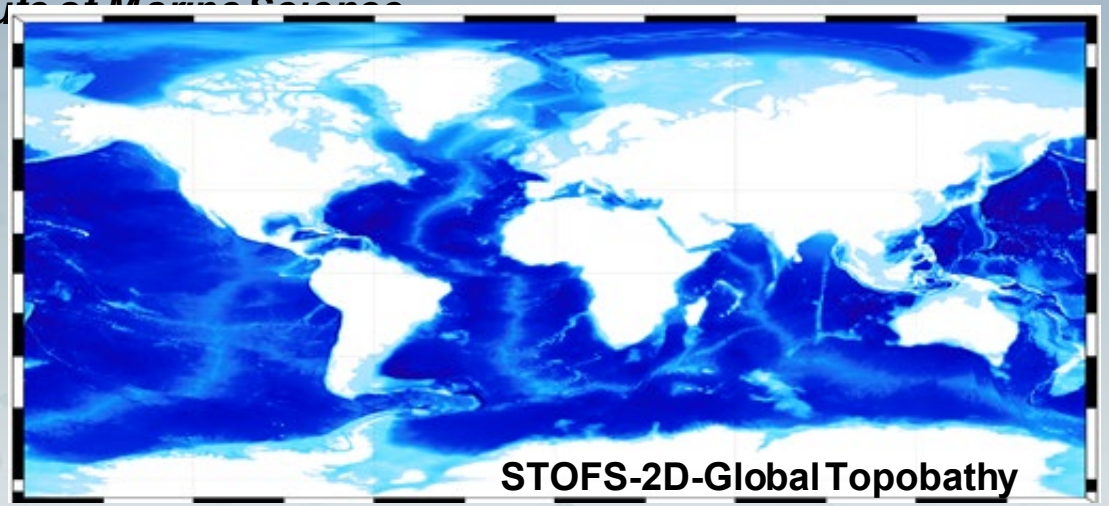
NOAA/NOS/OCS Surge & Tide Operational Forecast System (STOFS)

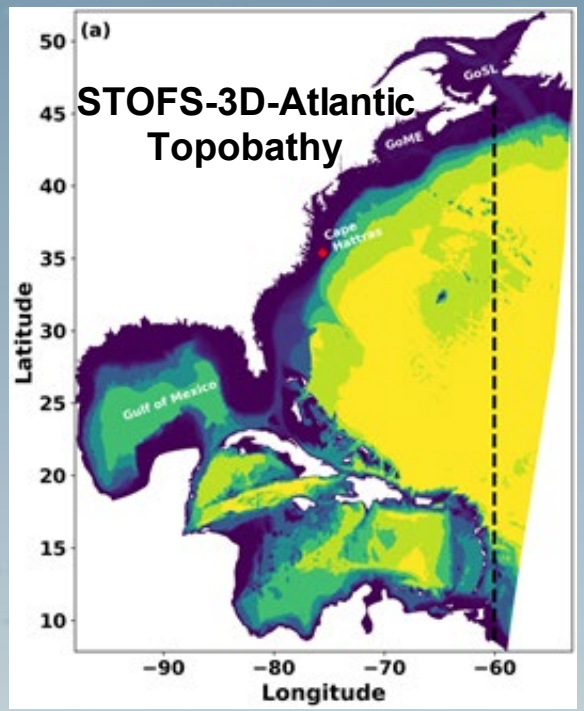
HSRP Update

***Greg Seroka**, **Saeed Moghimi**, Yuji Funakoshi, Zizang Yang, Lei Shi, Edward Myers, Corey Allen*
Coastal Marine Modeling Branch, Coast Survey Development Laboratory,
Office of Coast Survey, National Ocean Service

Academic partners:
Coleman Blakely, Dylan Wood, Aman Tejaswi, Maria Teresa Contreras Vargas, Joannes Westerink
University of Notre Dame

Fei Ye, Linlin Cui, Hao-Cheng Yu, Y. Joseph Zhang
Virginia Institute of Marine Science





NOAA Hydrographic Services Review Panel – Fall 2023
September 28, 2023

It takes a village to raise a child …

NOS Storm Surge Modeling Team

Saeed Moghimi, Panagiotis Velissariou, Soroosh Mani, Yuji Funakoshi, Greg Seroka, Lei Shi, Georgios Britzolakis, Zizang Yang, Bahram Khazaei, Fariborz Daneshvar, Yunfang Sun, Yi-Cheng Teng, Edward Myers, Corey Allen

Academic partners (>20 PIs, Scientists, Postdocs and PhD students)

- **University of Notre Dame**
- **Virginia Institute of Marine Science**
- Argonne National Laboratory
- National Center for Atmospheric Research
- Texas Advanced Computing Center
- Columbia River Inter-Tribal Fish Commission
- Louisiana State University
- Sandia National Laboratories
- University of Massachusetts – Dartmouth
- University of North Carolina at Chapel Hill
- Cooperative Institute for Great Lake Research
- Oregon State University

International partners

- Helmholtz-Zentrum Hereon, Germany
- Laboratório Nacional de Engenharia Civil, Portugal
- European Commission Joint Research Centre, Belgium
- International Hydrographic Organization
- United Nations

NOAA and agency partners

- National Ocean Service
  - The U.S. Integrated Ocean Observing System
  - Center for Operational Oceanographic Products and Services
  - National Geodetic Survey
- National Weather Service
  - **National Hurricane Center**
  - Office of Science and Technology Integration
  - Environment Modeling Center
  - Office of Water Prediction
- Oceanic and Atmospheric Research
  - Great Lakes Environmental Research Laboratory
  - Earth Prediction Innovation Center (EPIC)
- U.S. Geological Survey
- U.S. Environmental Protection Agency
- National Science Foundation

Industrial and cooperative partners

- UCAR
- Spatial Front Inc

End Users And Stakeholders

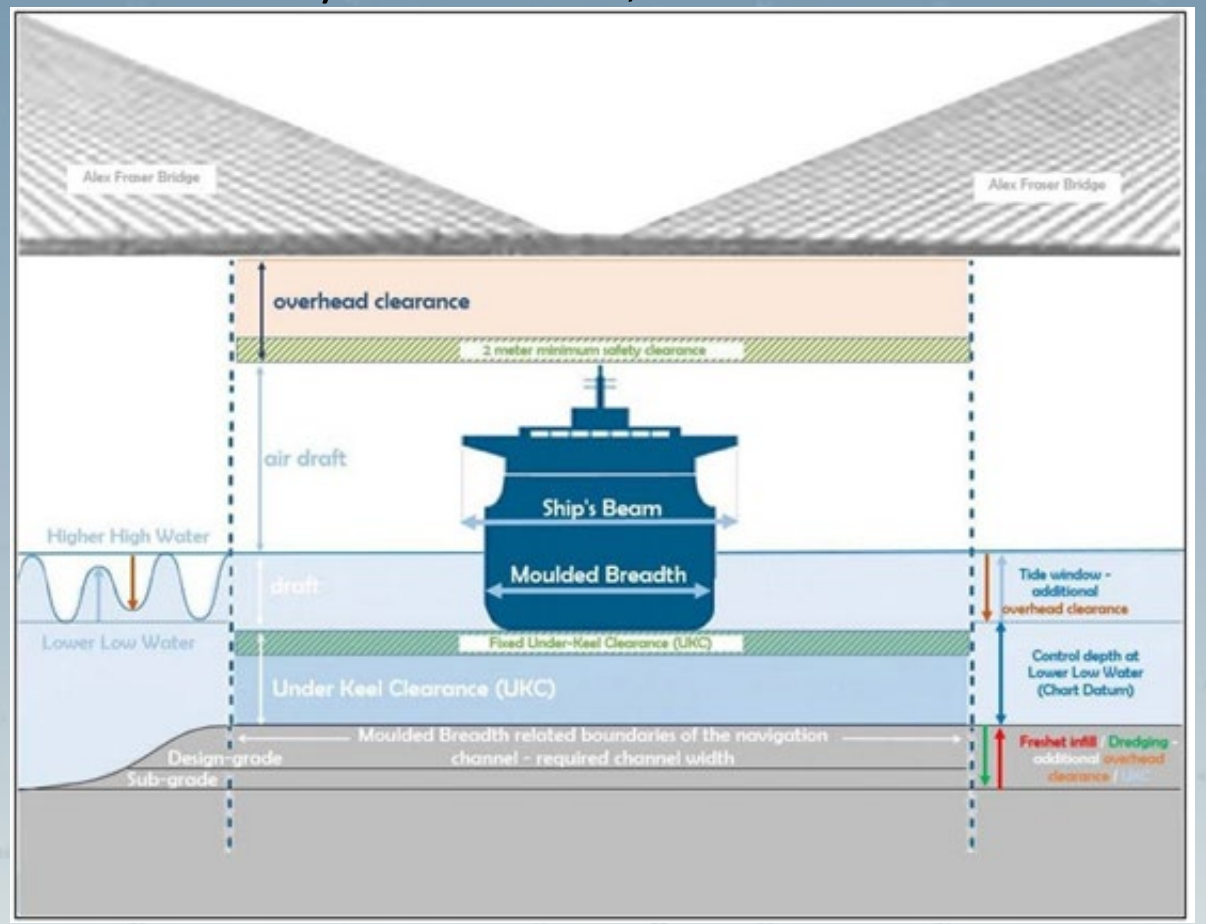
National Weather Service, e.g.

- NOAA Weather Forecast Offices (WFOs) to generate flood forecasts during winter storms
- NOAA National Hurricane Center (NHC) for operational storm surge forecast guidance
- NOAA National Water Center (NWC) and Environmental Modeling Center (EMC)

NWS Coastal Flood Statement

Mariners, e.g.

