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

Extratropical Surge & Tide Operational Forecast System (ESTOFS): Global Upgrade & Future Development

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Unified Forecast System (UFS) Users' Workshop
Regional Configurations and Extremes: Development and Applications
July 28 2020

Summary

Core Model Description (ADCIRC)

ADCIRC in the UFS

ESTOFS Description

Global ESTOFS Description

Global ESTOFS Validation

Acknowledgements

References

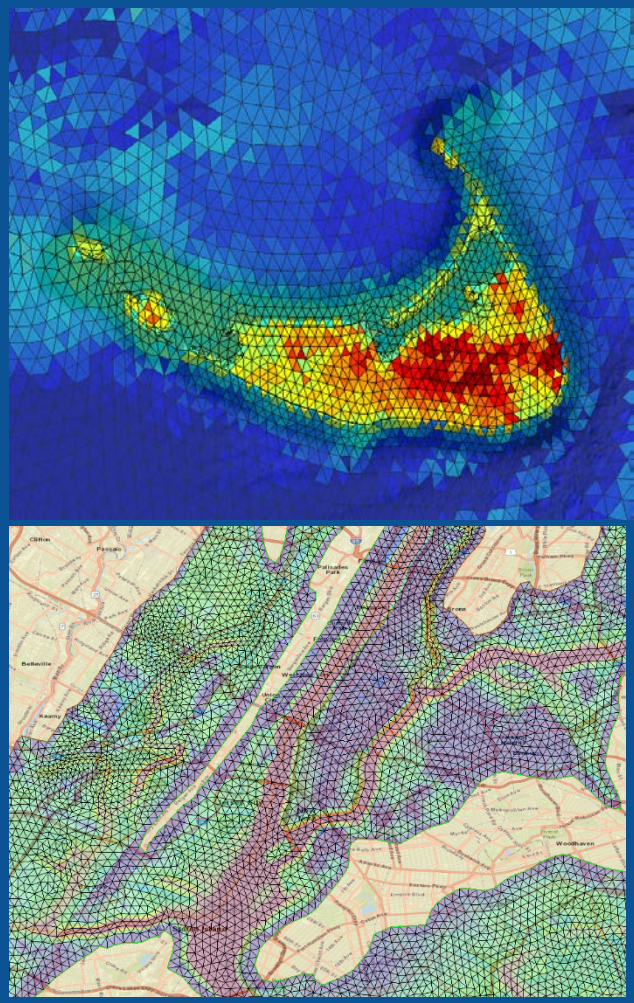
Core Model Description

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
  - ESMF
  - NEMS/NUOPC
- Large-scale domains
- Real-time bias correction options

ADCIRC v55

- Continuous Galerkin Finite Element Model
- 2DDI solution of GWCE, Momentum on Spherical CS
- SAL, Internal tides dissipation
- Option for the BPG
- Sea ice effect on wind drag

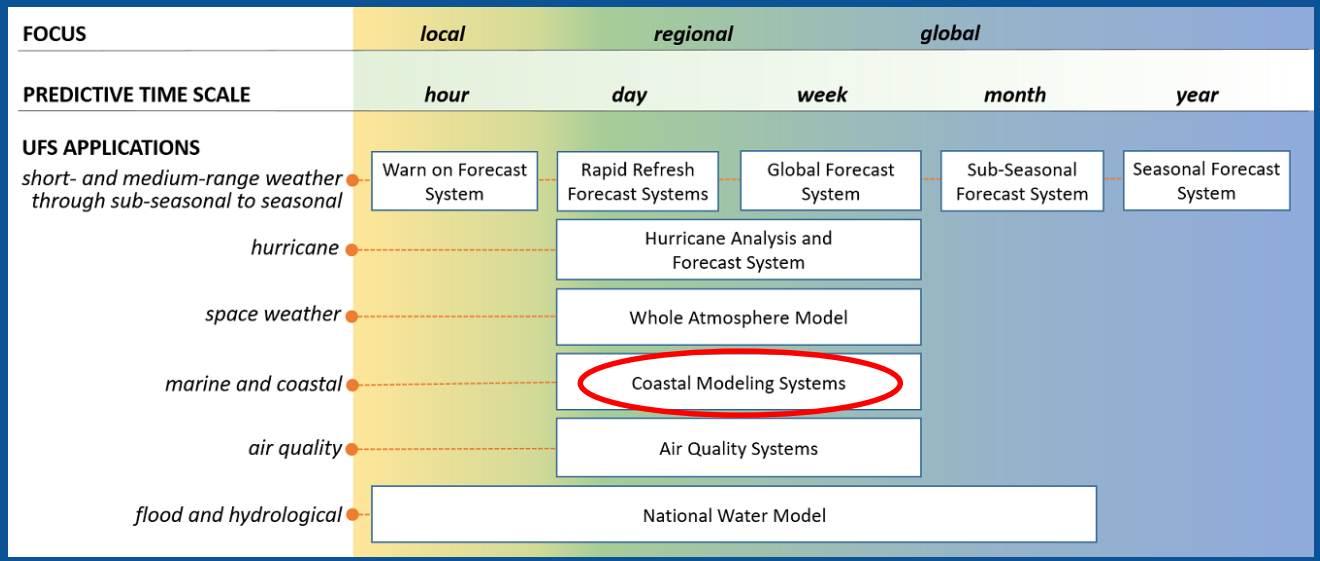


ADCIRC in the Unified Forecast System (UFS)

Benefits of having a model like ADCIRC as part of UFS:

- ADCIRC is a community model with a large user base
- ADCIRC represents the physics (e.g. tides, storm surge) very well, allows for variable resolution, is efficient
- Allows for an operational global ADCIRC model (e.g. Global ESTOFS) to be coupled to other UFS components, e.g. WAVEWATCH III
- ADCIRC will be part of a UFS Coastal Applications Team (led by Shachak Pe'eri of NOS) addressing coastal inundation

UFS
UNIFIED FORECAST SYSTEM



Extratropical Storm Surge & Tide Operational Forecast System (ESTOFS)

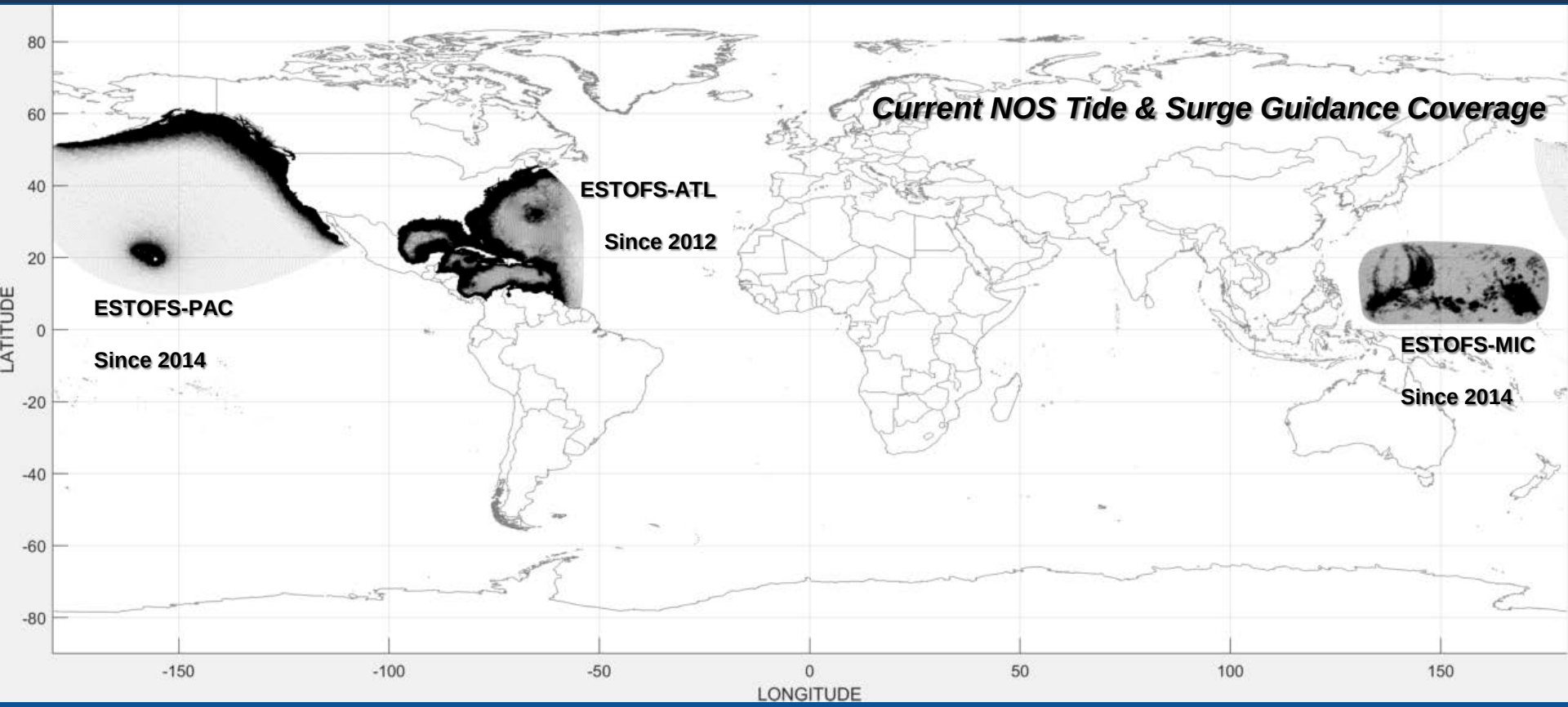
- ADCIRC core model
- Deterministic, continuously running water level forecast
- Driven by GFS atmospheric model (gridded U10, V10, MSLP, ICE)
- Computes tidal component (HTP), surge component (SWL) and their combination (CWL)

- 4 cycles a day: t00z, t06z, t12z, and t18z
- 6 hour nowcast followed by 7 days forecast

- Disseminated via AWIPS (GRIB2 and SHEF output), and NOMADS (GRIB2, SHEF, native netCDF)

- Provides boundary conditions to a downstream Nearshore Wave Prediction System (NWPS)

ESTOFS Description



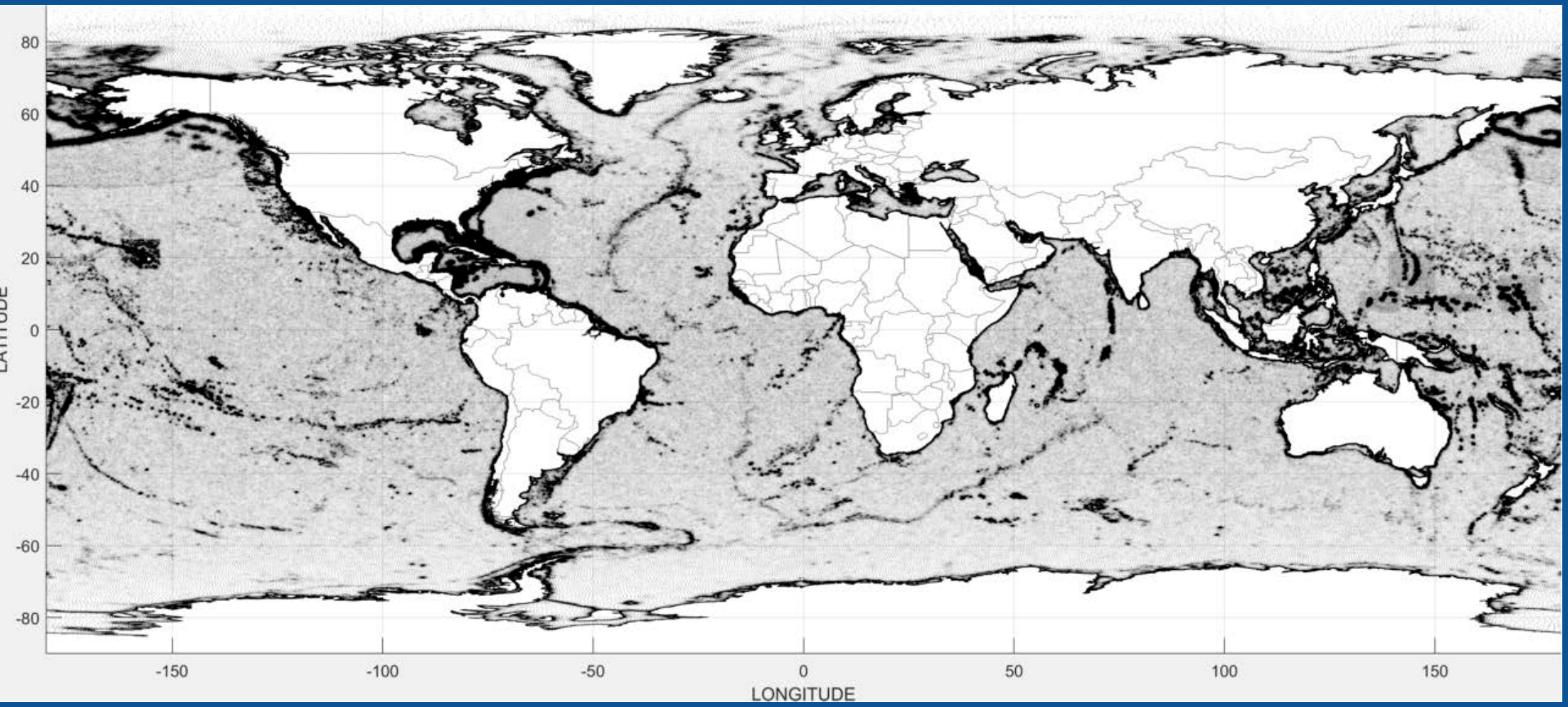
Gaps in Coverage:

