# Nutrient loads from estuaries to the coastal ocean; the role of resolution and vegetation on numerical estimates.

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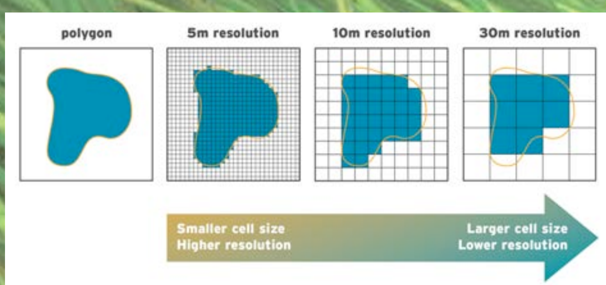
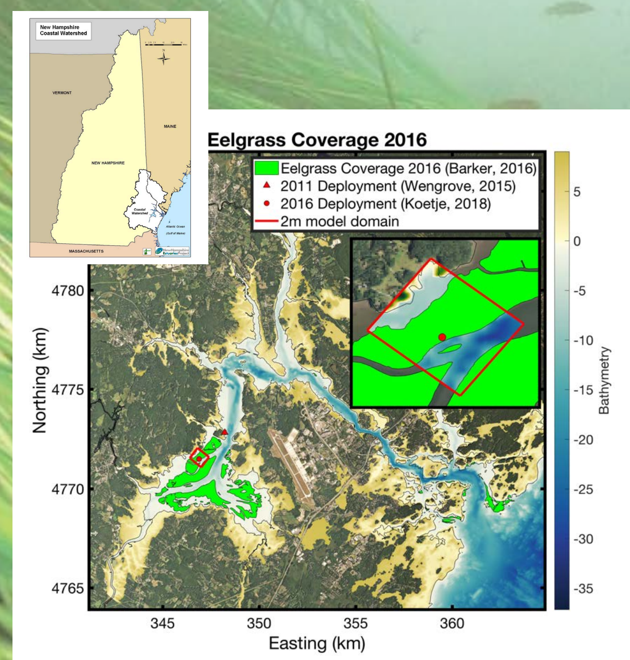
University of New Hampshire

## Resolution




https://www.jbarisk.com/news-blogs/dem-spatial-resolution-what-does-this-mean-for-flood-modellers/




## Vegetation

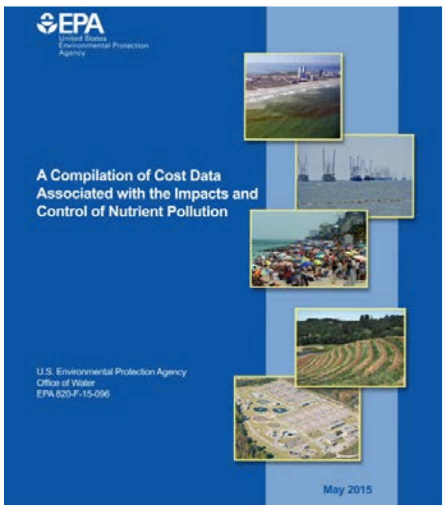

Photo courtesy Cornell Cooperative Extension Marine Program

# Nutrient loads from estuaries to the coastal ocean; the role of resolution and vegetation on numerical estimates.

**Why does it matter?**

# Nutrient loads from estuaries to the coastal ocean; the role of resolution and vegetation on numerical estimates.

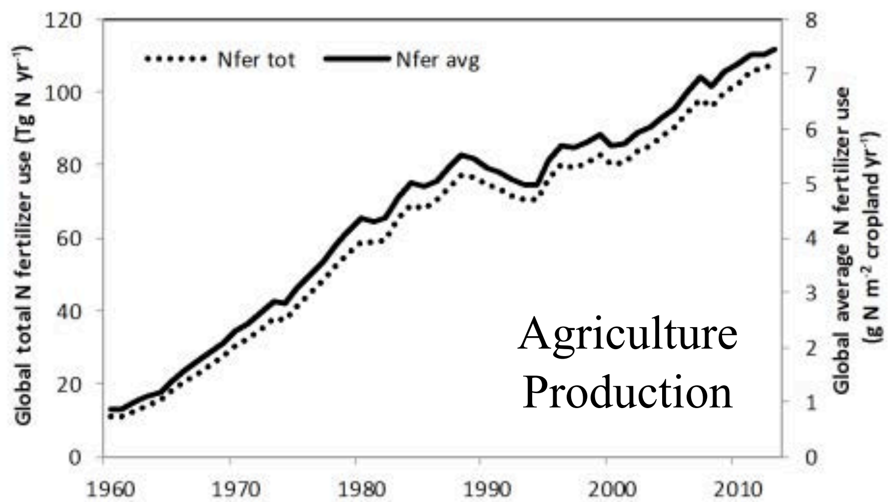
## Why does it matter?




Watershed Degradation Costs Global Cities $5.4 Billion in Water Treatment Annually

McDonald, R.I., Weber, K.F., Padowski, J., Boucher, T. & Shemie, D. (2016). Estimating watershed degradation over the last century and its impact on water-treatment costs for the world's large cities. PNAS, 201605354.

"Nutrient pollution, defined as excess amounts of nitrogen and phosphorus in aquatic systems, is one of the leading causes of water quality impairment in the United States."




C. Lu and H. Tian (2017): Global nitrogen and phosphorus fertilizer use for agriculture production

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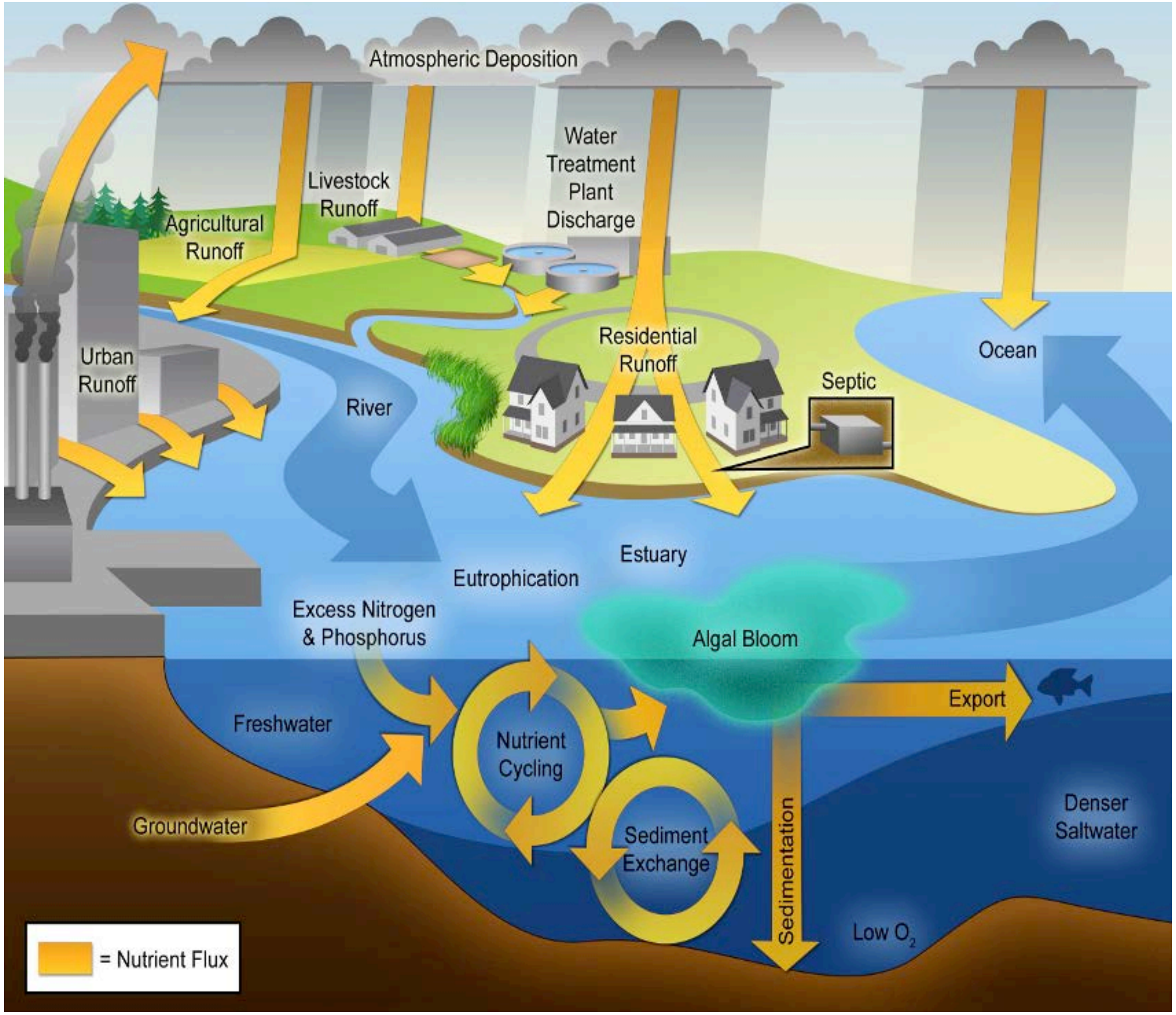

