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

Operational Storm Surge Forecast Systems Development at the United States National Ocean Service

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Storm Surge Modeling Systems Development

- ADCIRC -- **AD**vanced **CIRC**ulation Model for Oceanic, Coastal and Estuarine Waters (Luettich and Westerink, 1991)
- Non-linear interaction between tides and storm surge
- Inland flooding and inundation
- High-performance parallel computing environment
- High-resolution unstructured computational grids
- Gridded or parametric atmospheric forcing
- Ensemble forecasting capabilities
- Coupled systems development

ADCIRC unstructured model mesh: elevations and bathymetry around Nantucket Island (HSOFS grid)
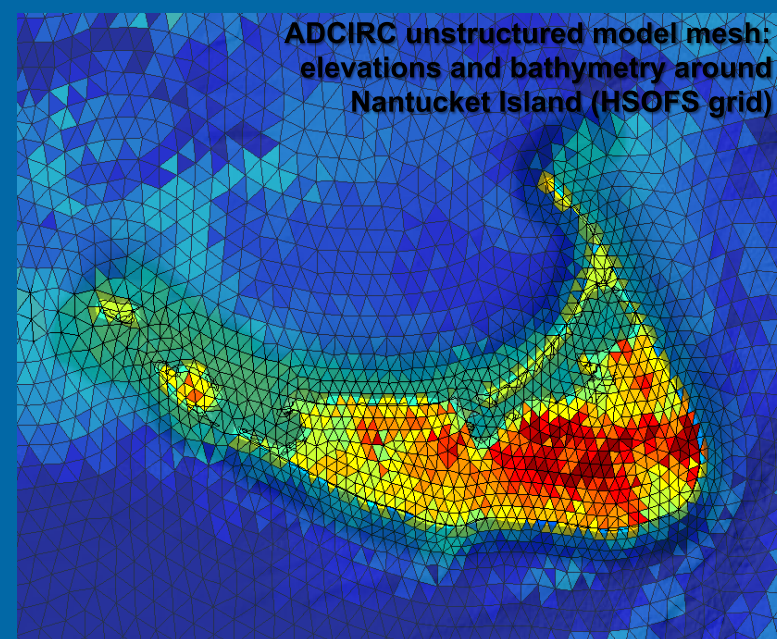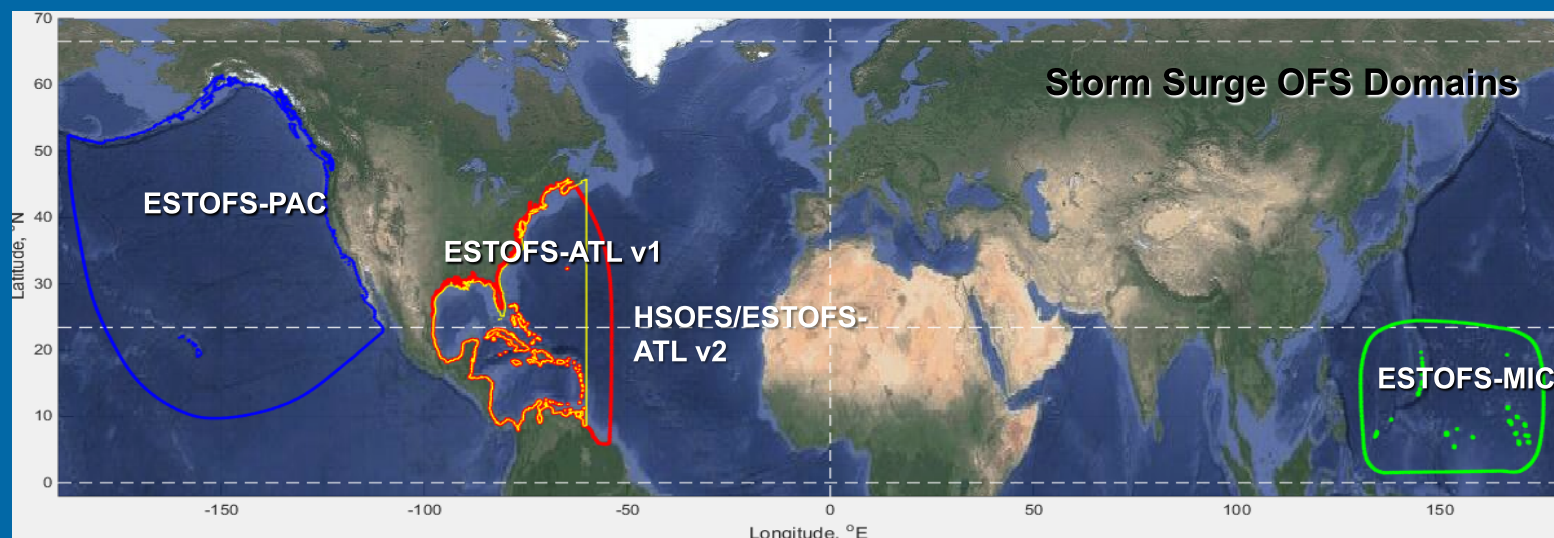
Model Skill Assessment and Validation

- Model error estimates relative to the observed water levels
- Hindcast validation against post-event data

Operational Support

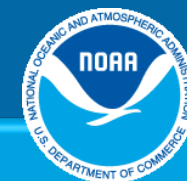- Real-time graphics output and validation during major events