- Western Alaska
- American Samoa
- Foreign Territories

Operational Needs:

- Unification of ESTOFS modeling infrastructure
- Reduction of bias and errors due to removal of the open ocean boundary
- Inclusion of internal tides
- Sea-ice effect on wind drag
- Bias correction

Global ESTOFS Description



Global ESTOFS mesh
8,063,409 nodes
15,478,900 elements

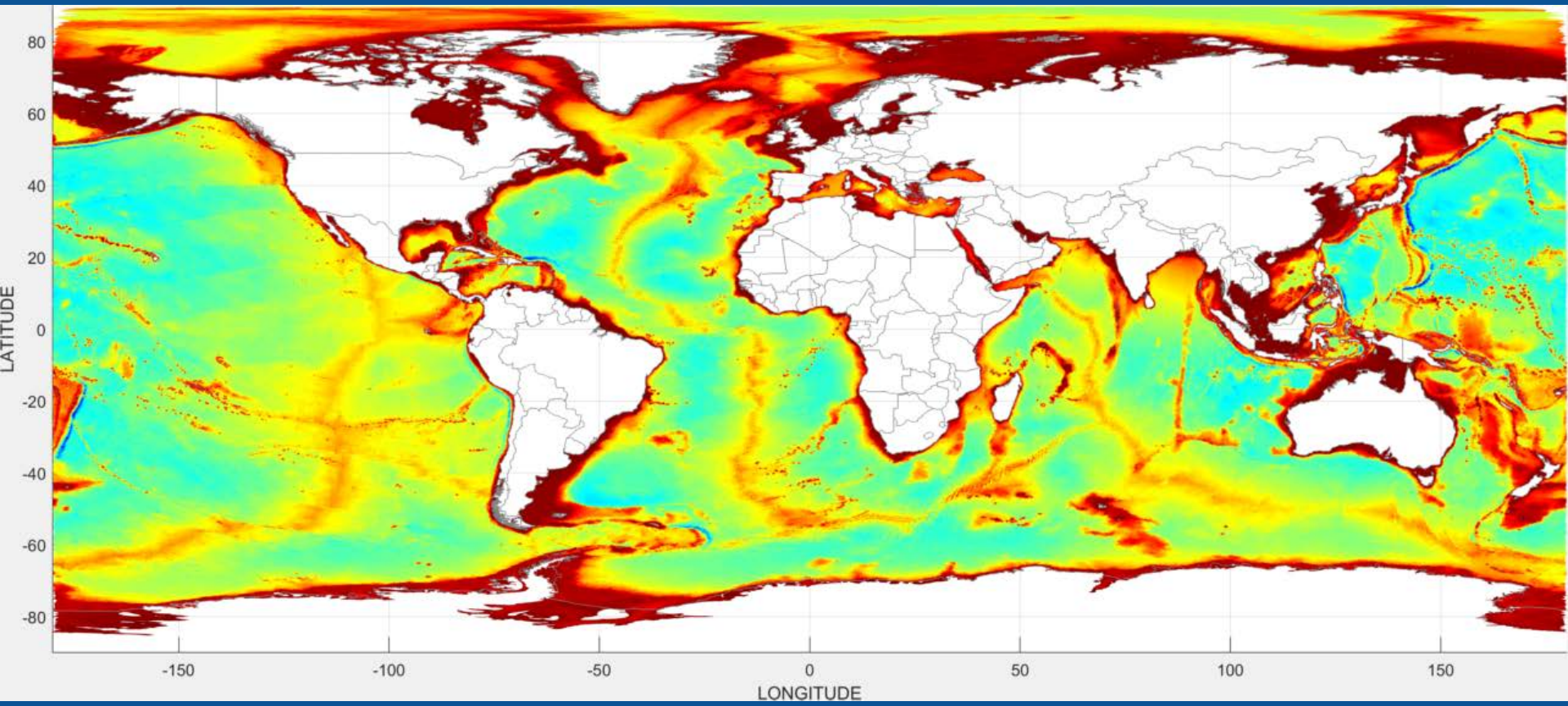
Point output
558 locations

Implemented late Oct 2020

Coastal resolution:
Up to 80 m for Hawaii and US West Coast
Up to 120m for US East Coast, PR, Micronesia, Alaska

Flood plain:
Up to 6m ASL elevation for US East Coast
Up to 20m ASL elevation for the Pacific Islands

Global ESTOFS Description



Configuration:

Q1,O1,P1,K1,N2,M2,S2,K2
Internal tides, SAL, ice
DT = 12 sec, explicit mode

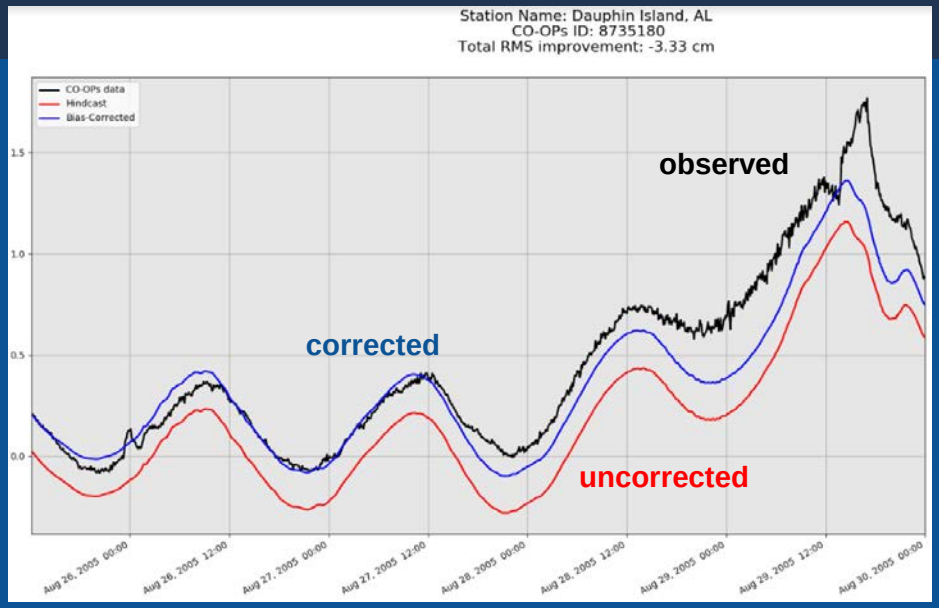
Bias Correction

Every cycle, using 2-day average WL anomalies

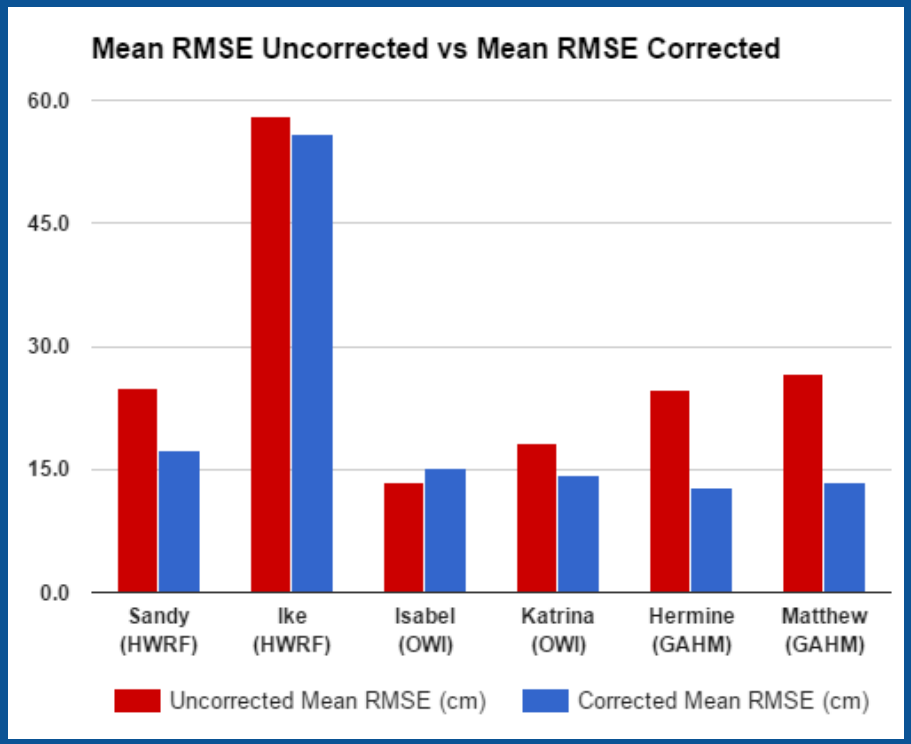
- anomaly = obs - tidal predictions
- correct residual, assuming tides are perfect
- inverted barometer (1 mbar ~ 1 cm) to maintain offset
- interpolate spatially between CO-OPS tide stations

Bias Correction Validation

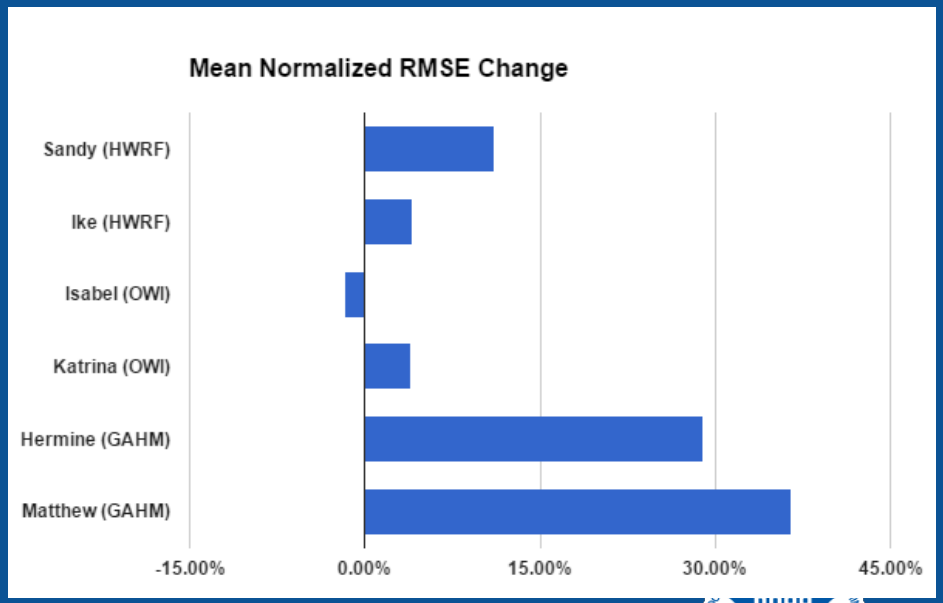
- RMSE reduction (coastal tide gauges)
- Significant improvement for 2012 Sandy, 2016 Matthew, 2016 Hermine, 2005 Katrina
- Small improvement for 2008 Ike
- 2% degradation for 2003 Isabel



2005 Katrina water levels at Dauphin Island, AL



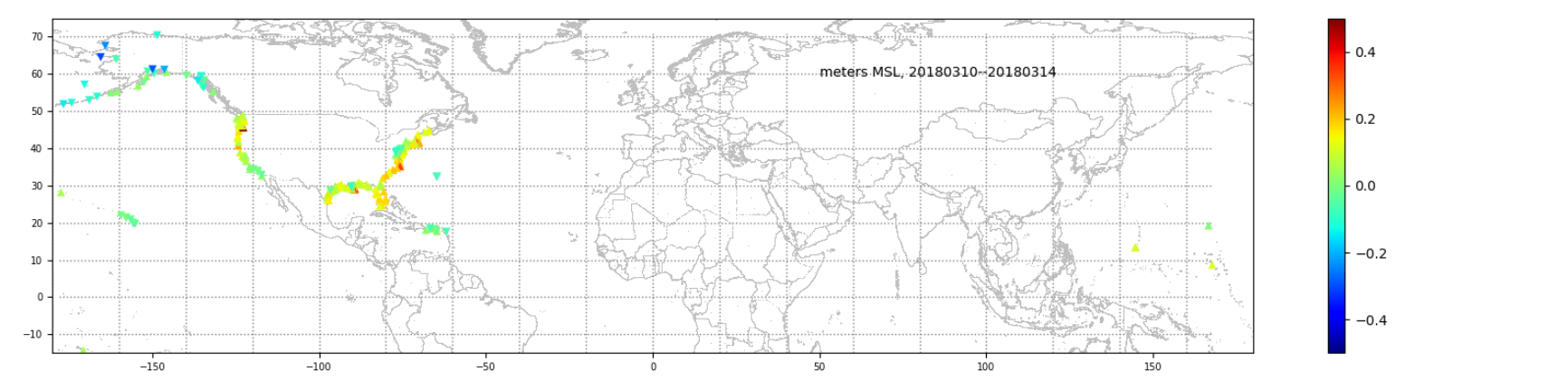
Hindcast results for RMSE reduction



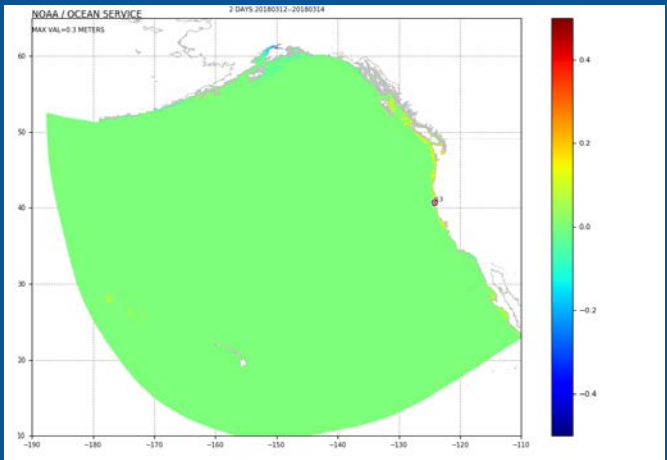
RMSE reduction normalized by surge magnitude

Bias Correction in Operations

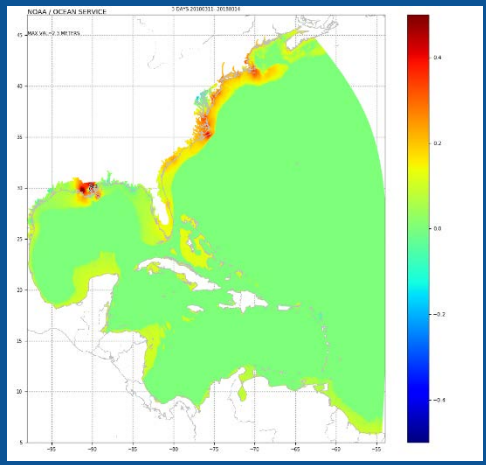
- Coastal water level offsets are updated each cycle (every 6 hours) on WCOSS
- Will be available for forecasters on http://polar.ncep.noaa.gov/estofs



Offset values at all active CO-OPS tide gauge locations.

