Apr 4th, 1:30 PM - 1:45 PM

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

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Speaker
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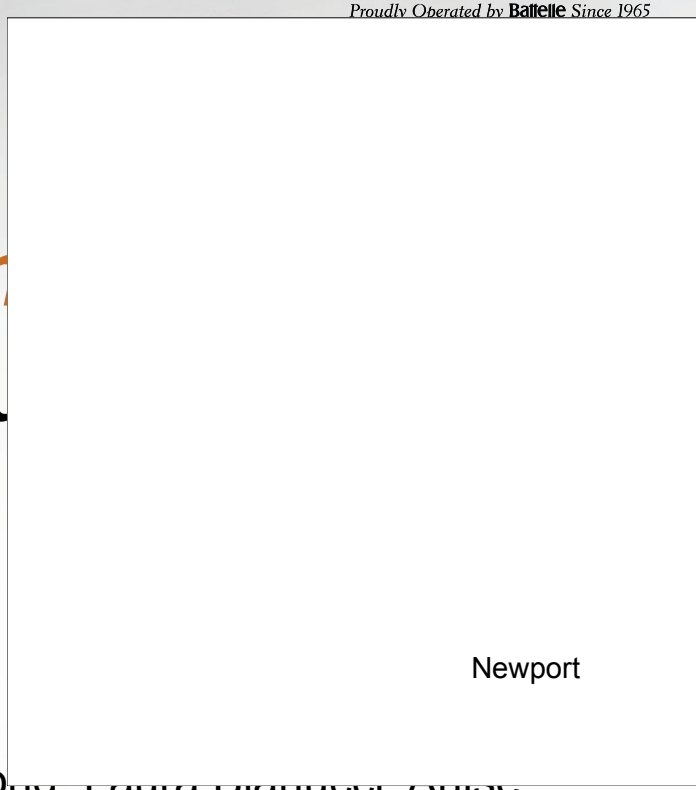
An Overview of the *Salish Sea Model*: Existence of Reflu Mixing and Recurring Hypoxia



Tarang Khangaonkar, Adi Nugraha, Wenwei Xu, Wen Long, Laura Blandon, Anise Ahmed, Teizeen Mohamedali, Greg Pelletier, and Cristiana Figueroa-Kaminsky