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

Storm Surge Model Guidance Systems

Storm Surge OFS Domains

ESTOFS-PAC

ESTOFS-ATL v1

HSOFS/ESTOFS-ATL v2
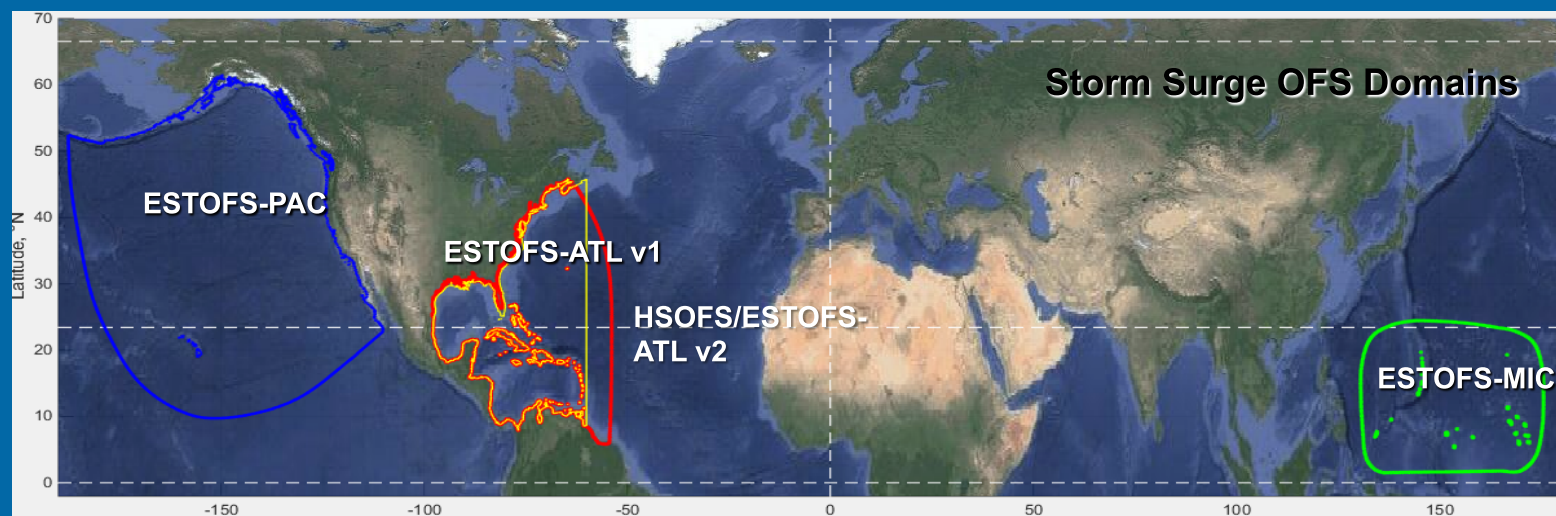
ESTOFS-MIC

| Component	ESTOFS-ATL	ESTOFS-PAC	ESTOFS-MIC	HSOFS-ATL
Grid resolution	160+ m	2+ km	500+ m	160+ m
Forcing	GFS 13km	GFS 55km	GFS 13km	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)	Planned	Yes	Yes
Live B.C. for NWPS	Yes	Yes	Planned	No
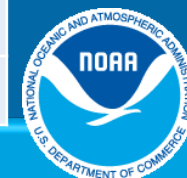
ESTOFS – Atlantic

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

Model Coverage
ESTOFS-ATL V1
ESTOFS-ATL V2

Model Grid Details
Galveston Bay, TX area
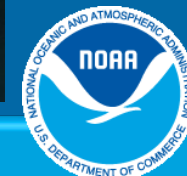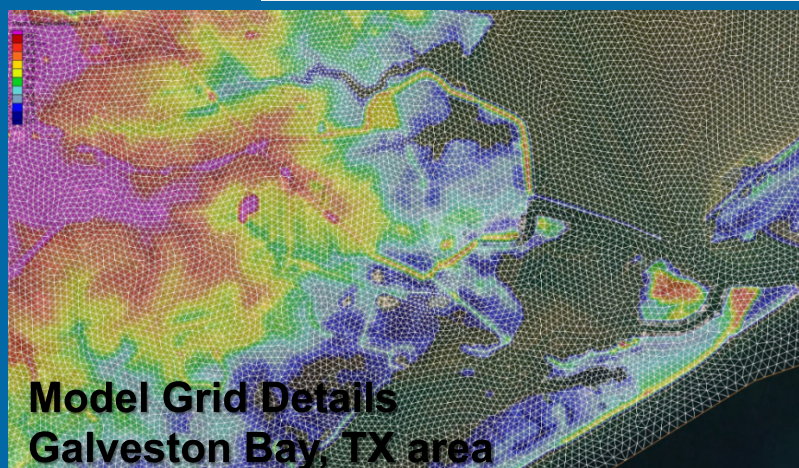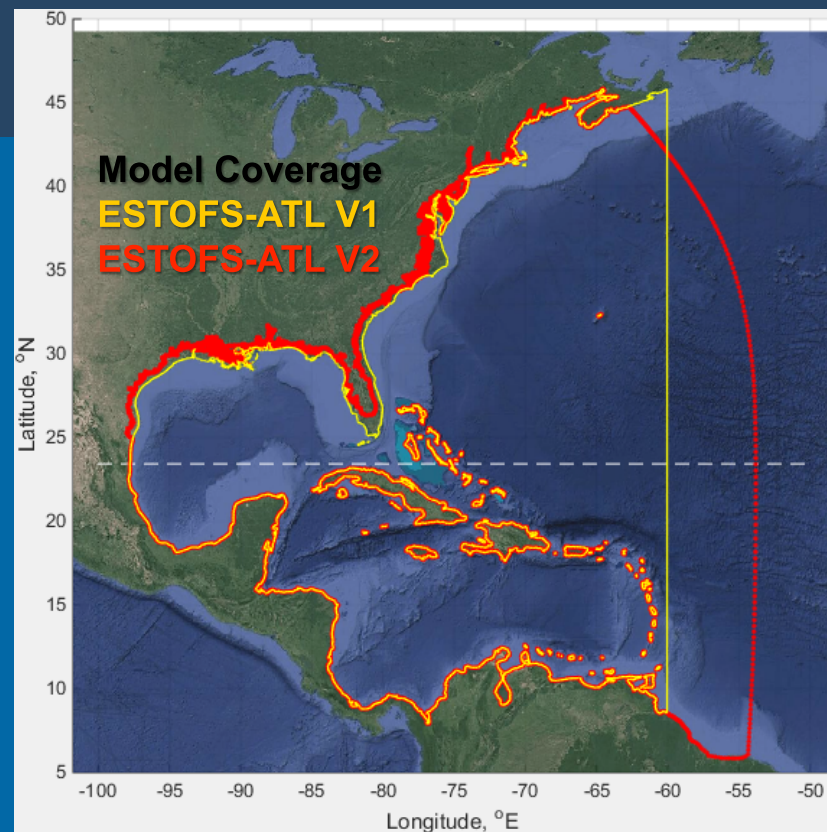
ESTOFS – Pacific

