UFS Coastal Applications Team

Water Quantity

Unifying Innovations in Forecasting Capabilities Workshop

Shachak Pe’eri, Andre Van der Westhuysen, and Philip Chu

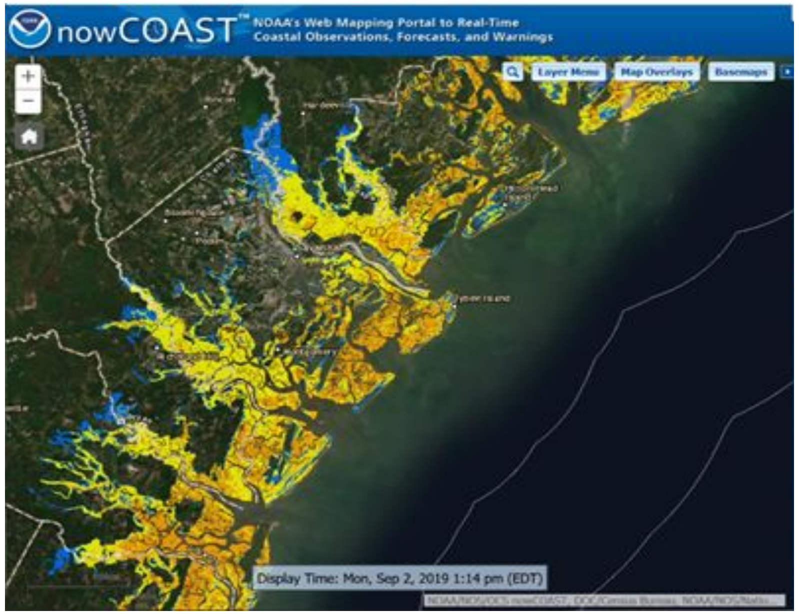
Safe, Efficient Navigation

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

Risk Reduction

Aftermath of Hurricane Michael in Mexico Beach, FL. (AP Photo/Gerald Herbert)