Pacific Northwest National Laboratory and Washington State Department of Ecology

2018 Salish Sea Ecosystem Conference

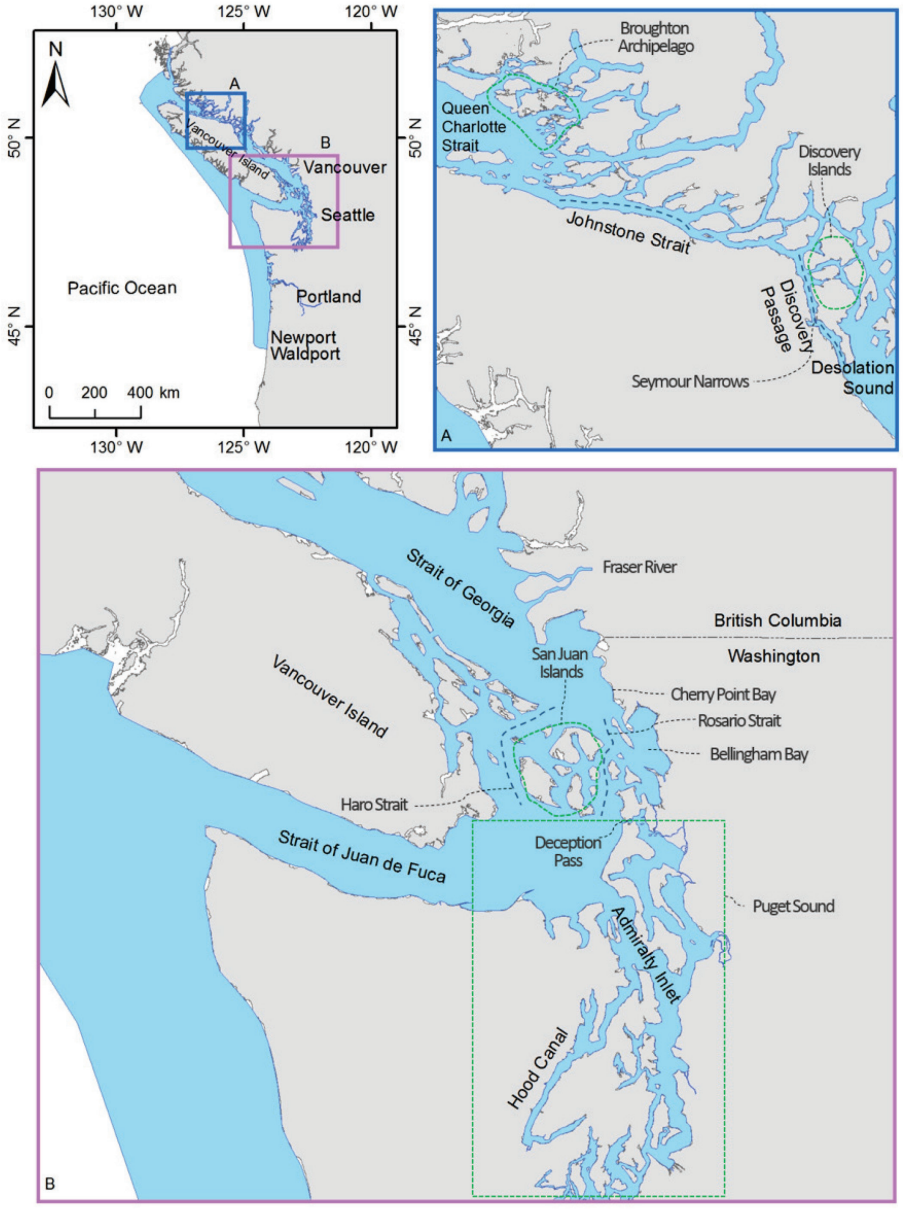
U.S. DEPARTMENT OF ENERGY

EPA United States Environmental Protection Agency

DEPARTMENT OF ECOLOGY State of Washington

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
  - <u>Objective:</u> 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

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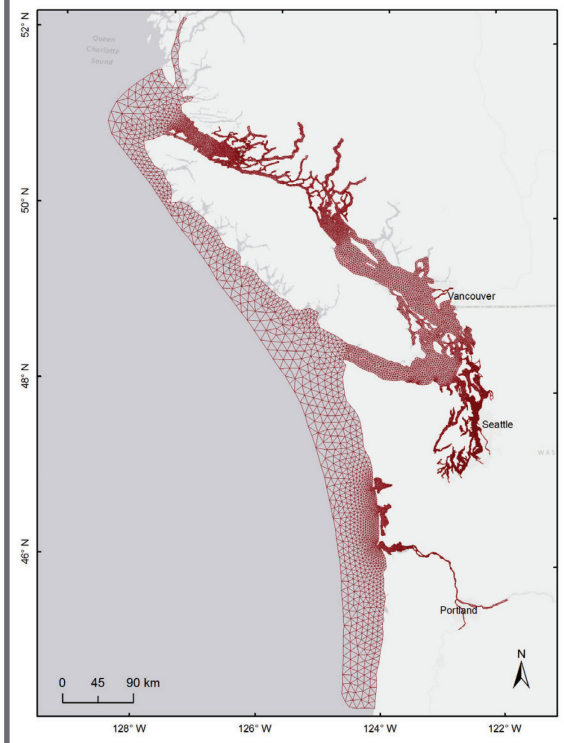
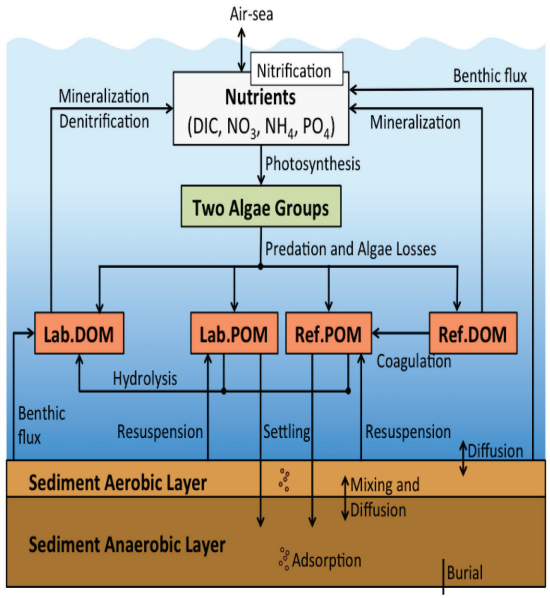
Salish Sea Model (SSM) - Grid



Biogeochemical Component



- **Sediment Diagenesis**
- **Carbonate Chemistry & pH**

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/
- Khangaonkar et al. (2011 a,b, 2012, 2013, 2016, 2017)
- Pelletier at al. 2017 a,b, Bianucci et al 2018,
- Khangaonkar et al 2018 (under review)]