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

Model Coverage

Hawaii

Model Grid
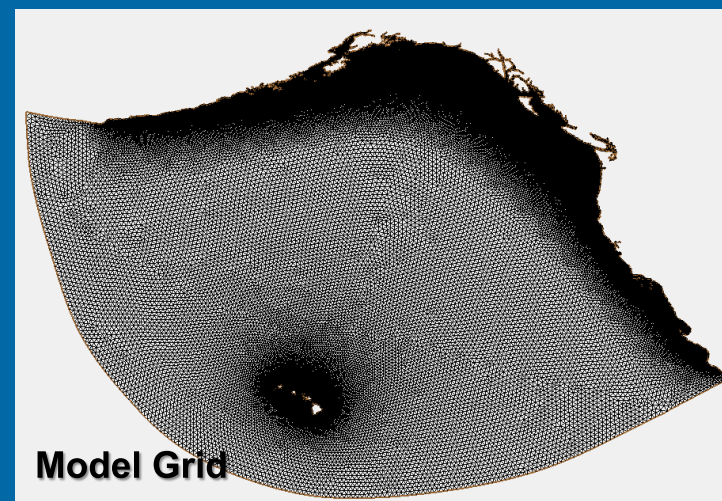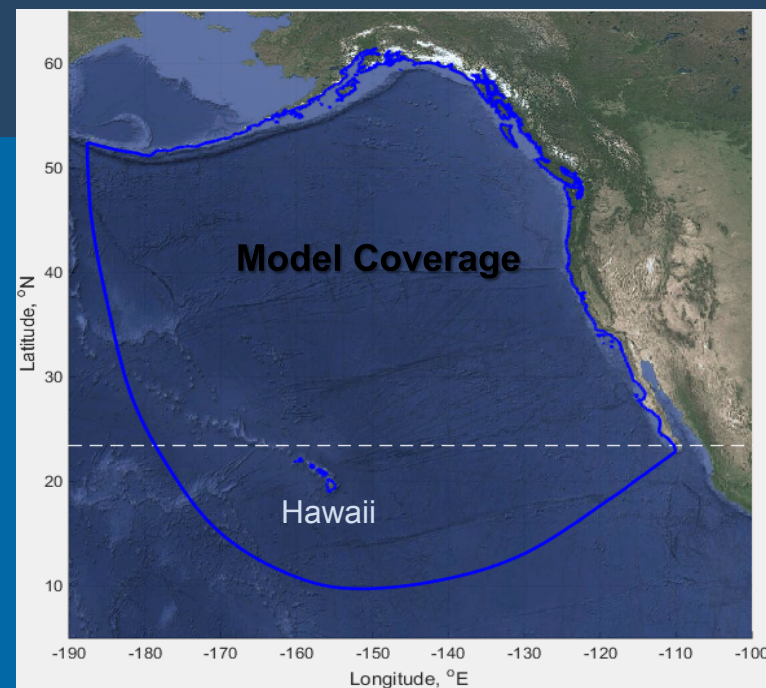
ESTOFS – Micronesia

