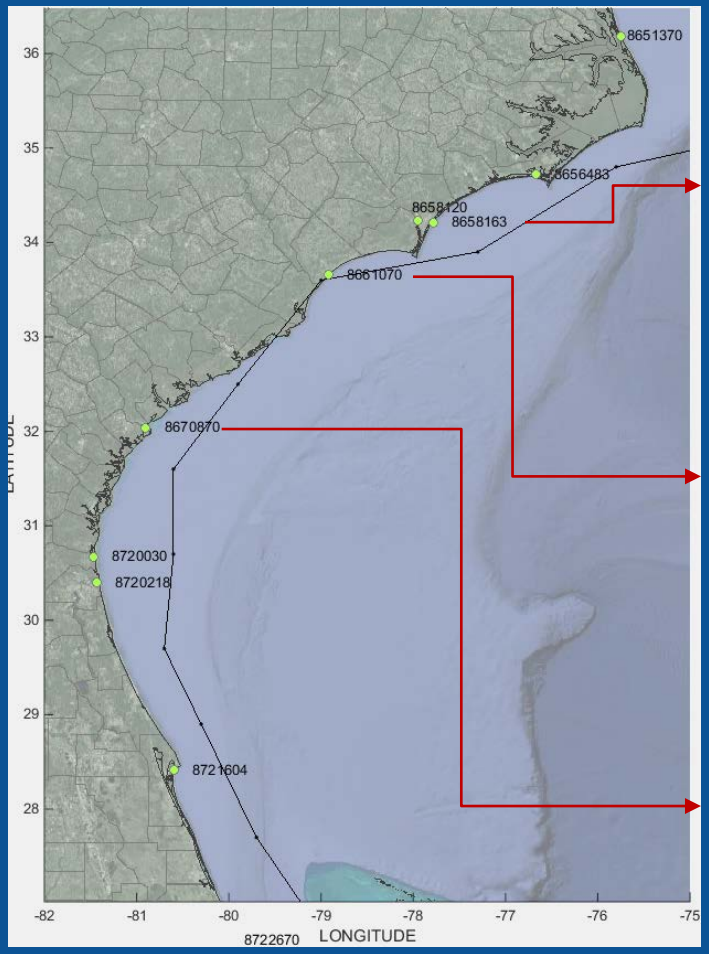


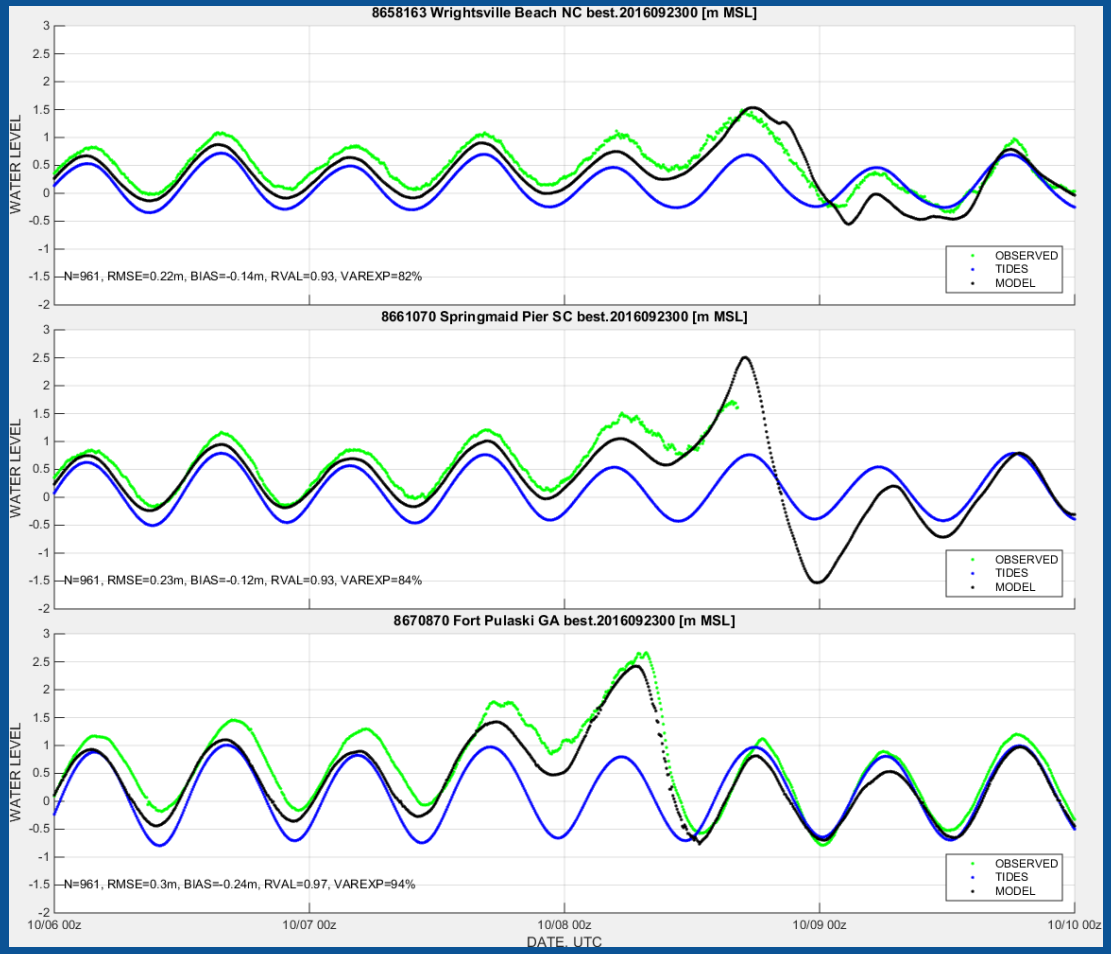
RMSE improvement in hindcast water levels due to bias correction.



Operational Forecast and Hindcast Model Skill Assessment



Selected CO-OPS tide gauges



Observed (green), predicted (blue) and modeled (black) water levels, meters MSL.