Total Water Level

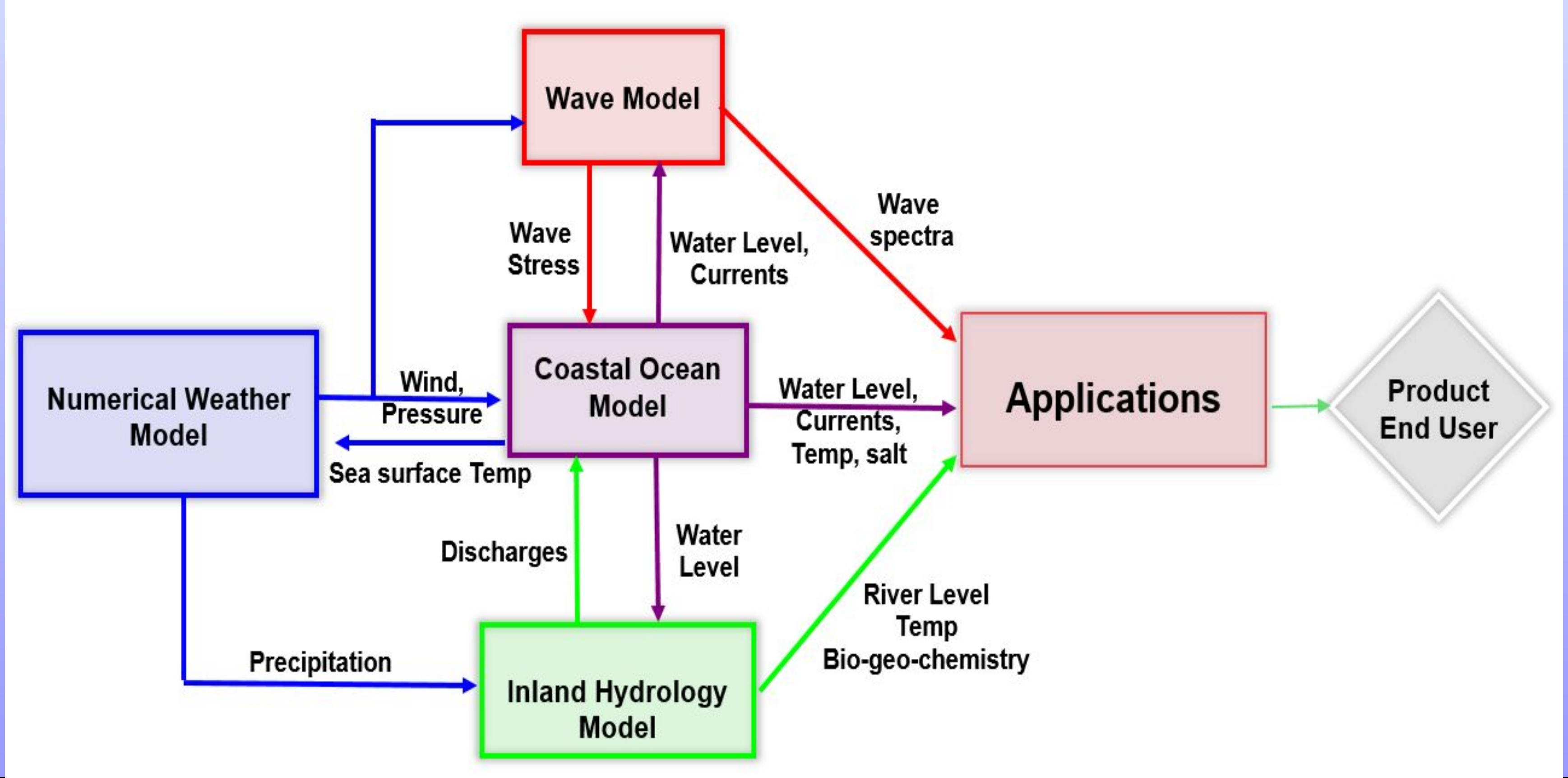


NWS Potential Storm Surge Flooding Map for Hurricane Dorian (NowCOAST - 9/2/2019)

Terms of Reference

The Unified Forecast System (UFS) Coastal Applications Team – Water Quantity created a Terms of Reference (ToR) in order establish the oversight and decision making process for the**:**

- *"The term **Water Quantity** is referring to the physical properties of the hydrodynamic models.*



UFS CAT Sub-application Team

Charter - The UFS Coastal Applications Team (CAT) - **Water Quantity** requested a marine navigation sub-application tiger team to generate consensus guidelines (i.e., metrics, criteria, and competing numerical oceanographic models) for a **model evaluation**.

These guidelines from all three sub-application team will be presented to the UFS Steering Committee for recommendations on who should be conducting the model evaluation and with what resources.

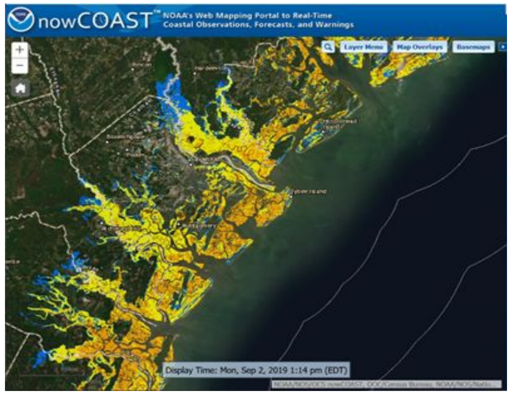
Application Themes

- **Safe, Efficient Navigation**
- **Risk Reduction**
- **Total water level (TWL) - Coastal flooding and inundation**

Safe, Efficient Navigation

Risk Reduction

Total Water Level



The road so far

Phase One

Form UFS Coastal Applications Team (CAT) - Water Quantity (CAWQuant)

Define CAWQuant sub-applications

Form 3 CAWQuant sub-application tiger teams

Tiger teams provide draft white papers:

- Criteria for evaluation
- Model candidates

Phase Two

Obtain feedback from modeling community & UFS Steering Committee on white papers and make revisions

Form coastal ocean model evaluation committees

- Identify ground rules
- Identify evaluation teams
- Test cases, …

Create a collaboration space (“sandbox”) for model evaluation (e.g. ~~EPIC,~~ NSF’s TACC)

Conduct model evaluation

Summarize evaluation results and report to UFS Steering Committee

Safe, Efficient Navigation

To support marine navigation in the waterways and ports of the U.S., mariners need forecast guidance of all the following variables: **water levels**, **surface water currents**, **sea and lake ice**, and **temperature and salinity**.