Hydrodynamic Model Simulation

Year 2014

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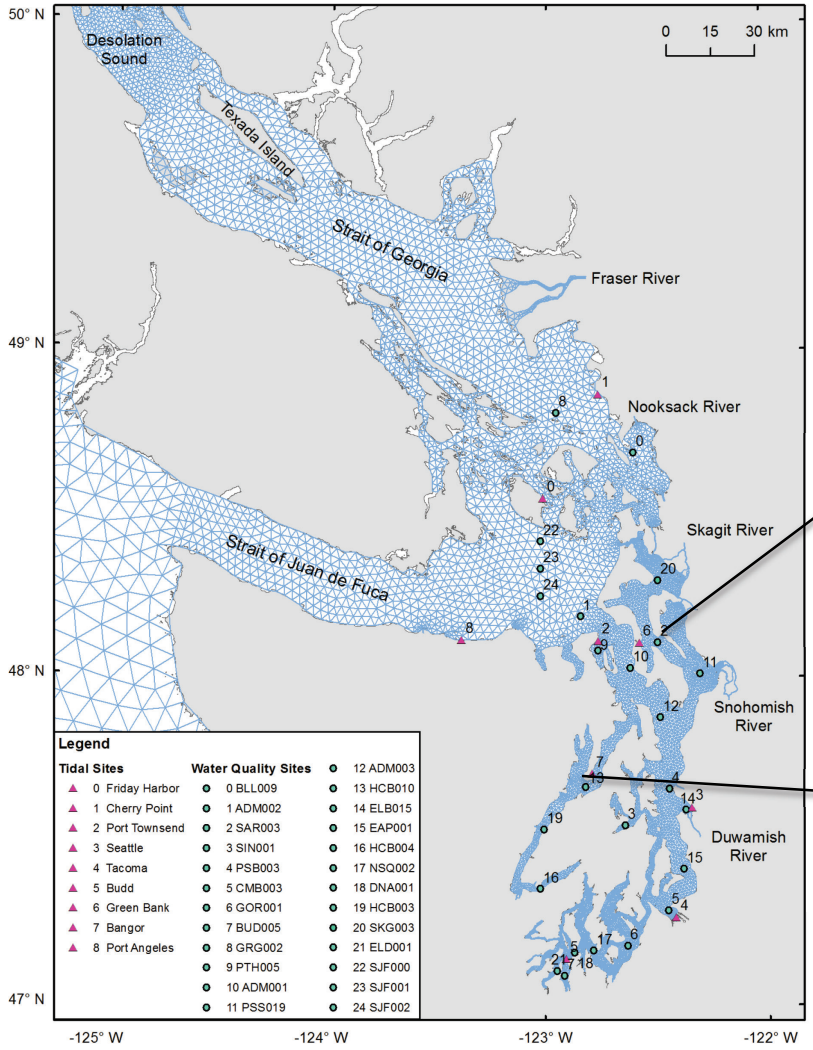
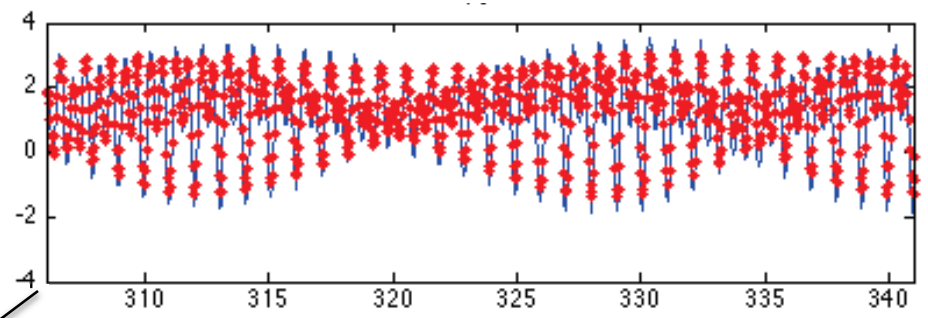
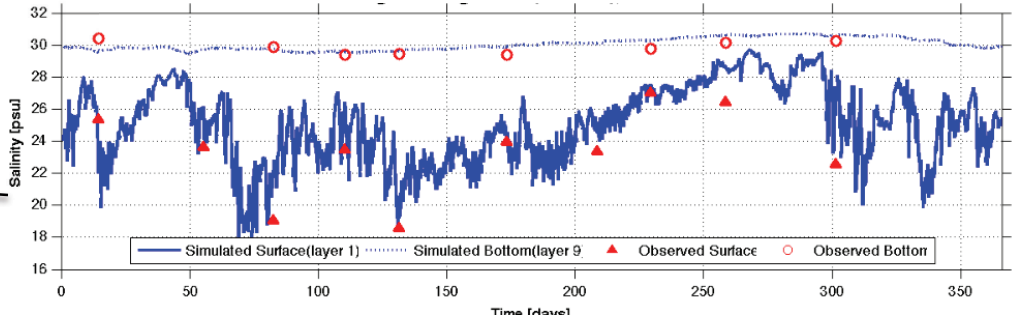