- Pilots of ships to navigate into ports safely and efficiently based on tide, current forecasts



Under keel clearance management system

NOS Storm Surge Modeling Team

Products and services

Operational

- **Surge & Tide Operational Forecast System (STOFS)**
  - Two-dimensional global ***(STOFS-2D-Global)***
  - Three-dimensional (density-layered) coastal storm surge including inland hydrology extremes ***(STOFS-3D-Atlantic)***

Pre-Operational

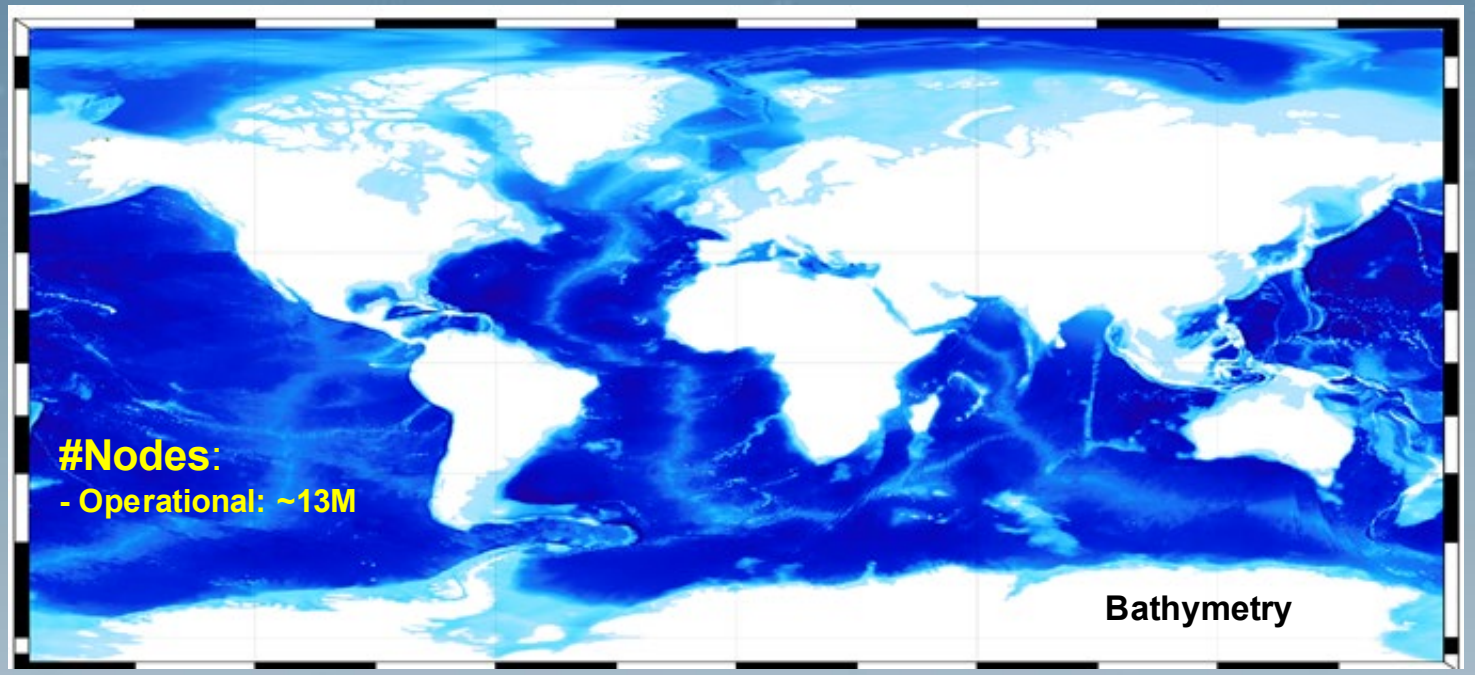
- **Surge & Tide Operational Forecast System (STOFS)**
  - Three-dimensional guidance system for Pacific Ocean in 2024 ***(STOFS-3D-Pacific)***

Research and development

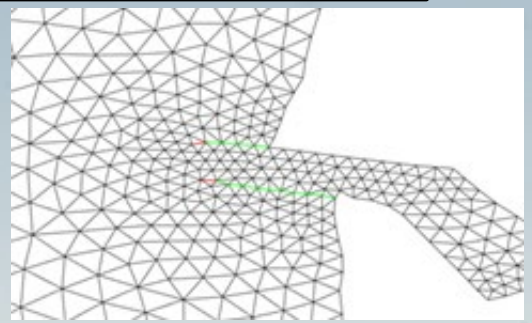
- Support development of the NOAA's Next-generation Probabilistic storm surge model (NHC-Psurge)
- Automated on-demand unstructured mesh generation (OCSMesh)
- Development of the NOAA's Next-generation Coastal Ocean Model Coupling infrastructure (UFS-Coastal)
- Supporting DoS Overseas Buildings Operations
- Three-Dimensional Guidance System for Alaska ***(STOFS-3D-Alaska)***

Three-dimensional coastal storm surge including inland hydrology extremes (***STOFS-3D-Atlantic v1.1.1***)

STOFS-2D-Global v1.1.1→ v2.1.0 Description



- **Core Model:** ADCIRC -- **AD**vanced **CIRC**ulation Model for Oceanic, Coastal and Estuarine Waters
- Driven by **GFS** winds, MSLP, ICE
- 4 cycles/day
- 6 hr nowcst, **7.5 day fcst water levels**: tides, surge, combination
- **Grid resolution:** coastal resolution at least 1.5 km globally, up to ~30-120 m for US coasts, AK, HI



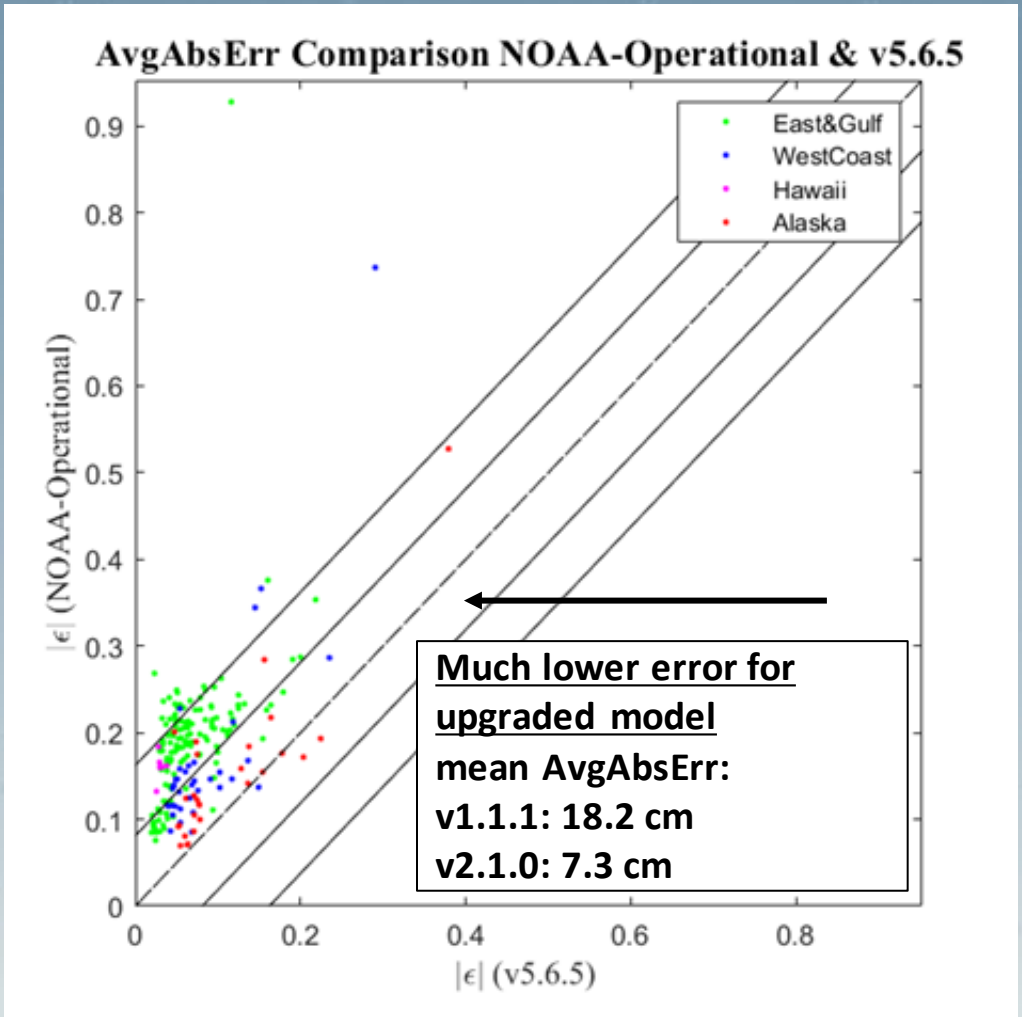
Tillamook Bay, Pacific
(~50m resolution mesh + **Jetties**)

Operational: v1.1.1
Upgrade (v2.1.0, implemented ~Dec 2023/Jan 2024):

- Include 5-day nowcast **bias correction at stations** where NOS/CO-OPS observations are available
- **Improved atmospheric (GFS) forcing** temporal resolution (hourly out to 5 days, then 3 hourly; currently it is all 3 hourly)
- **Improvements to coastal topobathy, mesh,** and friction

STOFS-2D-Global v1.1.1→ v2.1.0 Skill Assessment

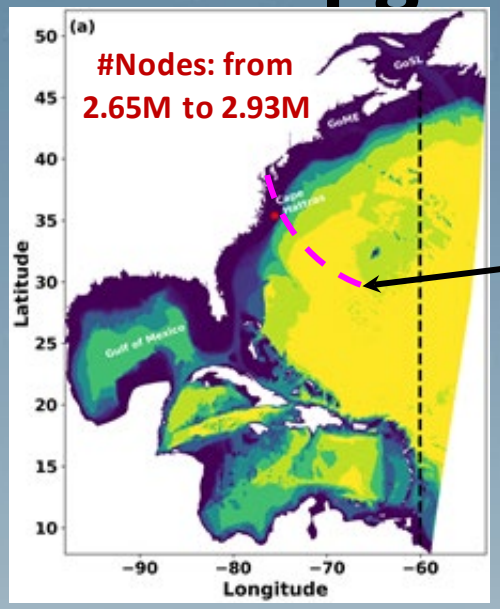
- 1 year hindcast (2017) performed, comparing operational to upgraded model (units meters)
- v1.1.1 (operational, referred to as "NOAA-Operational") v2.1.0 (upgraded, referred to as "v5.6.5 (Barotropic)"



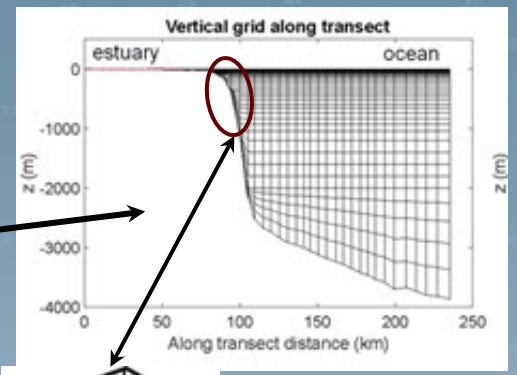
- STOFS-2D-Global is the most accurate global non-data-assimilated model with an **M2 tide mean absolute error in deep water of 1.95 cm.**
- Along the U.S. East/Gulf of Mexico coast the M2 tide errors at available NOS tidal stations are summarized as
  - R2 = 0.9848,
  - mean absolute error = 2.5 cm,
  - normalized RMS error = 0.089.