Other required user variables for marine navigation that were considered here and should be coordinated i. These variable include **wind and atmospheric pressure**, **riverine**, **wave forcing**, **shorefast ice**, and **ice pressure**.

Team Members:
Allison Allen (NOAA/NWS/AFS)
Eric Anderson (Colorado School of Mines)
Cristina Forbes (USCG-SAR)
Ayumi Fujisaki-Manome (U. of Mich./CIGLR)
Kevin A. Haas (Georgia Tech)
John Kelley (NOAA/NOS/OCS)
Carolyn Lindley (NOAA/NOS/CO-OPS)
Dan Roman (NOAA/NOS/NGS)
Charles Seaton (CRITFC)
Greg Seroka (NOAA/NOS/OCS)
Joe Sienkiewicz (NOAA/NWS/NCEP/OPC)
Neil Weston (NOAA/NOS/OCS)

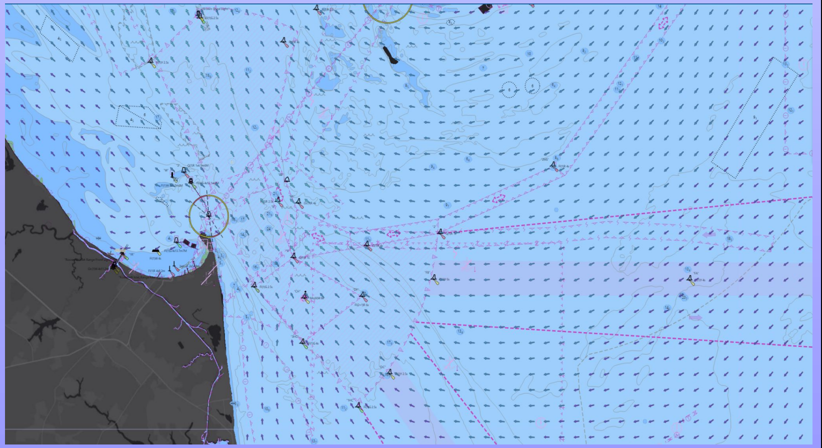
Navigation Theme - Background

These operational oceanographic forecast modeling systems for Navigation require to use **high resolution** (5 to 100 m nearshore), **3D** (layered) models for the **coastal domain and great lakes** (shallower than 100 m).

The existing forecast systems use different core 3D oceanographic models:

- Regional Ocean Modeling System (ROMS)
- Finite Volume Community Ocean Model (FVCOM)
- Princeton Ocean Model (POM)
- Semi-implicit Eulerian-Lagrangian Finite Element (SELFE)
- Environmental Fluid Dynamics Code (EFDC)

Top image: Electronic Chart Display and Information System (**ECDIS**). **Bottom image:** Current (IHO S-111) layer.



Requirements - Forecast configuration

- **Forecast frequency -** Every 6 hr
- **Forecast turnaround time -** < 1 hr before forecast cycle deadline (NWS), and before start of the next model forecast cycle (NOS)
- **Temporal resolution of output -** At least hourly, optimally up to 6 minutes
- Rescue (SAR)
- **Forecast range -** 5 to 7 days, 14 days for planning (monthly/seasonal for lake/sea ice)
- **Reliability -** 99 to 99.9%
- **Locations -** Coastal ocean, Great Lakes, including ports, harbors, bays, and connecting channels and rivers, and islands/atolls in the Pacific (e.g. Hawaiian Islands and Guam), Arctic and Antarctic passages.
- **Depth of currents -** Entire water column in order to provide currents at 4.5 m below surface for navigation and 0-1 m below surface for search and rescue (SAR)
- **Spatial reference system -** Vertical is chart datum ((e.g. NOAA: MLLW, LWD for Great Lakes), and Horizontal (WGS-84).
- **Horizontal resolution -** 10 m in rivers, O(10m) in shipping channels, 30 m for sea ice, 50 m-1,000m in inlets/bays, lakes, <=2,000 m around small islands, and 5,000 m in open ocean (1 km for surface currents in EEZ). It is also import to represent coastal shoreline structures, such as levees, piers, and offshore wind farms.