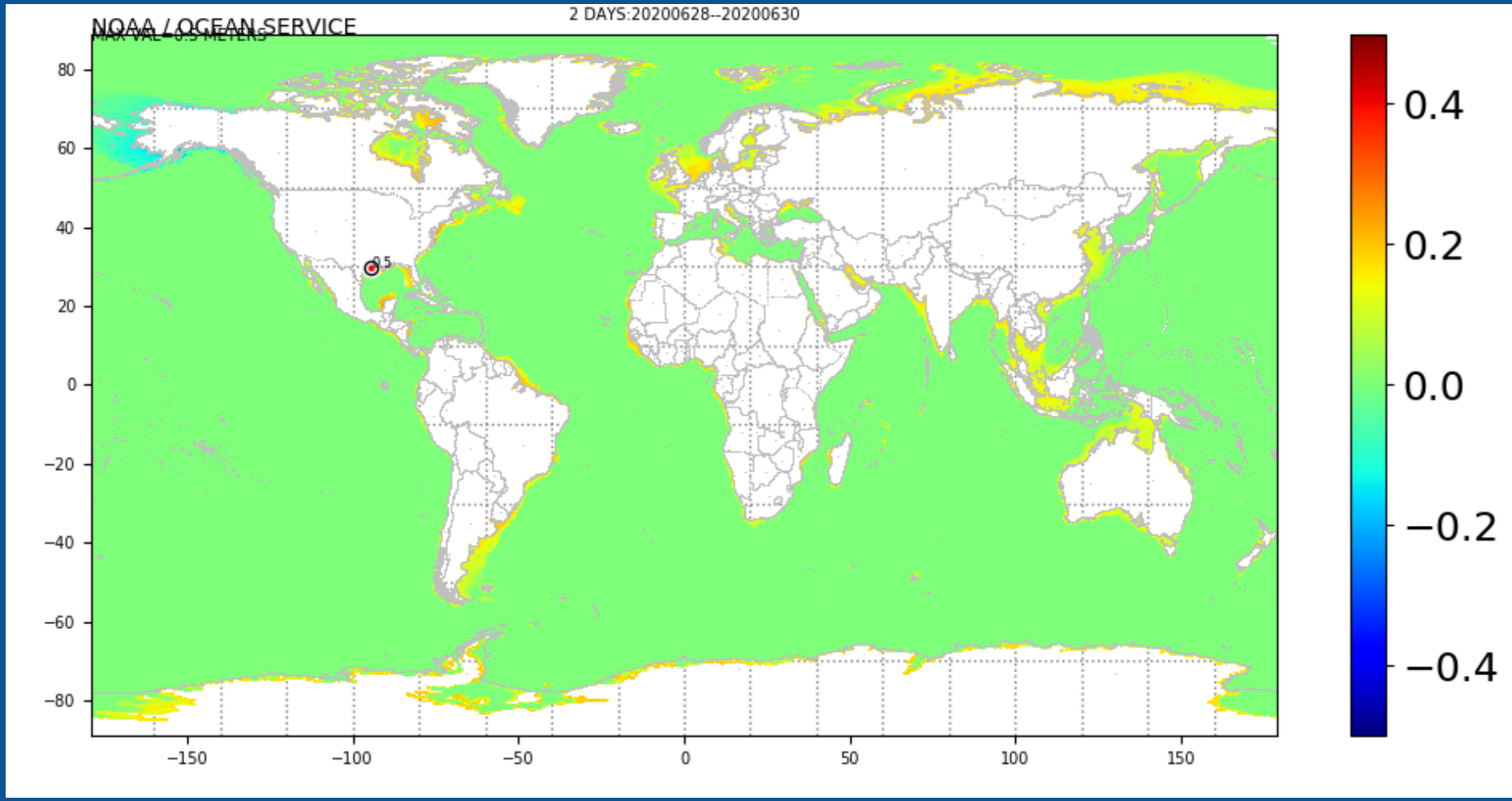


Interpolated offset surface for ESTOFS-Pacific



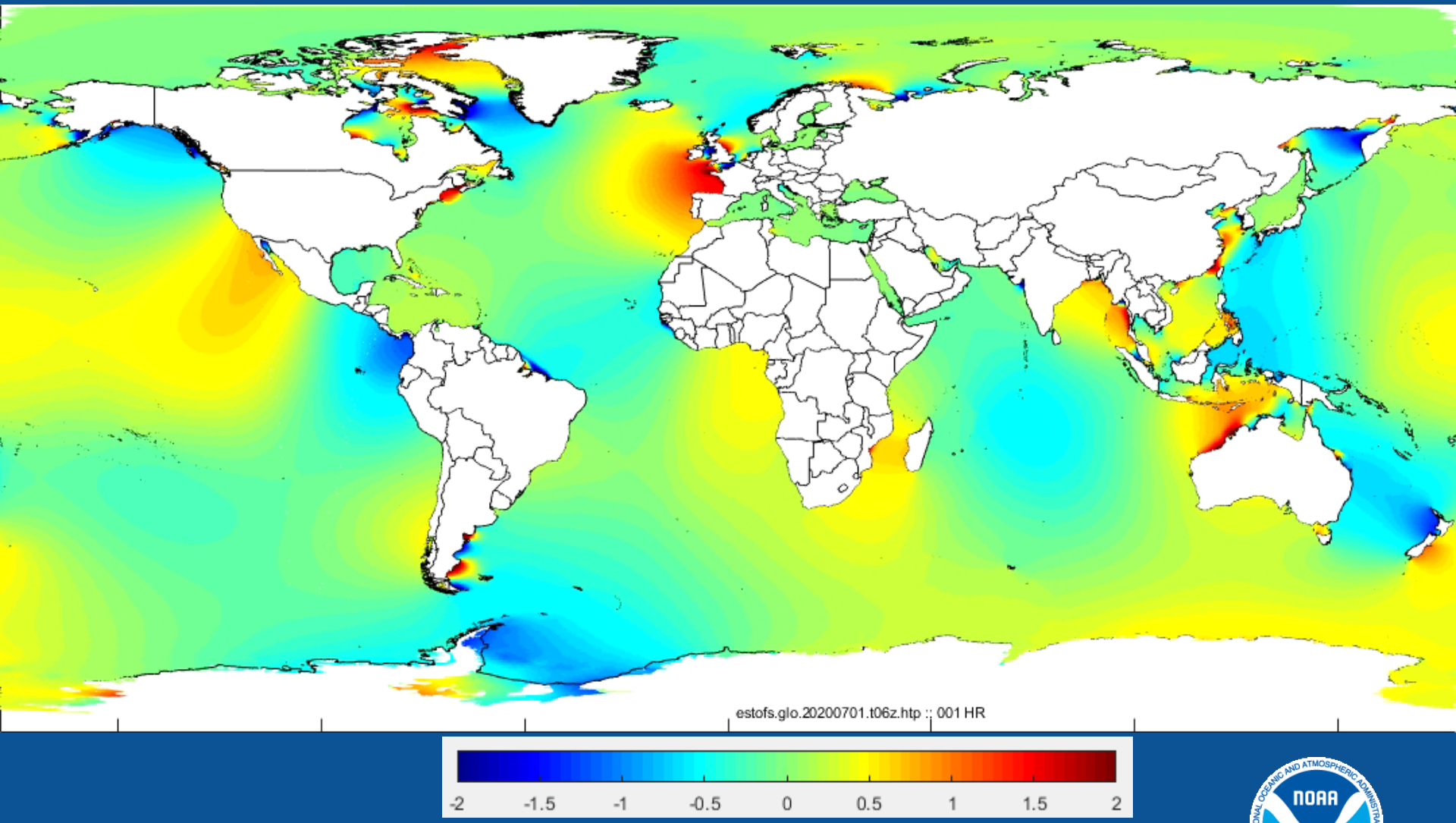
Interpolated offset surface for ESTOFS-Atlantic