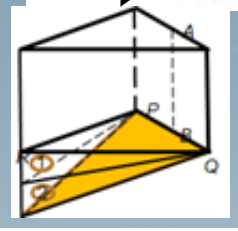
STOFS-3D-Atlantic v1.1.1→ v2.1.0 Upgrade

- **Core Model: SCHISM** - **S**emi-implicit **C**ross-scale **H**ydroscience **I**ntegrated **S**ystem **M**odel
- Driven by **GFS, HRRR** (Atm + precip) and **NWM**
- Non-tidal (elevation, velocity), temp and salt boundary condition from **RTOFS**
- Tidal boundary condition: **FES 2014**
- 1 cycle/day; 24 hr nowcst, **from 2 to 4 day fcst water levels, currents, temperature and salinity**
- **Grid resolution:** ~2-7 km in the ocean; 50-200 m in the main channels; **down to <10 m** in small streams and levees

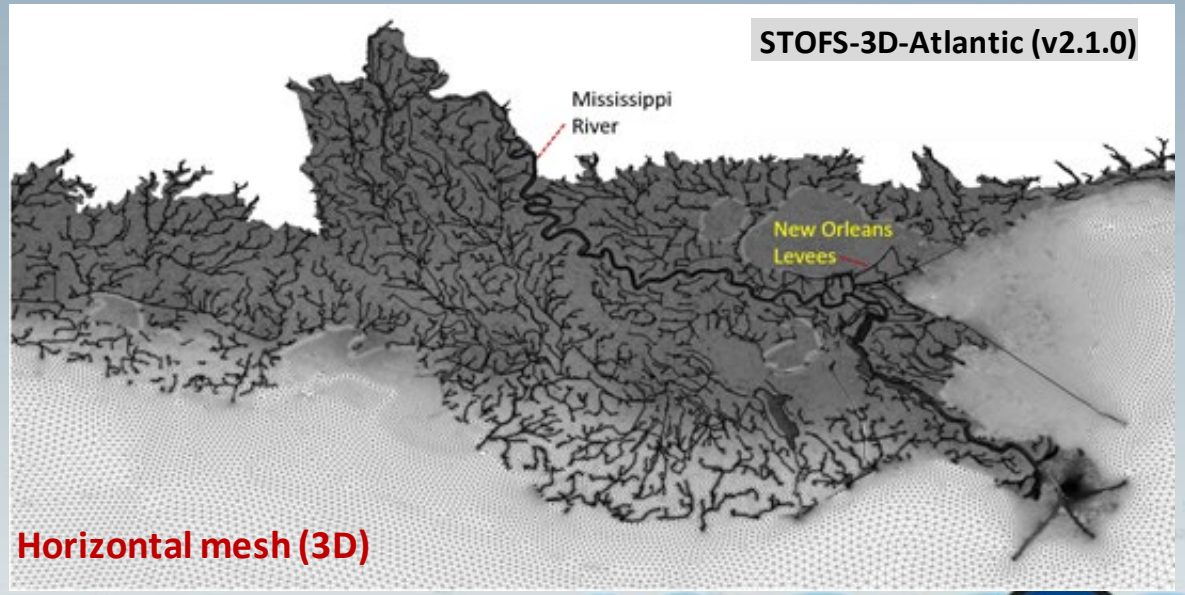


Vertical mesh (3D)





Terrain following **vertical mesh with varying number of layers** (LSC2): 11 on average



Upgrades for v2.0.0:

- **Major improvements to watershed mesh** (better resolving of river channels). Great South, Shinnecock Bays mesh improved
- **Incorporation of satellite altimetry obs (ADT).** Also, **xGEOID20b** used instead of NAVD88 for improved model initialization and vertical datum referencing
- Extending forecast horizon from 48 to **96 hours**
- **Expanding model coverage east and north** to include St. Lawrence R, improved boundary conditions

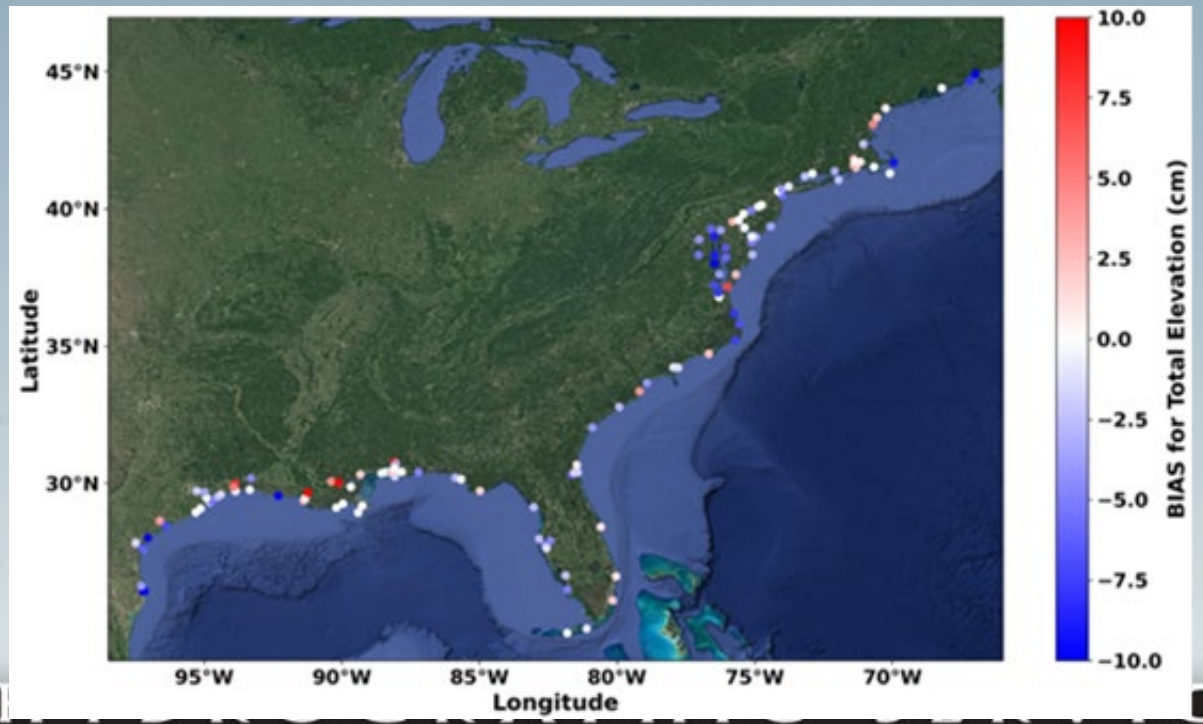
STOFS-3D-Atlantic v1.1.1→ v2.1.0 Skill Assessment

- **1 year hindcast (2015) performed, comparing operational to upgraded model**

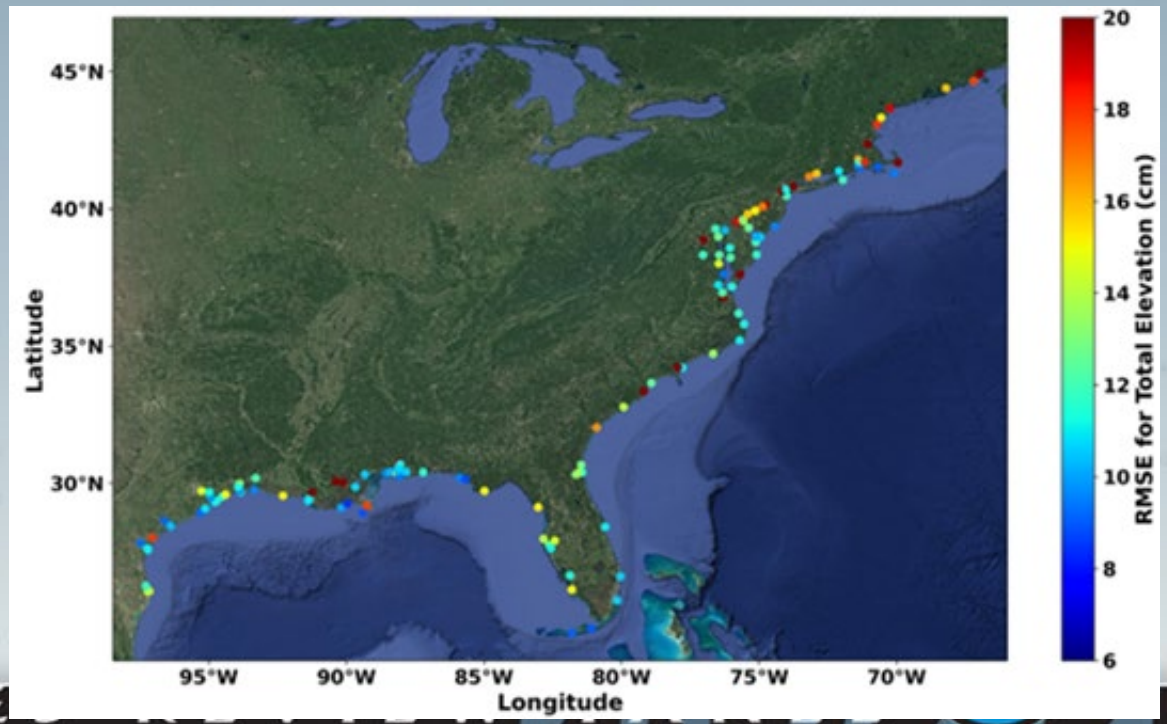
Overall statistics for total elev at all CO-OPS stations (uRMSE: unbiased RMSE; CC: correlation)

	CC	BIAS (cm)	RMSE (cm)	URMSE (cm)
v2.1.0	0.89	-1.8	14.0	13.1
v1.1.1	0.82	3.0	16.9	13.8