Total Water Level (TWL) –
Coastal flooding and inundation

Some 40% of the U.S. population live in coastal regions and is under the threat of inundation ranging from regular nuisance flooding to compound flooding from tropical cyclones. This vulnerable population requires actionable information on **weather time scales (1-2 weeks)** on the magnitude of flood levels arising from various sources, including tides, wind-driven surge, wave-driven surge, and rainfall run-off.

Forecast Guidance

NWS Potential Storm Surge Flooding Map for Hurricane Dorian for the SE coast of the U.S. displayed on nowCOAST on Sept. 2, 2019.

Team Members:

Andre v/d Westhuysen (Co-Lead, IMSG at NOAA/NWS/NCEP)
Fred Ogden (Co-Lead, NOAA/NWS/OWP)
Allison Allen (NOAA/NWS/AFS)
Cayla Dean (NOAA/NOS/CO-OPS)
Kara Doran (USGS/St. Petersburg)
Trey Flowers (NOAA/NWS/OWP)
Tracy Fanara (NOAA/NOS/IOOS)
Ruoying He (NC State)
Carolyn Lindley (NOAA/NOS/CO-OPS)
Chris Massey (USACE)
Margaret Palmsten (USGS/St. Petersburg)
Brett Sanders (UC Irvine)
John Warner (USGS/Woods Hole)
Brian Zachry (NOAA/NWS/NCEP/NHC)

Total Water Level – Background

NOAA currently maintains a number of **stand-alone operational models** to address these user requirements, including the Probabilistic Surge model (**P-Surge**), Probabilistic Extratropical Storm Surge Model (**PETSS**), Extratropical Surge and Tide Operational Forecast System (**ESTOFS**), Nearshore Wave Prediction System (**NWPS**), and the National Water Model (**NWM**).

To better model all relevant physics, and for better efficiency, these separate coastal modeling systems need to be replaced by an **integrated coastal modeling system** that can dynamically link all contributing processes to provide **Total Water Level (TWL) forecast guidance** that would meet all user requirements for both **tropical** and **extratropical** conditions.

Total Water Level – User Requirements

A. Primary users of TWL guidance

- NOAA/NWS National Centers and Coastal Weather Forecast Offices
- NOAA/NWS River Forecast Centers
- USACE Districts
- USGS Water Science Centers and Storm Team
- FEMA, State and Local Emergency Managers
- Local coastal managers (County and City level)
- Insurance industry, DOE, Spotter networks

B. Community users of TWL model

- USGS, USACE, Navy, DOE
- Academia

Hourly guidance out 7 days:

- Water level
- Wave height
- Wave period
- Wave direction
- Streamflow
- Maximum inundation height
- Maximum inundation extent
- Erosion
- Rip currents

(incl. Uncertainty estimates)

Total Water Level – Coupled System Design

An **ESMF/NUOPC coupled forecast application** that will provide model guidance over the coastal zones of all US regions and territories, including CONUS, Alaska, Hawaii, Puerto Rico, the Great Lakes, amongst others. It will feature a flexible resolution mesh with a resolution of O(100m) to O(1km) in the offshore and over the continental shelf, to O(10m) in the nearshore and inundated areas, and O(1km) along streams further inland. In the future, the ambition is to describe flooding at a street level resolution.