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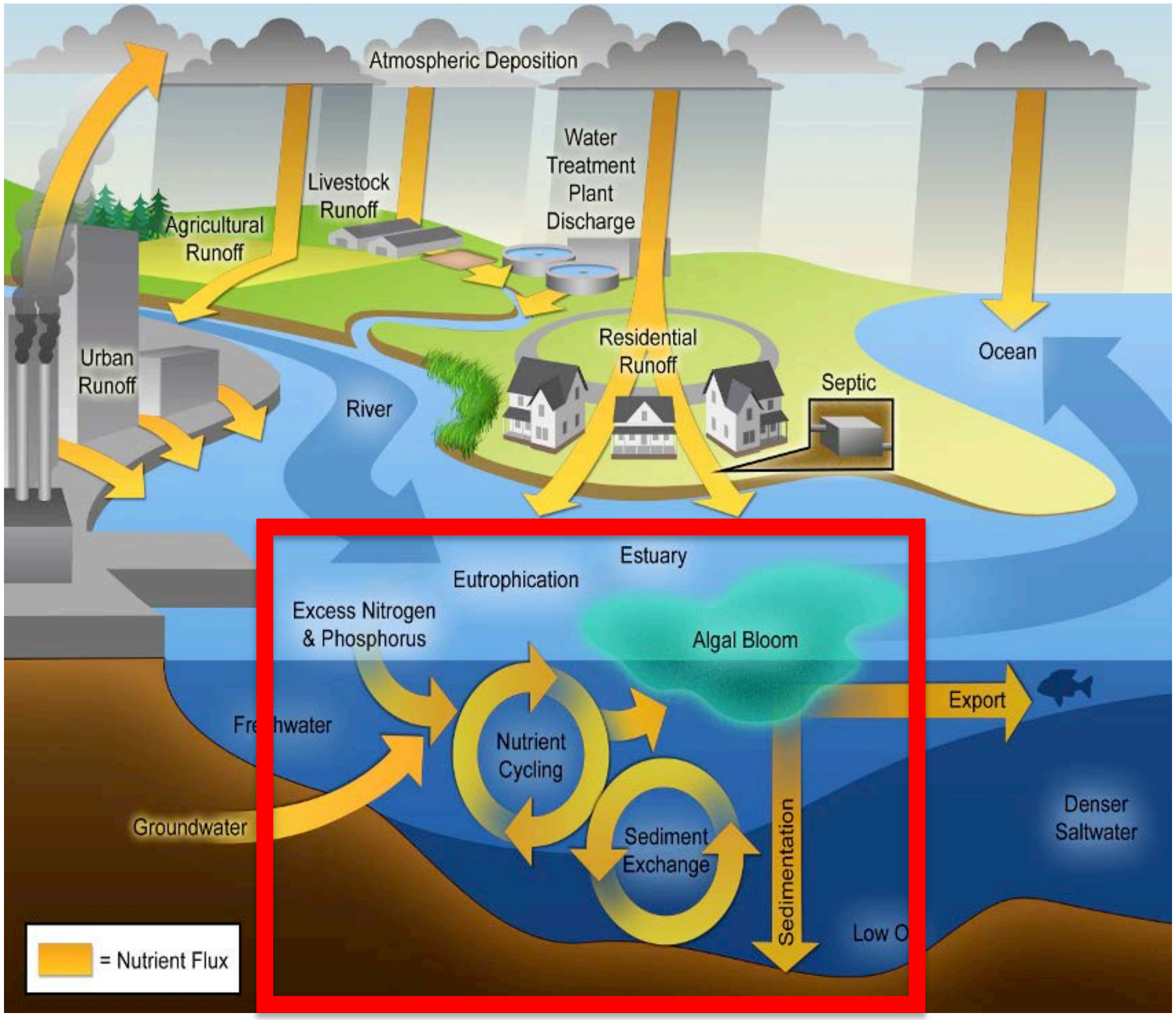



**Where my research fits in**

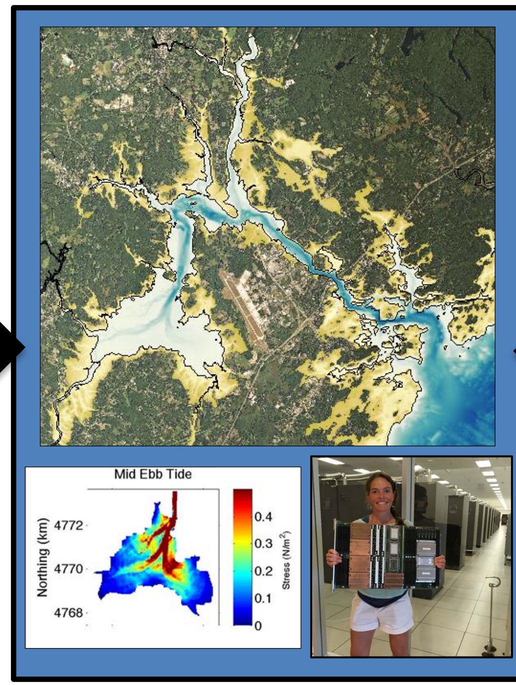
# Research Question:

Does sediment resuspension from mudflats significantly contribute to nutrient loading in estuaries?

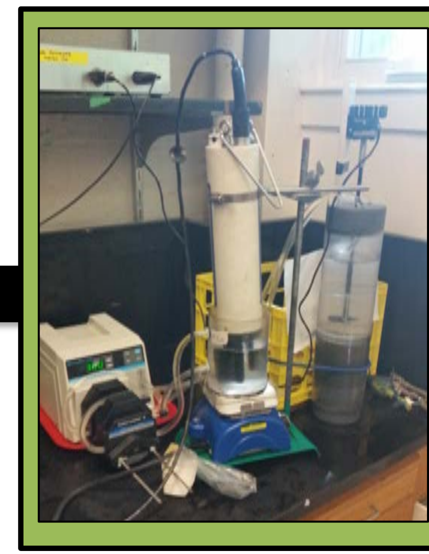
What is the relative importance of **model resolution** and the presence of **subaquatic vegetation** on the distribution of shear stress, and thereby sediment resuspension and nutrient loading, in these environments?

**Observations**

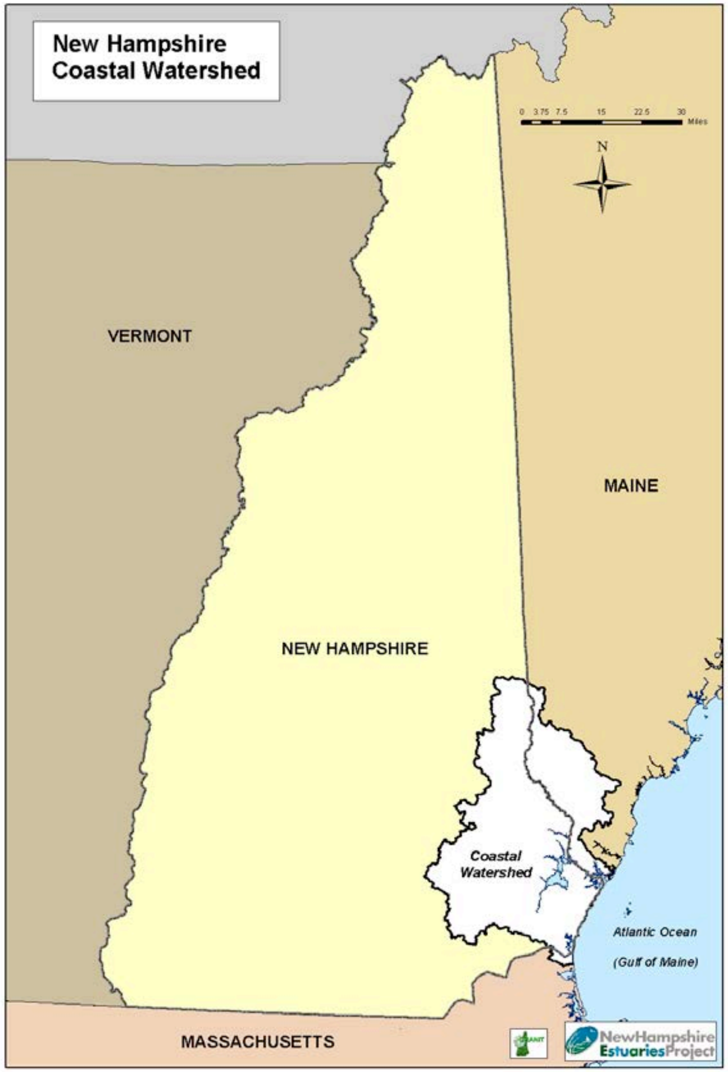
**Numerical Modeling**




**Lab studies**



# EPA - National Estuary Program (NEP)



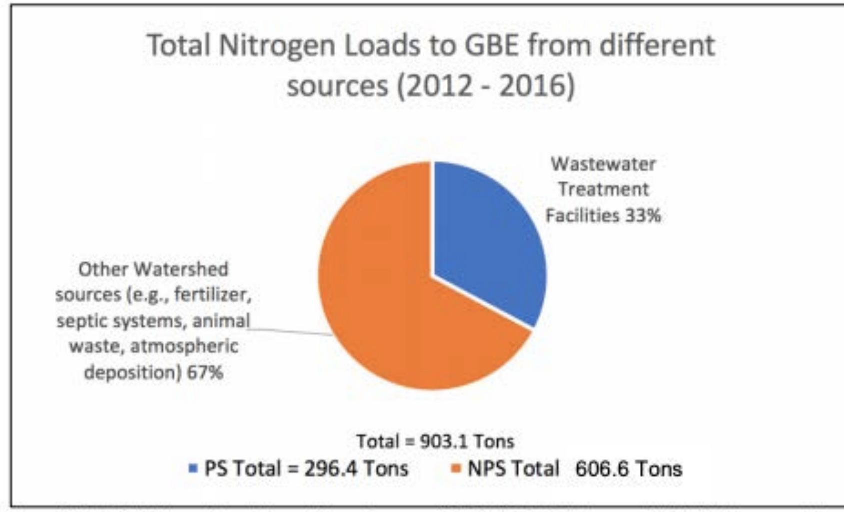
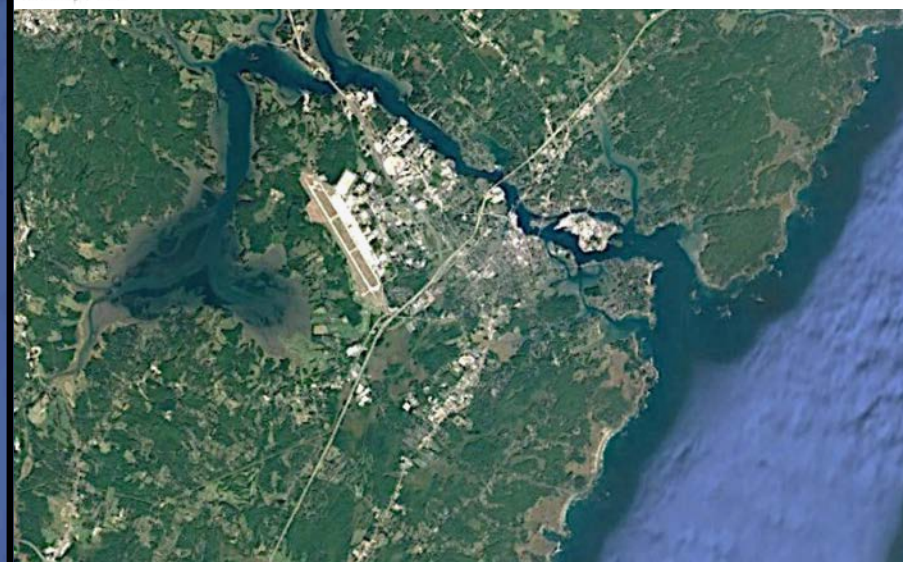




Figure NL-2. Total Nitrogen Loads from different sources (2012 to 2016). Data Source: NH Water Resources Research Center, UNH.