Bias v2.1.0



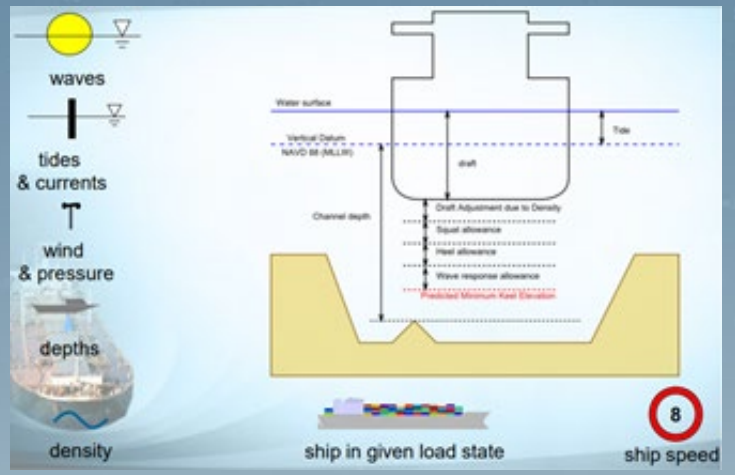
RMSE v2.1.0

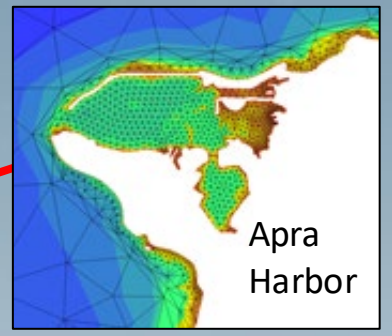


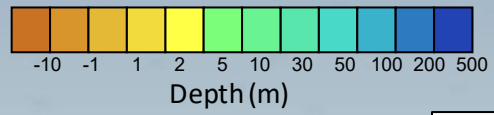
STOFS-3D-Pacific (Pre-Operational)

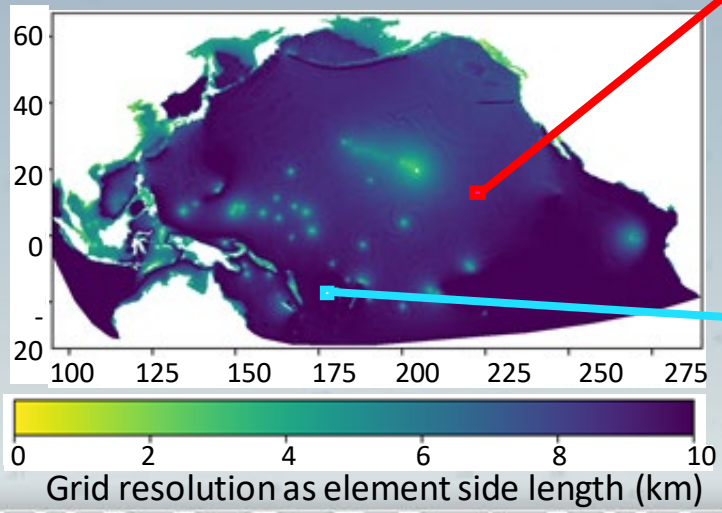
Pacific Ocean enhancements to STOFS:

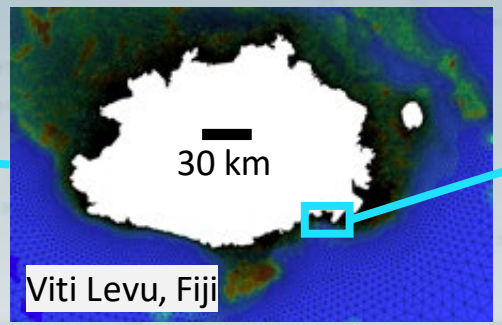
- area of high priority
- higher resolution, improved mesh in key areas
- improved bathymetry
- **ocean model enhancements to provide not only water level forecast guidance but also surface currents for navigation**
- **end goal is to support under keel clearance, route planning for key Pacific ports**

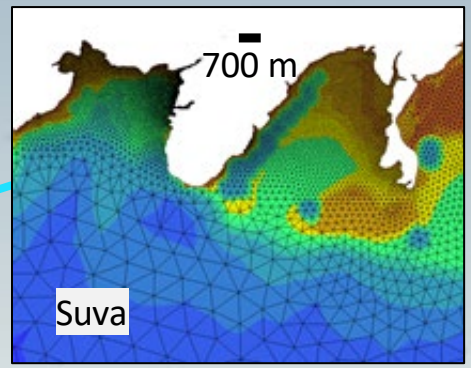






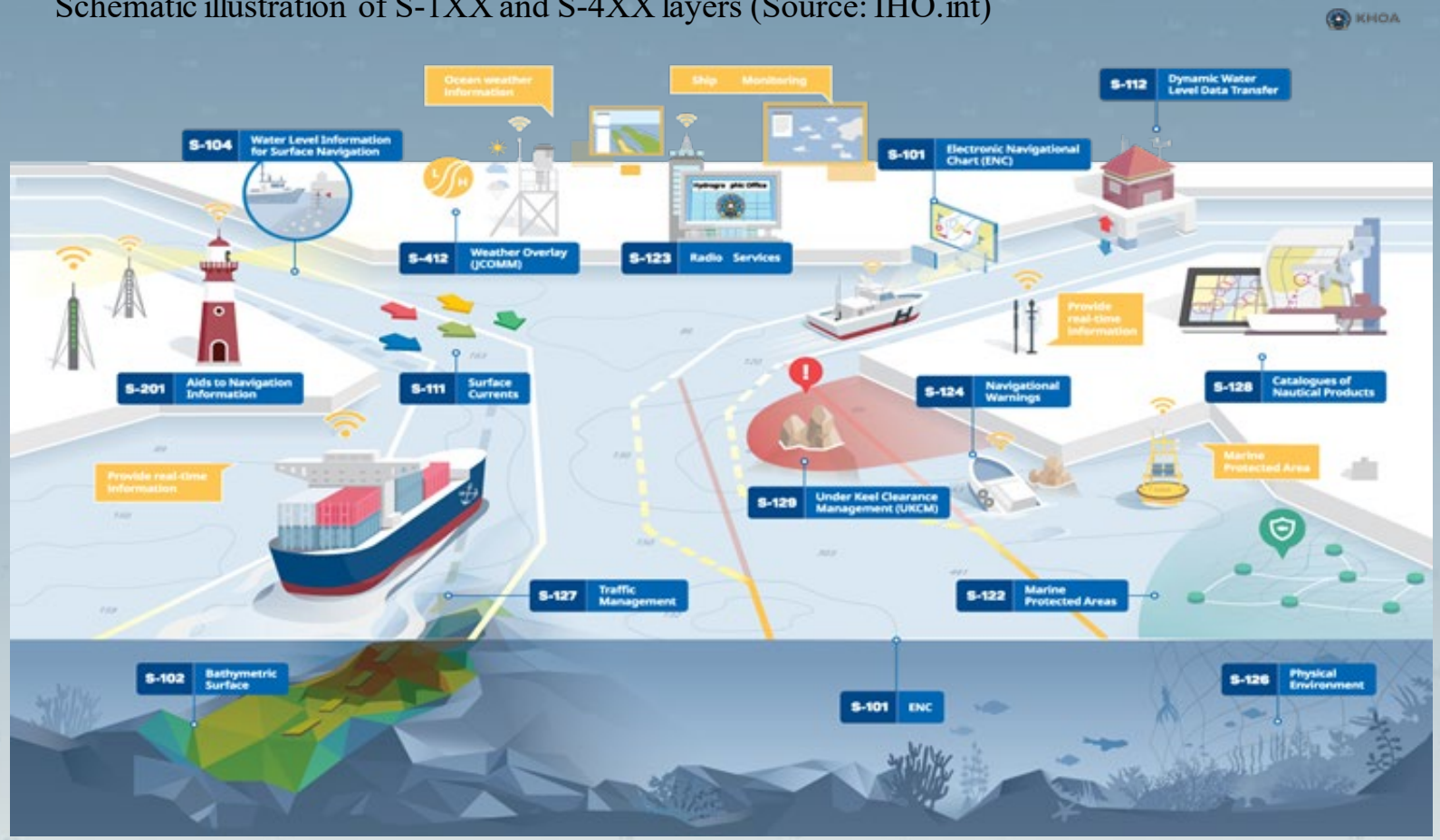






Precision Marine Navigation

Schematic illustration of S-1XX and S-4XX layers (Source: IHO.int)



Electronic Chart Display and Information System (ECDIS) Layers

IHO: (S-101 to S-199)

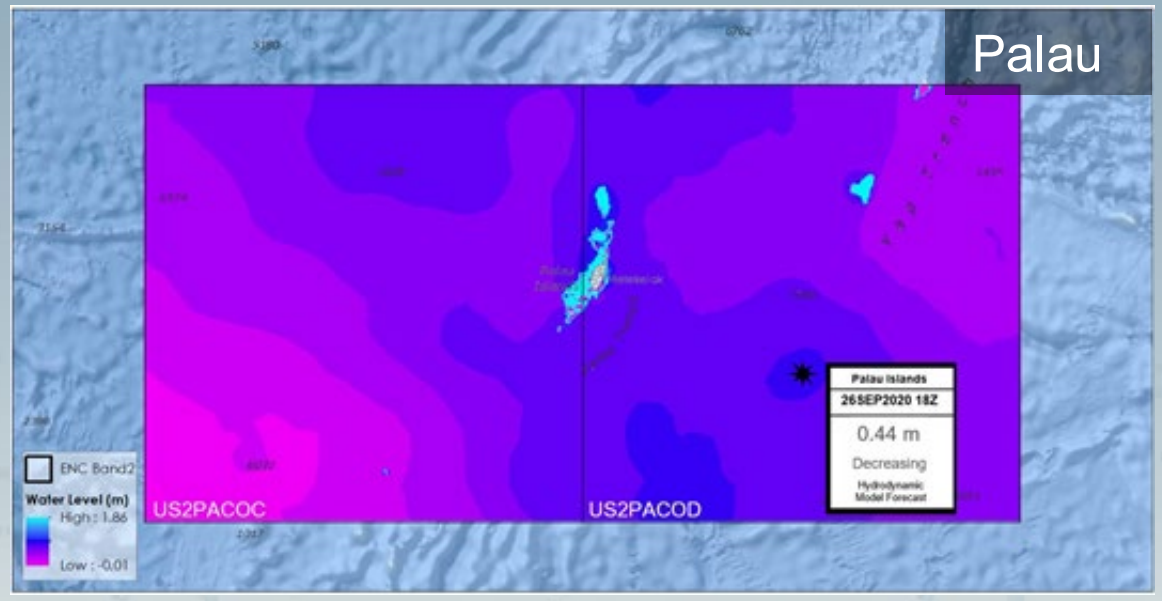
- S-101 Electronic Navigational Chart (ENC)
- S-102 Bathymetric Surface
- S-103 Sub-surface Navigation
- **S-104 Water Level Information for Surface Navigation – in progress with NGS and CO-OPS**
- **S-111 Surface Currents**