• 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 2017

Model Coverage

Model Grid
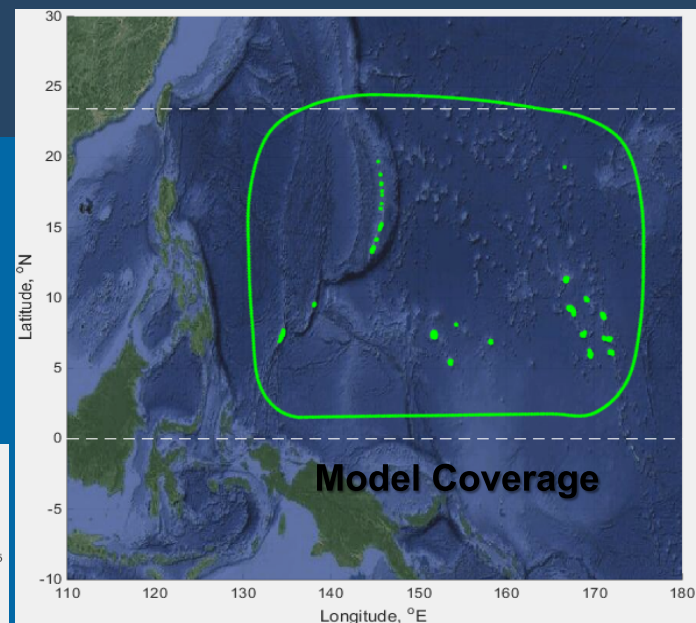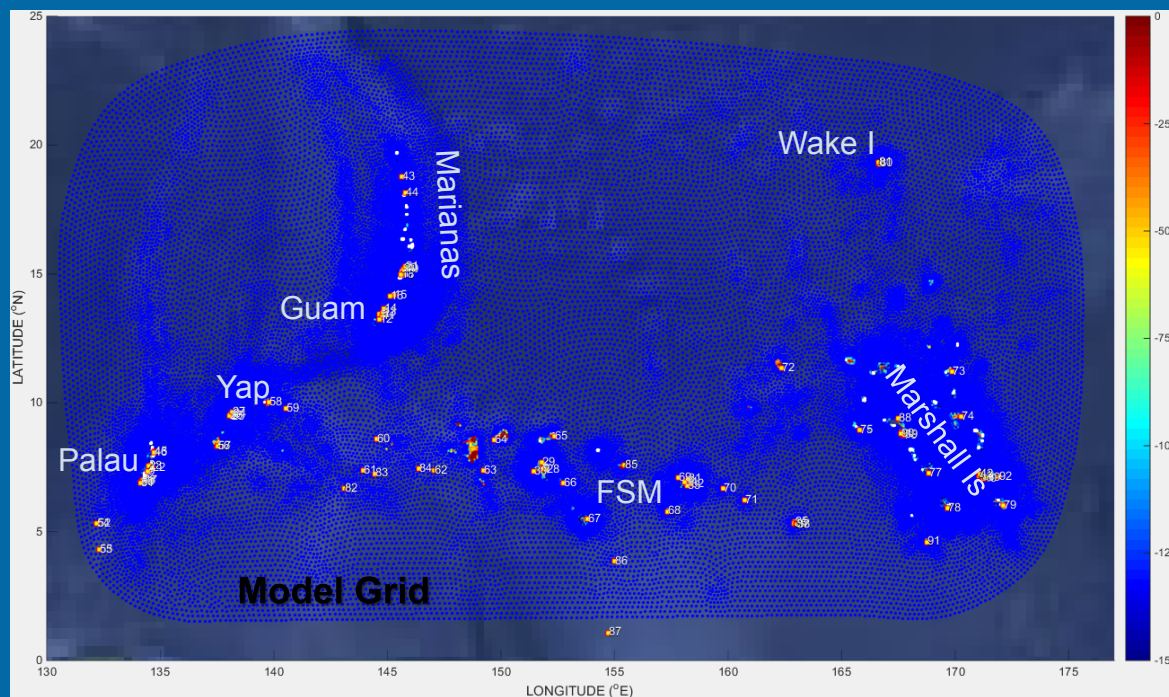
- GFS 13-km forcing
- 24-hr nowcast + 180-hr forecast
- Will provide live boundary conditions for regional wave models
- Water levels at 4 CO-OPS tide gauges and 40+ populated islands and warning points
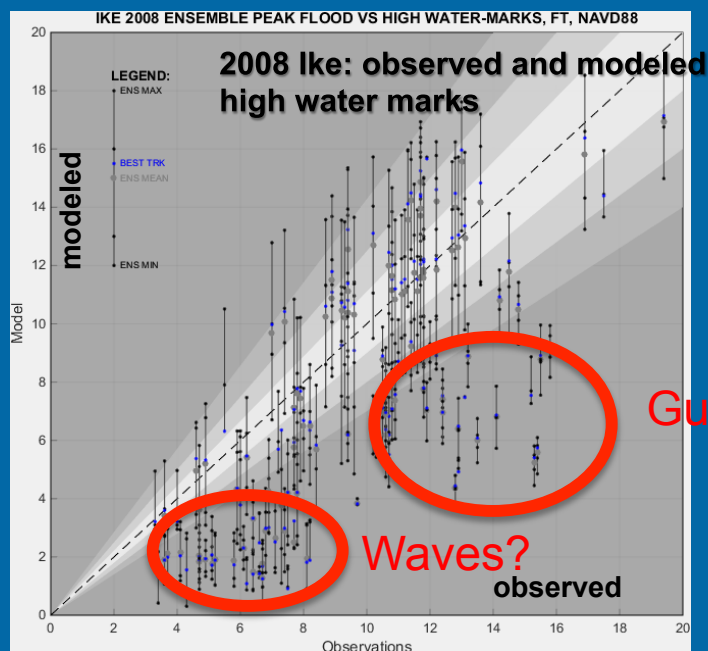
On-Demand Ensemble Modeling
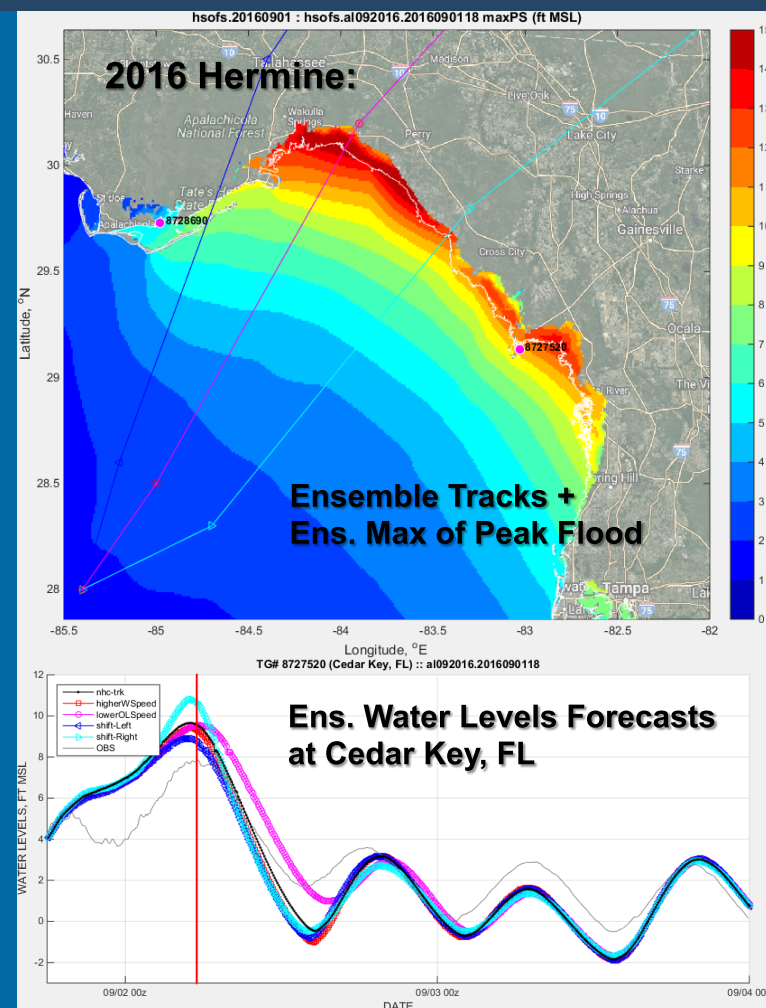
HSOFS implemented for ESTOFS-ATL domain
• 2-year testing phase with NWS National Hurricane Center
• Augments existing SLOSH/P-Surge capabilities with a high-fidelity estimates near landfall, or in post-event hindcasts
• Provides uncertainty estimates of NHC Best Track product

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.