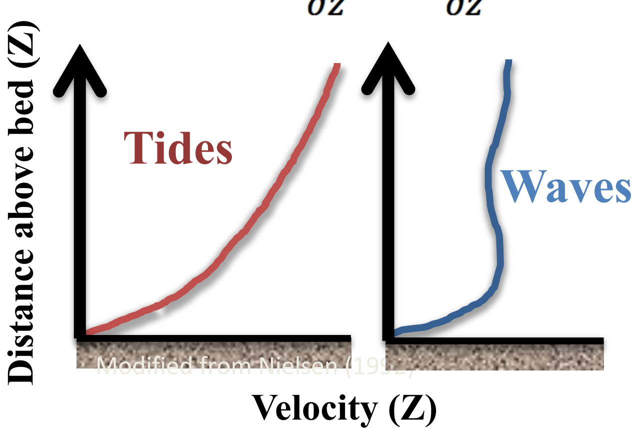
# Shear Stress and Nutrient Loading

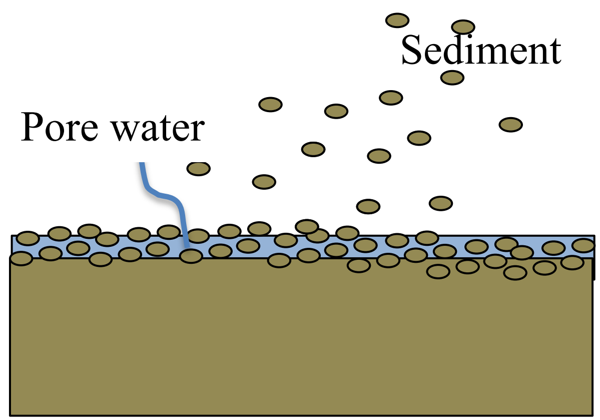
Applied Shear stress → Sediment Resuspension → Nutrient/Pollutant Release

$$\tau_b > \tau_{critical}$$

**Function of hydrodynamics**

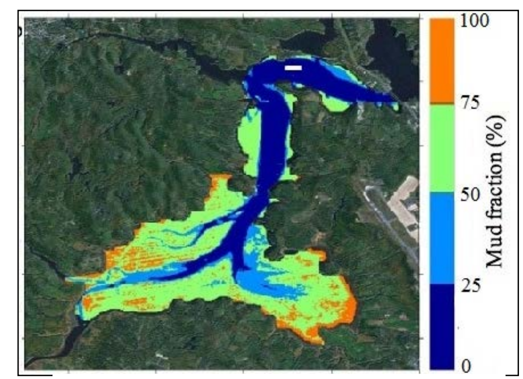
$$\tau_b \propto \mu \frac{\partial u}{\partial z} \propto \rho \upsilon \frac{\partial u}{\partial z}$$




**Function of sediment characteristics**

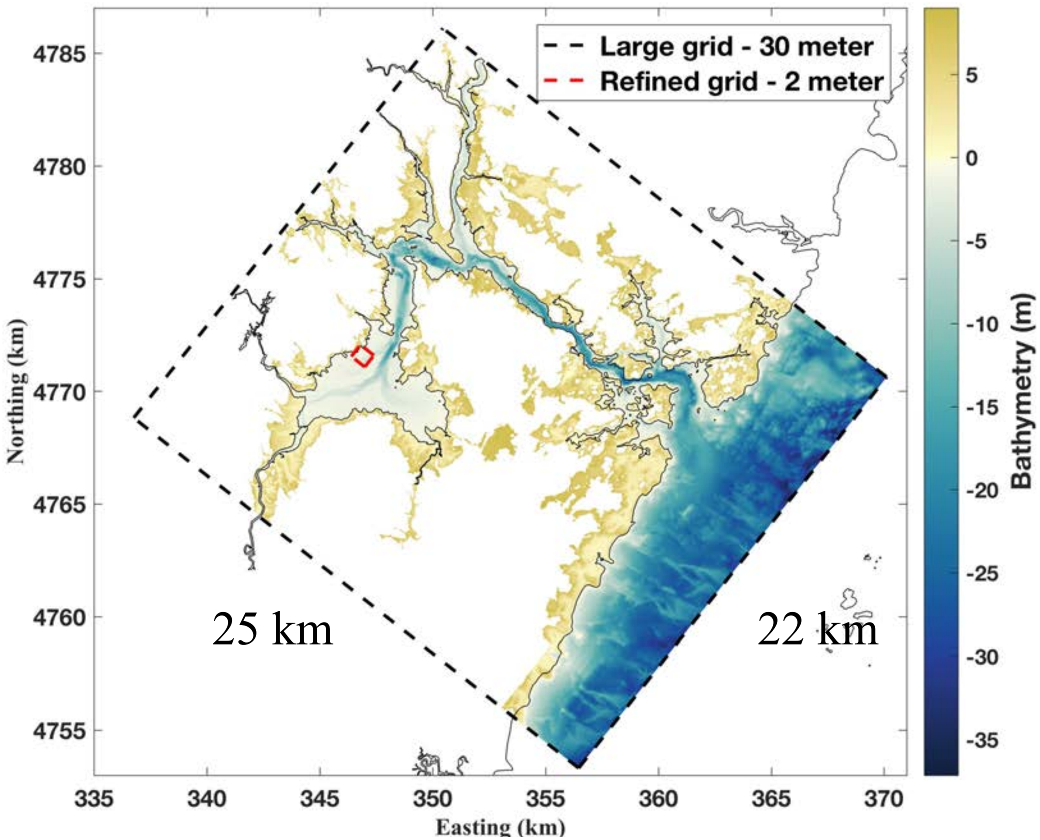
**Where's the mud?**

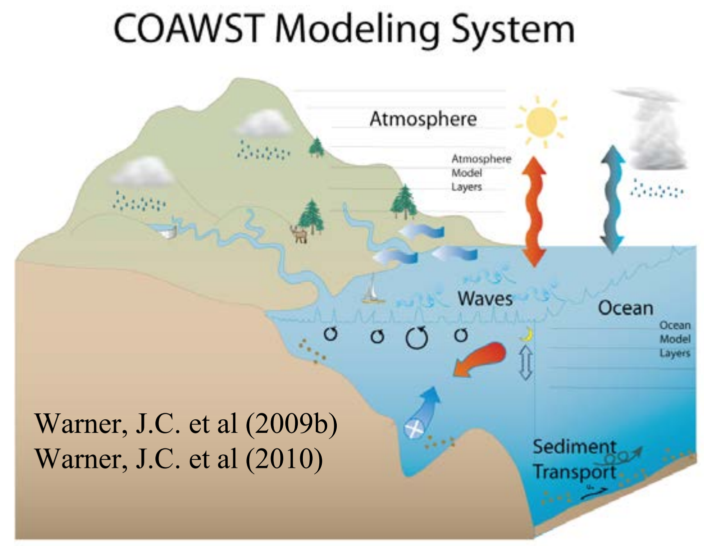



>50% mud fraction
0.35 N/m2 for nutrient release
Percuoco (2013)

****Need bay-wide estimates of shear stress****

# Model Setup




**C** – Coupled

**O** – Ocean (**ROMS**)

**A** – Atmosphere (WRF)

**W** – Wave (SWAN)

**ST** – Sediment Transport

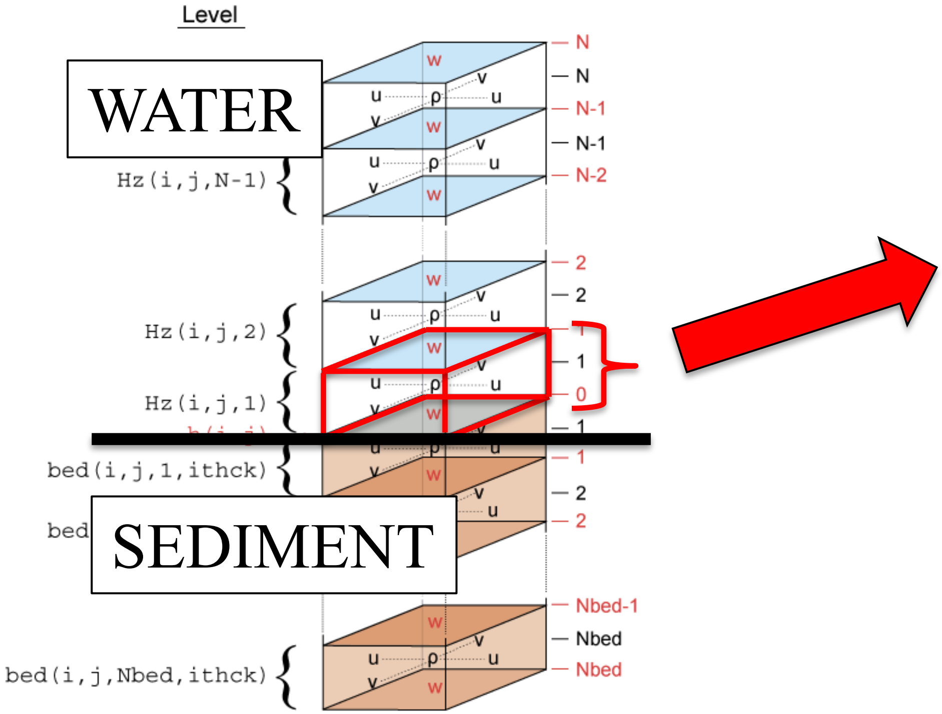
**Horizontal: 30 m, 10m*** BLUE WATERS SUSTAINED PETASCALE COMPUTING

**Vertical: 8 vertical sigma layers**

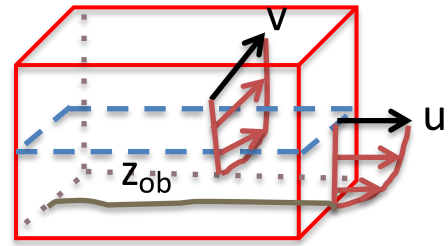
**R**egional **O**cean **M**odeling **S**ystem (**ROMS**)

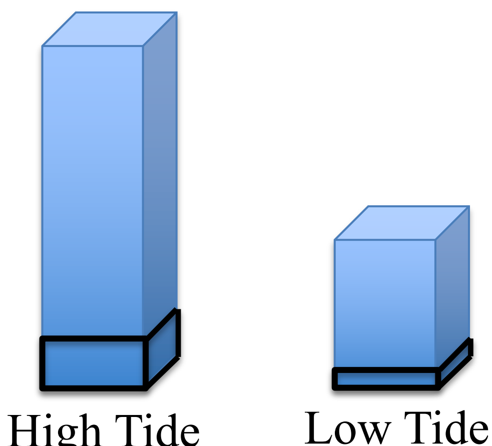
- Solves finite difference approx. of RANS equations
- Written in F90/95, uses C-preprocessing to activate different options. Output data is written into NetCDF files for post-processing.