WMO/IOC: (S-411 to S-414)

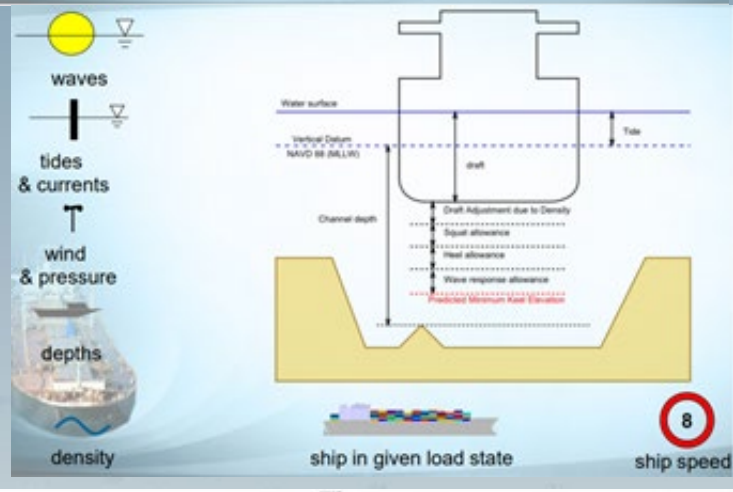
- S-411 JCOMM Ice Information
- S-412 JCOMM Weather Overlay
- S-413 Weather and Wave Conditions
- S-414 Weather and Wave Observations

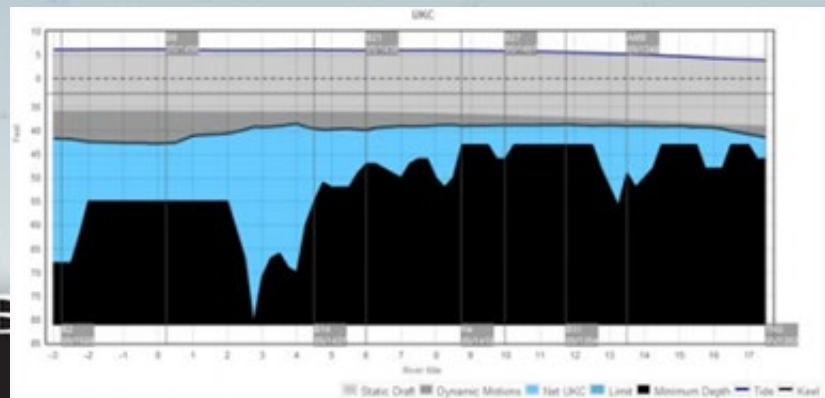
Navigation Support: S-104 Water Levels

- One of our biggest challenges: our coastal ocean models are initially referenced to MSL or NAVD88. **For charting/navigation, we need to use chart datum, e.g. MLLW or LAT.**
- STOFS forecast guidance is being encoded in formats following IHO's S-100 Universal Hydrographic Data framework
- For example, **S-104 water levels relative to chart datum**
- Mariners can use water level forecasts for improved route monitoring

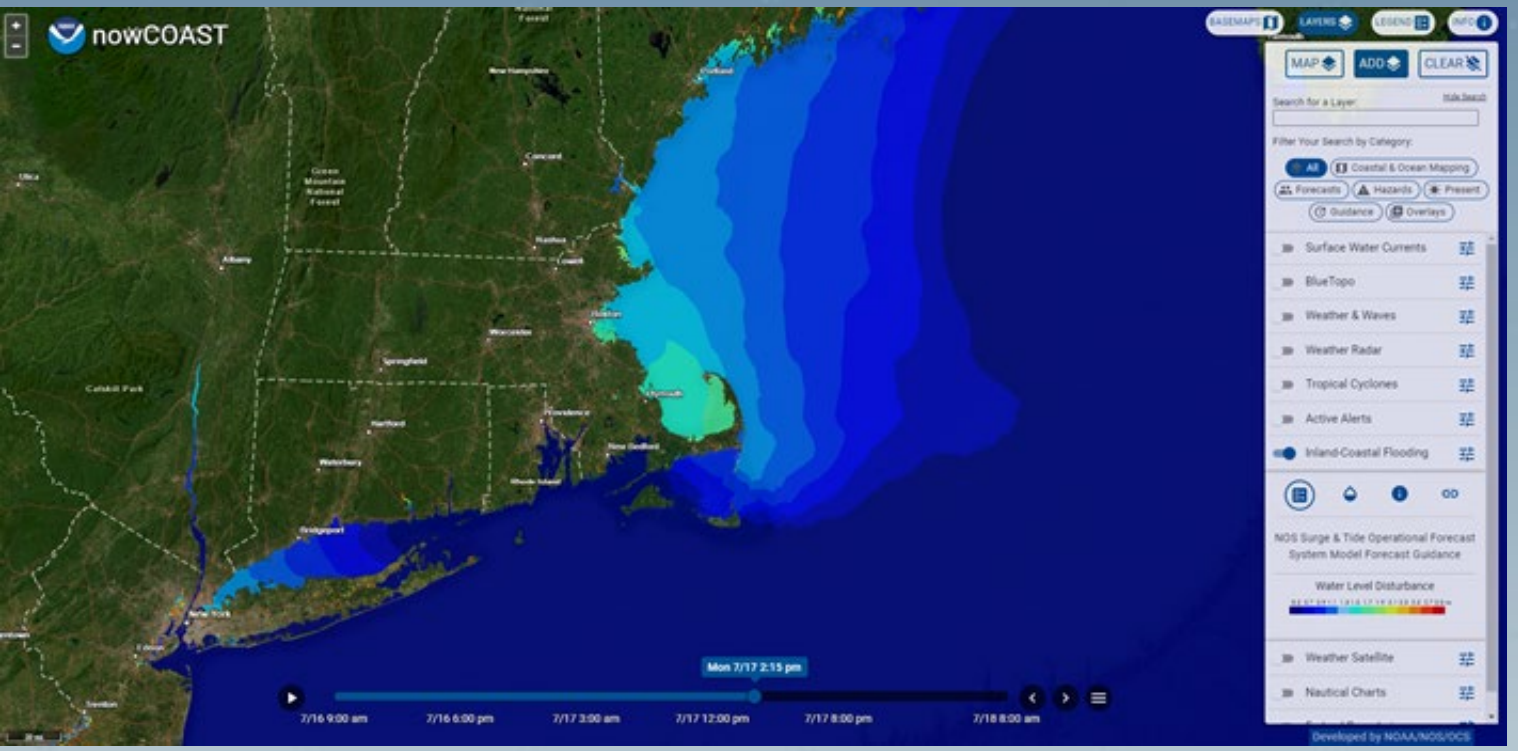


Prototype **S-104 water level forecast guidance from STOFS-2D-Glo, produced and displayed on Electronic Navigational Chart (ENC) Band 2 tiles for Palau in the Pacific Ocean.**

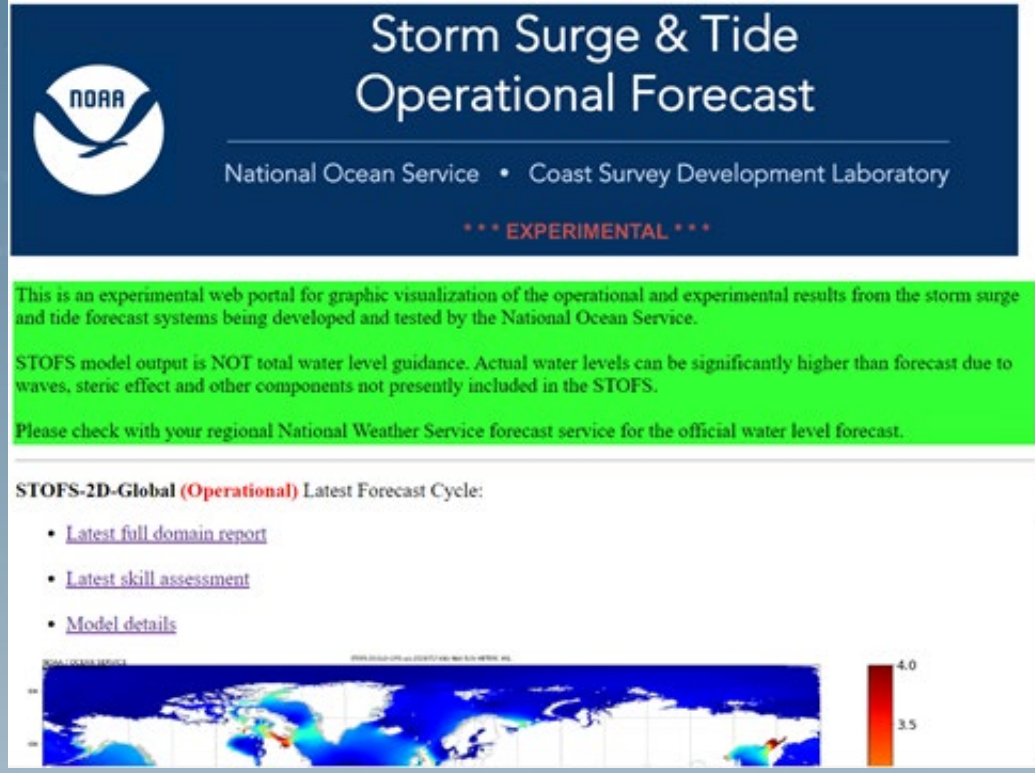




How To Access STOFS Results



nowcoast.noaa.gov
Screenshot of STOFS-3D-Atl water level forecast guidance displaying nowCOAST's map viewer