Bias Correction in Operations



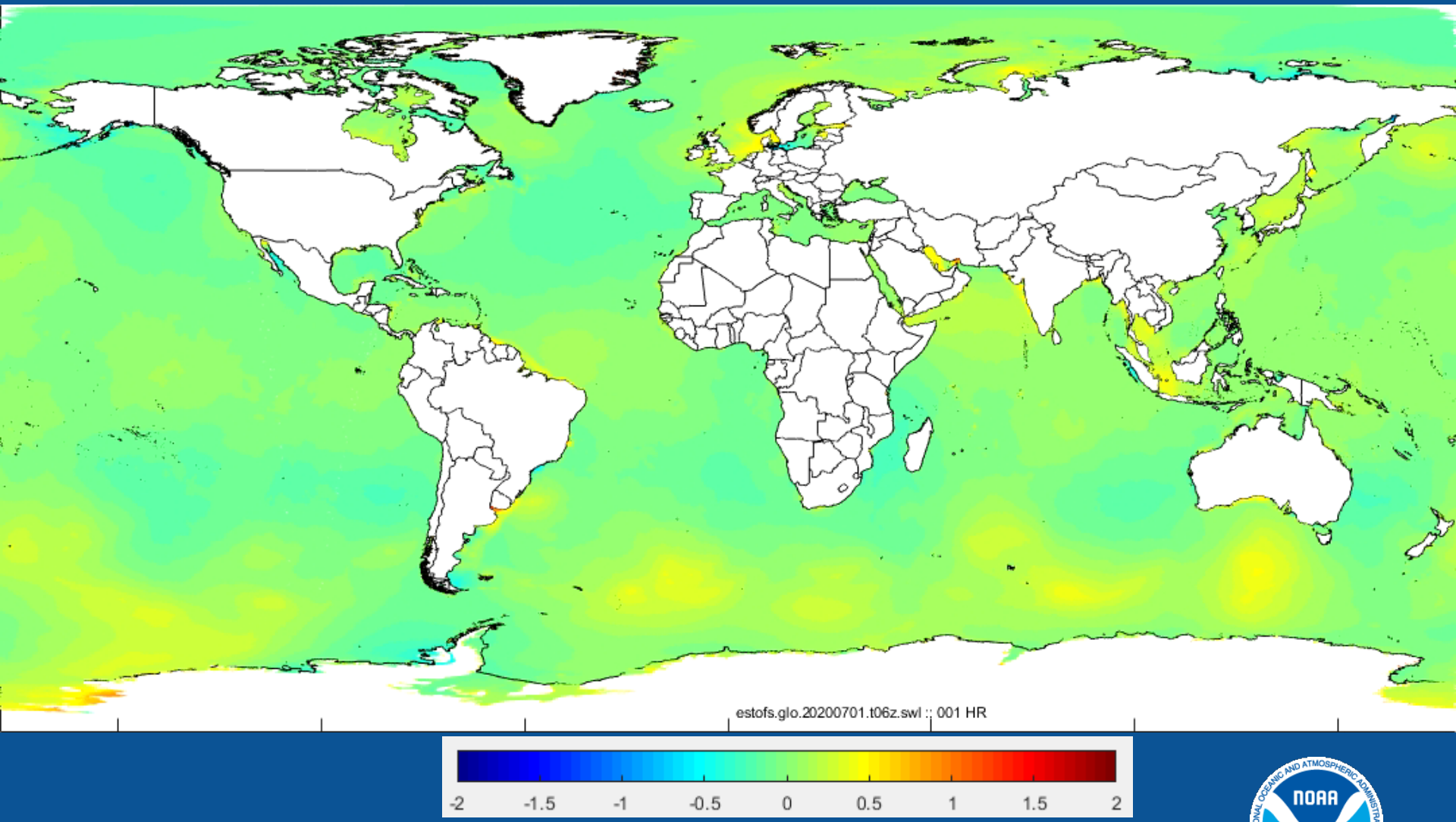
Global ESTOFS Validation

2020/07/01 t06z cycle :: HTP evolution



Global ESTOFS Validation

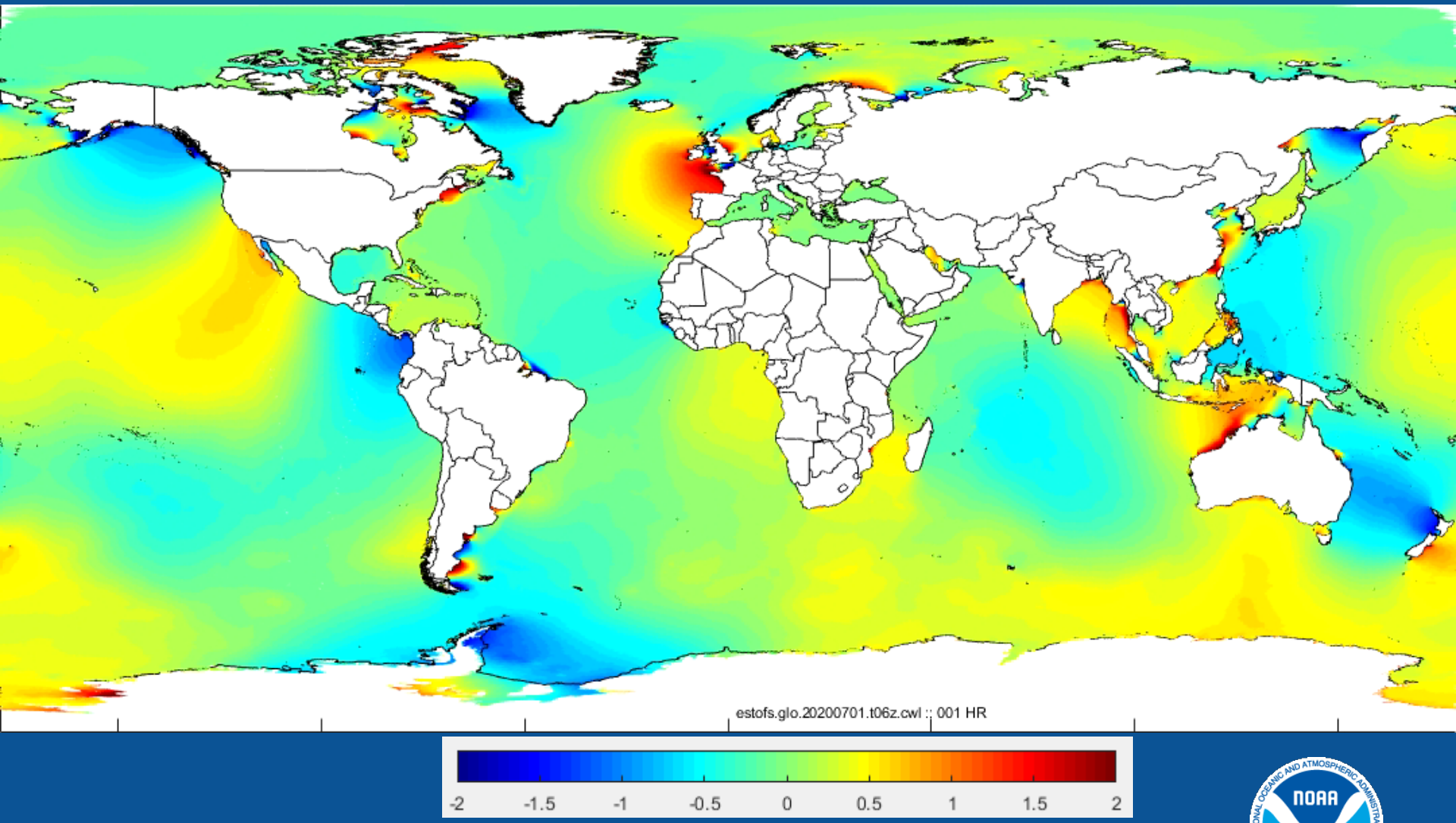
2020/07/01 t06z cycle :: SWL evolution



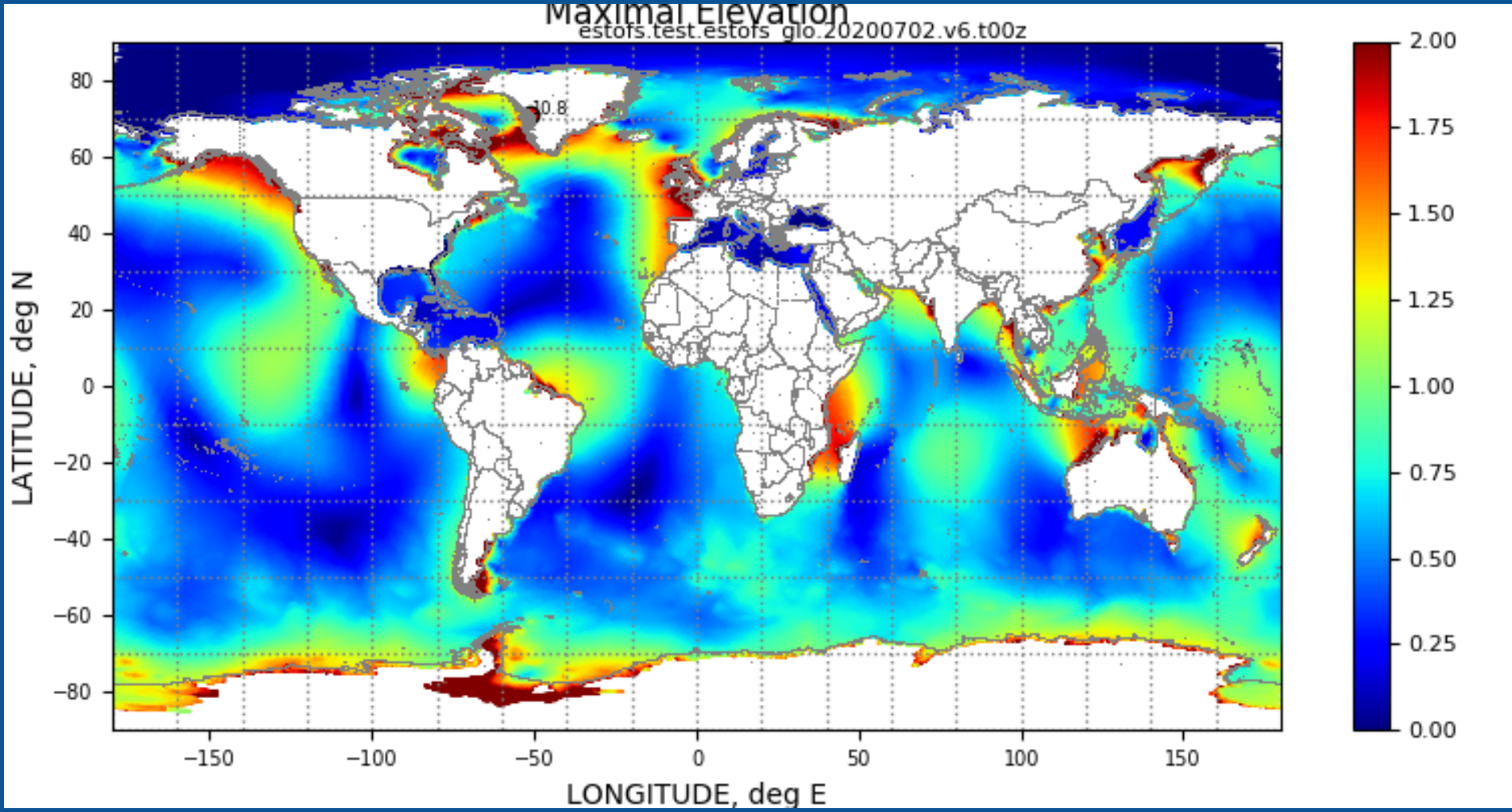
Office of Coast Survey

Global ESTOFS Validation

2020/07/01 t06z cycle :: CWL evolution

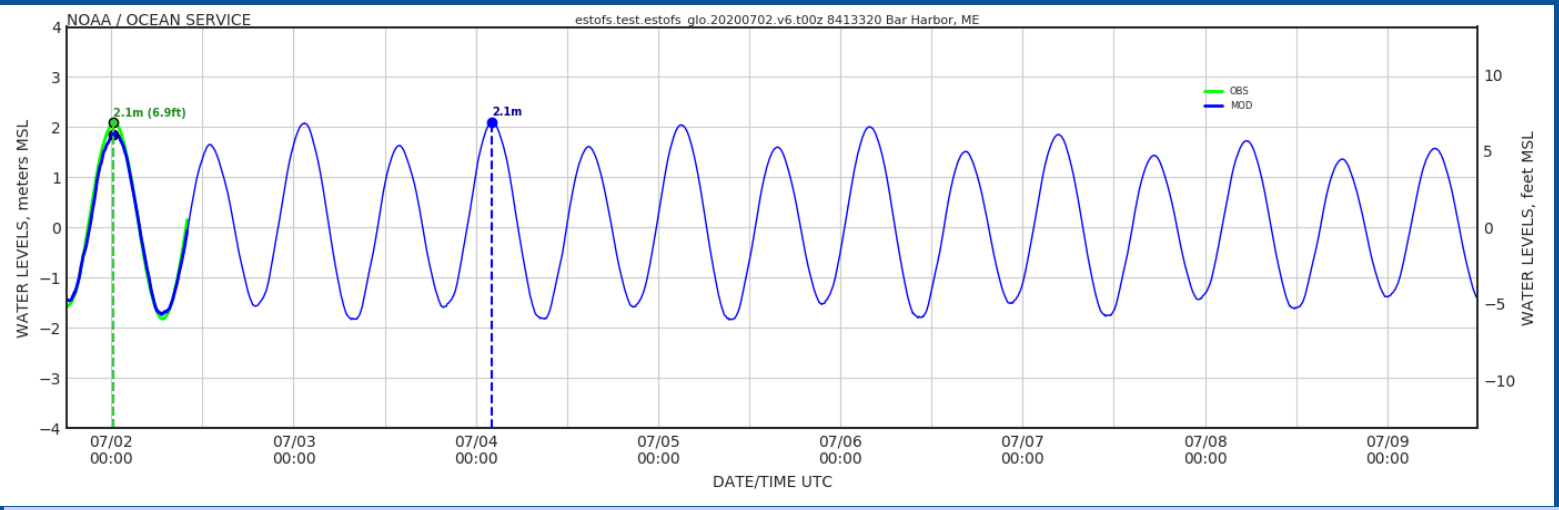


Global ESTOFS Validation

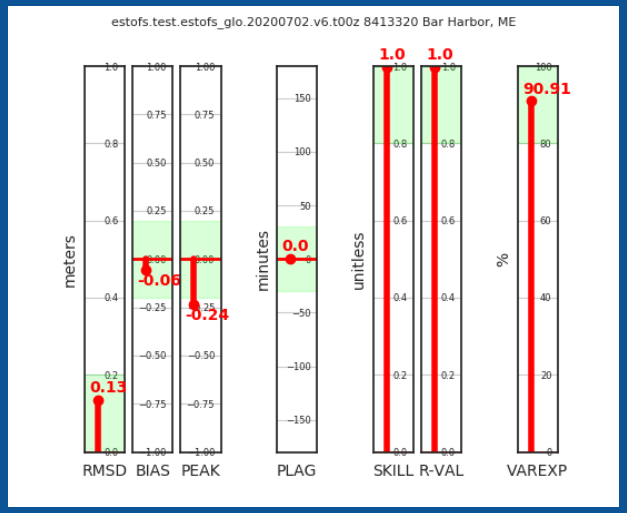


Maximal forecasted water levels, 20200702 t00z cycle

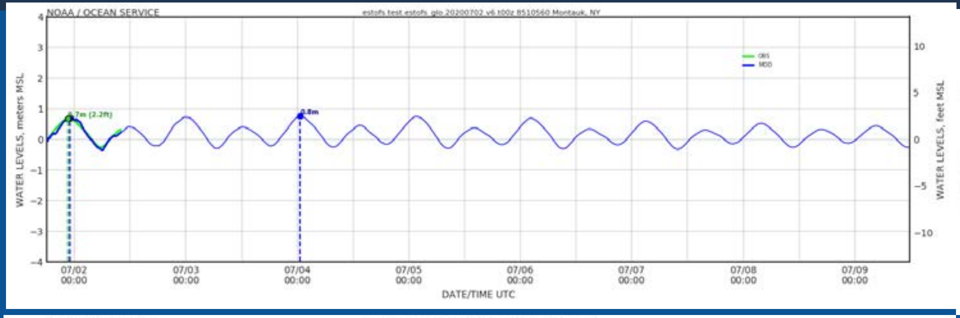
Global ESTOFS Validation

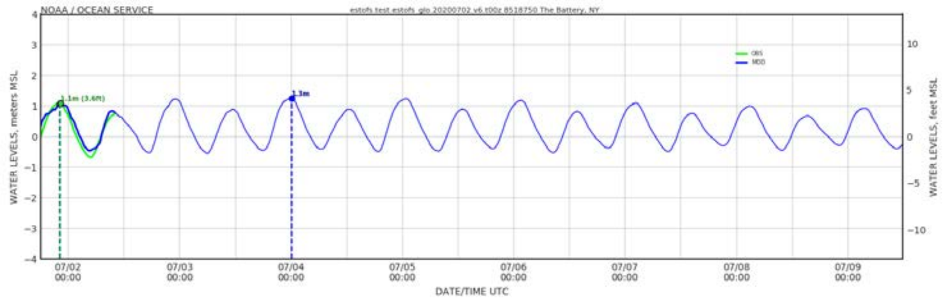


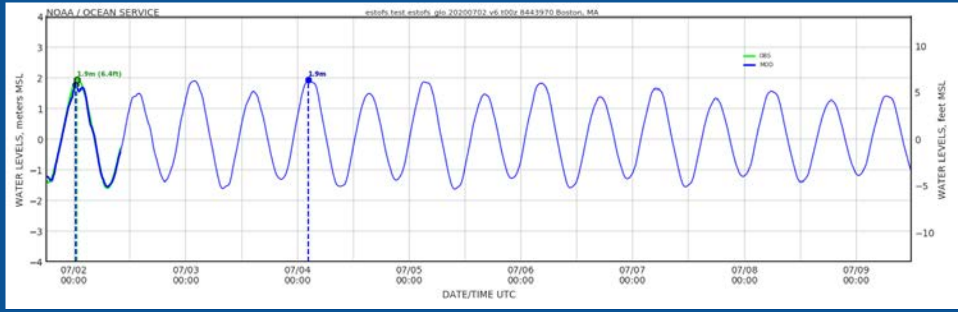
rmsd	peak	plag	bias	vexp	skil	rval	npts
0.13	-0.24	0.0	-0.06	90.91	1.0	1.0	160