# Numerical based estimates of bed shear stress




Lowest Water Cell




Classic Logarithmic
"Law of the Wall" Formulation

$$|u| = \frac{u_*}{\kappa} \ln\left(\frac{z}{z_0}\right)$$

$$(\tau_b^x) = \rho_0 \left(\frac{\kappa}{\ln(z/Z_{ob})}\right)^2 u|u|$$

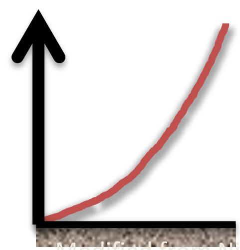
$$(\tau_b^y) = \rho_0 \left(\frac{\kappa}{\ln(z/Z_{ob})}\right)^2 v|v|$$

# Model Setup : Configuration and Boundary Conditions

- **Initial Forcing**
  - Tide – OSU TPS output (M2, S2, N2, 01, K1)

- **Lateral Boundary Condition**
  - Closed (N,E,W)
  - Open on the Southern Edge (Rotated 53 degrees)

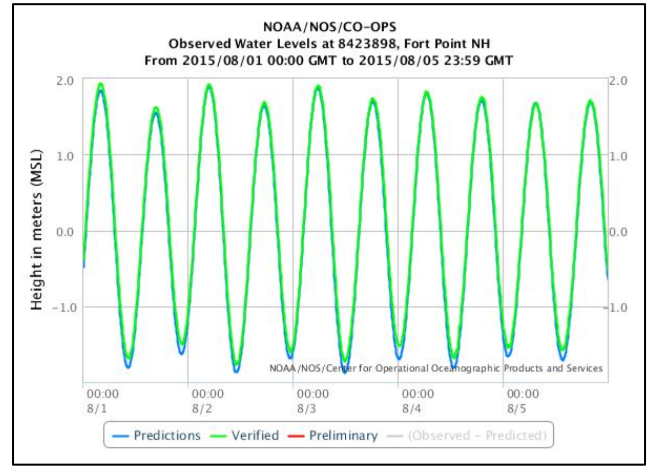
- **Bottom Boundary Condition**
  - Logarithmic drag law
  - $z_o = 0.02$m*

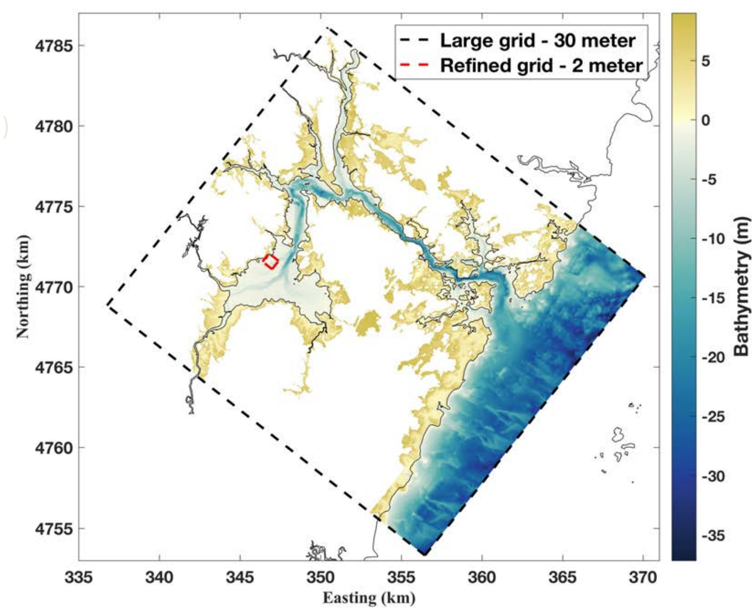


Modified from Nielsen (1992)

- **Wetting and Drying**
  - Warner et al 2013

- **Data Output**:
  - 30 day run
  - 30 minute average file - Shear Stress
  - 5 minute station data - model validation

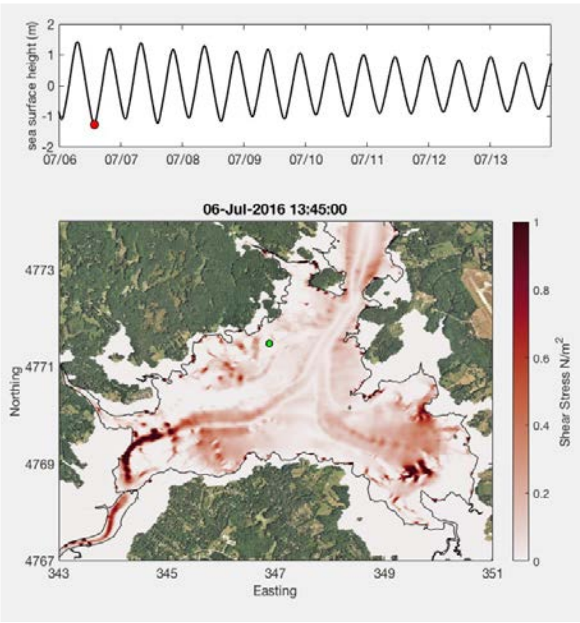



*Cook et al, 2019. Ocean Modelling.

# Numerical estimates of the distribution of bed shear stress

Low Tide

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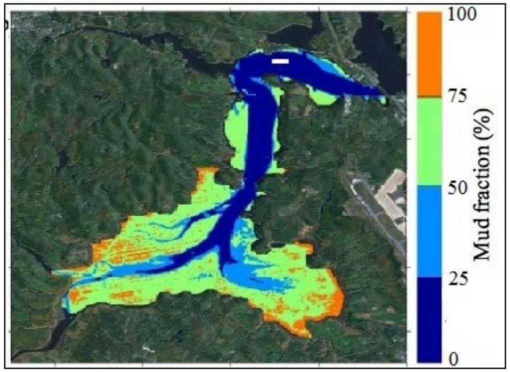


>50% mud fraction
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Percuoco (2013)

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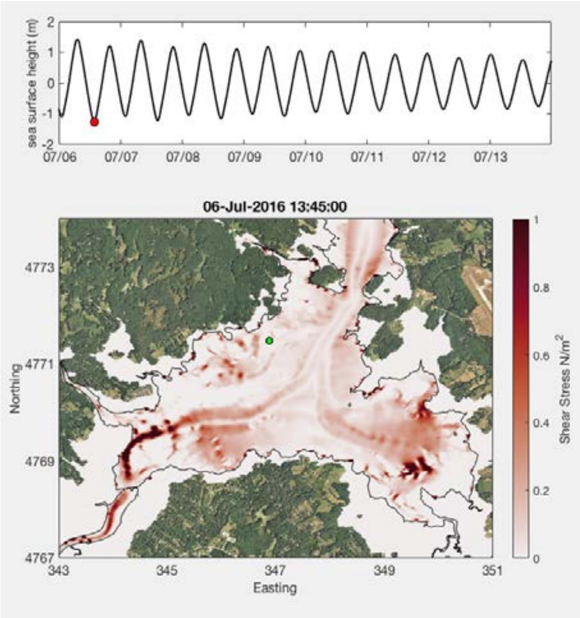
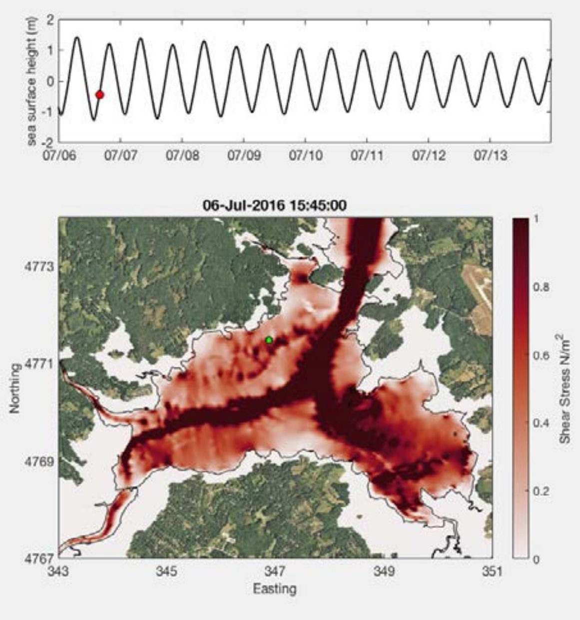



Flooding Tide

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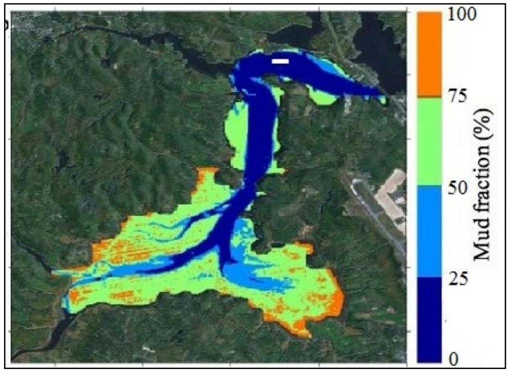


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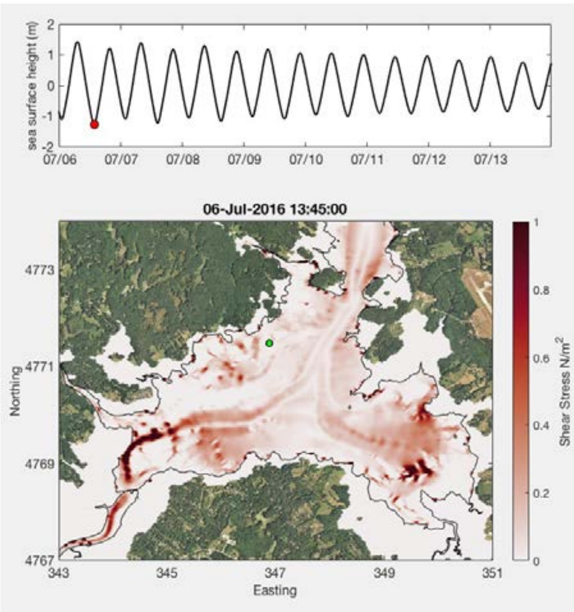