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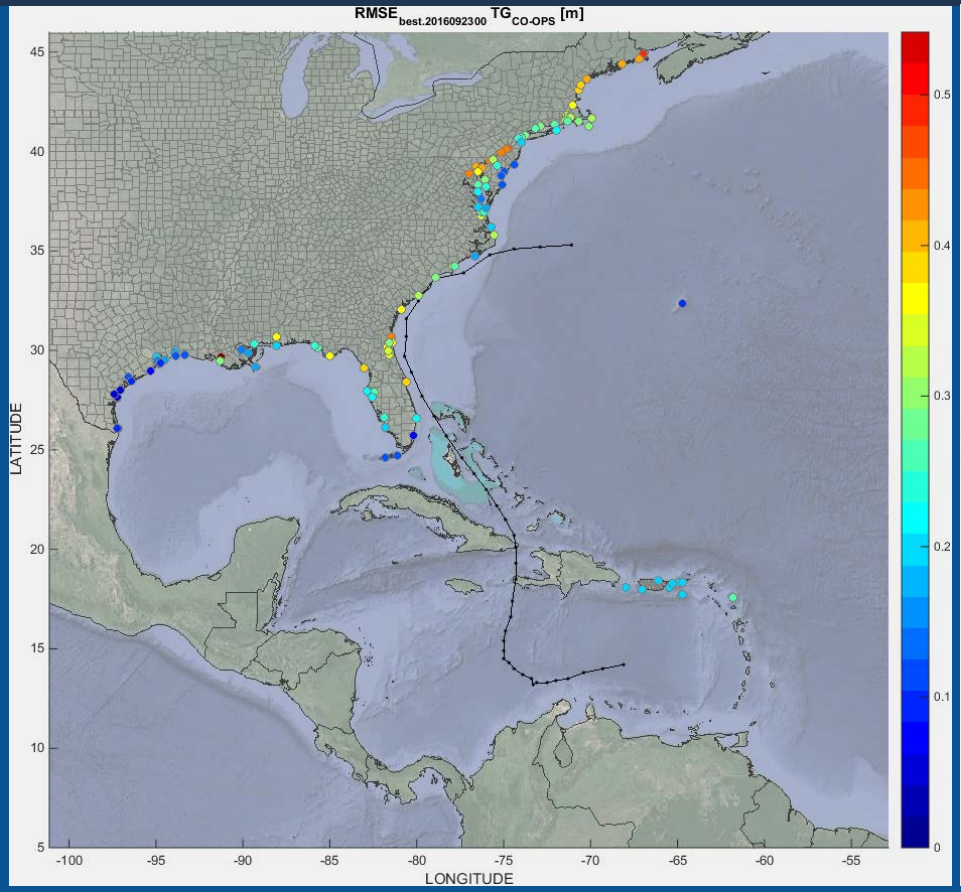