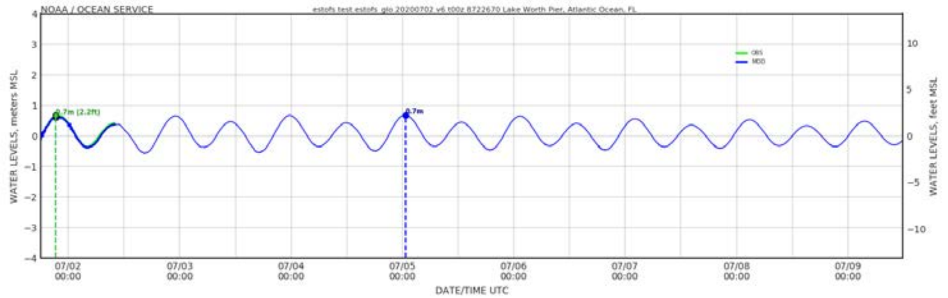


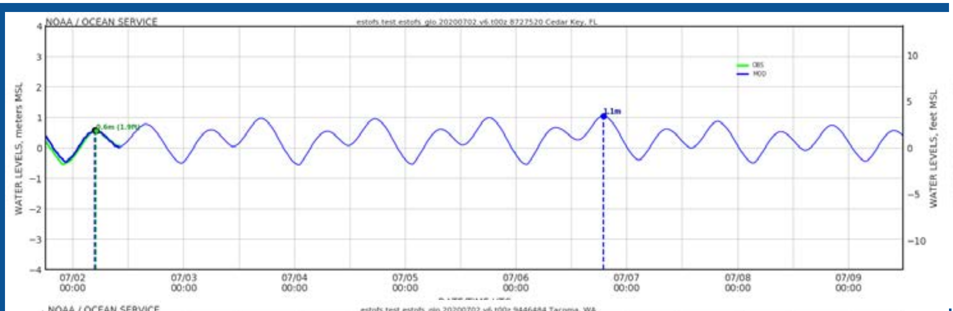
Global ESTOFS Validation

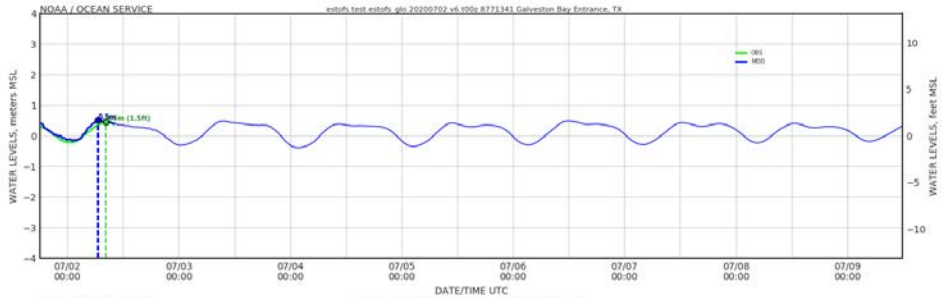


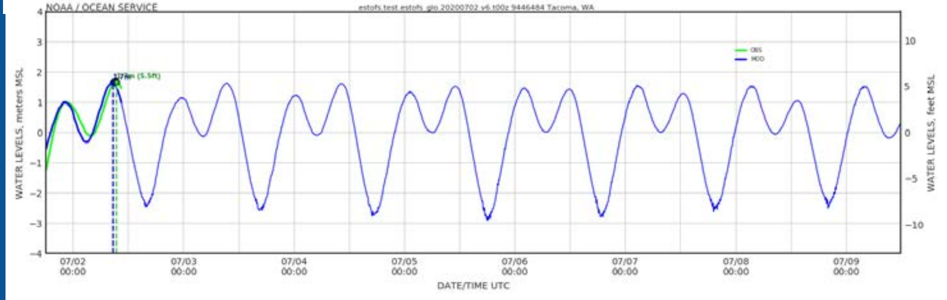


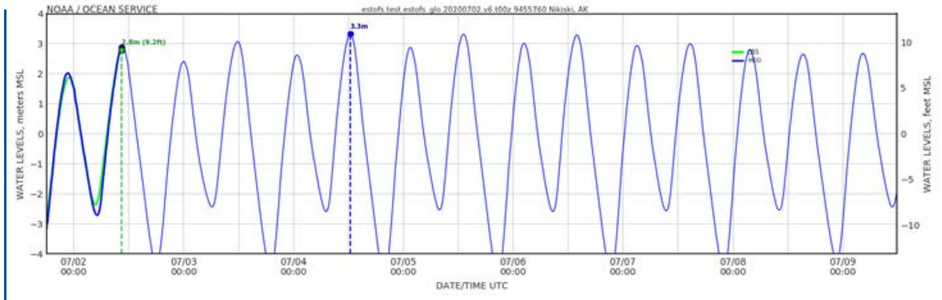




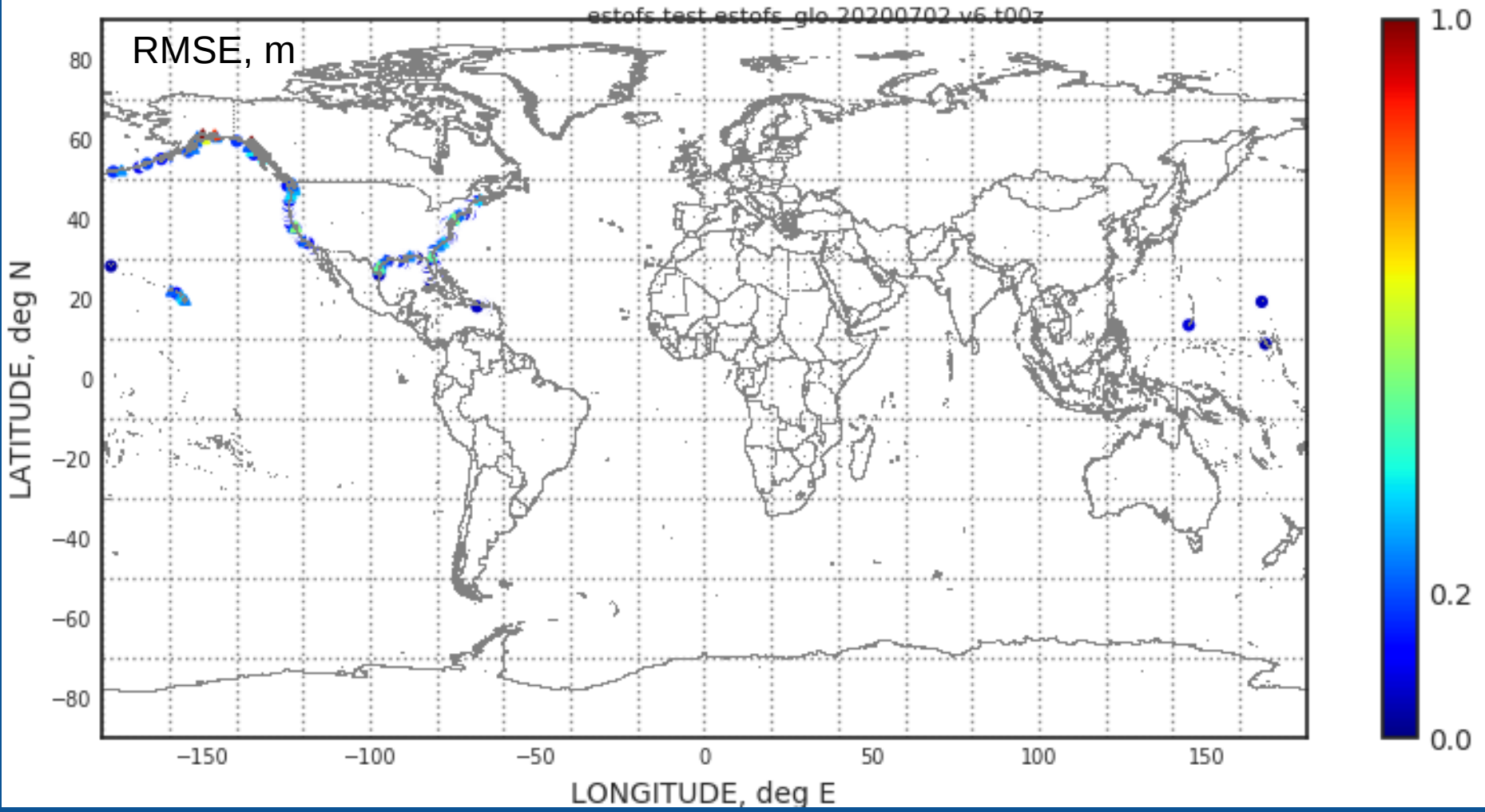




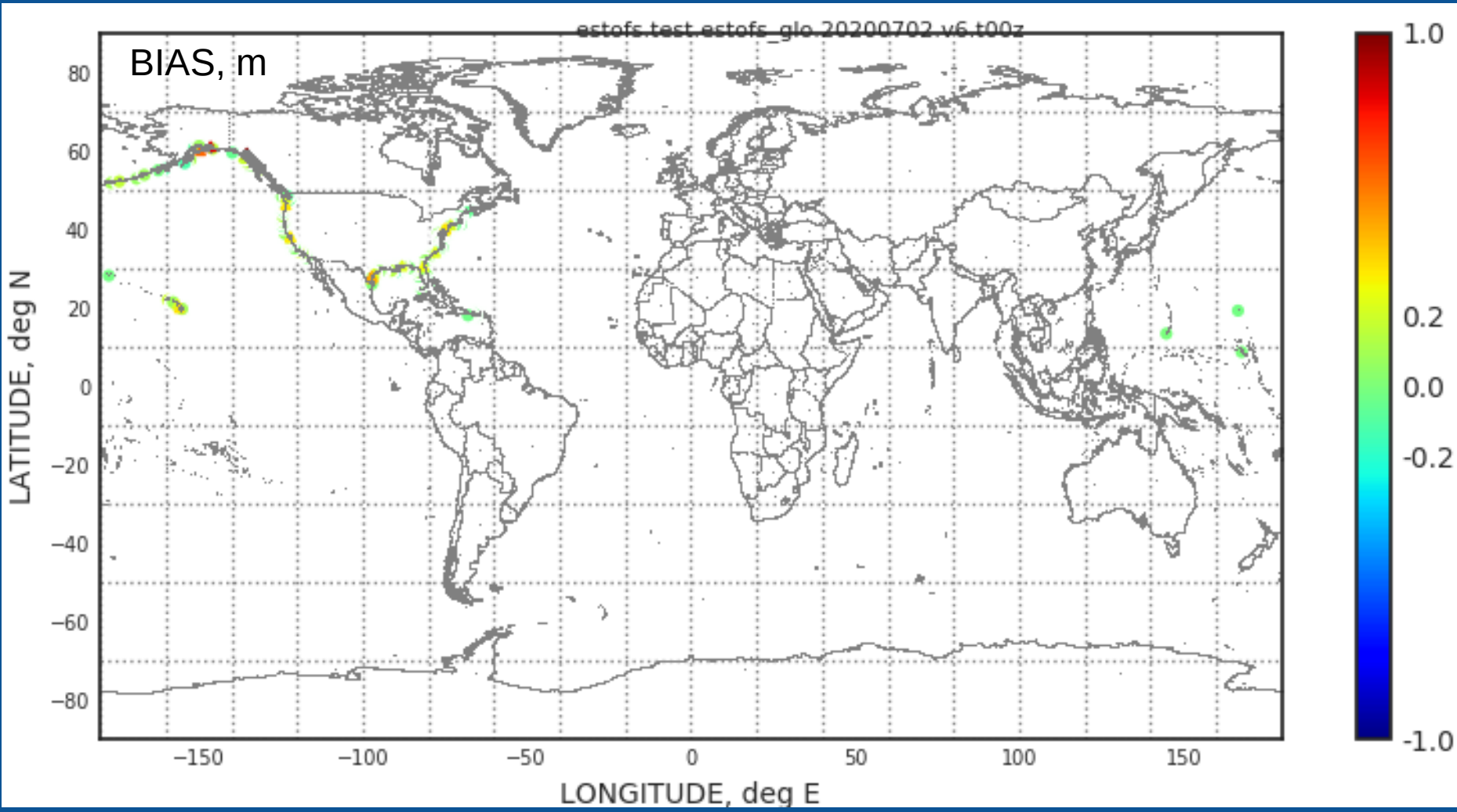




Global ESTOFS Validation



Global ESTOFS Validation



Global ESTOFS Validation

2020 06/30 t00z

ESTOFS-Global

rmsd	peak	plag	bias	vexp	skil	rval
0.17	0.1	5.66	0.08	65.37	0.91	0.92

307 stations

ESTOFS-ATL

rmsd	peak	plag	bias	vexp	skil	rval
0.18	-0.15	-4.53	-0.15	72.18	0.8	0.97

114 stations

ESTOFS-PAC

rmsd	peak	plag	bias	vexp	skil	rval
0.2	-0.05	-42.39	-0.1	73.54	0.9	0.9

61 stations

ESTOFS-MIC

rmsd	peak	plag	bias	vexp	skil	rval
0.07	-0.02	-171.0	-0.06	74.73	0.96	0.98

4 stations

Future of Global ESTOFS

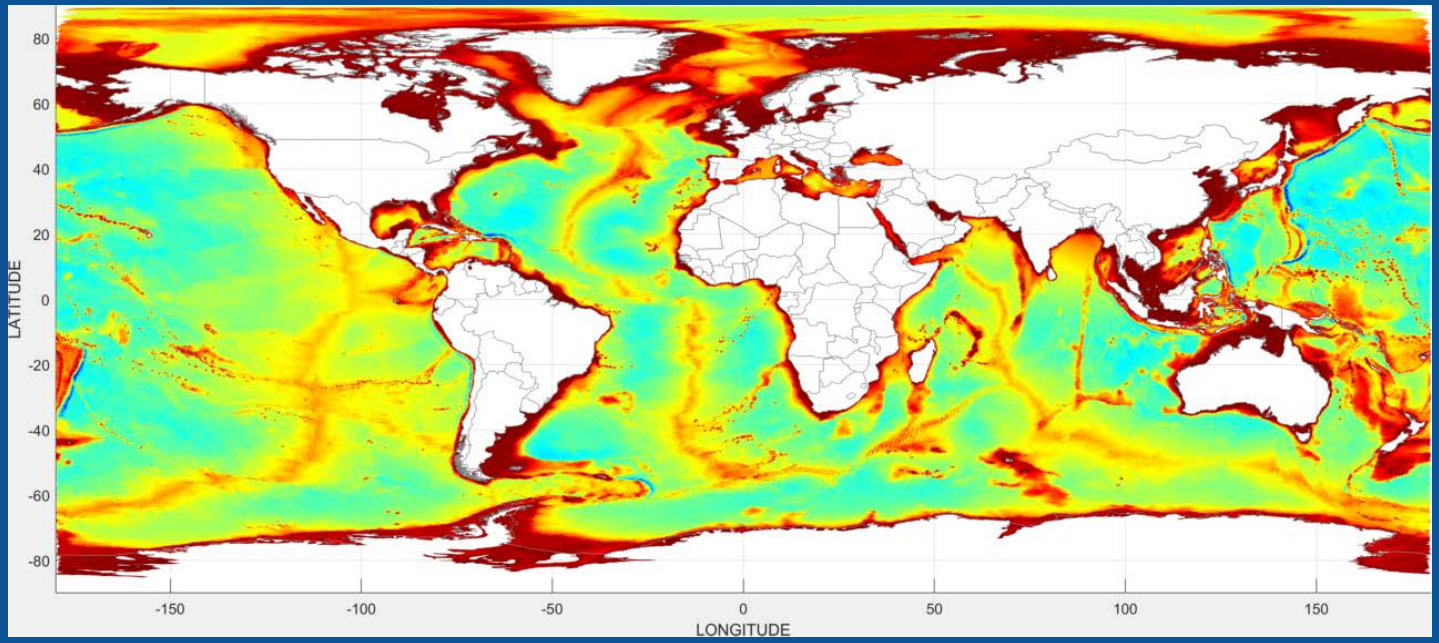
Within NEMS, couple Global ESTOFS to:

- the National Water Model
- Global RTOFS
- other model applications

Pacific Ocean enhancements:

- area of high national priority
- higher resolution, improved mesh
- improved bathymetry
- skill assessment to evaluate improvements