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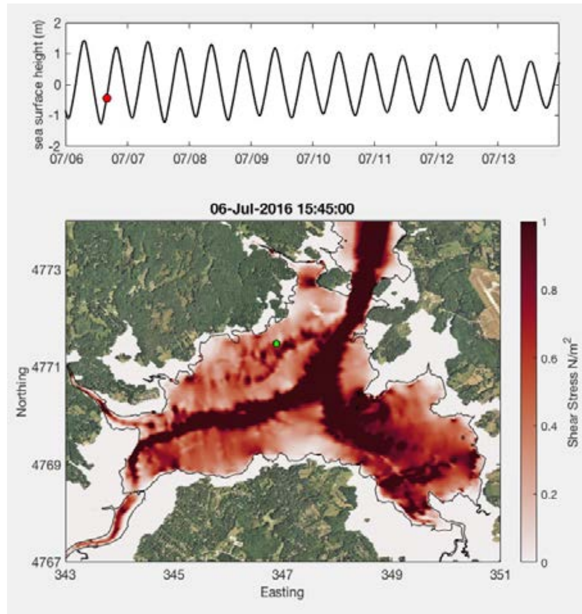
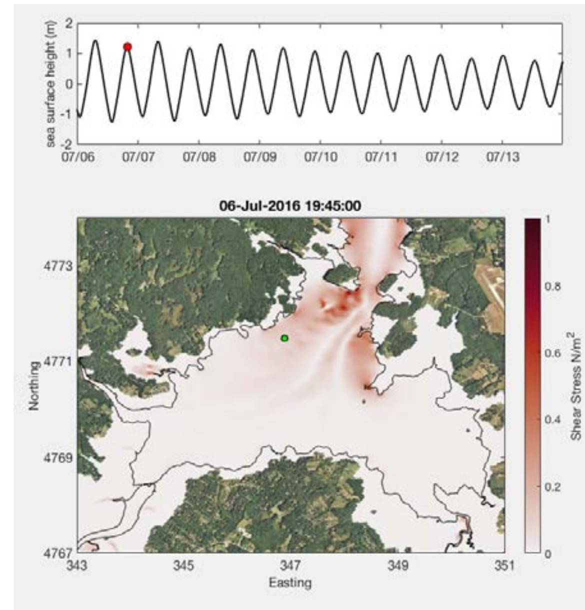



High Tide

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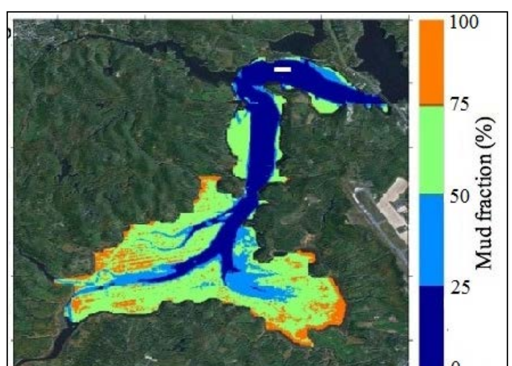


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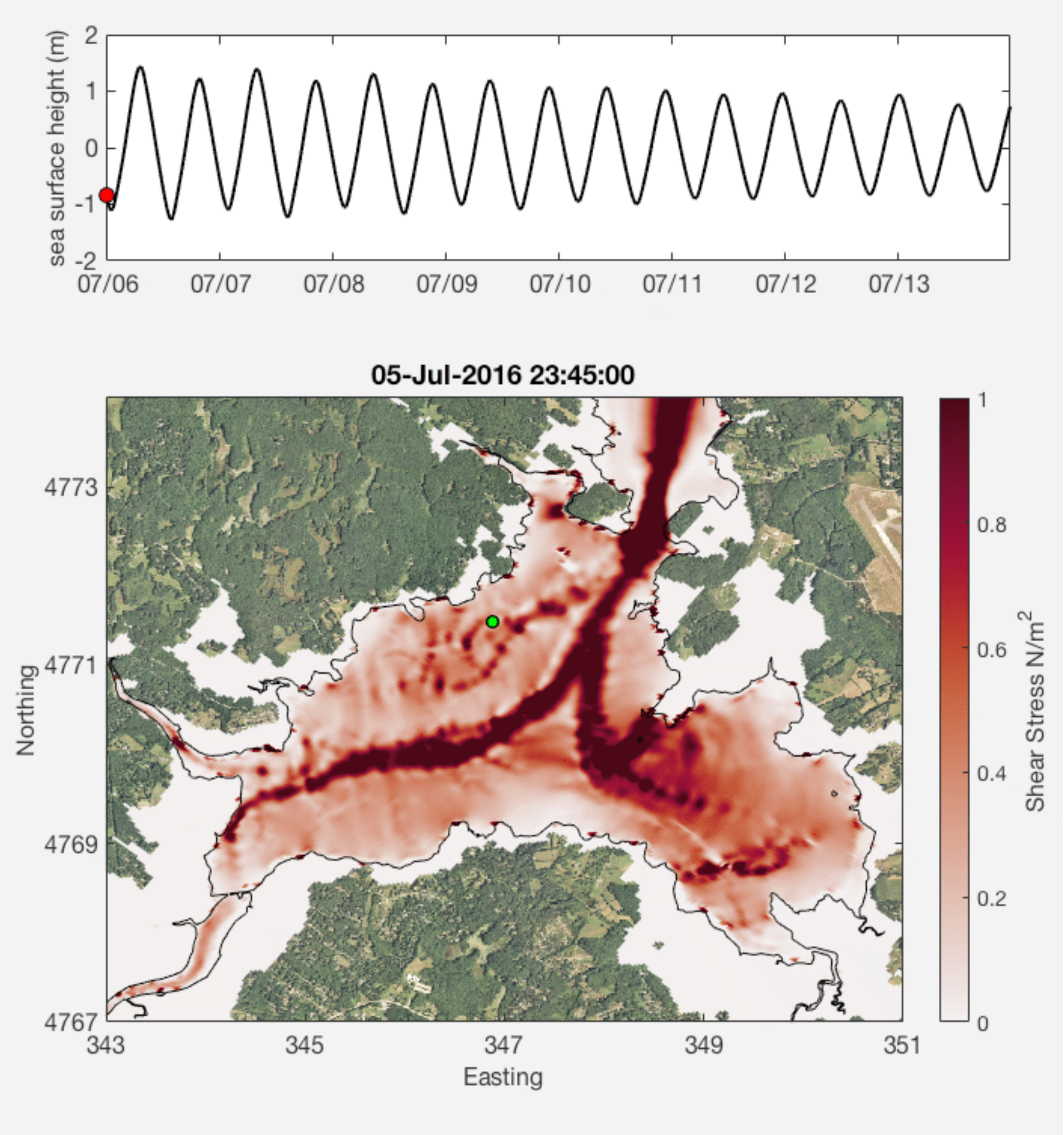
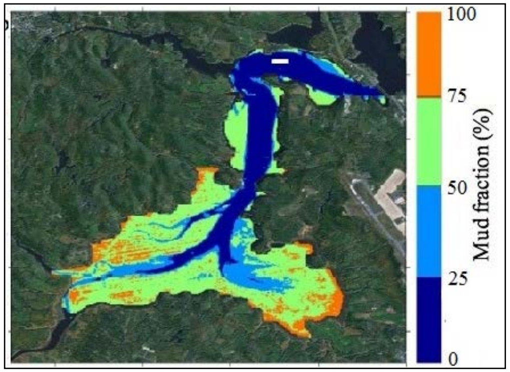


# Application : Nutrient Loading

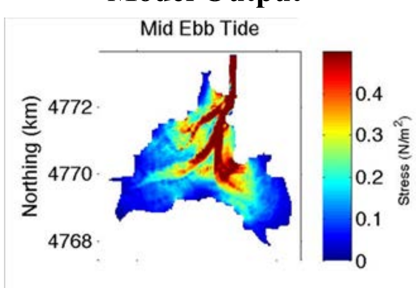
## Step 1: Area with > 50% mud fraction



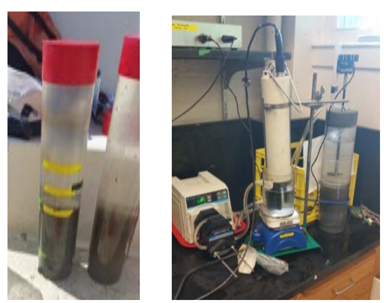

[Lippmann(2013) ; Poppe (2013) ; Humberston (2015)]

## Step 2: Area with shear stress > 0.35 N/m²

**Model Output**




**Lab Studies**



[Percuoco et al. (2015);
Wengrove et al. (2015)]

## Step 3: Calculate Nutrient Load (across entire bay)

$$\left(\underline{Area_{\tau_w > \frac{0.35N}{m^2}}}\right)\left(1.3\,\frac{mmol\ DIN}{m^2}\right)\left(\frac{1\ mol\ N}{1\ mol\ DIN}\right)\left(\frac{kg}{10^6 mmol}\right)\ldots$$

$$\left(14.0067\,\frac{g\ N}{mol\ N}\right) = kg\ Nitrogen$$

$$\left(\underline{Area_{\tau_w > 0.35N/m^2}}\right)\left(0.21\,\frac{mmol\ P}{m^2}\right)\left(\frac{kg}{10^6 mmol}\right)$$

$$\left(30.973761\,\frac{g\ P}{mol}\right) = kg\ Phosphorus$$

Wengrove et al. (2015) made the first estimate of nutrient loading from sediments during tropical storm Irene

**What about a typical tidal cycle?**

# Application : Nutrient Loading

## How do tides compare to other sources?

| | Dissolved Inorganic Nitrogen (DIN) | Phosphorus (P) |
|---|---|---|
| | (kg/month) | (kg/month) |
| **River** [A]<br>(Fall, Sept-Nov) | 1,200 | 70 |
| (Winter, Dec-Feb) | 3,700 | 92 |
| (Spring, Mar-May) | 17,000 | 720 |
| (Summer, June-Aug) | 1,300 | 120 |
| **Sediments (modeled)** | **747** | **267*** |
| | (kg/event) | (kg/event) |
| **Event (Storm-Irene)** [B] | 220 | 80* |
| **One Tidal Cycle (Average)** | **25** | **9*** |
| **Neap Tide (Minimum)** | **13** | **5*** |
| **Spring Tide (Maximum)** | **91** | **33*** |

[A] Oczkowski (2002) [B] Wengrove (2015) * Based on results from Percuoco (2013). Uptake not considered for Phosphorus.