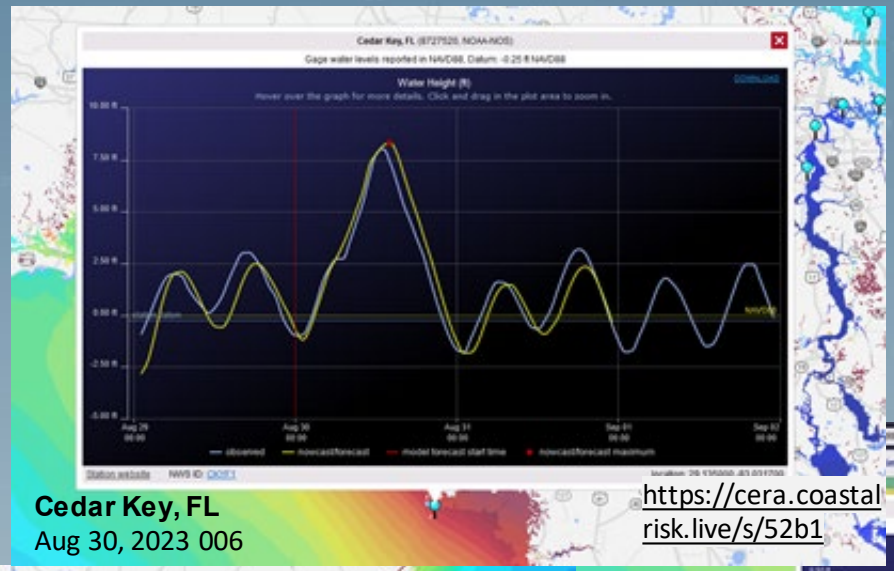


polar.ncep.noaa.gov/estofs/
Screenshot of experimental STOFS landing page

Other options:
National Weather Service (NWS) Ocean Prediction Center:
https://ocean.weather.gov/estofs/estofs_surge_info.php

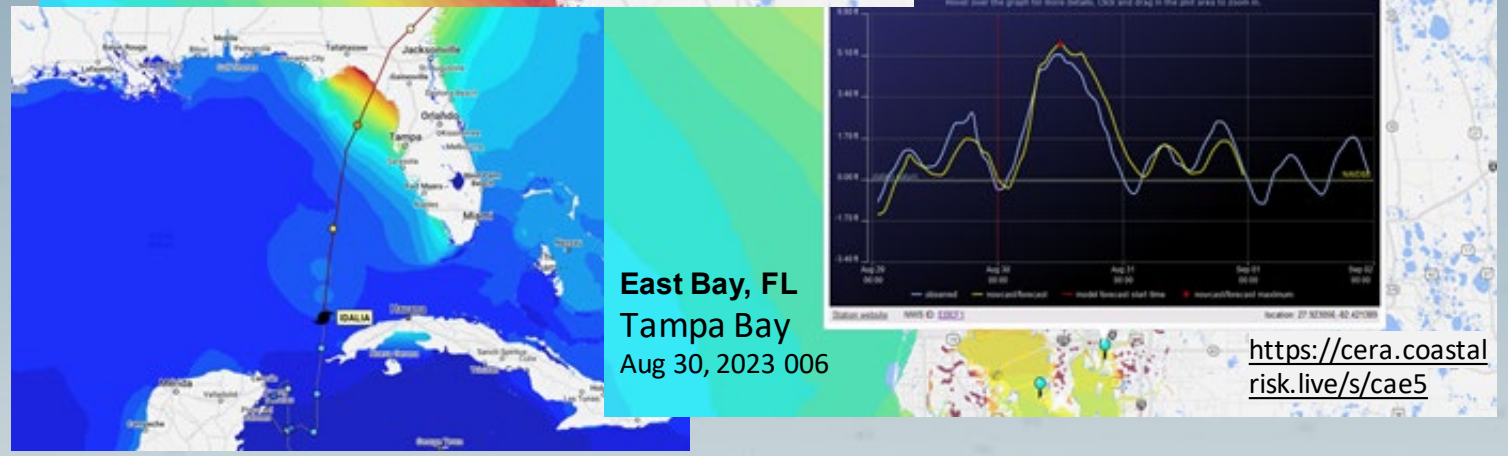
NWS NOMADS:
https://nomads.ncep.noaa.gov/

How To Access STOFS Results



Cedar Key, FL
Aug 30, 2023 006

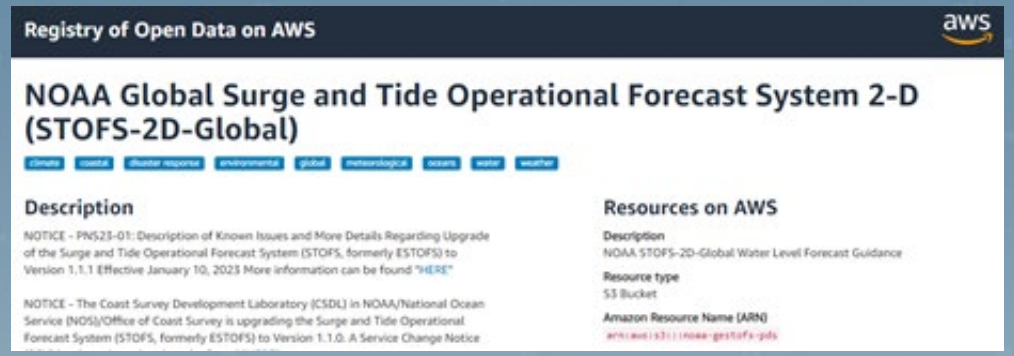
https://cera.coastalrisk.live/s/52b1



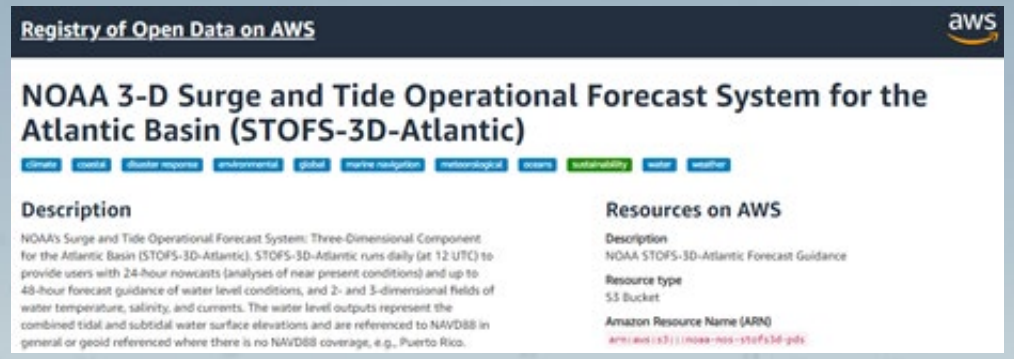
East Bay, FL
Tampa Bay
Aug 30, 2023 006

https://cera.coastalrisk.live/s/cae5

https://cera.coastalrisk.live/
(Username: nos.surge@noaa.gov Password: nos.surge)
Screenshots of STOFS-3D-Atl water level forecast guidance for Idalia (2023)



registry.opendata.aws/noaa-gestofs
Screenshot of STOFS-2D-Glo output on Amazon cloud (AWS) via NOAA Open Data Dissemination



registry.opendata.aws/noaa-nos-stofs3d
Screenshot of STOFS-3D-Atl output on Amazon cloud (AWS) via NOAA Open Data Dissemination

Thanks for your attention!

Contacts

STOFS-2D-Global
Yuji.Funakoshi@noaa.gov

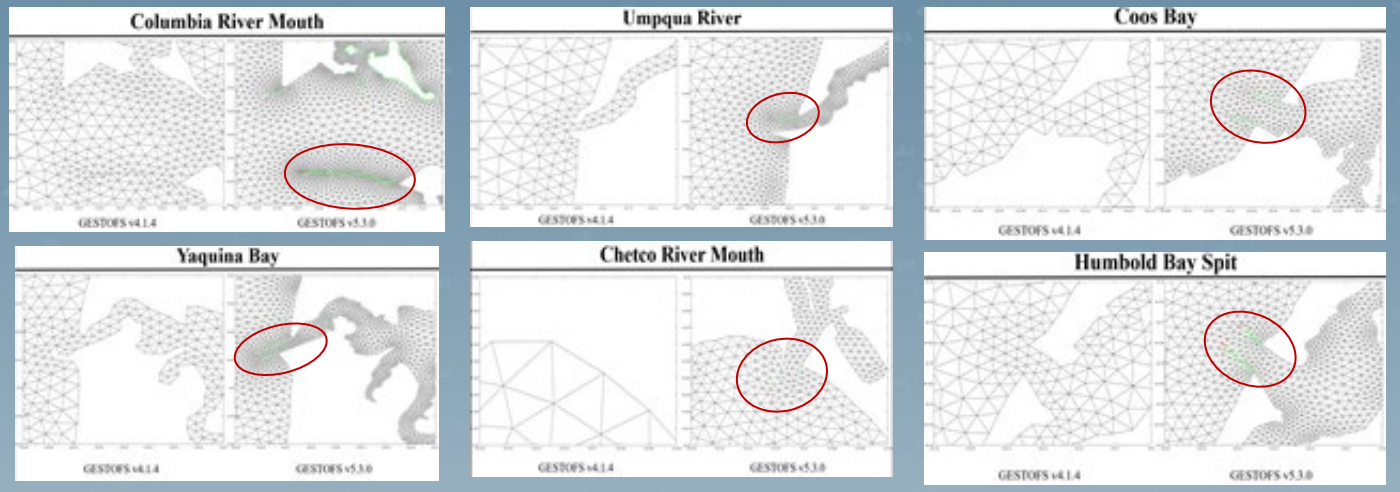
STOFS-3D-Atlantic
Zizang.Yang@noaa.gov

STOFS-3D-Pacific
L.Shi@noaa.gov

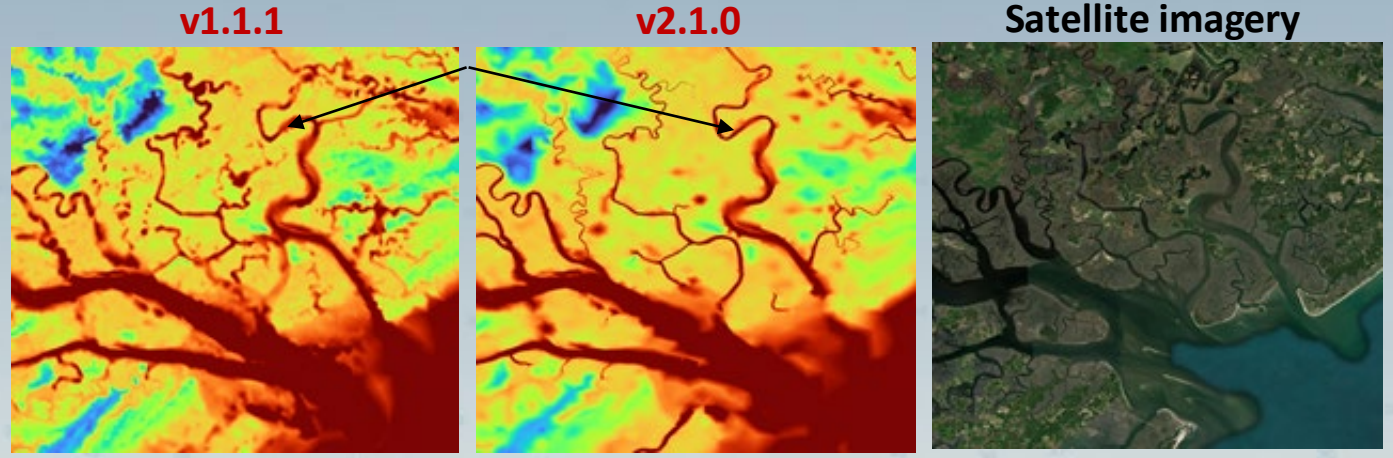
General STOFS related requests
Gregory.Seroka@noaa.gov
Saeed.Moghimi@noaa.gov

nowcoast.noaa.gov
polar.ncep.noaa.gov/estofs/
https://cera.coastalrisk.live/
https://registry.opendata.aws/noaa-nos-stofs3d/
https://registry.opendata.aws/noaa-gestofs/