Improved ADCIRC computational efficiency using community efforts



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The Water Institute of the Gulf:
Zachary Cobell

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Pringle, W. J.: Global Storm Tide Modeling on Unstructured Meshes with ADCIRC v55 - Simulation Results and Model Setup, Zenodo, doi:10.5281/zenodo.3911282, 2020.

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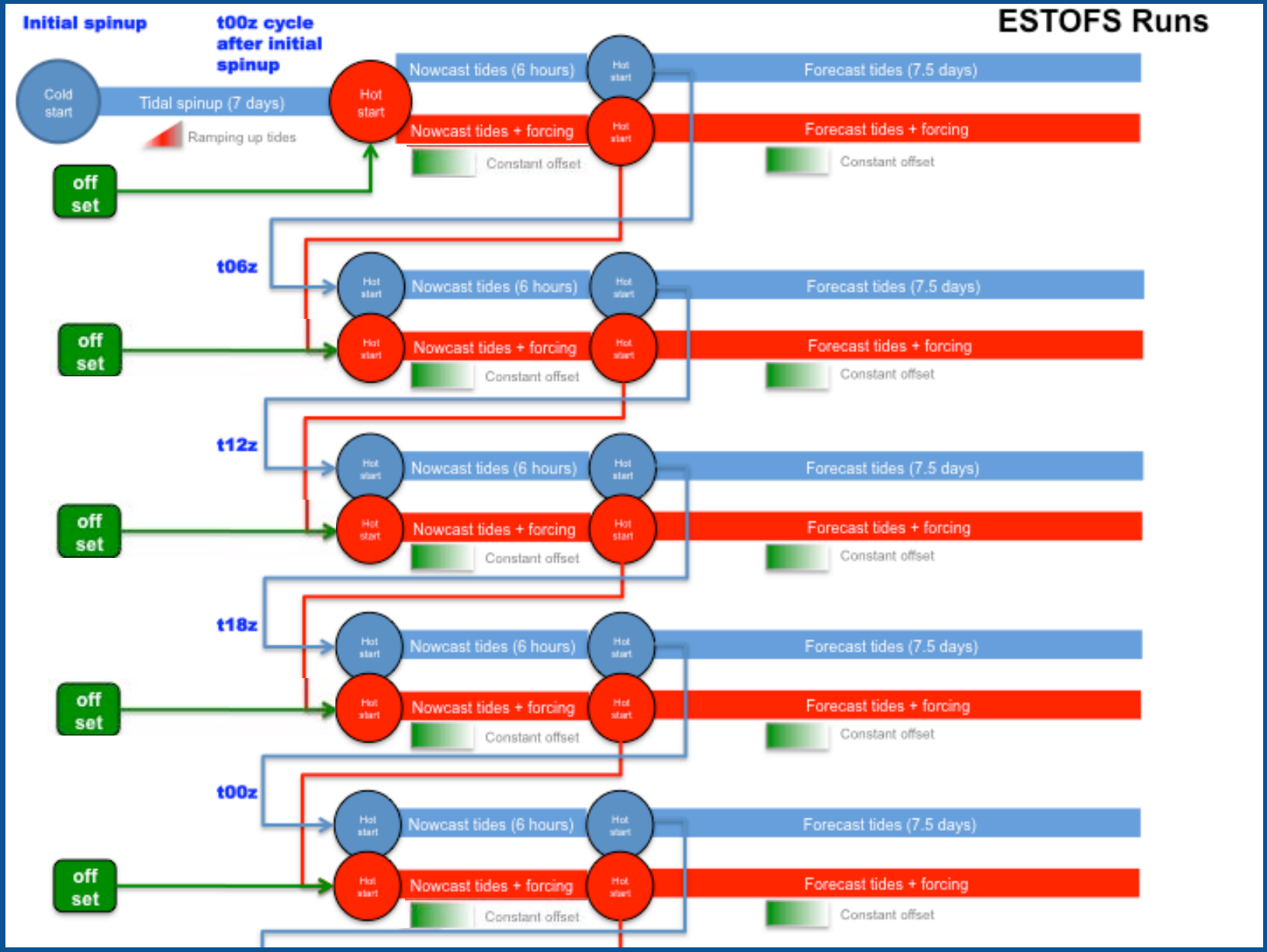
Thank you!

Extra Slides

ESTOFS Description



ESTOFS Description

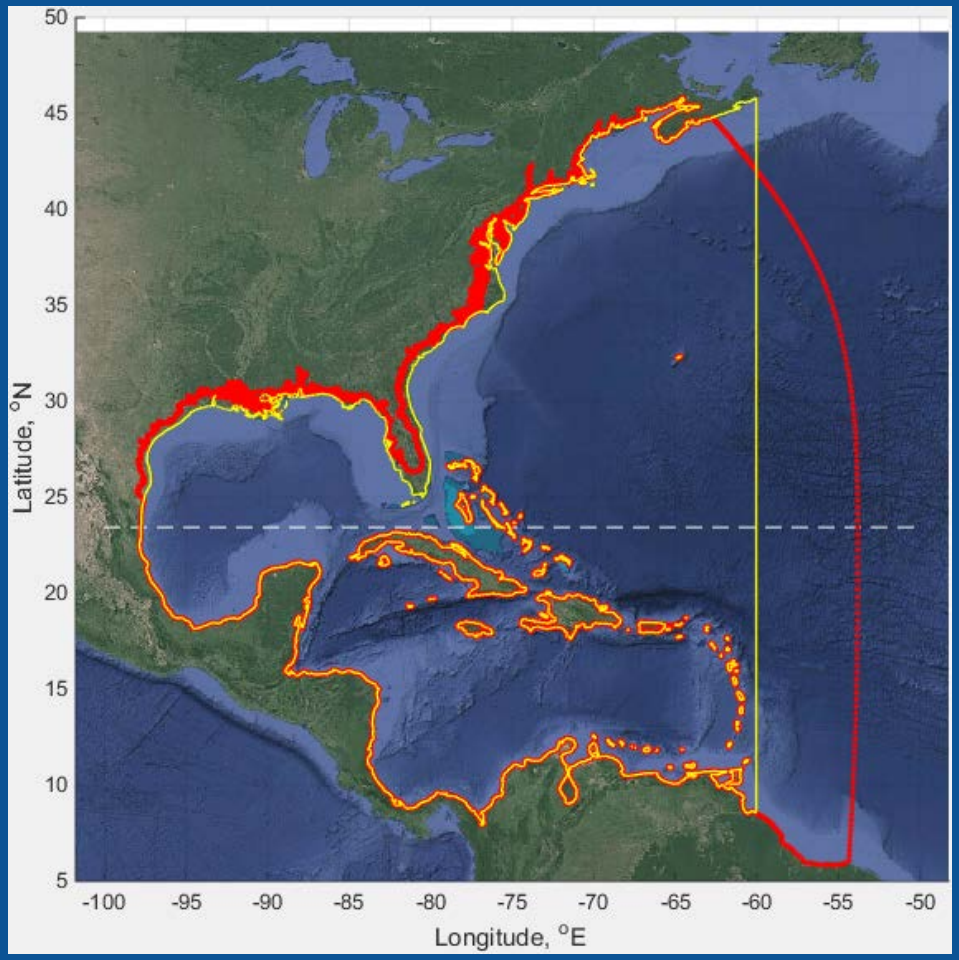
Component	ESTOFS-ATL	ESTOFS-PAC	ESTOFS-MIC
Grid resolution	160+ m	2+ km	200+ m
Forcing	GFS 13km	GFS 55km	GFS 13km
Ensembles	1	1	1
Forecast frequency/ lead time	4/day up to 7 days	4/day up to 7 days	4/day up to 7 days
Inland flooding	Yes	No	Yes
Coupling	No	No	No
Data assimilation	No	No	No

ESTOFS Description

ESTOFS-ATL in operation since 2012

Major Upgrade (April 24 2017)

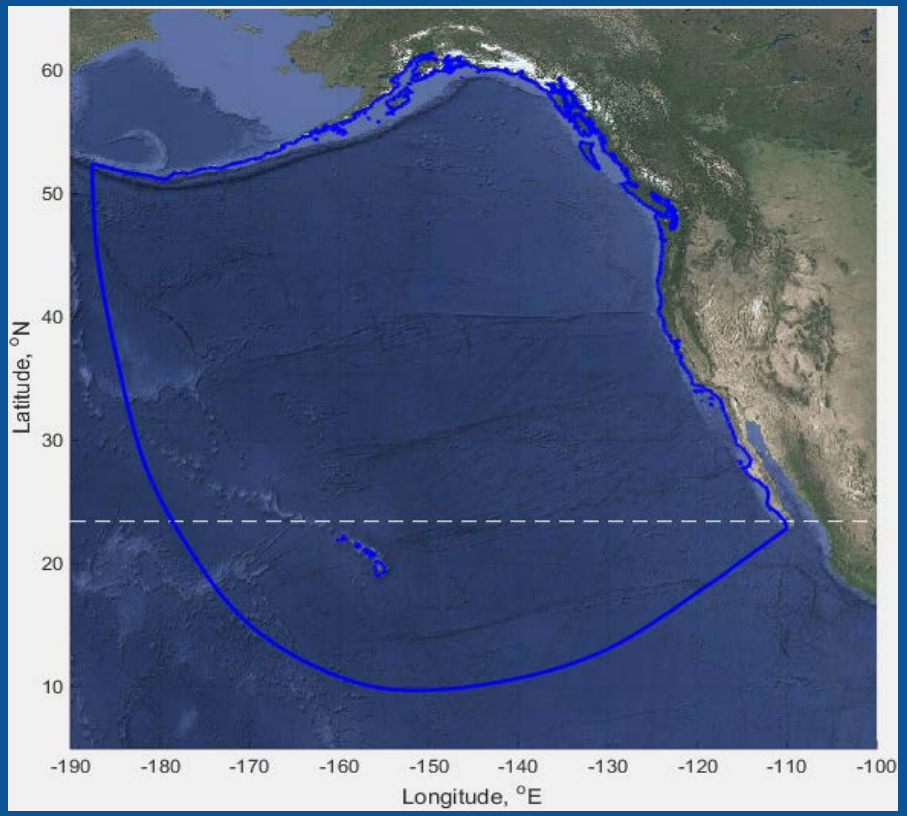
- Covers US East and Gulf Coast + Caribbean
- HSOFS grid + inland flooding
- Up to 10 m elevation
- 200 m coastal resolution
- 1.8M nodes
- GFS 13-km forcing
- 128 point output



