An overview of the Salish Sea model: existence of reflux mixing and recurring hypoxia

Tarang Khangaonkar  
*Pacific Northwest National Laboratory (U.S.), tarang.khangaonkar@pnnl.gov*

Adi Nugraha  
*Pacific Northwest National Laboratory (U.S.), adi.nugraha@pnnl.gov*

Wenwei Xu  
*Pacific Northwest National Laboratory (U.S.), wenwei.xu@pnnl.gov*

Wen Long  
*Tecplot, United States, w.long@tecplot.com*

Laura Bianucci  
*Canada. Department of Fisheries and Oceans, Laura.Bianucci@dfo-mpo.gc.ca*

*See next page for additional authors*

Follow this and additional works at: [https://cedar.wwu.edu/ssec](https://cedar.wwu.edu/ssec)

Part of the [Fresh Water Studies Commons](https://cedar.wwu.edu/ssec), [Marine Biology Commons](https://cedar.wwu.edu/ssec), [Natural Resources and Conservation Commons](https://cedar.wwu.edu/ssec), and the [Terrestrial and Aquatic Ecology Commons](https://cedar.wwu.edu/ssec)


This Event is brought to you for free and open access by the Conferences and Events at Western CEDAR. It has been accepted for inclusion in Salish Sea Ecosystem Conference by an authorized administrator of Western CEDAR. For more information, please contact westerncedar@wwu.edu.
Speaker

This event is available at Western CEDAR: https://cedar.wwu.edu/ssec/2018ssec/allsessions/11
An Overview of the Salish Sea Model: Existence of Reflux Mixing and Recurring Hypoxia


Pacific Northwest National Laboratory and Washington State Department of Ecology

2018 Salish Sea Ecosystem Conference
Background

Study Area and Motivation

- **PNNL Salish Sea Model Development**
  - 2009 - present
  - Need for a comprehensive predictive computational tool for management of the Salish Sea Ecosystem

- **U.S. EPA / Ecology NEP Grant**
  - Objective: Evaluate the effects of current and potential future nutrient loads on dissolved oxygen (DO) levels in Puget Sound
Salish Sea Model – PNNL / Ecology / EPA
Hydrodynamics and Water Quality

Salish Sea Model (SSM) - Grid

Biogeochemical Component

Model Specifications

Hydrodynamic Model
- FVCOM (Chen et al 2003)
- 3-D Baroclinic
- 10-layers, sigma coordinates
- Boundaries
  - Strait of Juan de Fuca
  - Strait of Georgia
  - S, T, and Elevation
- Meteorology
  - UW – WRF Model
- Hydrology
  - River flows
  - Watershed models

Water Quality Model
- CE-QUAL-ICM / USACE
- FVCOM-ICM (Kim and Khangaonkar 2011)
- Nutrients, phytoplankton/algae, carbon, DO, …, 19 variables
- Benthic fluxes, pH
- Boundary loads based on DFO monitoring data
- Point source loads (99)…

Salish Sea Model – http://salish-sea.pnnl.gov/
- Pelletier et al. 2017 a,b, Bianucci et al 2018,
- Khangaonkar et al 2018 (under review)
Hydrodynamic Model Simulation
Year 2014

Tides – Greenbank, Whidbey Basin

Salinity – Bangor, Hood Canal
Salinity Gradients
Salish Sea Surface Layer

Freshwater Inflows to Salish Sea (2014)

- Whidbey Basin: 1.09E+03, 16%
- Hood Canal: 1.30E+02, 2%
- Central Puget Sound and Admiralty Inlet: 2.76E+02, 4%
- Strait of Juan de Fuca and Bellingham Bay: 6.74E+02, 10%
- South Puget Sound: 1.39E+02, 2%
- Fraser River: 3.18E+03, 46%
- Georgia Strait N. of San Juan Islands: 1.42E+03, 20%
Circulation in the Salish Sea
Northwest Straits

[Khangaonkar et al. (2017) – Ocean Modelling]
Circulation in the Salish Sea
Puget Sound – Reflux flows