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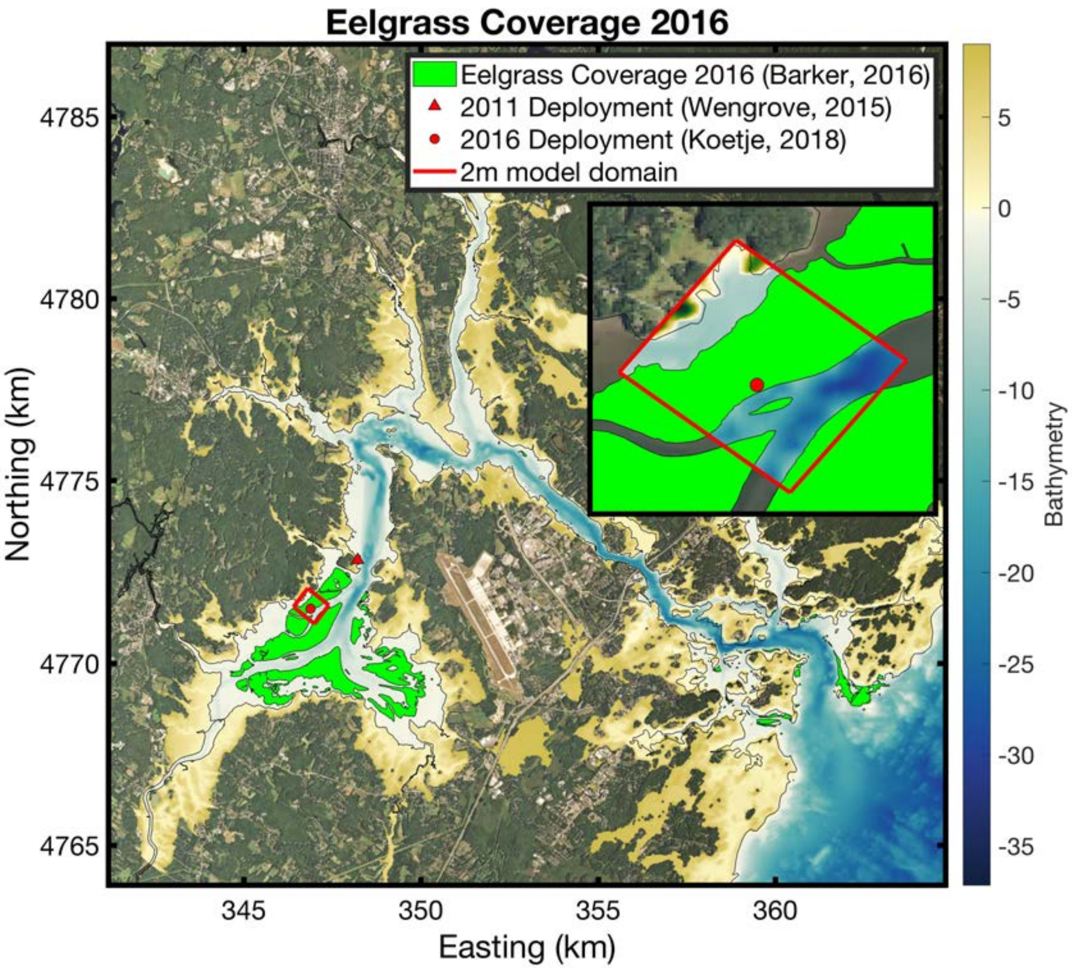
Ok…. So what about resolution and vegetation?

# The role of vegetation



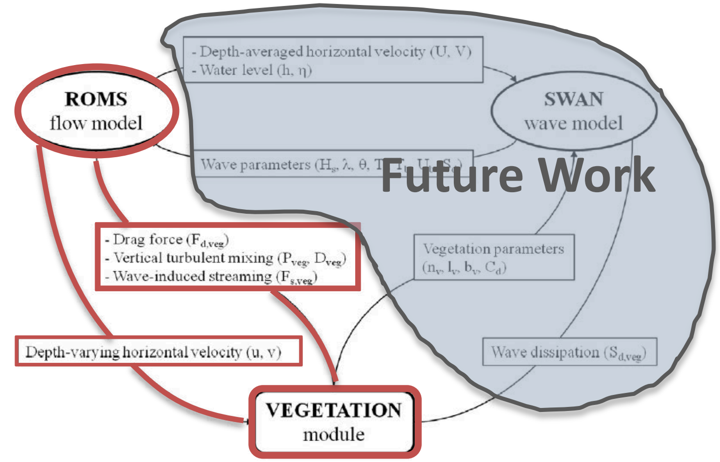




**Fig. 2.** Diagram showing data exchanges between the flow model, the wave model, and the vegetation module in COAWST.

[Beudin, 2017]

LONG TERM DATASET!
Seagrass.net (1983 - present)


Presented at Woods Hole Oceanographic Institute (WHOI) in February, 2019

# The role of resolution and vegetation

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| **Sediments (30m)** | **747** | **267*** |
| **Sediments (10m)** | **719** | **257*** |
| **Eelgrass included** | **614** | **219*** |
| | (kg/event) | (kg/event) |
| **Event (Storm-Irene)** [B] | 220 | 80* |
| **One Tidal Cycle (Average)** | **25**<br>**24**<br>**20** | **9***<br>**9***<br>**7*** |
| **Neap Tide (Minimum)** | **13**<br>**9**<br>**10** | **5***<br>**4***<br>**3*** |
| **Spring Tide (Maximum)** | **91**<br>**80**<br>**56** | **33***<br>**28***<br>**20*** |

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# Research outcomes

- Validated a high res ocean model (30m) and published a paper in Ocean Modeling (Feb 14$^{th}$, Cook *et al* 2019)

- Vegetation is important for trapping sediment and preventing legacy nutrient loading (paper in prep)

- No real gain in using the 10m grid - great for computational savings!

Blue waters was instrumental in taking our modeling research to the next level. UNH is growing its modeling group, and this fellowship allowed me to grow and open up funding and support for more students

# Fellowship Outcomes

- AGU Ocean Sciences Conference, 2018
- Ocean Modeling publication, 2019
- COFDL talk at MIT-Woods Hole Oceanographic Institute (MIT-WHOI), 2019
- Two more publications, summer/fall 2019
- Undergraduate mentorship, summer 2018-2019

<u>Ongoing:</u>

- HPC shared knowledge with lab group
- Shared data with local scientists

# Conference Goals

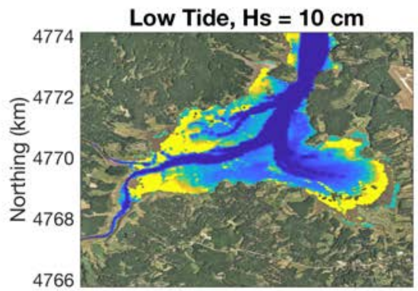
*(key challenges, bucket list, etc.…)*

- Improve workflow
  - 10-200 GB and 2 TB netCDF files
  - From dataset generation to accessing and visualizing and disseminating results

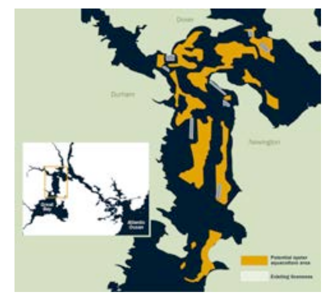
- Best practices for disseminating/sharing data?
  - End-users and stakeholders

# Future Work

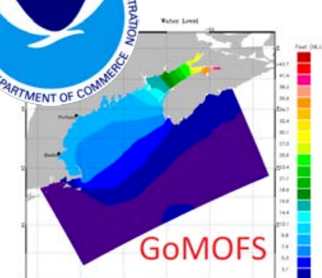
- Waves!




- Oyster restoration

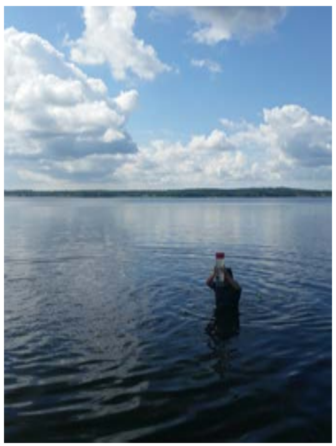


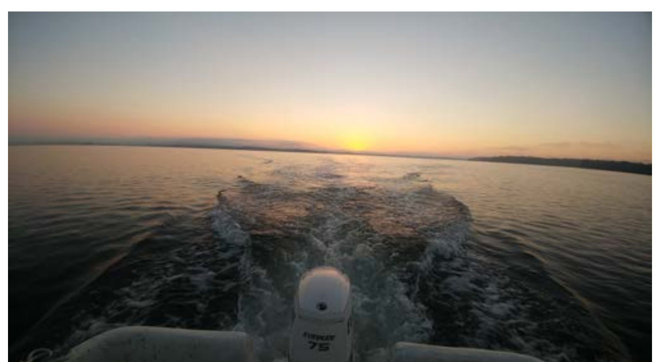
- Model Coupling
  - watershed models to coastal ocean models
  - estuarine models to regional ocean models

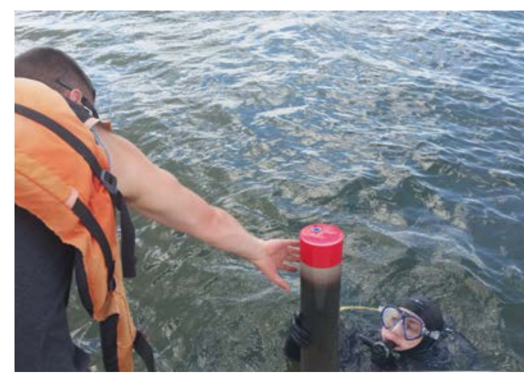



# Remember: We all live downstream!

## Thank you for your attention
## Questions?



# By the numbers…

- XE nodes
- 10 meter grid (30 day run)
  - 2200x2500x8 = 44,000,000 grid cells
  - 14,000 node hours
- 30 meter grid (30 day run)
  - 734x834x8 = 4,897,248 grid cells
  - 20 nodes - 640 processors
  - 900 node hours

# Oyster Restoration By Design

IMPROVING THE HEALTH OF NEW HAMPSHIRE'S ESTUARY ONE OYSTER AT A TIME

Above: Handfuls of oysters. © Jennifer Emerling; Below: Hauling cages of oysters. © Jennifer Emerling.

