Narragansett Bay ROMS: Model-Data Comparisons of Currents and Hydrography

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NBC Workshop: Just Another Day on the Upper-Upper Bay
August 5, 2015
Background on Modeling Effort

• Model development has been an ongoing process over past 5-10 years.
• Major impetus: CHRP Narragansett Bay Hypoxia project (Funded by NOAA-CHRP and RI-BRWCT).
  • ROMS model used to parameterize material transports in ecological box model of the Bay.
  • For this application, require a realistically forced model that captures the variability in circulation and mixing occurring in NB in response to time-variable forcing (river inflows, wind, heat fluxes, tides, oceanic variability).
Use of Field Observations to Assess the Skill of the Numerical Model

- Numerical circulation model is a **Computer Program**, and as people used to say in the early days of computers regarding programs: “**Garbage in, Garbage out**”.

- Before using model output for any application, it is crucial to verify the performance of the model.

- In this presentation, I will evaluate the skill of our ROMS Narragansett Bay model in simulating water surface elevation, currents, hydrography (temperature and salinity), and vertical density stratification using observations.
ROMS N-Bay Circulation Model

Nested (ROMS) configuration:
- Low resolution model extending onto continental shelf provides boundary conditions for high-resolution Bay model (50-100m resolution in upper Bay).
- Sigma vertical coordinate (15 levels).
- Vertical mixing parameterized using $k$-$\varepsilon$ turbulence closure.
- Horizontal viscosity/diffusivity scaled by grid spacing.
- Forced with:
  - Measured river/WWTF inflows (green symbols).
  - Winds from WRF met. model analysis (UMASS).
  - Radiative forcing from N.A.R.R. (NOAA).
  - Local met. measurements (T.F. Green and PORTS).

Model Domains:
- Low resolution
- Nested high resolution

Forcing from regional model output (UMASS)+ADCIIRC tides
River/WWTF discharges
Skill Assessment: Site Locations

Observations:
- Surface elevation (NOAA tide gauges).
- Currents (URI ADCPs).
- Temperature and Salinity (URI/DEM buoys)
Skill Assessment: Site Locations

**Tide Gauges (surface elevation):**
- Providence (Prov.)
- Conimicut (Conim.)
- Quonset (Quon.)
- Newport (Newp.)

**ADCPs (current profiles):**
- West Passage Channel 2006 (WP)
- East Passage Channel 2006 (EPc)
- East Passage Shoal 2006 (EPs)
- East Passage Channel 2007 (EP07)
- Betw. Prudence and Conanicut 2007 (MD07)

**Monitoring Buoys (T and S, surf & bott):**
- Bullock Reach (BR)
- Conimicut (CP)
- North Prudence (NP)
- Mount View (MV)
- Quonset (QP)
- Popasquash Point (PP)
- T-Wharf (TW)
- Greenwich Bay Marina (GB)
- Mount Hope Bay (MH)
Evaluation of Model Skill


\[
Skill = 1 - \frac{\sum_{i=1}^{N} (T_{mod} - T_{obs})^2}{\sum_{i=1}^{N} (|T_{mod} - \overline{T_{obs}}| + |T_{obs} - \overline{T_{obs}}|)^2}
\]

Skill=1: perfect model  \hspace{1cm} T_{obs} = observed value
Skill=0: useless model  \hspace{1cm} T_{mod} = model-predicted value

For surface elevation and currents, skill evaluated for:
A. Raw data.
B. Subtidal signal (low pass filtered, cutoff period =36 h).
C. Tidal signal (Raw-Subtidal).

Reference:
ROMS Model-Data Comparison: Sea Level at Providence (2006-2007)

Skill
Raw: 0.955
Subtidal: 0.851
Tidal: 0.967
### Model Skill: Sea Level 2006-07

**Skill Definition:**

\[
Skill = 1 - \frac{\sum_{i=1}^{N} (T_{mod} - T_{obs})^2}{\sum_{i=1}^{N} (|T_{mod} - T_{obs}| + |T_{obs} - T_{obs}|)^2}
\]

<table>
<thead>
<tr>
<th>Site</th>
<th>Raw</th>
<th>Subtidal</th>
<th>Tidal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Providence</td>
<td>0.955</td>
<td>0.851</td>
<td>0.967</td>
</tr>
<tr>
<td>Conimicut</td>
<td>0.957</td>
<td>0.844</td>
<td>0.970</td>
</tr>
<tr>
<td>Quonset</td>
<td>0.960</td>
<td>0.818</td>
<td>0.978</td>
</tr>
<tr>
<td>Newport</td>
<td>0.963</td>
<td>0.841</td>
<td>0.980</td>
</tr>
</tbody>
</table>

Skill (*major axis current*)
Raw: 0.894
Subtidal: 0.846
Tidal: 0.906
Model Skill: Depth-Averaged Major Axis Currents 2006-07

Skill Definition: 

\[ \text{Skill} = 1 - \frac{\sum_{i=1}^{N}(T_{mod} - T_{obs})^2}{\sum_{i=1}^{N}(|T_{mod} - \bar{T}_{obs}| + |T_{obs} - \bar{T}_{obs}|)^2} \]