Tides – Greenbank, Whidbey Basin



Salinity – Bangor, Hood Canal



Salinity Gradients

Salish Sea Surface Layer

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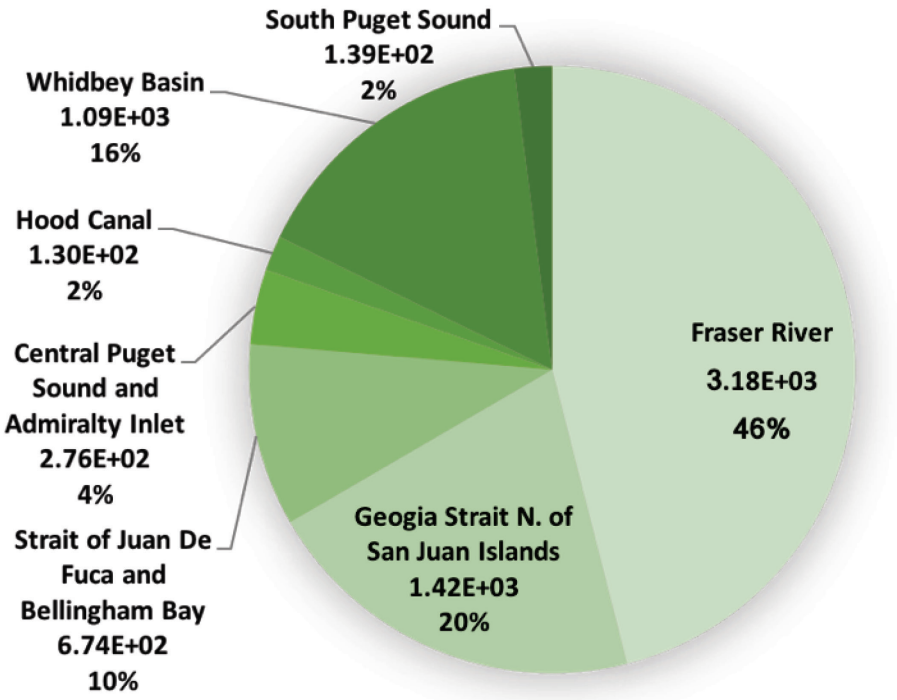
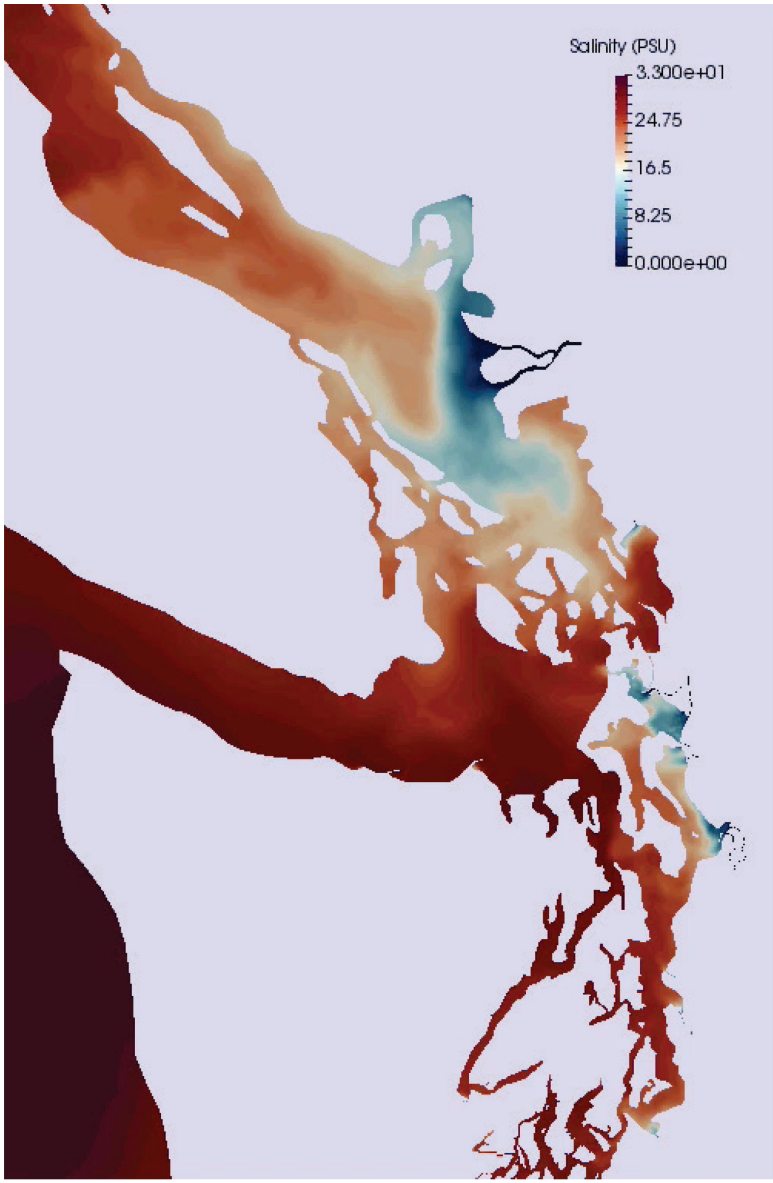