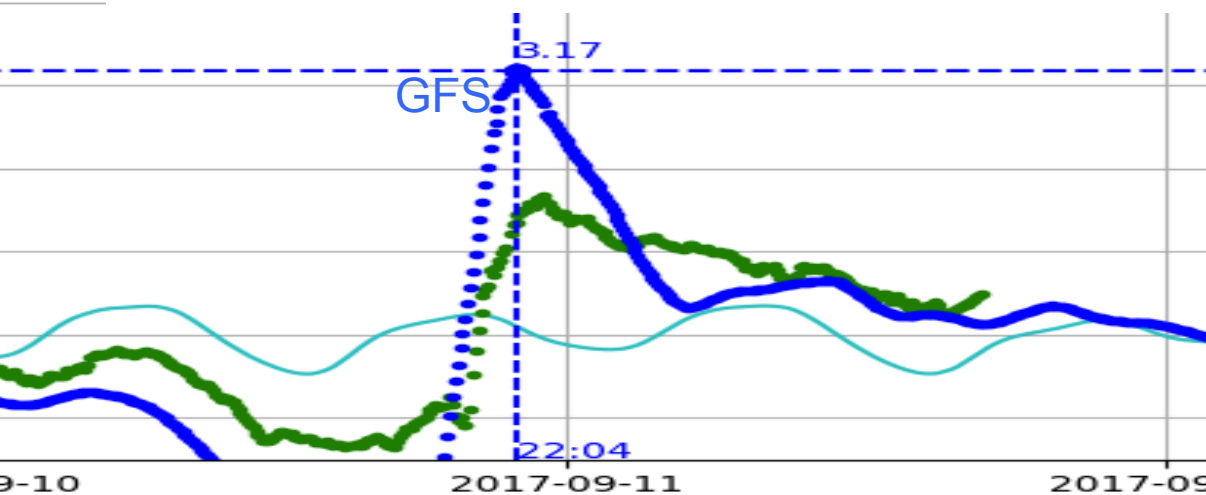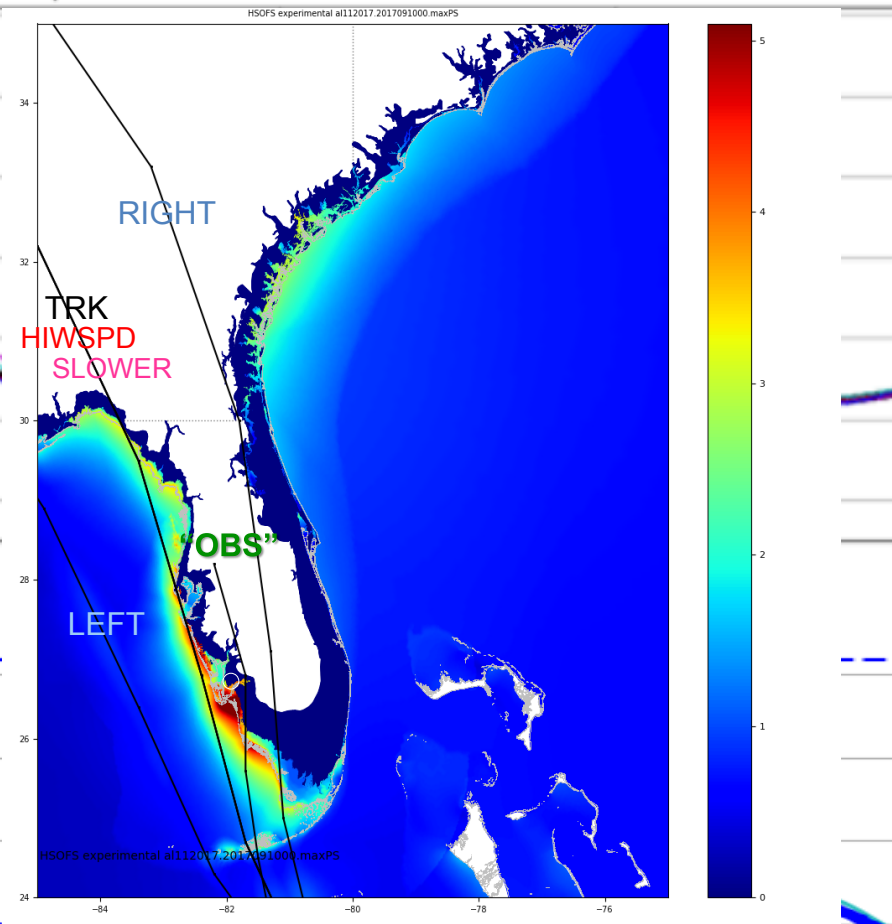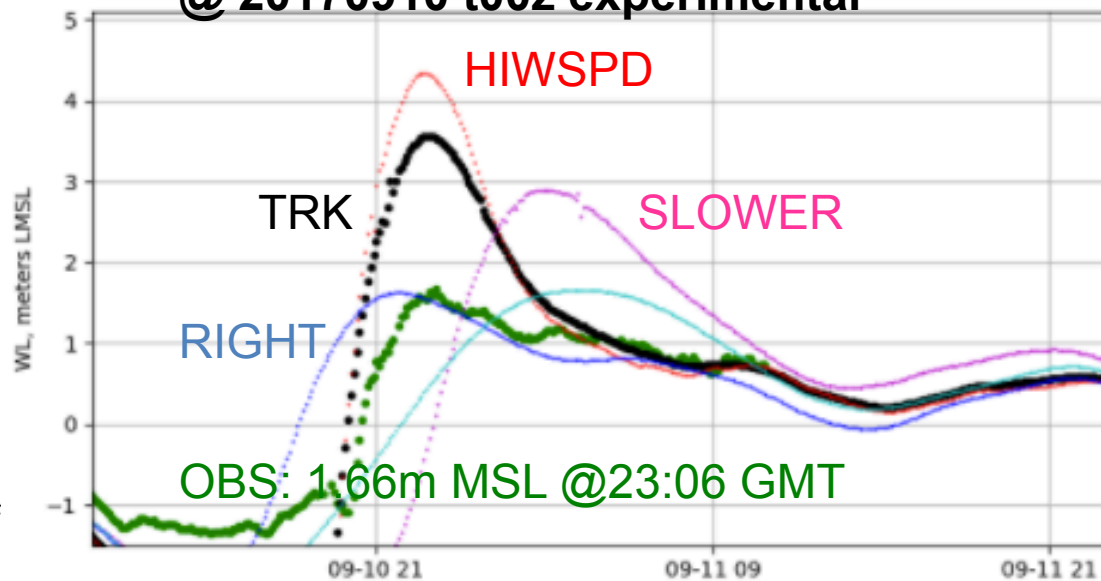**Track Uncertainty Estimates: Perturb only size and intensity**