System components: Circulation, **Wave**, **Sea ice**, **Hydrology**, and **Morphology**

Operational requirements:

- Deterministic versus Probabilistic
- Model robustness
- Computational speed
- Community modeling within **ESMF/NUOPC** (in conjunction with **BMI**) framework

Circulation component candidates: ADCIRC, DFLOW, FVCOM, and **SCHISM**

Risk Reduction

Coastal areas are especially vulnerable to hazards, now and in the future, posed by waves, tsunamis and surges associated with sea level change and coastal storms. Changing climate, geological processes and continued urbanization and economic investment have increased the vulnerability of coastal areas to natural disasters.

Hindcast analysis

Aftermath of Hurricane Michael in Mexico Beach, FL.
AP Photo/Gerald Herbert

Team Members:

Diego Arcas (NOAA/OAR/PMEL)
Kevin Hass (Georgia Tech)
Maoyi Huang (NOAA/OAR/WPO)
Saeed Moghimi(NOAA/NOS/OCS)
Shachak Peeri (NOAA/NOS/OCS)
William Pringle (DoE/Argonne)
Charles Seaton (CRITFC)
Arthur Taylor (NOAA/NOS/STI)
Andre Van der Westhuysen (NOAA/NOS/EMC)
John Warner (USGS/WHOI)
Yong Wei (University of Washington)
Zhaoqing Yang (DoE/PNNL)
Julio Zyserman (NOAA/NWS/OWP)

Risk Reduction Theme - Background

This sub-application team defined **risk reduction** as a **risk management technique** that involves reducing the damaging consequences in the form of human or financial loss. In order to better understand past coastal hazard events and also potential coastal exposure to specific hazards, **hindcast analysis** is used to support the development of products such as hazard maps and coastal flooding return periods.

As such, hindcast coastal applications are grouped into two main time-scale groups:

- **Short term:** disaster mitigation, coastal resiliency and support local and federal authorities (e.g. COASTAL Act) on the order of **up to 1 year**
- **Long term:** reanalysis studies that use time scales greater than **25 years** , including probabilistic hazard analysis

Requirements - COASTAL Act

Consumer Option for an Alternative System to Allocate Losses (COASTAL) Act: Produce detailed “post-storm assessments” in the aftermath of a damaging tropical cyclone that strikes the U.S. or its territories using output from a hindcast model (90 days after a “Named Storm Event Model” (NSEM)), the assessments will indicate the strength and timing of damaging winds and water at a given location in the area impacted by the tropical cyclone.

In October 2012, FEMA communicated to NOAA that 90% accuracy (as it pertains to the COASTAL Formula) shall be achieved for a Named Storm when all of the following criteria are met:

1) **Data for boundary and forcing conditions**
2) **Correlation with observations**
3) **Wind/flood damage portions**

Requirements - Tsunami Applications

The NOAA/OAR/PMEL National Tsunami Hazard Mitigation Program (NTHMP) is the NOAA-sponsored Program for ensuring the validity of models for use in the design of Tsunami Evacuation Maps. Additionally, PMEL and the NWS Tsunami Warning Centers (TWCs) defined together key requirements for Tsunami models to be used in real-time forecasting.

Hindcasting of past tsunami events includes:

1) **Post-event analysis**: This modeling activity refers to tsunami modeling and analysis in the immediate aftermath of tsunami impact.

2) **Long-term hindcasting** of tsunami modeling that can extend from decades to thousands of years.

Common metrics used to evaluate tsunami models are water levels, inundation area and flow speed. Additional criteria includes:

- **Data Assimilation**
- **Performance**
- **Processing time**

Common user requirements - as a basis for model evaluation

- Generated consensus user requirements between the three sub-application teams include:
  - The required priority user variables: **water levels, surface water currents, sea and lake ice, and water temperature and salinity**.
  - Other required user variables for that were considered include winds and waves.
- Developed criteria for selecting oceanographic models, based on those user requirements and the UFS framework.
  - The UFS framework requires a **community model approach, coupling in the ESMF/NUOPC framework,** and **data assimilation in the JEDI framework**.
- Applied those criteria to select an initial list of oceanographic models for further consideration.
  - Navigation: **FVCOM, MOM6, ROMS,** and **SCHISM** .
  - Risk Reduction: **ADCIRC, DFLOW, FVCOM, MOM6, SLOSH, ROMS** and **SCHISM**.
  - TWL: **ADCIRC, DFLOW, FVCOM,** and **SCHISM**.

