Simulation of Tides Through a Narrow Inlet at Guilford, CT

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Study area: a salt marsh system in Guilford, CT
Motivations:

- Salt marshes connect to coastal waters through narrow inlets.
- Marshes and culverts affect the amount of flooding extent and create challenges in predicting flood water level.
Google Earth  2006/10 Ebb tides  2020/02 Flood tides
How does the inlet impact the tides?
Month-long water level observations during winter 2020

- 1/3 tidal amplitude reduction
- Tidal phase lag

Inside the salt mash

The narrow inlet constraints the tidal flow
# Hydrodynamic models

<table>
<thead>
<tr>
<th>Model</th>
<th>Grid type</th>
<th>2D circulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>ROMS</td>
<td>Arakawa-C</td>
<td>Yes</td>
</tr>
<tr>
<td>FVCOM</td>
<td>unstructured, finite volume</td>
<td>Yes</td>
</tr>
<tr>
<td>ADCIRC</td>
<td>unstructured, finite element</td>
<td>Yes</td>
</tr>
<tr>
<td>SCHISM</td>
<td>unstructured, finite element</td>
<td>Yes</td>
</tr>
</tbody>
</table>
Numerical simulations

- Domain: a 3-m deep pool with an inlet
- Inlet length 15m (49ft); width 5, 10, or 15m.
- Resolution: 1m x 0.5m at inlet
- Horizontal eddy viscosity coefficient, $2m^2s^{-1}$.
- Quadratic bottom friction, $C_d 0.003$.
- 1-m amplitude $S_2$ tide is imposed from left.
- Run 24 hours, only use the last 12-hour results.
- 4 models: ROMS, FVCOM, ADCIRC, SCHISM
Modeled water levels inside and outside the inlet

Strength of the inlet constraint
- Narrow inlet > wide inlet
- ROMS > FVCOM > ADCIRC-a
- ROMS ≈ FVCOM-jetty > SCHISM-equì
- SCHISM-equì > SCHISM-right
Across-inlet profile of the along-inlet current during flood tides

Lateral shear of the current
- No, the FVCOM case
- Yes, the others
Along-inlet momentum balance with lateral shear: ROMS

Pressure gradient force = Horizontal eddy viscosity

(Pressure drop caused by the along-inlet water level drop)  (lateral eddy mixing introduced by the bank friction)
Along-inlet profiles of the water level and current during flood tides

- With lateral shear: water level drops through the inlet
- Without lateral shear: water level drops at the inlet heads
Momentum balance without lateral shear: FVCOM

Pressure gradient force = Horizontal eddy viscosity

(Pressure drop caused by the along-inlet water level drop)  (Uneven velocity changing)
A two-dimensional time varying problem

\[ \frac{\partial \eta}{\partial t} + \frac{\partial U}{\partial x} + \frac{\partial V}{\partial y} = 0 \]

\[ \frac{\partial U}{\partial t} + U \frac{\partial U}{\partial x} + V \frac{\partial U}{\partial y} - fV + g \frac{\partial \eta}{\partial x} - \nu \nabla^2 U = 0 \]

\[ \frac{\partial V}{\partial t} + U \frac{\partial V}{\partial x} + V \frac{\partial V}{\partial y} + fU + g \frac{\partial \eta}{\partial y} - \nu \nabla^2 V = 0, \]

A two-point time varying problem

- Momentum balance
- Water exchange only through the inlet

\[ \frac{\partial \eta_{in}}{\partial t} = \alpha (D + \eta_{out})(\eta_{out} - \eta_{in}) \]
The simple prediction model

\[ \frac{\partial \eta_{in}}{\partial t} = \alpha(D + \eta_{out})(\eta_{out} - \eta_{in}) \]

\[ \alpha = \left( \frac{1}{2\gamma - \frac{1}{24}} \right) \frac{gW^3}{\varepsilon AL} \]

\[ \alpha = \frac{g\beta W^2}{(\pi - 2)\varepsilon A} \]
Water levels inside the salt marshes observed vs. simple model with lateral shear
Conclusions

• Both field observation and model study show that a narrow inlet has strong constraint on water exchange between basins.

• Four hydrodynamic models (ROMS, FVCOM, ADCRIC, & SCHISM) are compared on the inlet constraints problem. The results can direct model selection and grid design in coastal modeling.

• Horizontal eddy viscosity plays important role on balance the sharp water level change through the inlet.

• A couple of simple predicting models are developed based on different the momentum balance scenarios from the numerical simulation, which can provide quick and useful guidance on water exchange rates at the inlet for ecologists and coastal engineers.
Thank you