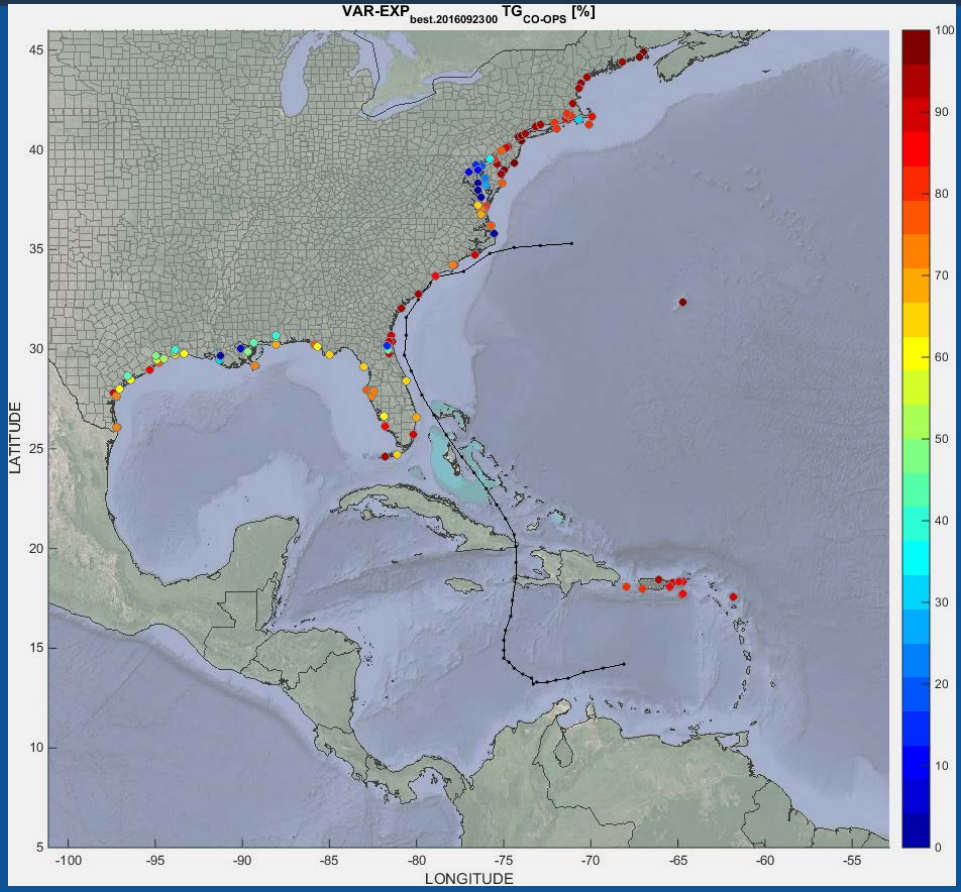
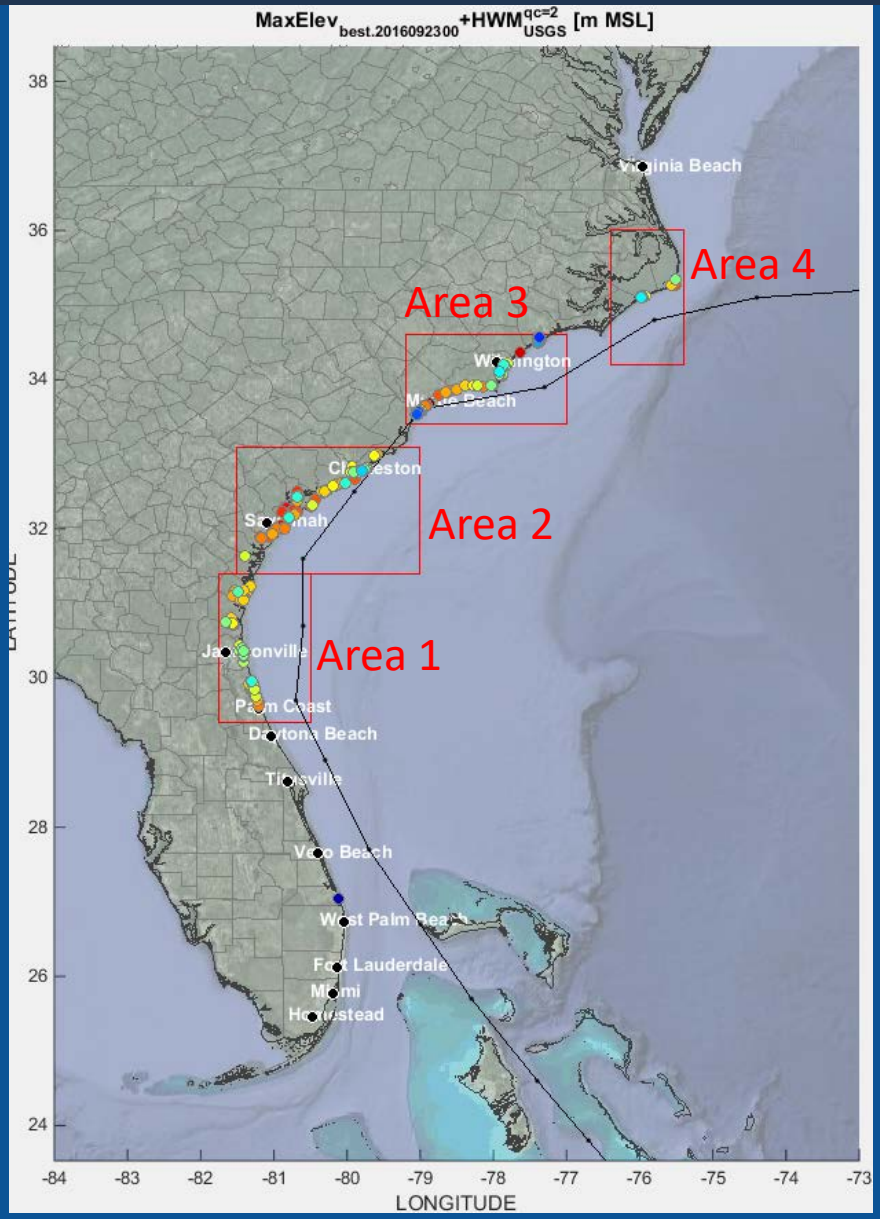


