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

Salme Cook, University of New Hampshire
sc10@wildcats.unh.edu

Resolution

Vegetation

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

Why does it matter?

We’re all part of a watershed

And we all live downstream

Estuary

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

Why does it matter?

“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.”

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


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

**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?
EPA - National Estuary Program (NEP)
Tidally dominant (1-3 m/sec current, 2-4 m tide range)
Low river input (<2% of tidal prism)
Tidal Channels with fringing mudflats

Total Nitrogen Loads to GBE from different sources (2012 - 2016)

- Other Watershed sources (e.g., fertilizer, septic systems, animal waste, atmospheric deposition) 57%
- Wastewater Treatment Facilities 33%
- Total = 903.1 Tons
  - PS Total = 296.4 Tons
  - NPS Total = 606.6 Tons

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

Function of hydrodynamics

\[ \tau_b \propto \mu \frac{\partial u}{\partial z} \propto \rho v \frac{\partial u}{\partial z} \]

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

Horizontal: 30 m, 10m
Vertical: 8 vertical sigma layers

C – Coupled
O – Ocean (ROMS)
A – Atmosphere (WRF)
W – Wave (SWAN)
ST – Sediment Transport

Regional Ocean Modeling System (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

**Classic Logarithmic “Law of the Wall” Formulation**

\[ |u| = \frac{u_*}{\kappa} \ln \left( \frac{Z}{z_0} \right) \]

\[ (\tau^x_b) = \rho_0 \left( \frac{\kappa}{\ln(z/Z_{ob})} \right)^2 u |u| \]

\[ (\tau^y_b) = \rho_0 \left( \frac{\kappa}{\ln(z/Z_{ob})} \right)^2 v |v| \]
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
  – $z_0 = 0.02\text{m}^*$

• **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

Where’s the mud?

>50% mud fraction
0.35 N/m² for nutrient release
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Numerical estimates of the distribution of bed shear stress

Low Tide

Flooding Tide

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Percuoco (2013)
Numerical estimates of the distribution of bed shear stress

Low Tide

Flooding Tide

High Tide

Where’s the mud?

>50% mud fraction
0.35 N/m² for nutrient release
Percuoco (2013)
Numerical estimates of the distribution of bed shear stress
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: Mid Ebb Tide]

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

[Lab Studies: Percuoco et al. (2015); Wengrove et al. (2015)]

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

\[
\left( \frac{\text{Area}_{r_w>0.35N/m^2}}{m^2} \right) \left( 1.3 \frac{\text{mmol DIN}}{m^2} \right) \left( \frac{1 \text{ mol N}}{1 \text{ mol DIN}} \right) \left( \frac{\text{kg}}{10^6 \text{mmol}} \right) = \text{kg Nitrogen}
\]

\[
\left( \frac{\text{Area}_{r_w>0.35N/m^2}}{m^2} \right) \left( 0.21 \frac{\text{mmol P}}{m^2} \right) \left( \frac{\text{kg}}{10^6 \text{mmol}} \right)
\]

\[
\left( 30.973761 \frac{g \text{ P}}{\text{mol}} \right) = \text{kg Phosphorus}
\]

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?

<table>
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<tr>
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### Application: Nutrient Loading

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Ok…. So what about resolution and vegetation?
The role of vegetation

Future Work

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

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

• Validated a high res ocean model (30m) and published a paper in Ocean Modeling (Feb 14th, 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

Ongoing:
• 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)
  – \(2200 \times 2500 \times 8 = 44,000,000\) grid cells
  – 14,000 node hours
• 30 meter grid (30 day run)
  – \(734 \times 834 \times 8 = 4,897,248\) 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

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

Oyster Restoration
Oyster Restoration
The role of resolution: Model configuration

<table>
<thead>
<tr>
<th></th>
<th>30 meter grid</th>
<th>10 meter grid</th>
<th>2 meter grid</th>
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<tbody>
<tr>
<td>DT</td>
<td>1 s</td>
<td>1 s</td>
<td>0.5 s</td>
</tr>
<tr>
<td>Horizontal Resolution</td>
<td>734 x 834</td>
<td>2201 x 2501</td>
<td>327 x 377</td>
</tr>
<tr>
<td></td>
<td>(22 km x 25 km)</td>
<td>(22 km x 25 km)</td>
<td>(0.65 km x 0.74 km)</td>
</tr>
<tr>
<td>Vertical resolution</td>
<td>8 sigma layers</td>
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</tr>
<tr>
<td>Run Length</td>
<td>5 days</td>
<td>5 days</td>
<td>3 days</td>
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<tr>
<td>$z_0$</td>
<td>0.015 m</td>
<td>0.015 m</td>
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Other: Wetting and Drying algorithm, Tides ramped up over 1 day

Forcing: Analytical Tide
OSU Tidal Prediction Software (OSU-TPS)

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<thead>
<tr>
<th>Constituent</th>
<th>Amplitude</th>
<th>Phase</th>
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<tbody>
<tr>
<td>M2</td>
<td>1.374</td>
<td>123.01</td>
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<tr>
<td>N2</td>
<td>0.303</td>
<td>53.88</td>
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<td>S2</td>
<td>0.209</td>
<td>138.92</td>
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<tr>
<td>O1</td>
<td>0.082</td>
<td>63.59</td>
</tr>
<tr>
<td>K1</td>
<td>0.119</td>
<td>335.45</td>
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Corresponding to 8/1/2015
The role of resolution

Piscataqua River-Great Bay

- 30 meter, 10 meter and 2 meter grid
- LIDAR and bathymetry
- Has been validated with Tidal Dissipation characteristics and vertical structure of the currents

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

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<tr>
<th>(N/m²)</th>
<th>2 m grid</th>
<th>10 m grid</th>
<th>30 m grid</th>
<th>Observations</th>
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<tbody>
<tr>
<td>Flood</td>
<td>0.27</td>
<td>0.3</td>
<td>0.45</td>
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<td>Ebb</td>
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