2016 Hermine:

Ensemble Tracks + Ens. Max of Peak Flood

hsofs.20160901 : hsofs.al092016.2016090118 maxPS (ft MSL)

Ens. Water Levels Forecasts at Cedar Key, FL

TG# 8727520 (Cedar Key, FL) :: al092016.2016090118

IKE 2008 ENSEMBLE PEAK FLOOD VS HIGH WATER-MARKS, FT, NAVD88

2008 Ike: observed and modeled high water marks

LEGEND:
ENS MAX
BEST TRK
ENS MEAN
ENS MIN

Gustav?

Waves?

observed

@ 20170910 t00z experimental
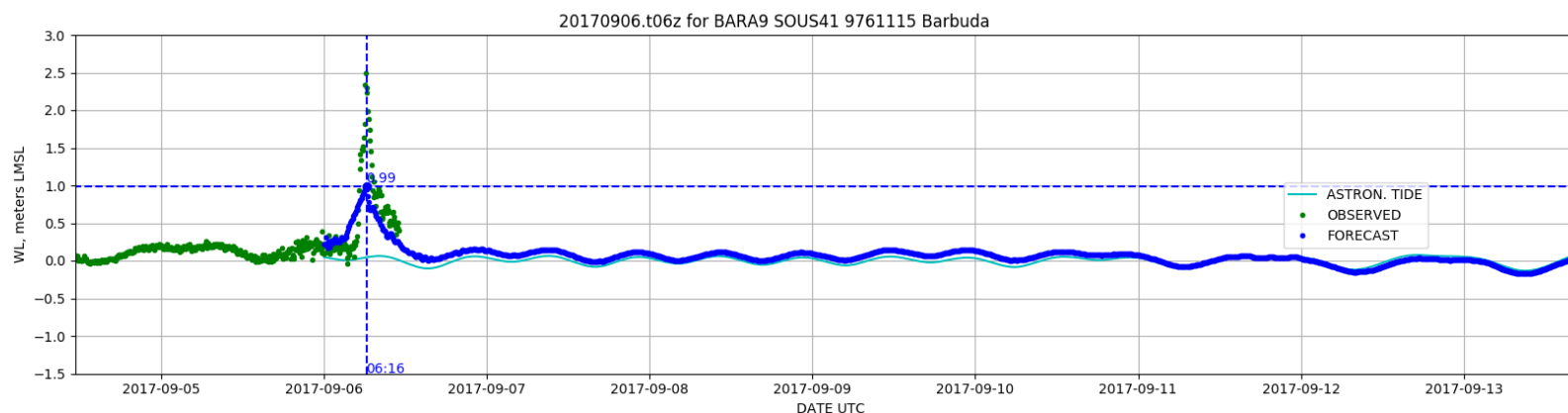
Naples, Gulf of Mexico, FL

2017 Irma in the Caribbean, Micronesia, mid-ocean islands:
• Low-resolution meshes
• Waves account for up to 70% of the WL