A. **Resolution**
B. **Stability, Accuracy and computational efficiency**
C. **Code management**
D. **Coupling**
E. **Data Assimilation (DA)**
F. **NOAA Readiness Levels**
G. **Geographic coverage**
H. **License (C00)**

You are here

Form UFS Coastal Applications Team (CAT) - Water Quantity (CAWQuant)

Define CAWQuant sub-applications

Form 3 CAWQuant sub-application tiger teams

Tiger teams provide draft white papers:

- Criteria for evaluation
- Model candidates

Phase One

Obtain feedback from modeling community & UFS Steering Committee on white papers and make revisions

Form coastal ocean model evaluation committees

- Identify ground rules
- Identify evaluation teams
- Test cases, …

Create a collaboration space ("sandbox") for model evaluation (e.g. ~~EPIC,~~ NSF's TACC)

Phase Two

Conduct model evaluation

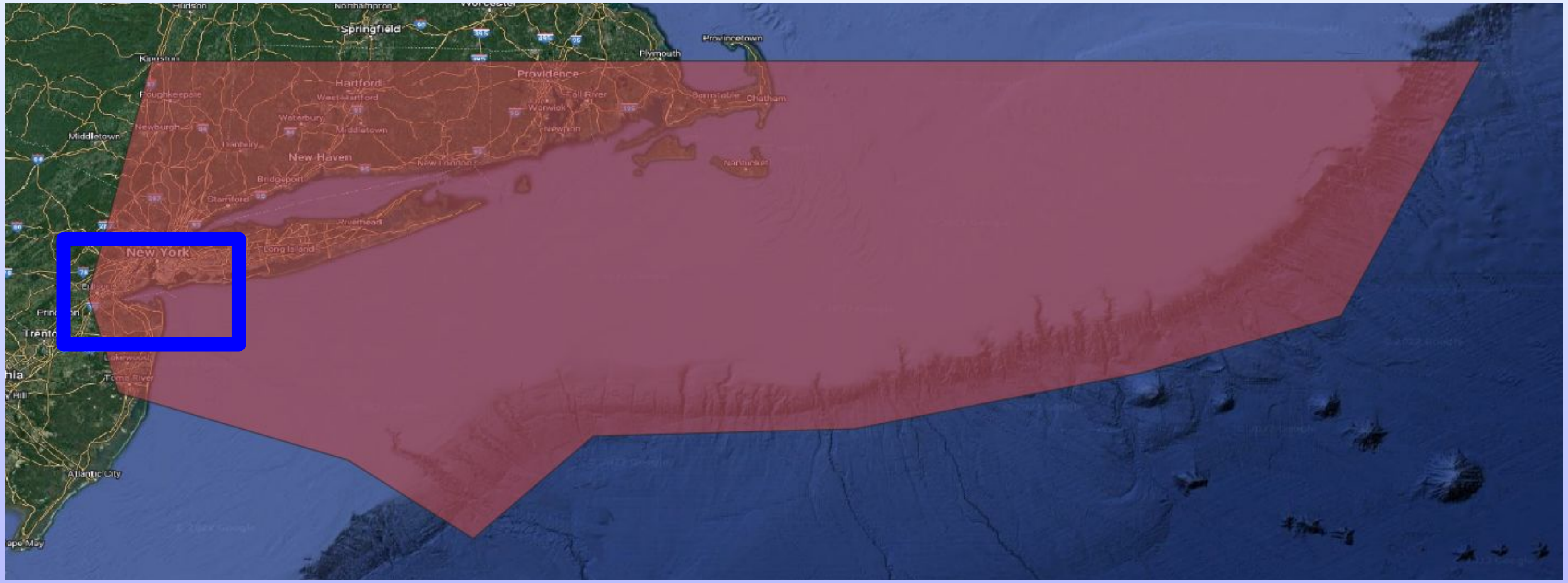
Summarize evaluation results and report to UFS Steering Committee