<table>
<thead>
<tr>
<th>Site</th>
<th>year</th>
<th>Site ID</th>
<th>Raw</th>
<th>Subtidal</th>
<th>Tidal</th>
</tr>
</thead>
<tbody>
<tr>
<td>West Passage Channel</td>
<td>2006</td>
<td>WP</td>
<td>0.812</td>
<td>0.724</td>
<td>0.812</td>
</tr>
<tr>
<td>East Passage Channel</td>
<td>2006</td>
<td>EPc</td>
<td>0.894</td>
<td>0.846</td>
<td>0.906</td>
</tr>
<tr>
<td>East Passage Shoal</td>
<td>2006</td>
<td>EPs</td>
<td>0.832</td>
<td>0.512</td>
<td>0.876</td>
</tr>
<tr>
<td>East Passage Channel</td>
<td>2007</td>
<td>EP07</td>
<td>0.865</td>
<td>0.737</td>
<td>0.869</td>
</tr>
<tr>
<td>Between Prudence and Conanicut Islands</td>
<td>2007</td>
<td>MD07E</td>
<td>0.932</td>
<td>0.617</td>
<td>0.938</td>
</tr>
</tbody>
</table>
Evaluation of Model Skill (Hydrography)

- For $T$, $S$, $\Delta \rho$ compute the mean difference (bias) at each location and then examine skill of demeaned variables (fluctuations about the mean).

\[
\text{Bias} = \frac{1}{N} \sum_{i=1}^{N} T_{\text{mod}} - \frac{1}{N} \sum_{i=1}^{N} T_{\text{obs}}
\]

Mean of Model - Mean of Obs.

\[
T'_{\text{mod}} = T_{\text{mod}} - \frac{1}{N} \sum_{i=1}^{N} T_{\text{mod}}
\]

\[
T'_{\text{obs}} = T_{\text{obs}} - \frac{1}{N} \sum_{i=1}^{N} T_{\text{obs}}
\]

- Use Taylor Diagram as visual aid in evaluating model.
**Bias**
- Tsurf: -0.6 C
- Tbott: -0.7 C
- Ssurf: 0.3
- Sbott: -0.2

**Skill**
- Tsurf: 0.98
- Tbott: 0.98
- Ssurf: 0.95
- Sbott: 0.81
ROMS Model-Data Comparison: T/S at Bullock

Bias
Tsurf: -0.9 C
Tbott: 0.5 C
Ssurf: -0.2
Sbott: -2.5

Skill
Tsurf: 0.99
Tbott: 0.97
Ssurf: 0.95
Sbott: 0.68

A = observations
B = Bullock
C = Conimicut
D = North Prudence
E = Mount View
F = Quonset
G = Popasquash
H = T-Wharf
I = Greenwich Bay
J = Mount Hope Bay
### Skill Definition:

\[
Skill = 1 - \frac{\sum_{i=1}^{N}(T_{mod} - T_{obs})^2}{\sum_{i=1}^{N}(|T_{mod} - T_{obs}| + |T_{obs} - T_{obs}|)^2}
\]

<table>
<thead>
<tr>
<th>Site</th>
<th>Tsurf</th>
<th>Tbott</th>
<th>Ssurf</th>
<th>Sbott</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bullock</td>
<td>0.99</td>
<td>0.97</td>
<td>0.95</td>
<td>0.68</td>
</tr>
<tr>
<td>Conimicut</td>
<td>0.98</td>
<td>0.98</td>
<td>0.95</td>
<td>0.81</td>
</tr>
<tr>
<td>North Prudence</td>
<td>0.99</td>
<td>0.99</td>
<td>0.93</td>
<td>0.87</td>
</tr>
<tr>
<td>Mount View</td>
<td>0.99</td>
<td>0.98</td>
<td>0.96</td>
<td>0.89</td>
</tr>
<tr>
<td>Quonset</td>
<td>0.98</td>
<td>0.98</td>
<td>0.90</td>
<td>0.91</td>
</tr>
<tr>
<td>Popasquash</td>
<td>0.99</td>
<td>0.98</td>
<td>0.93</td>
<td>0.88</td>
</tr>
<tr>
<td>T-Wharf</td>
<td>0.99</td>
<td>0.99</td>
<td>0.93</td>
<td>0.83</td>
</tr>
<tr>
<td>Greenwich Bay</td>
<td>0.99</td>
<td>0.99</td>
<td>0.88</td>
<td>0.77</td>
</tr>
<tr>
<td>Mount Hope Bay</td>
<td>0.98</td>
<td>0.98</td>
<td>0.97</td>
<td>0.91</td>
</tr>
</tbody>
</table>
ROMS Model-Data Comparison: Vertical Density Difference at Bullock, 2006-2007

\[ \Delta \rho = \rho_{bott} - \rho_{surf} \]