20170906.t06z for BARA9 SOUS41 9761115 Barbuda

Need for coupled surge/wave modeling

•NOS is leveraging COASTAL Act in collaboration with EMC/NCEP to enable coupled guidance
• Using NEMS/NUOPC in leu of NOAA's Unified Modeling approach
• Developing a NUOPC layer for ADCIRC to be coupled with WaveWatch III
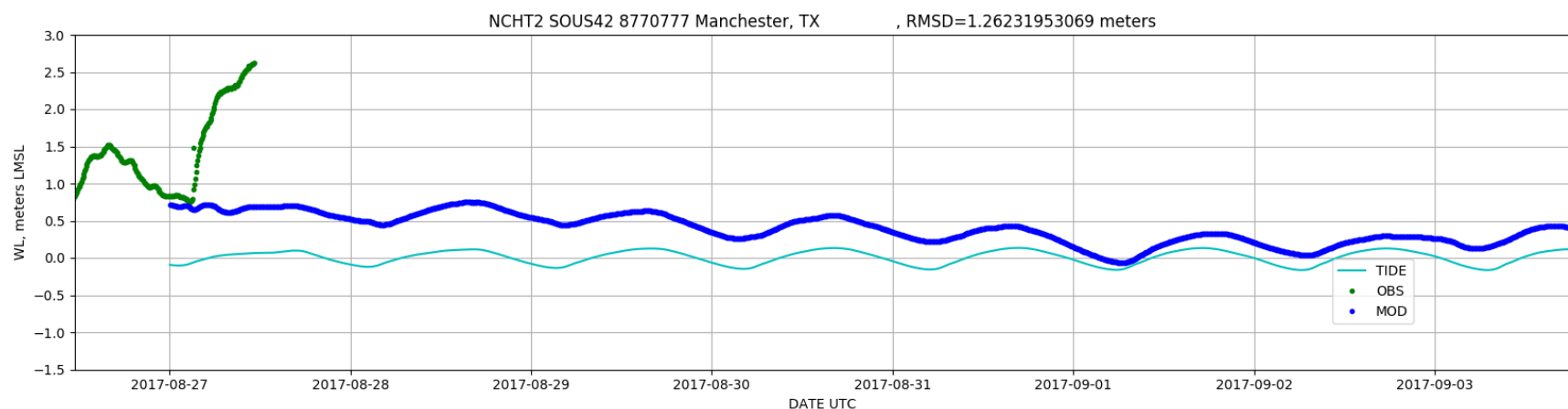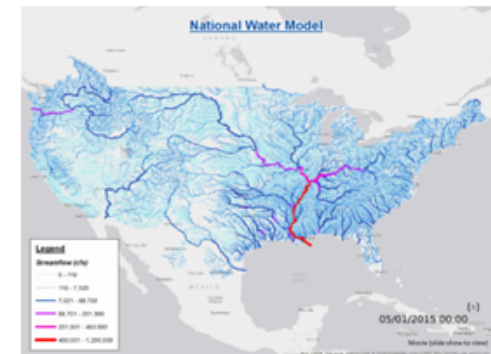
Missing Pieces…

2017 Harvey:
• Freshwater flooding

Current River Forecast Points (~3,600)

NWM Streamflow Output Points (~2.7 mil)

+

NCHT2 SOUS42 8770777 Manchester, TX , RMSD=1.26231953069 meters

• Integrate with National Water Model to provide two-way coupling
• One option is a mediator system to accept O.B.C. from coastal model and River discharge from NWM
• Working with Office of Water Prediction on a solution

Linear Biases
- Due to steric effects, other unresolved processes
- Implemented using pseudo-pressure loading physics
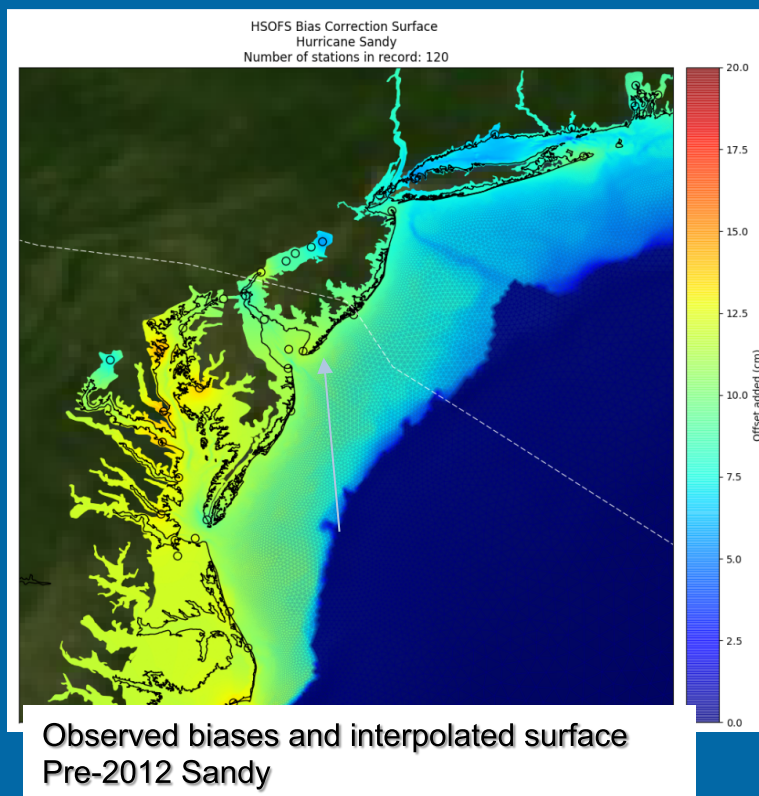- Imposed initial WL offsets are computed from WL data
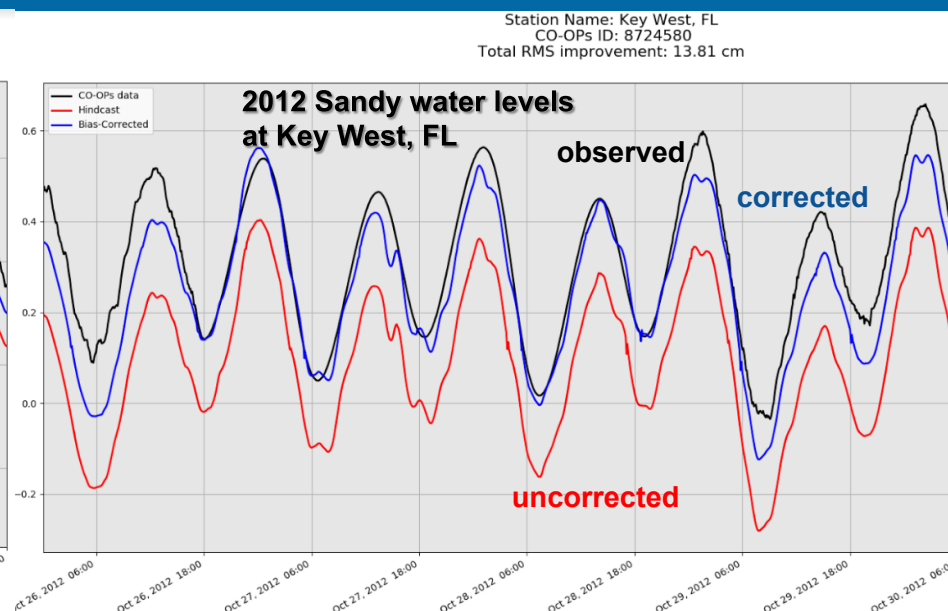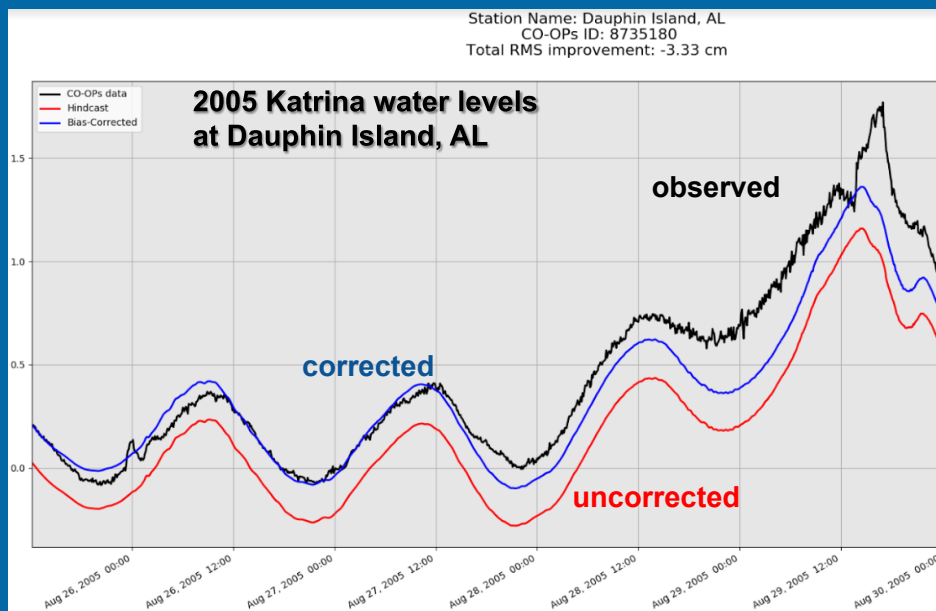
Linear Biases