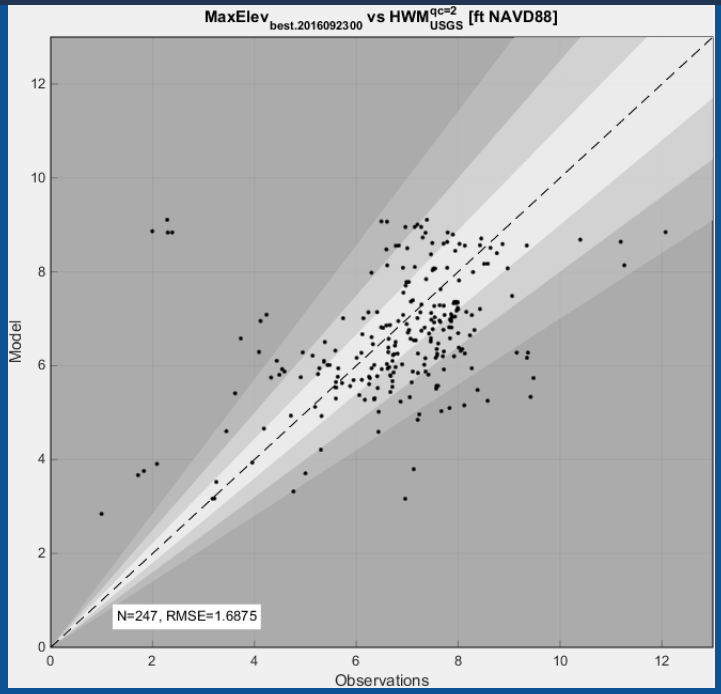
Values of RMS errors, in meters, plotted at locations of CO-OPS tide gauges.