STOFS-2D-Global: resolving West Coast inlets/jetties



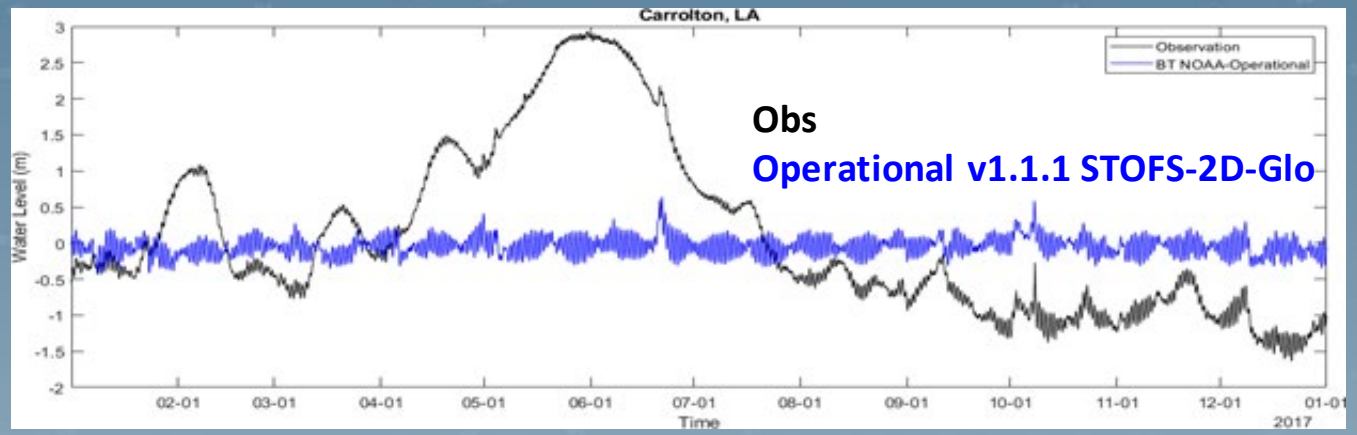
STOFS-3D-Atlantic: watershed mesh improvements

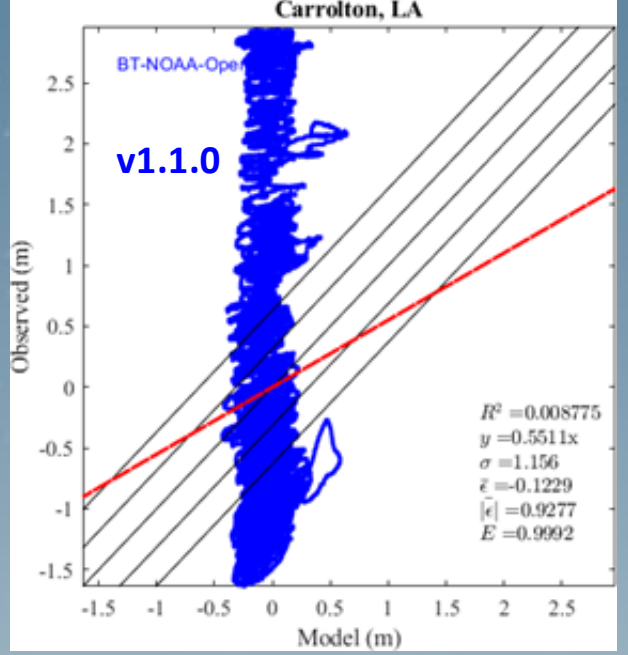


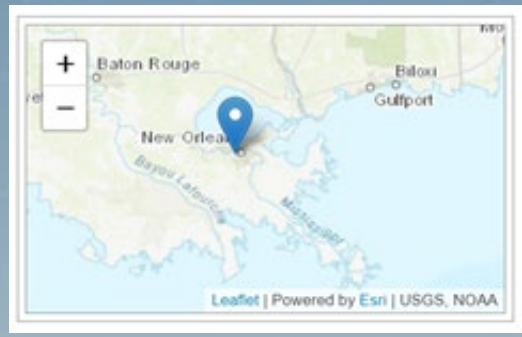
Using 1D NWM segments to guide the mesh generation

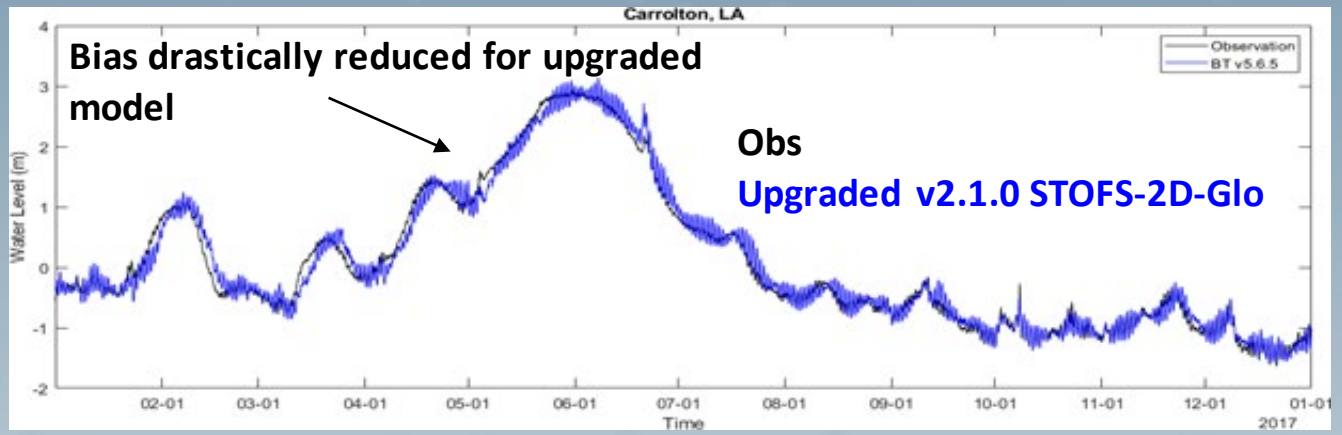
2D rivers, directly based on DEM

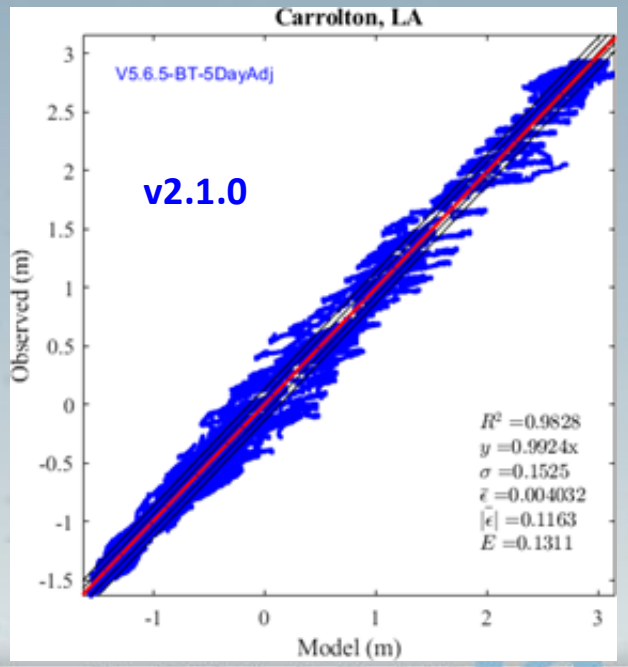
Supplementary Slides

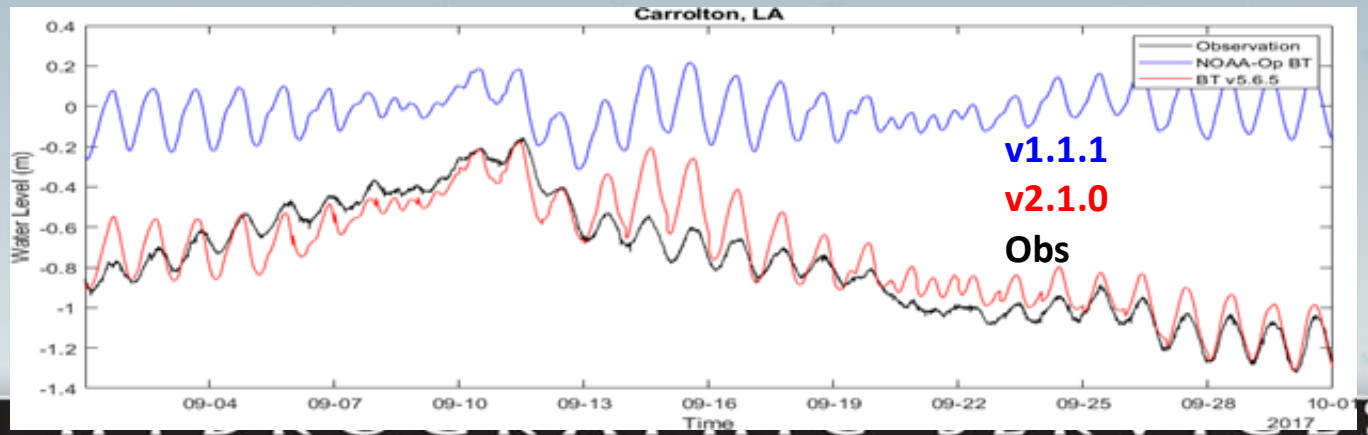

Carrolton, LA
Observation
BT NOAA-Operational
Water Level (m)
Time
2017
Obs
Operational v1.1.1 STOFS-2D-Glo