-- solved,

-- assimilation of coastal WL data

-- potentially assimilate altimetry, 3D OFS fields…

HSOFS Bias Correction Surface
Hurricane Sandy
Number of stations in record: 120

Observed biases and interpolated surface
Pre-2012 Sandy

- On-demand NOS systems will be receiving this option with the next upgrade

- Extratropical systems will have runtime bias correction in FY19

Experimental Dissemination

http://polar.ncep.noaa.gov/estofs
-- prototype portal for quick model output graphics
-- Maximal forecasted elevations maps
-- Storm tide time-series
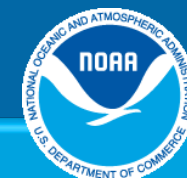-- Coastal WL offsets

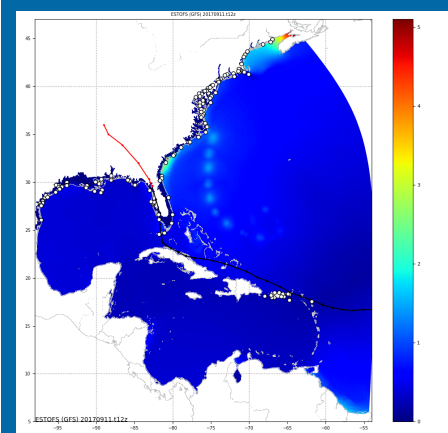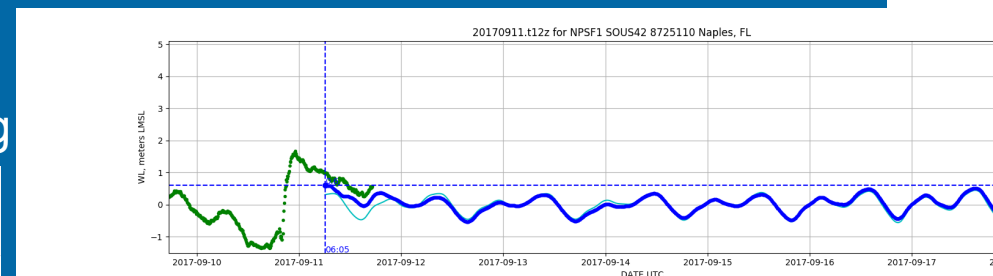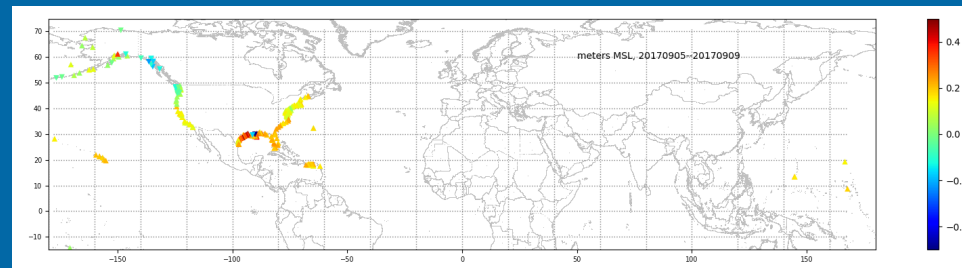http://github.com/grapesh/csdlpy-1.0.1/
Python stack for ESTOFS pre- post-processing

Storm Surge & Tide Operational Forecast

National Ocean Service • Coast Survey Development Laboratory

*** EXPERIMENTAL ***