ESTOFS Description

ESTOFS-PAC in operation since 2014

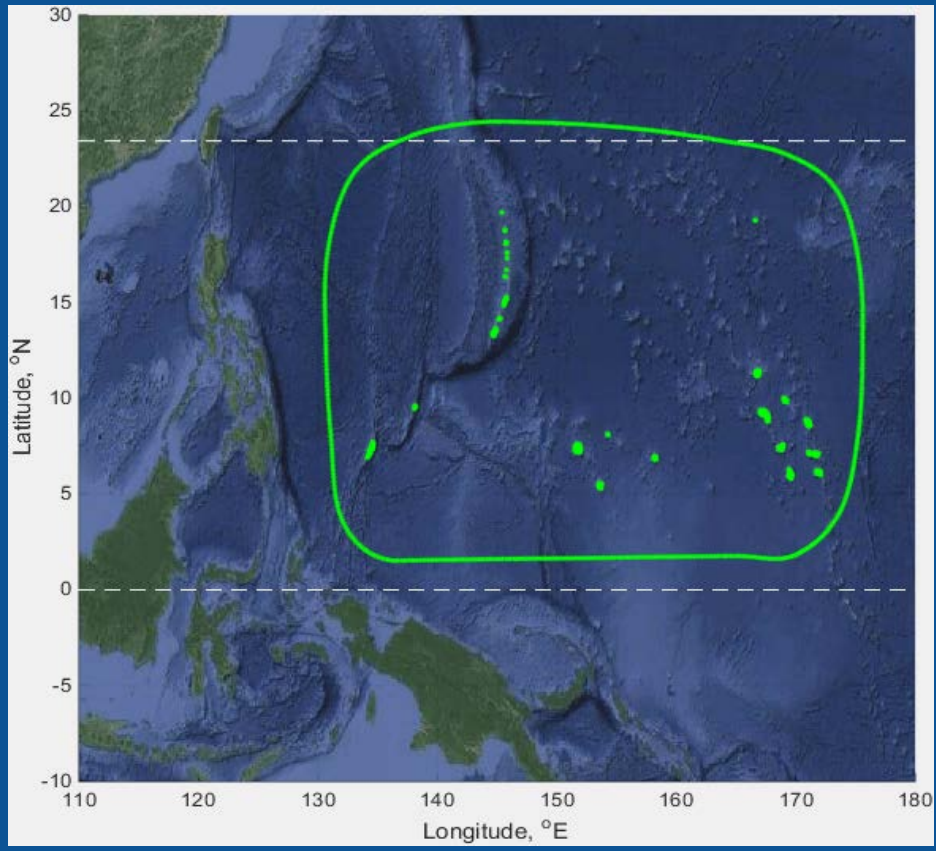
- Covers US West Coast and Hawaii
- 1-3km coastal resolution
- 132K nodes
- GFS 55-km forcing
- 71 point output



ESTOFS Description

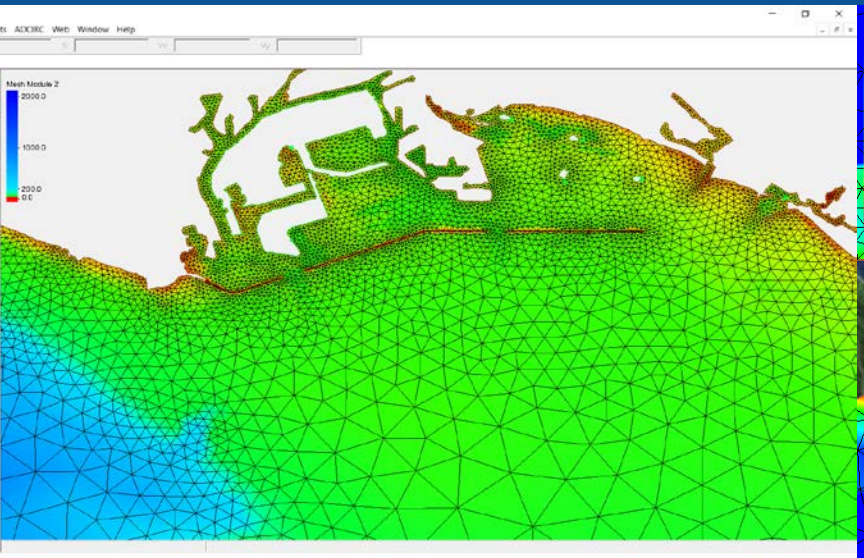
ESTOFS-MIC in operation since 2014

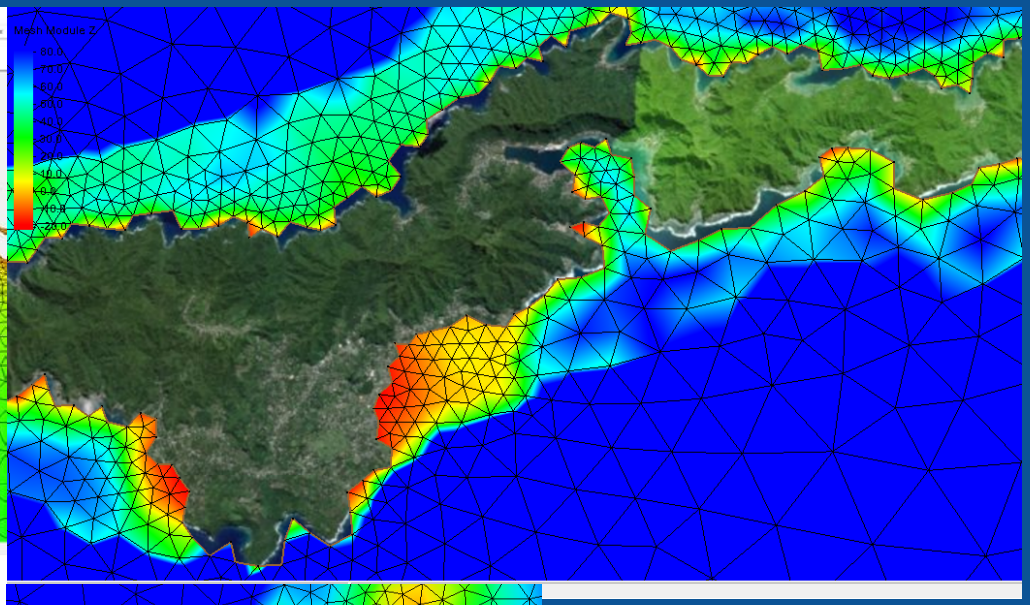
- Covers Palau, Mariana Islands, Fed State of Micronesia, Marshall Islands, Wake Island
- 234K nodes
- Up to 200 m coastal resolution
- Overland up to 10m elevation
- 89 point output

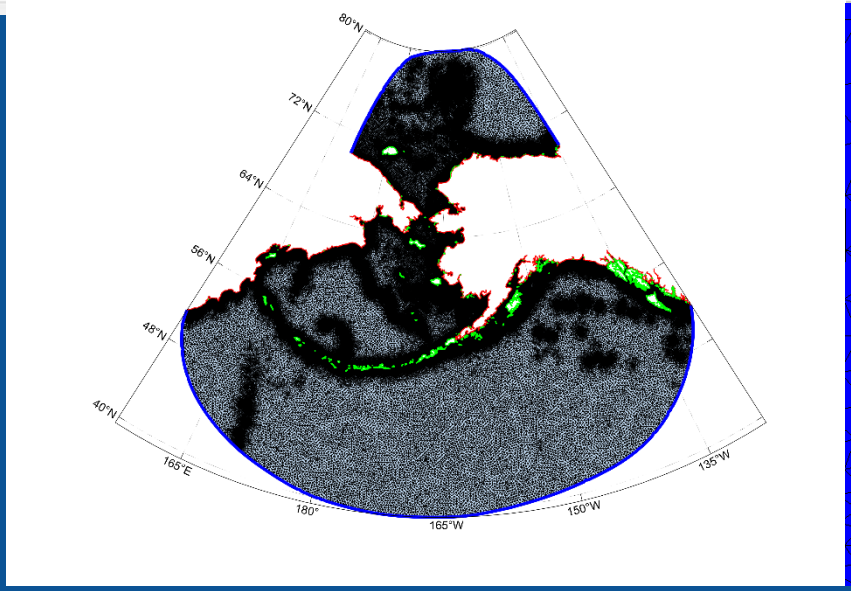


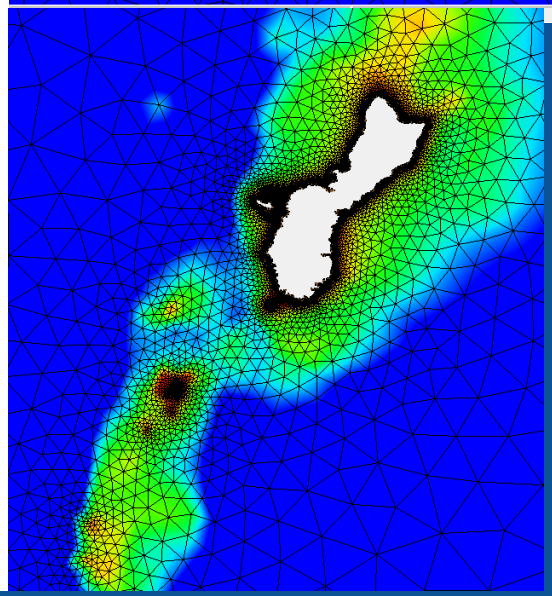
Global ESTOFS Description

OceanMesh2D



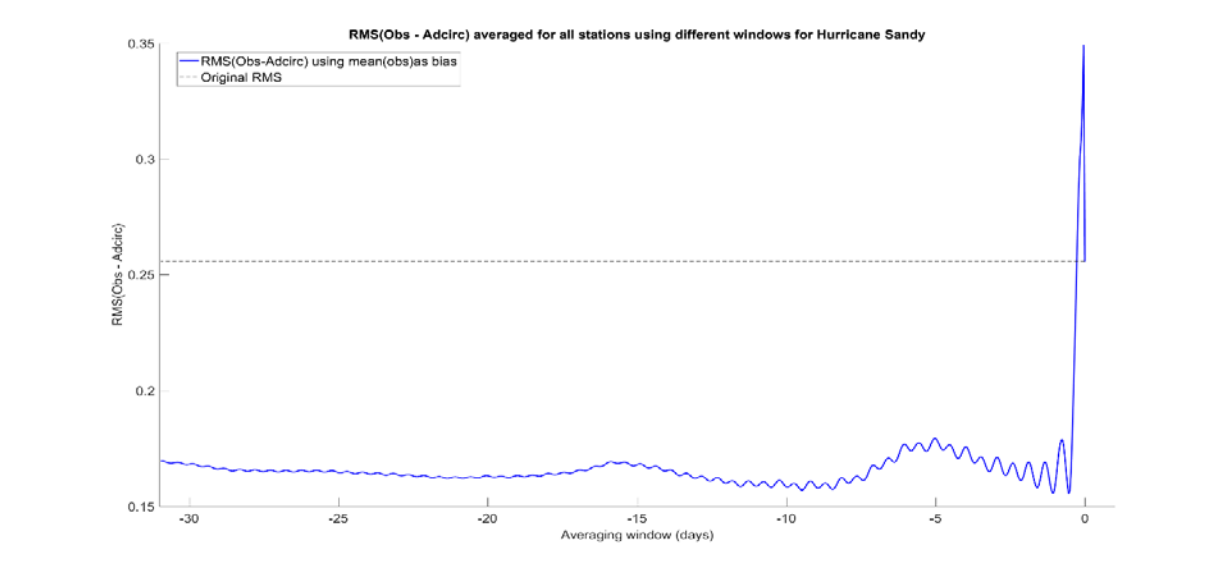






Bias Correction Implementation

- Determining the time scale for offset computations
  - HF variability on shorter scales (1-2 days)
  - Seasonal variability on 2+ weeks scales
  - 3-7 days window most relevant to coastal inundation guidance
  - 3 days applies best for rapid tropical and extratropical signals



RMS Reduction for 2012 Sandy Hindcast as a Function of Time-Averaging Window Size

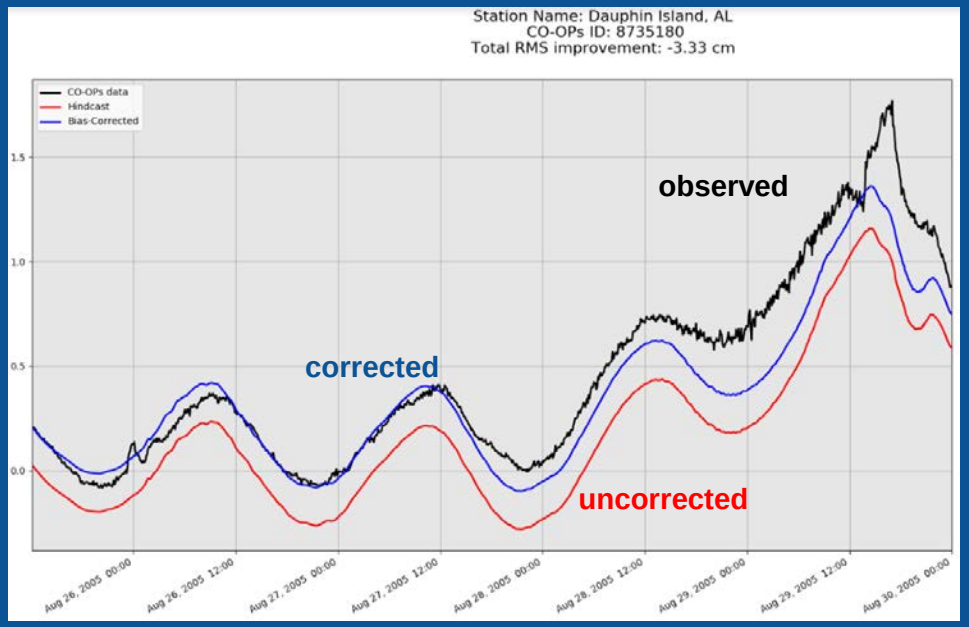
Time-averaging window size was chosen from hours to a month, and the resulting bias was applied to the model as initial offset.