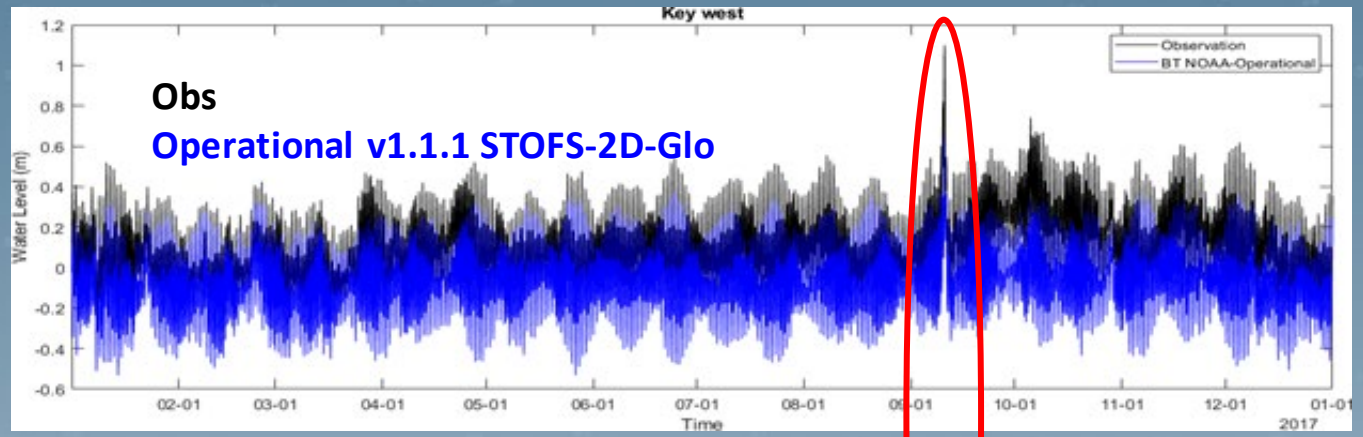

Carrolton, LA
BT-NOAA-Ope
v1.1.0
Observed (m)
Model (m)
R^2 =0.008775
y =0.5511x
σ =1.156
$\bar{\epsilon}$ =-0.1229
$|\epsilon|$ =0.9277
E =0.9992

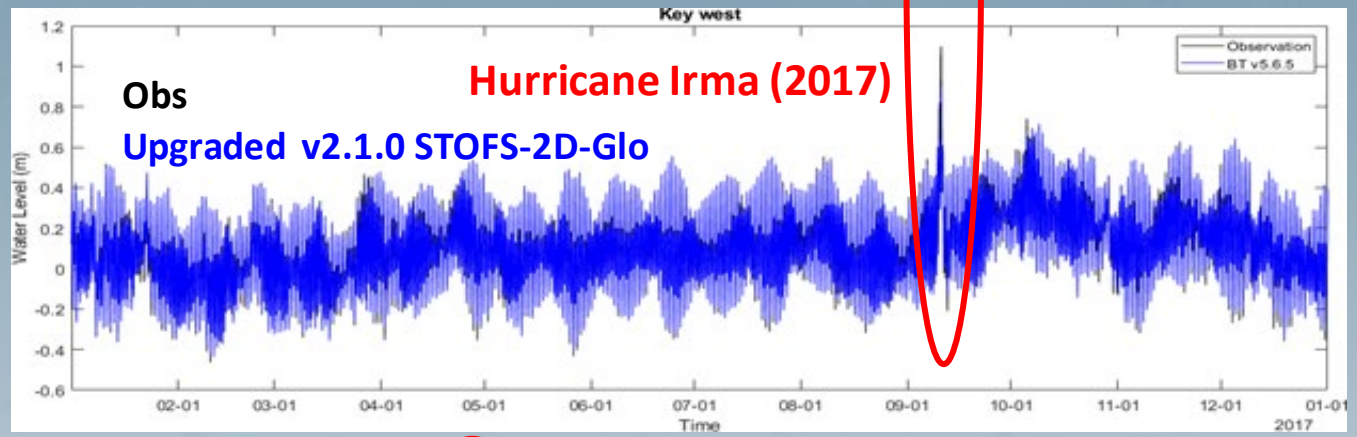

Baton Rouge
Biloxi
Gulfport
New Orlea
Leaflet | Powered by Esri | USGS, NOAA

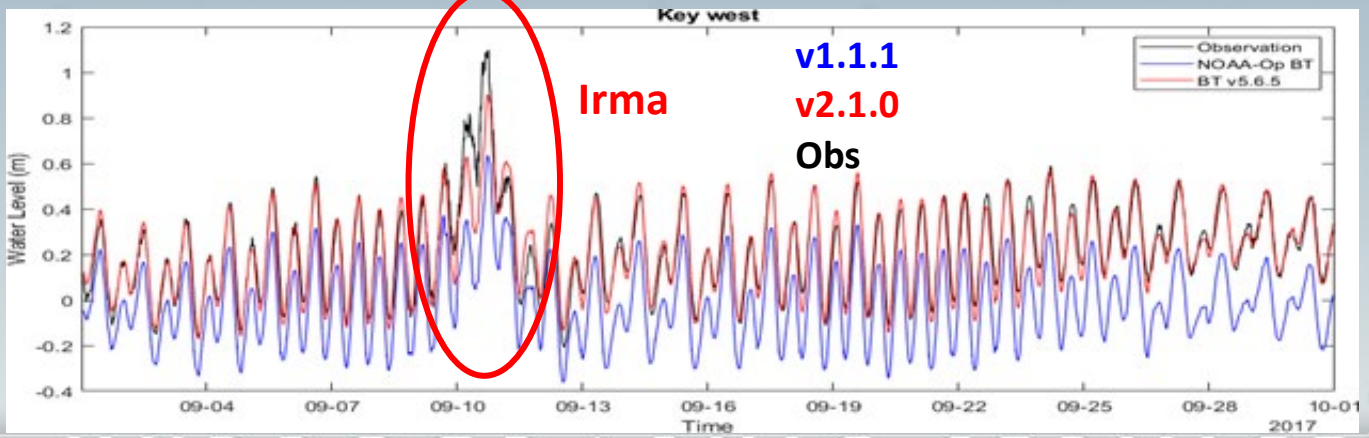

Carrolton, LA
Bias drastically reduced for upgraded model
Observation
BT v5.6.5
Water Level (m)
Time
2017
Obs
Upgraded v2.1.0 STOFS-2D-Glo

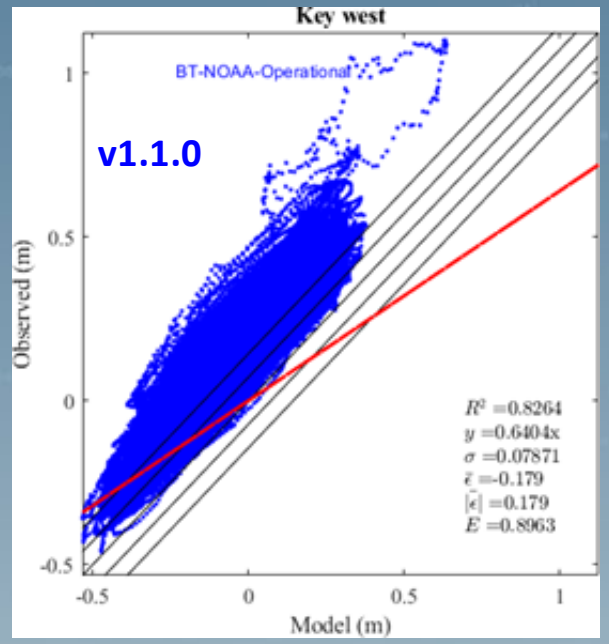

Carrolton, LA
V5.6.5-BT-5DayAdj
v2.1.0
Observed (m)
Model (m)
R^2 =0.9828
y =0.9924x
σ =0.1525
$\bar{\epsilon}$ =0.004032
$|\epsilon|$ =0.1163
E =0.1311

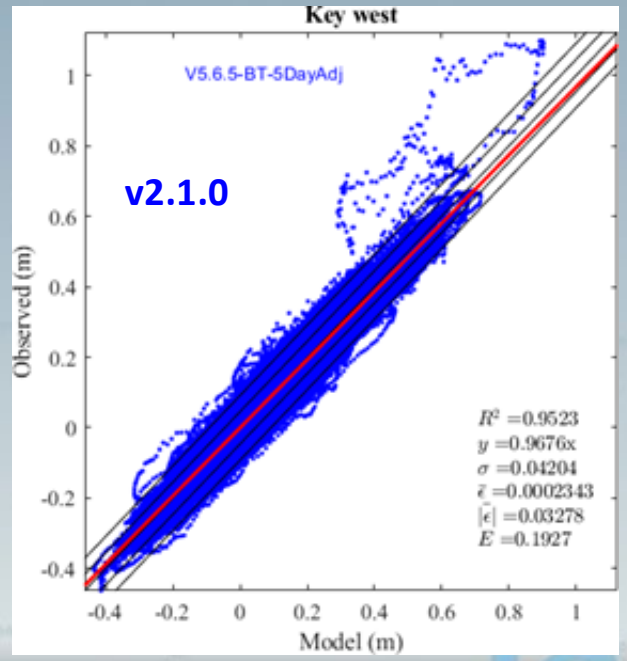

Carrolton, LA
Observation
NOAA-Op BT
BT v5.6.5
Water Level (m)
Time
2017
v1.1.1
v2.1.0
Obs


Key west
Obs
Operational v1.1.1 STOFS-2D-Glo
Observation
BT NOAA-Operational
Water Level (m)
Time
2017


Key west
Obs
Upgraded v2.1.0 STOFS-2D-Glo
Hurricane Irma (2017)
Observation
BT v5.6.5
Water Level (m)
Time
2017


Key west
Irma
v1.1.1
v2.1.0
Obs
Observation
NOAA-Op BT
BT v5.6.5
Water Level (m)
Time
2017


Key west
BT-NOAA-Operational
v1.1.0
Observed (m)
Model (m)
R^2 =0.8264
y =0.6404x
σ =0.07871
$\bar{\epsilon}$ =-0.179
$|\bar{\epsilon}|$ =0.179
E =0.8963


Key west
V5.6.5-BT-5DayAdj
v2.1.0
Observed (m)
Model (m)
R^2 =0.9523
y =0.9676x
σ =0.04204
$\bar{\epsilon}$ =0.0002343
$|\bar{\epsilon}|$ =0.03278
E =0.1927


Everglades National Park
Key West
Leaflet | Powered by Esri | USGS, NOAA