Starting around (End of Summer - Early Fall) September 2022

Study sites

Primary: New York Harbor

Secondary: Cook Inlet, AK



Inventory:

- Models (High priority):
- Observations (High priority):
  - Water level
  - Water Temp
  - Salt
  - Water currents
- DEM (High priority):

- Shoreline (High priority):

ATM forcing

- HRRR only for Harbor; GFS/HRRR nested

Ocean Boundary condition

- GRTOFS / HYCOM / ROMS
- Mesh generation
- Model target resolution ~ 50m the goal is to resolve a navigation channel with ~200m width (i.e., DEM at 8 m resolution).
- Hindcast Period: 3 months (in case it is too much, reduce to 2 months) not including warm-up period
- Runtime performance: 3-month simulation needs to run within ***x*** amount of time.

Time table - Piggyback approach

	Navigation	TWL Risk
Interview the developers and providing access to TACC. (1-2 mo)	+2 mo.	+4 mo. (ADCIRC; DFLOW)
First round evaluation - Evaluating the model independently from other models (6 mo)	+8 mo.	+10 to 12 mo.
First round feedback - Results will be shared with the developers. (1-2 mo)	+10 mo.	+12 to 16 mo.
Second round evaluation - (One way) coupling the model with atmospheric models (GFS/HRRR) (6 mo)	+16 mo.	+16 to 22 mo.
Second round feedback - Results will be shared with the developers. (1-2 mo)	+18 mo.	+18 to 24 mo.
Third round evaluation - Coupling the model with atmosphere model and wave (WAVEWATCHIII) (6 mo)	+24 mo.	+24 to 30 mo.
Third round feedback - Results will be shared with the developers (1-2 mo)	+26 mo.	+26 to 32 mo.
Fourth round Evaluation/feedback - Coupling the model with atmosphere, wave, hydrological (NWM) models* (6 mo + 2 mo)	??	+34 to 40 mo.
Report preparation (2 mo)	+28 mo.	+36 to 42 mo.

* Mainly, for the TWL theme effort. Coupling with NWM will also support navigation (currents)

Time table

For each evaluation team (sub-application), we will require the following steps:

1. Provide access to model developers and testers to compile and test the model candidate on the TACC infrastructure using standard test cases
2. Model developers to optimize the compilation given standard compilers and libraries to a reliable and performance state (4 to 6 weeks).
3. A committee within CAWQuant in order to provide the testers with clear guidance for model evaluation and documenting results
4. Perform standard test runs for a given region and a given specified computational time / resources to allow fair quantitative model intercomparison and their performances for a given sub-application (see next slide).
5. Prepare final recommendations for the UFS SC

Conventional HPC support

National Science Foundation's (NSF)
Texas Advanced Computing Center (TACC)

- NSF's TACC will provide the UFS CAT the Frontera supercomputer as a HPC resource for pre-operational testing, model output post-processing, and preparation.
- The UFS CAT will create a collaboration space ("sandbox") for model evaluation.
- This sanbox will provide the same conditions (e.g, grid resources, geography or weather event, and other boundary conditions) for testing the coastal models.

The **Texas Advanced Computing Center (TACC)** designs and operates powerful computing resources. The center's mission is" *to enable discoveries that advance science and society through the application of advanced computing technologies*".

UFS Coastal Application Team

(Water Quantity) - Status Update (July, 2022):

Phase 1: Completed.