Bias Correction Implementation

- ADCIRC v53+ Pseudo-Pressure Loading option (Luettich et al, AMS 2017)
  - adds another term to actual atmospheric pressure field
  - provides force to maintain water surface offset in place
  - computes using Inverted Barometer relationship (1 mbar ~ 1 cm)

- In operations:
  - computed prior to nowcast
  - ramped in during nowcast
  - persists during the forecast

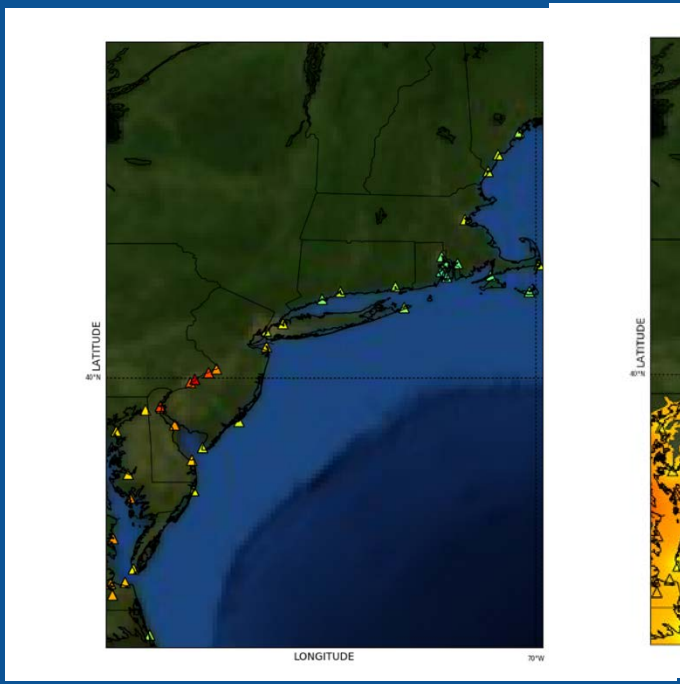
- Application Caveats:
  - Not intended to improve tides
  - Should not “replace” model dynamics



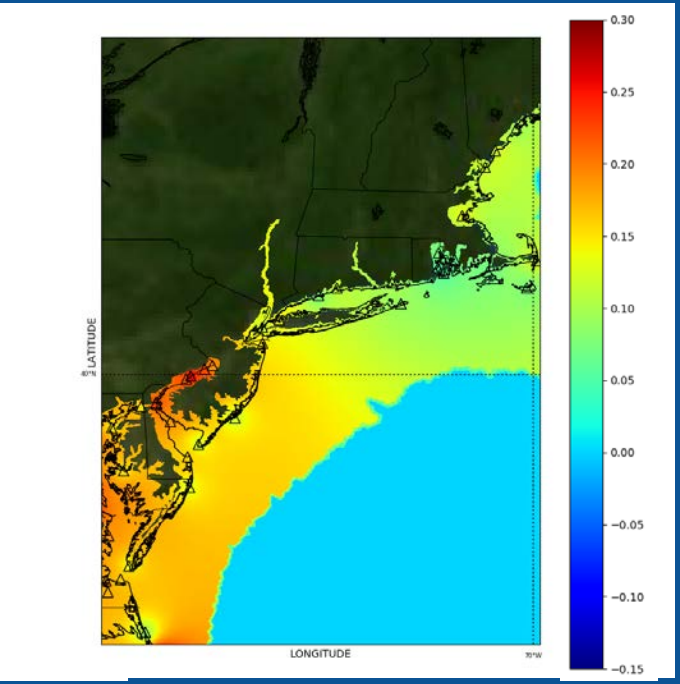
2005 Katrina water levels at Dauphin Island, AL

Bias Correction Implementation

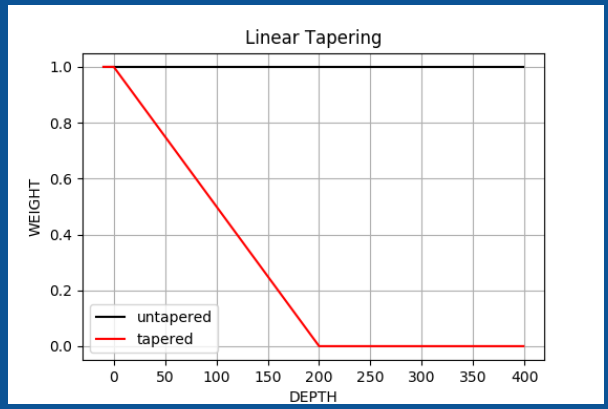
- Spatial Interpolation of the Sparse Values
  - Offsets are computed at CO-OPS tide gauge locations
  - ADCIRC requires offset values at each grid point of the unstructured mesh
  - Use Shepard's IDW method
  - Taper with depth over the continental shelf
  - Taper with distance from the observations



Offset values at CO-OPS tide gauge locations



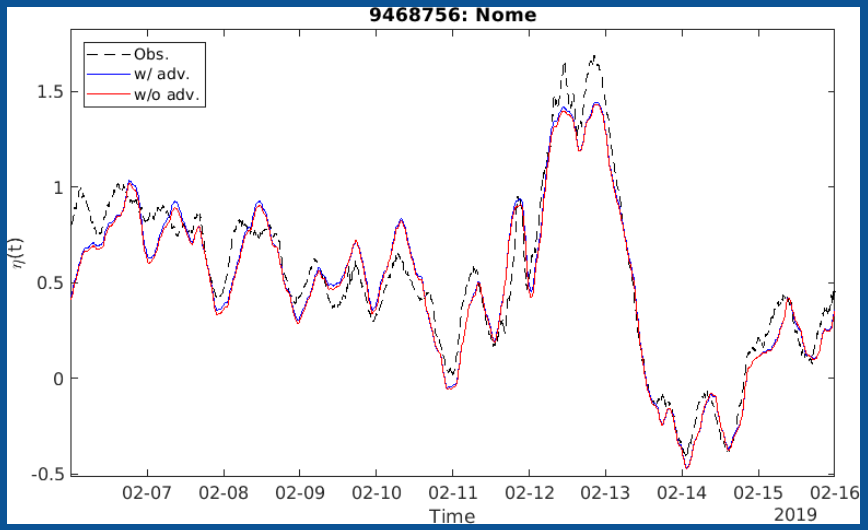
Interpolated offset surface

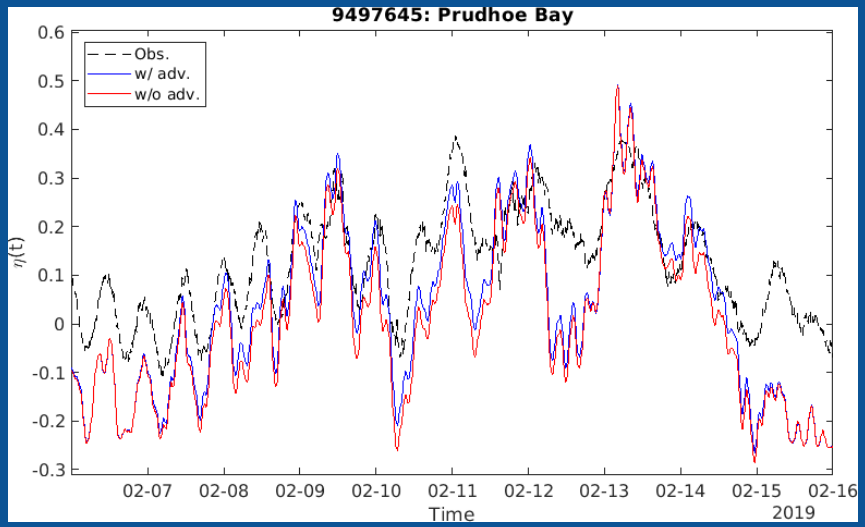


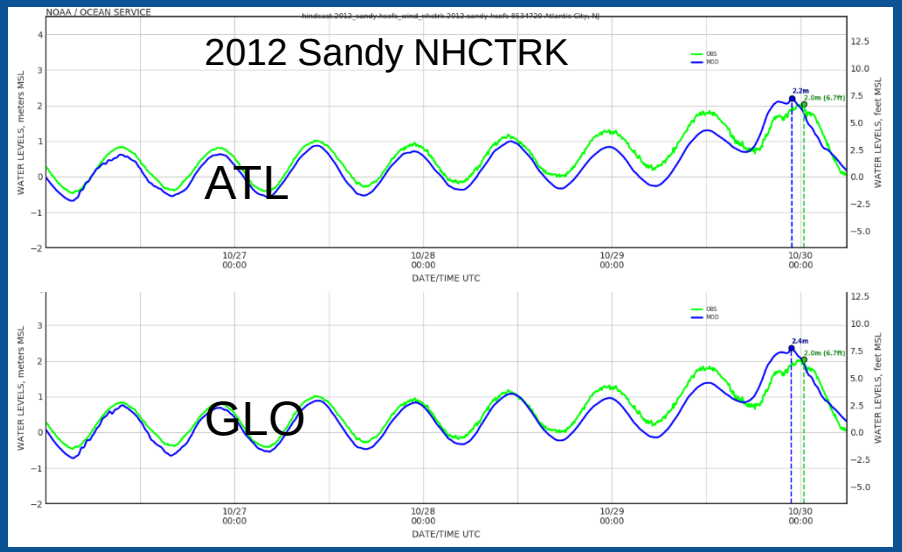
Linear tapering with depth of the IDW result

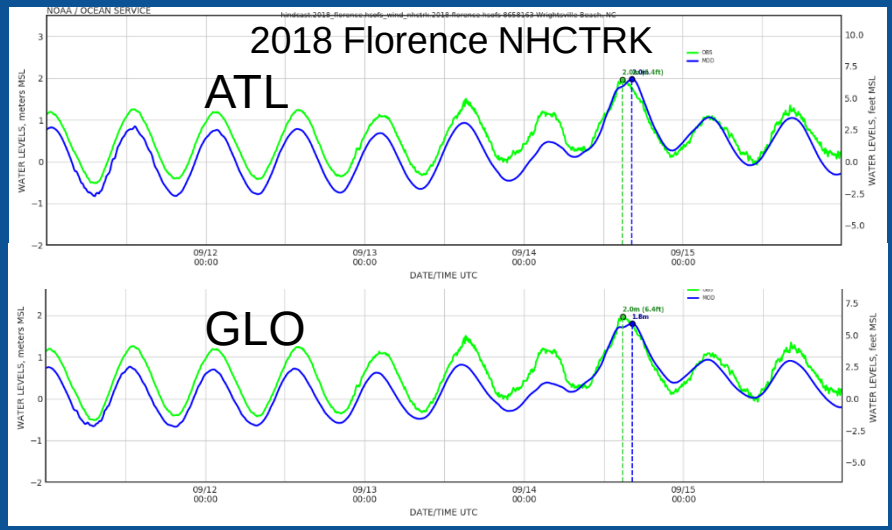
Global ESTOFS Validation

ET winter storm Alaska 2019









Global ESTOFS User Feedback and Evaluation

3 April 2020 – EE Coordination Meeting
3 April 2020 – PNS sent to NWS HQ
8 June 2020 – User Evaluation phase began

Collected responses from:

- Andre Van der Westhuyzen (NWPS, EMC/NCEP)
- Christopher Brenchley (HFO)
- John Bravender (HFO)
- Nelson Vaz (Upton WFO, NY)
- David Vallee (NWS NorthEast River Forecast Center)
- Joe Sienkiewicz (NWS OPC)
- Robert Rohli (LSU)

NWPS Analysis:

Andre's slidedeck