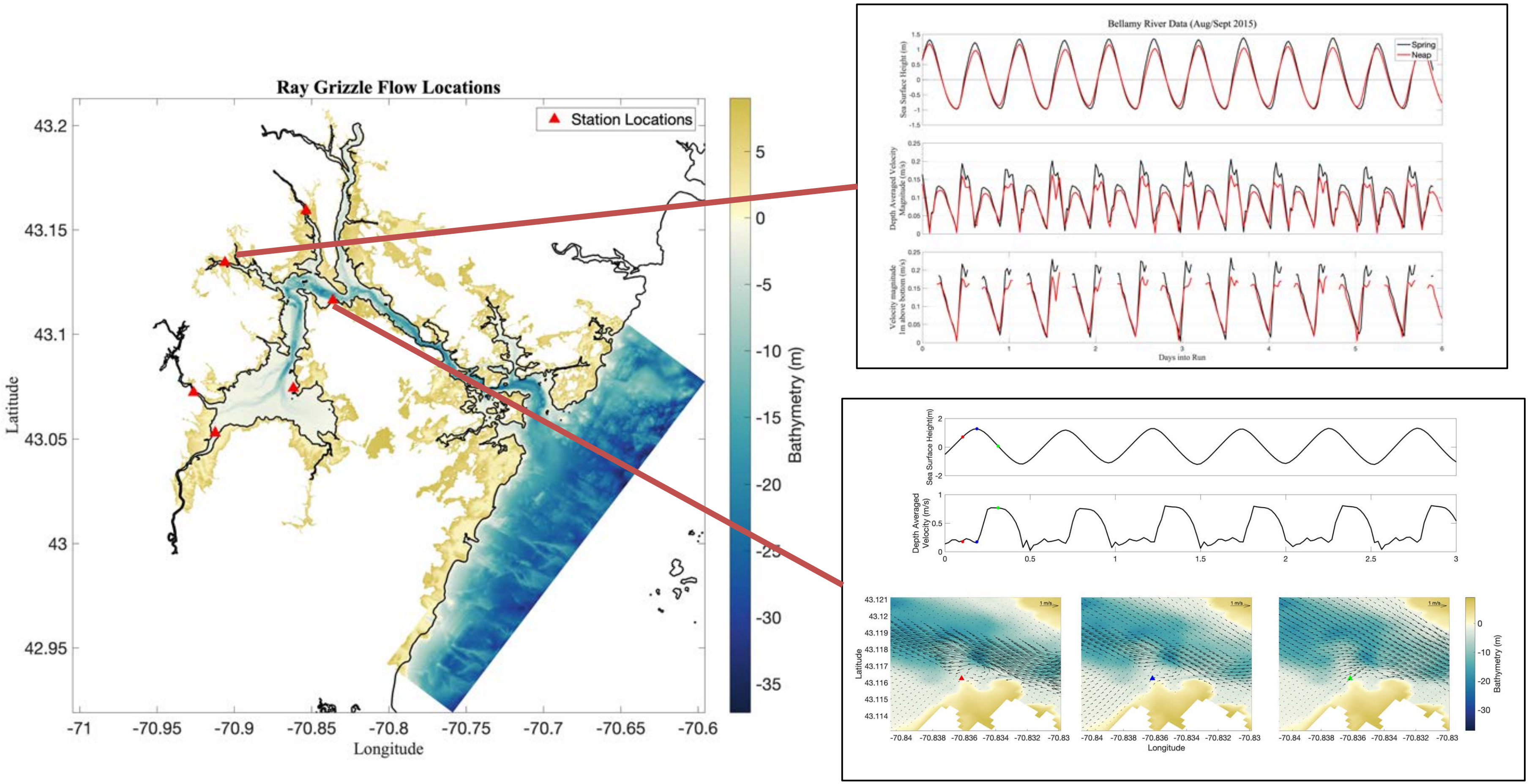
Oysters are nitrogen sinks

- Feed on phytoplankton, digest some nitrogen, and incorporate into shells and soft tissue
- Water Clarity - Filter about 30 gallons of water a day
- Provide habitat
- 90% losses in oyster reefs in the 90's due to oyster diseases (across mid-Atlantic)

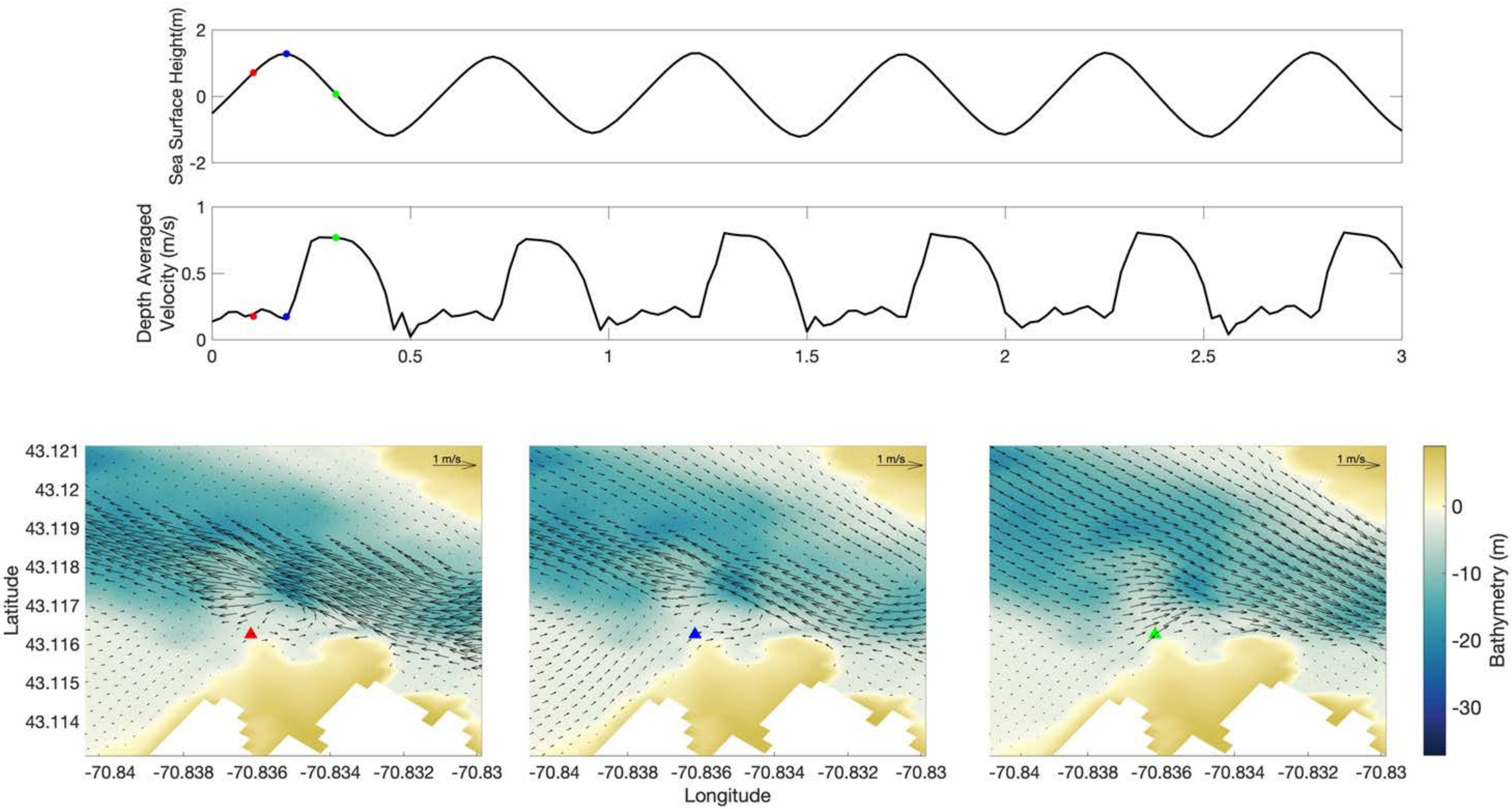
"It's never going to be a huge amount of nitrogen. I suspect it will be below 5 percent of the nitrogen that goes into the estuary, but 5 percent is 5 percent," - Ray Grizzle, PhD

University of New Hampshire. "First comprehensive study of New Hampshire oyster farming." ScienceDaily. ScienceDaily, 4 March 2016. <www.sciencedaily.com/releases/2016/03/160304120823.htm>.