Tiger teams (Navigation, Risk Reduction and Total Water Levels provided the UFS SC white papers that include:

1. Criteria for evaluation

A. Resolution
B. Stability, Accuracy and computational efficiency
C. Code management
D. Coupling
E. Data Assimilation (DA)
F. NOAA Readiness Levels
G. Geographic coverage
H. License (C00)
I. Open source code

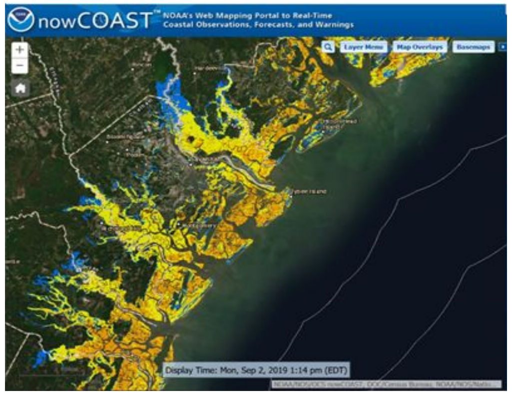
2. Model candidates

	Navigation	Risk-Coastal	TWL - Coastal
ADCIRC		X	X
D-FLOW		X	X
FVCOM	X	X	X
MOM6	X		
ROMS	X	X	
SCHISM	X	X	X
SLOSH		X	

Safe, Efficient Navigation

Risk Reduction

Total Water Level



UFS Coastal Application Team

(Water Quantity) - Status Update (July, 2022):

Phase 2: Summer-Fall, 2022

a. Create a collaboration space (“sandbox”) for model evaluation (NSF’s TACC) - **Completed (May).**

b. Communicate with the developers to match expectations on the process and receive feedback from them (we will have reps from the different sub-application teams and co-leads). We will also share all three white papers with the developers. **(May-July)**

c. Identify academic and government testers. Testers must be at least graduate students with experience in coastal and ocean modeling. **(May-July) - NOS has provided $600K through the NWI to support this task.**

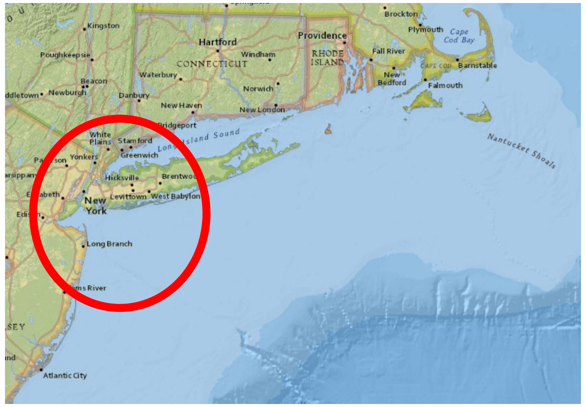
d. Provide skill assessment documentation to the developers and testers. **(July-August)**

e. **Testing will begin around September.**

Frontera supercomputer will be used for pre-operational testing, model output post-processing, and preparation.

This supercomputer is intuitive and easy to use interface to manage team members accessing resources

Study site



It takes a village to raise a child

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Tim Cockerill (NSF/TACC)

Thanks for your attention!

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Cayla Dean (NOAA/NOS/CO-OPS)

Reggie Beach (Navy/ONR)

Trey Flowers (NOAA/NWS/OWP)

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Extra slides

Accuracy and product formats

- **Water level accuracy -** 15 cm (0.5 ft) based on ~2003 estimates of pilots' needs for under keel clearance; for time of high water and time of low water, 0.5 hr (assist in selecting port arrival/departure times)
- **Surface current accuracy -**
  - Speed: 26 cm/sec (0.5 kt); time of max flood or ebb 30 min; for slack water times, 15 min
  - Direction: 22.5 degrees provided current speed is not less than 26 cm/s (0.5 kt)
  - (Note - For USCG SAR: 0.1 m/sec / 10 degrees)
- **Sea and Lake accuracy -** Depth/thickness 10 cm, concentration 10%, extent 10%, motion .25km/day / 10 degrees
- **Water density accuracy -**
  - Desired accuracy of a forecast of a ship's draft is to the nearest 7.5 cm:
  - (Note - or vessel draft of 15.25 m (50 ft) (largest existing around 2003) and acceptable error in draft of 7.5 cm, acceptable error X is 3.5 psu for salinity and 7.7C for water temperature)
- **Product formats -** S-100/HDF5, GRIB2, Web mapping services, GIS compatible files, NetCDF, SHEF; documentation describing files