Bias = -2 kg/m$^3$
Skill = 0.75
Vertical Density Difference, 2006-2007

Bias

Taylor Diagram

B = Bullock
C = Conimicut
D = North Prudence
E = Mount View
F = Quonset
G = Popasquash
H = T-Wharf
I = Greenwich Bay
J = Mount Hope Bay
### Model Skill: Vertical Density Difference 2006-07

#### Skill Definition:

\[
Skill = 1 - \frac{\sum_{i=1}^{N}(T_{mod} - T_{obs})^2}{\sum_{i=1}^{N}(|T_{mod} - \overline{T_{obs}}| + |T_{obs} - \overline{T_{obs}}|)^2}
\]

<table>
<thead>
<tr>
<th>Site</th>
<th>Skill (vertical density diff.)</th>
</tr>
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<tbody>
<tr>
<td>Bullock</td>
<td>0.75</td>
</tr>
<tr>
<td>Conimicut</td>
<td>0.91</td>
</tr>
<tr>
<td>North Prudence</td>
<td>0.90</td>
</tr>
<tr>
<td>Mount View</td>
<td>0.90</td>
</tr>
<tr>
<td>Quonset</td>
<td>0.86</td>
</tr>
<tr>
<td>Popasquash</td>
<td>0.91</td>
</tr>
<tr>
<td>T-wharf</td>
<td>0.88</td>
</tr>
<tr>
<td>Greenwich Bay</td>
<td>0.36</td>
</tr>
<tr>
<td>Mount Hope Bay</td>
<td>0.95</td>
</tr>
</tbody>
</table>
2010 Hydrography Model Evaluation
Taylor Diagrams, Temperature/Salinity 2010

A = observations
B = Bullock
C = Conimicut
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## Model Skill: Hydrography 2010

**Skill Definition:**

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Skill = 1 - \frac{\sum_{i=1}^{N} (T_{mod} - T_{obs})^2}{\sum_{i=1}^{N} (|T_{mod} - T_{obs}| + |T_{obs} - T_{obs}|)^2}
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<td>Quonset</td>
<td>0.96</td>
<td>0.92</td>
<td>0.87</td>
<td>0.85</td>
</tr>
<tr>
<td>Popasquash</td>
<td>0.96</td>
<td>0.90</td>
<td>0.86</td>
<td>0.73</td>
</tr>
<tr>
<td>T-Wharf</td>
<td>0.97</td>
<td>0.98</td>
<td>0.76</td>
<td>0.67</td>
</tr>
<tr>
<td>Greenwich Bay</td>
<td>0.96</td>
<td>0.97</td>
<td>0.80</td>
<td>0.80</td>
</tr>
<tr>
<td>Mount Hope Bay</td>
<td>0.95</td>
<td>0.88</td>
<td>0.89</td>
<td>0.85</td>
</tr>
</tbody>
</table>
ROMS Model-Data Comparison: Vertical Density Difference at Bullock, 2010

\[ \Delta \rho = \rho_{bott} - \rho_{surf} \]

Bias = 0.5 kg/m³
Skill = 0.89
Vertical Density Difference, 2010

Bias

Taylor Diagram

B = Bullock
C = Conimicut
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E = Mount View
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Model Skill: Vertical Density Difference 2010

Skill Definition:

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<table>
<thead>
<tr>
<th>Site</th>
<th>Skill (vertical density diff.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bullock</td>
<td>0.89</td>
</tr>
<tr>
<td>Conimicut</td>
<td>0.79</td>
</tr>
<tr>
<td>North Prudence</td>
<td>0.81</td>
</tr>
<tr>
<td>Mount View</td>
<td>0.72</td>
</tr>
<tr>
<td>Quonset</td>
<td>0.78</td>
</tr>
<tr>
<td>Popasquash</td>
<td>0.73</td>
</tr>
<tr>
<td>T-wharf</td>
<td>0.66</td>
</tr>
<tr>
<td>Greenwich Bay</td>
<td>0.47</td>
</tr>
<tr>
<td>Mount Hope Bay</td>
<td>0.71</td>
</tr>
</tbody>
</table>
Model Skill Assessment, Summary

**Sea Level and Currents**
Tidal timescales:
- Elevation skills > 0.9
- Current skills > 0.8
- Slight under-prediction of tides.

Subtidal timescales:
- Elevation skills > 0.8
- Current skills > 0.6 (except at EPs s~0.5)
- Subtidal fluctuations under-predicted.

**Hydrography and Stratification**
- Temperature generally simulated well.
  - Significant bias (1-3 deg) during some years.
  - Skills generally > 0.9.
- Model performance for salinity more variable (spatially).
  - Biases of 1-3 psu at some sites.
  - Skills > 0.65.
- Density stratification simulated well at some sites/fair at others.
  - Skill generally > 0.7
  - Model underestimates stratification during high discharge.
Model Skill Assessment, Summary

- Model provides a reasonably accurate simulation of time variable circulation and hydrography.

- Iterative process underway to improve model fidelity:
  - Need to prescribe vertical structure of river inflows?
  - Background vertical mixing too high?
  - Problems with Bay mouth boundary conditions?