Values of variance in data that is explained by the model (a measure of coherence), in %, plotted at locations of CO-OPS tide gauges.

Operational Forecast and Hindcast Model Skill Assessment

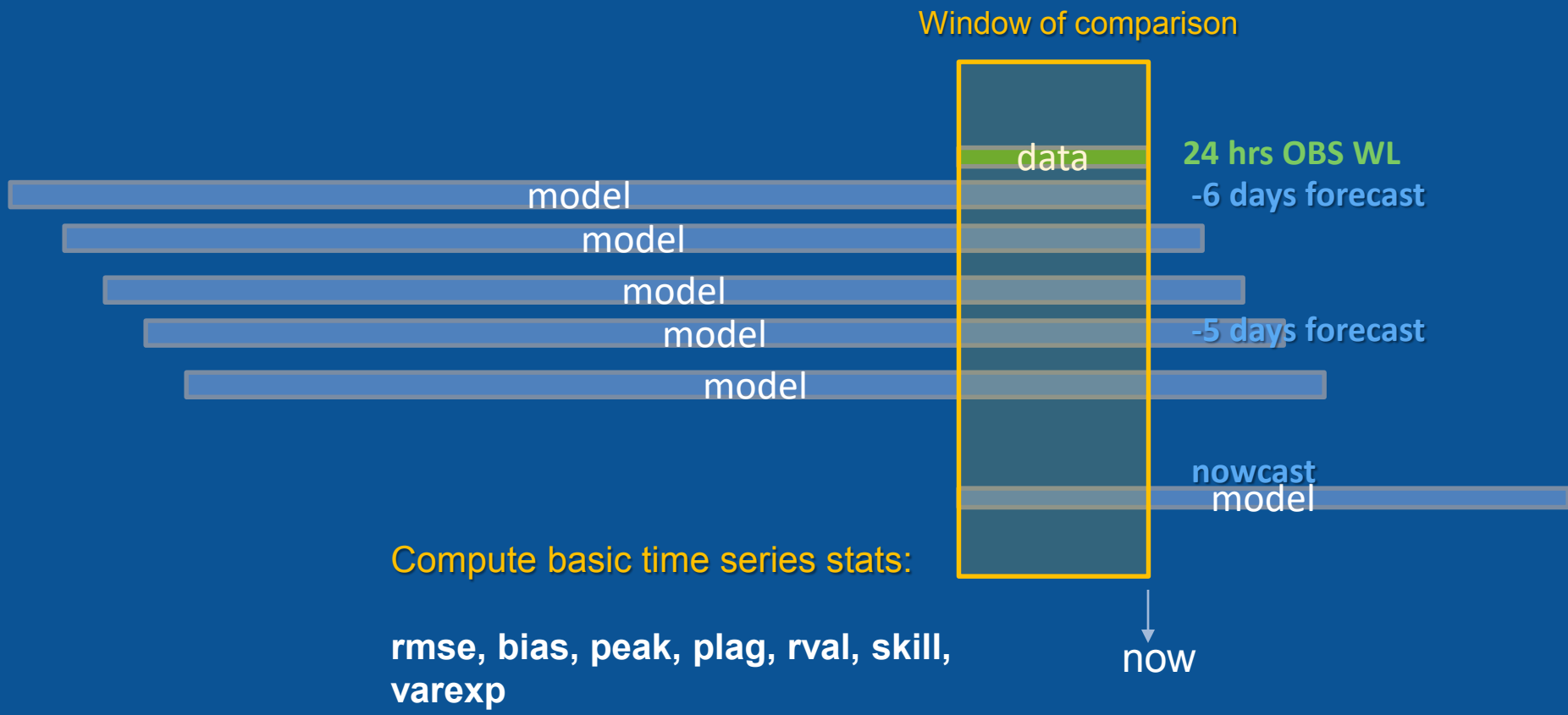




Modeled peak surge vs HWM data, feet NAVD88.
Dashed line is 1:1 fit. Shades of gray show areas of 0-10%, 10-20%, 20-30%, 30%+ errors.

Four areas corresponding to HWM data clusters have been selected and analyzed separately.

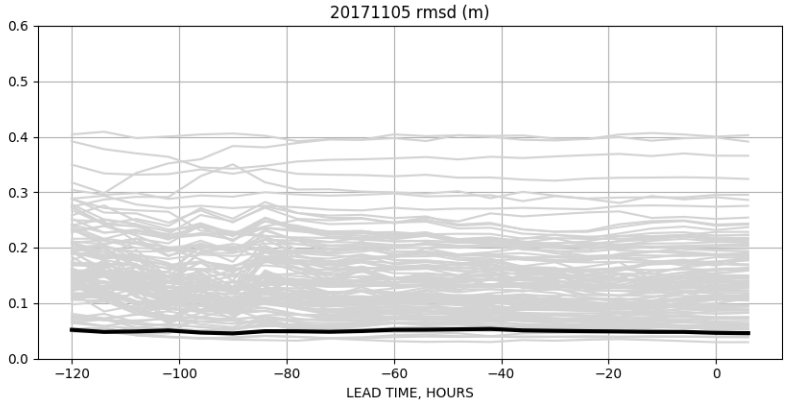