SJF = Strait of Juan de Fuca
ADM = Admiralty Inlet
HARO = Haro Strait
R = Reflux Flow at Admiralty Sill (estimated at 19 k, ≈ 60% of surface outflow)
HNV/PSB = Hansville, Puget Sound
EP/CP = East Passage / Colvos Passage
TN = Tacoma Narrows

“Circulation in Embracing Sills”
- Ebbesmeyer et al. 1984

[Ebbesmeyer et al. (1984) – *Ocean Modelling*]
Biogeochemical Model Simulation
WQ - 2014
Progression DO
Neah Bay to South Puget Sound
Hypoxia in Hood Canal
Effect of Fjordal Circulation & Residence

Month: October

Distance Transect [km]

Depth [m]

DO [mgL⁻¹]

October 2014
Bottom Water Hypoxia in Salish Sea

Occurrences of Hypoxia in Puget Sound

Bottom Hypoxia (DO<2mg/L) Occurrence (Days)
SSM Simulation Y2014

Legend
1. Hood Canal
2. Dabob Bay
3. Discovery Bay
4. Penn Cove
5. East Sound
6. Bellingham Bay
7. Samish Bay
8. Port Susan Bay
9. Henderson Bay

Source: Puget Sound Partnership
2009 State of the Sound
Salish Sea Model - Summary

- Salish Sea Model – Puget Sound and Northwest Straits

- Hydrodynamic Model (Expanded Domain)
  - Validation of the Circulation in Embracing Sills
    - Nearly 2/3rd of surface outflow is refluxed back to Puget Sound near the Admiralty Inlet sill
    - [Khangaonkar et al. (2017) – Ocean Modelling]
  - Salish Sea Circulation Maps

- Biogeochemical Model of Salish Sea
  - Nutrients, phytoplankton (two algae groups) and carbon
  - Sediment diagenesis
  - Carbonate chemistry – alkalinity and pH
  - Hypoxia – sensitive to Nutrient Loads
    - [Khangaonkar et al. (2018) – JGR Oceans (under review)]
Comparison to Historical Measurements

Tidally averaged currents data

(Data source: Cokelet [1990] - PMEL).
## Representative Model Error Statistics (2014)

### Tides

<table>
<thead>
<tr>
<th>ME (m)</th>
<th>MAE (m)</th>
<th>RMSE (m)</th>
<th>RME (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>-0.03</td>
<td>0.29</td>
<td>0.35</td>
<td>7.8%</td>
</tr>
</tbody>
</table>

### Salinity

<table>
<thead>
<tr>
<th>ME (ppt)</th>
<th>RMSE (ppt)</th>
</tr>
</thead>
<tbody>
<tr>
<td>-0.12</td>
<td>0.97</td>
</tr>
</tbody>
</table>

### Temperature

<table>
<thead>
<tr>
<th>ME (°C)</th>
<th>RMSE (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>-0.28</td>
<td>0.76</td>
</tr>
</tbody>
</table>

### Water Quality

#### DO

<table>
<thead>
<tr>
<th>ME (mg/L)</th>
<th>RMSE (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>-0.24</td>
<td>0.99</td>
</tr>
</tbody>
</table>

#### Nitrate

<table>
<thead>
<tr>
<th>ME (ug/L)</th>
<th>RMSE (uM/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.96</td>
<td>6.49</td>
</tr>
</tbody>
</table>

#### Algae (Chl – a)

<table>
<thead>
<tr>
<th>ME (ug/L)</th>
<th>RMSE (ug/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.83</td>
<td>4.37</td>
</tr>
</tbody>
</table>

#### Phosphate

<table>
<thead>
<tr>
<th>ME (mg/L)</th>
<th>RMSE (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>-0.67</td>
<td>0.93</td>
</tr>
</tbody>
</table>

#### pH

<table>
<thead>
<tr>
<th>ME</th>
<th>RMSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.12</td>
<td>0.21</td>
</tr>
</tbody>
</table>