# Oyster Restoration



# Oyster Restoration

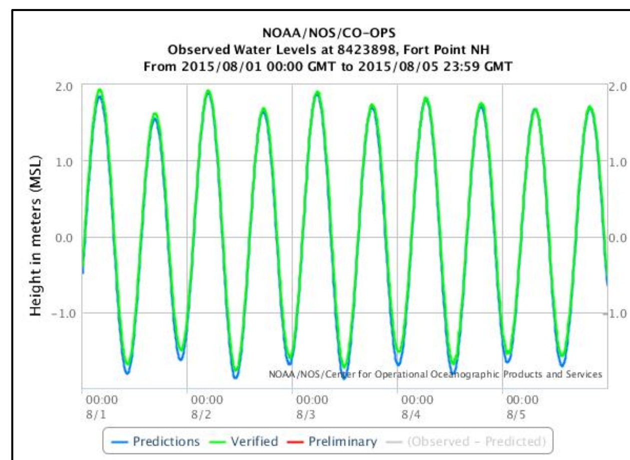


# **The role of resolution**: Model configuration

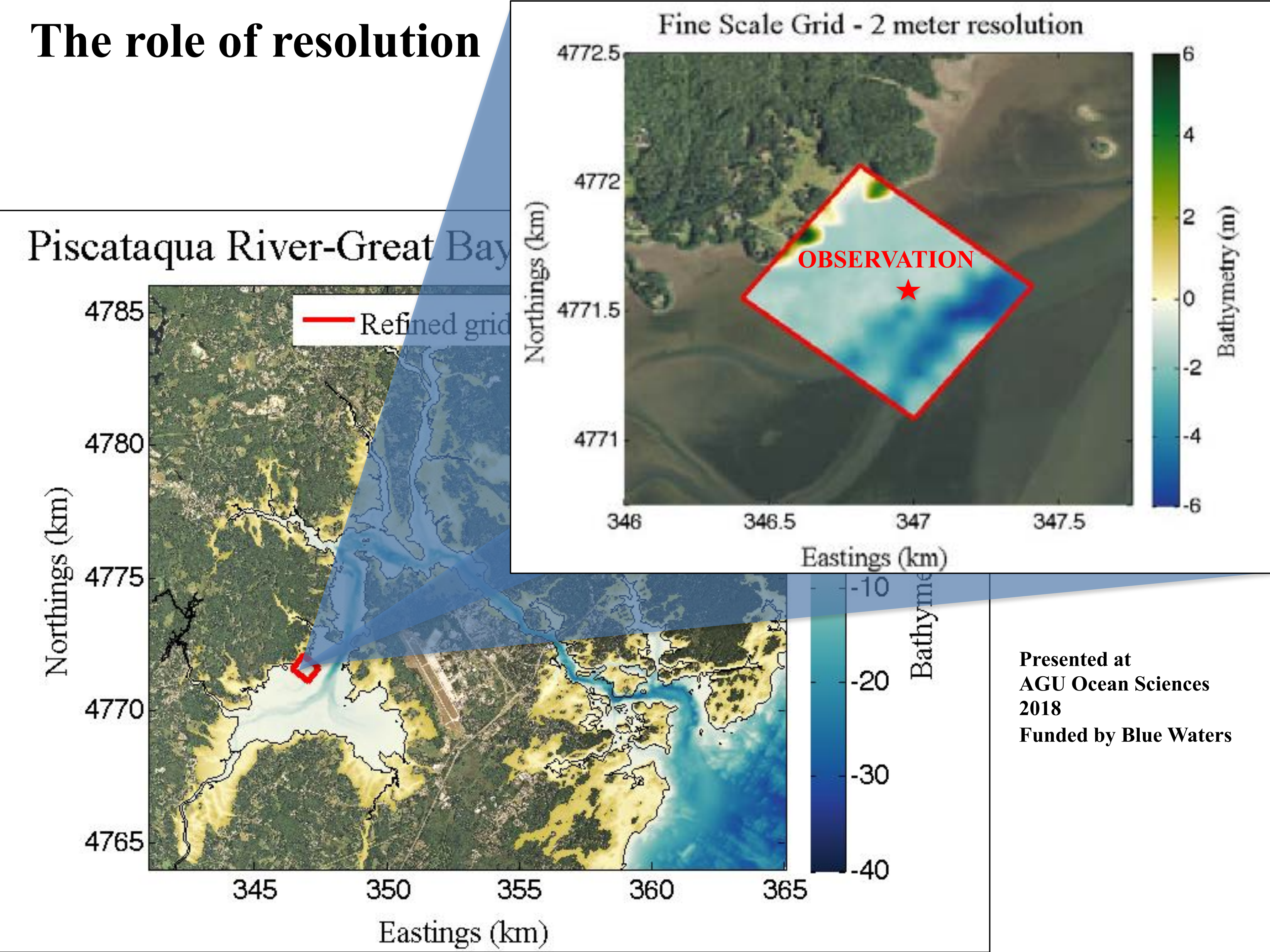
| | **30 meter grid** | **10 meter grid** → | **2 meter grid** |
|---|---|---|---|
| DT | 1 s | 1 s | 0.5 s |
| Horizontal Resolution | 734 x 834 (22 km x 25 km) | 2201 x 2501 (22 km x 25 km) | 327 x 377 (0.65 km x 0.74 km) |
| Vertical resolution | 8 sigma layers | 8 sigma layers | 8 sigma layers |
| Run Length | 5 days | 5 days | 3 days |
| $z_o$ | 0.015 m | 0.015 m | 0.015 m |
| Other: Wetting and Drying algorithm, Tides ramped up over 1 day | | | |

| **Forcing: Analytical Tide** OSU Tidal Prediction Software (OSU-TPS) | | |
|---|---|---|
| Constituent | Amplitude | Phase |
| **M2** | **1.374** | **123.01** |
| N2 | 0.303 | 53.88 |
| S2 | 0.209 | 138.92 |
| O1 | 0.082 | 63.59 |
| K1 | 0.119 | 335.45 |

Corresponding to 8/1/2015

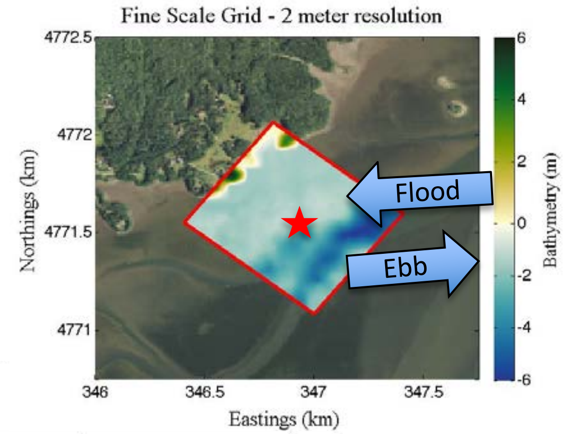


# The role of resolution

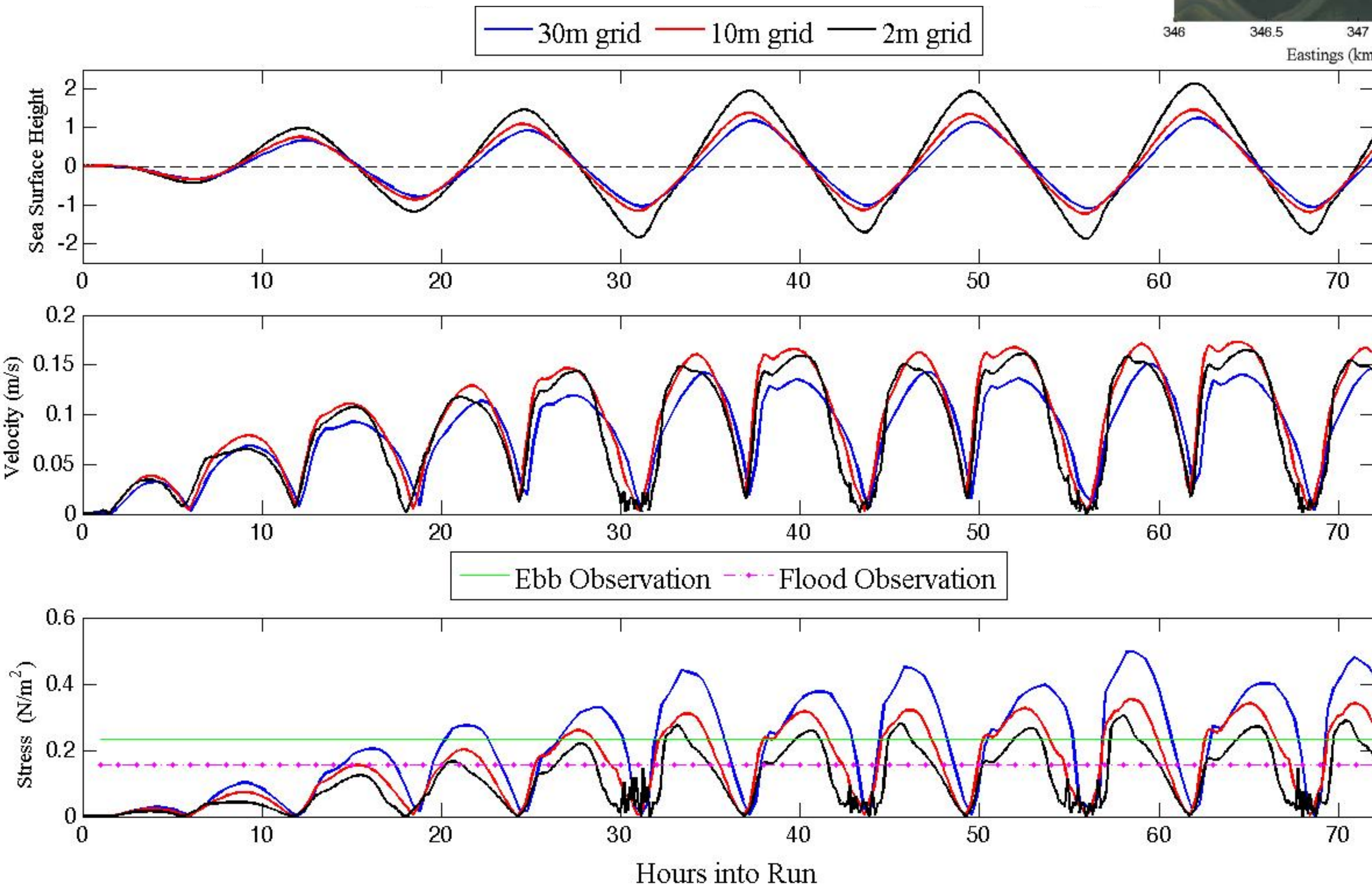



**Presented at**
**AGU Ocean Sciences**
**2018**
**Funded by Blue Waters**

# The role of resolution

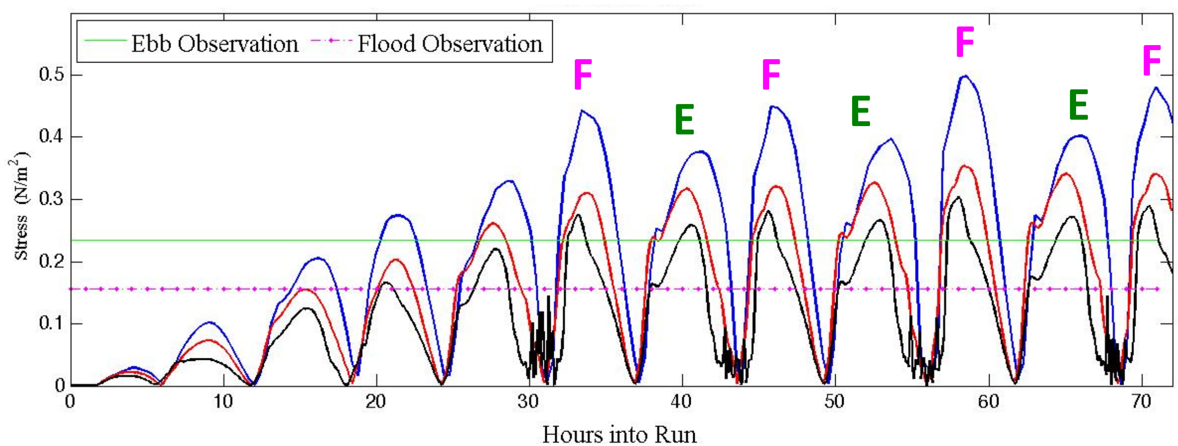



* Same location as shear stress estimate from observations



**The role of resolution:** Is there a model resolution that can accurately represent bed shear stress? If so, what is it?

1) 2 meter grid has best estimate of bed shear stress, however flood is overestimated
2) vertical resolution should also be increased (maybe 15 sigma layers) to better resolve bottom stress on flood tides




| (N/m²) | 2 m grid | 10 m grid | 30 m grid | Observations |
|---|---|---|---|---|
| Flood | 0.27 | 0.3 | 0.45 | 0.16 |
| Ebb | 0.25 | 0.3 | 0.37 | 0.23 |