Operational Forecast and Hindcast Model Skill Assessment

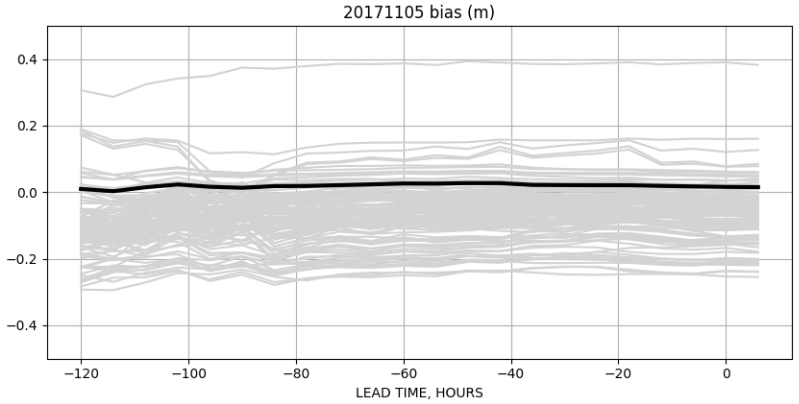


Compute basic time series stats:

rmse, bias, peak, plag, rval, skill, varexp

Operational Forecast and Hindcast Model Skill Assessment





Skill of atm. forcing → Skill of ocean response

- Quantitative forcing inter-comparison
- Quantitative surge model inter-comparison
- Determining the applicability
- Determining the best lead times for on-demand applications

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