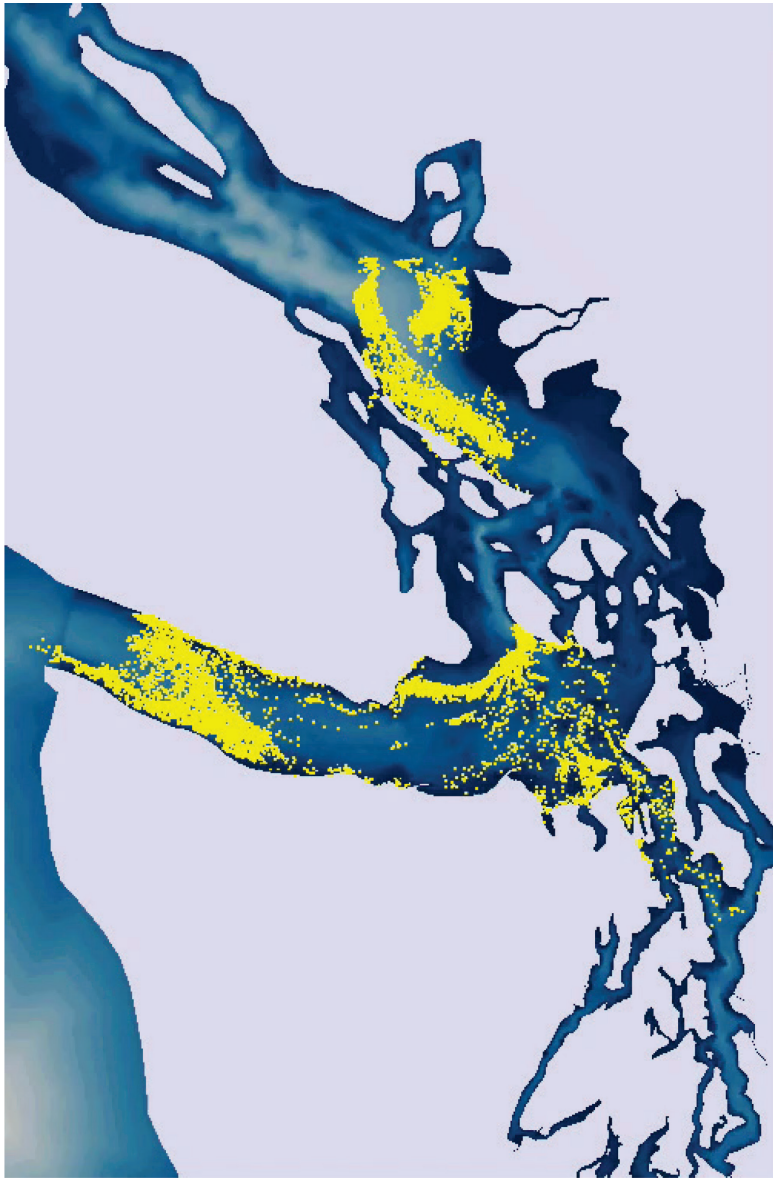
Freshwater Inflows to Salish Sea (2014)





Tidal Currents & Transport



Circulation in the Salish Sea

Northwest Straits

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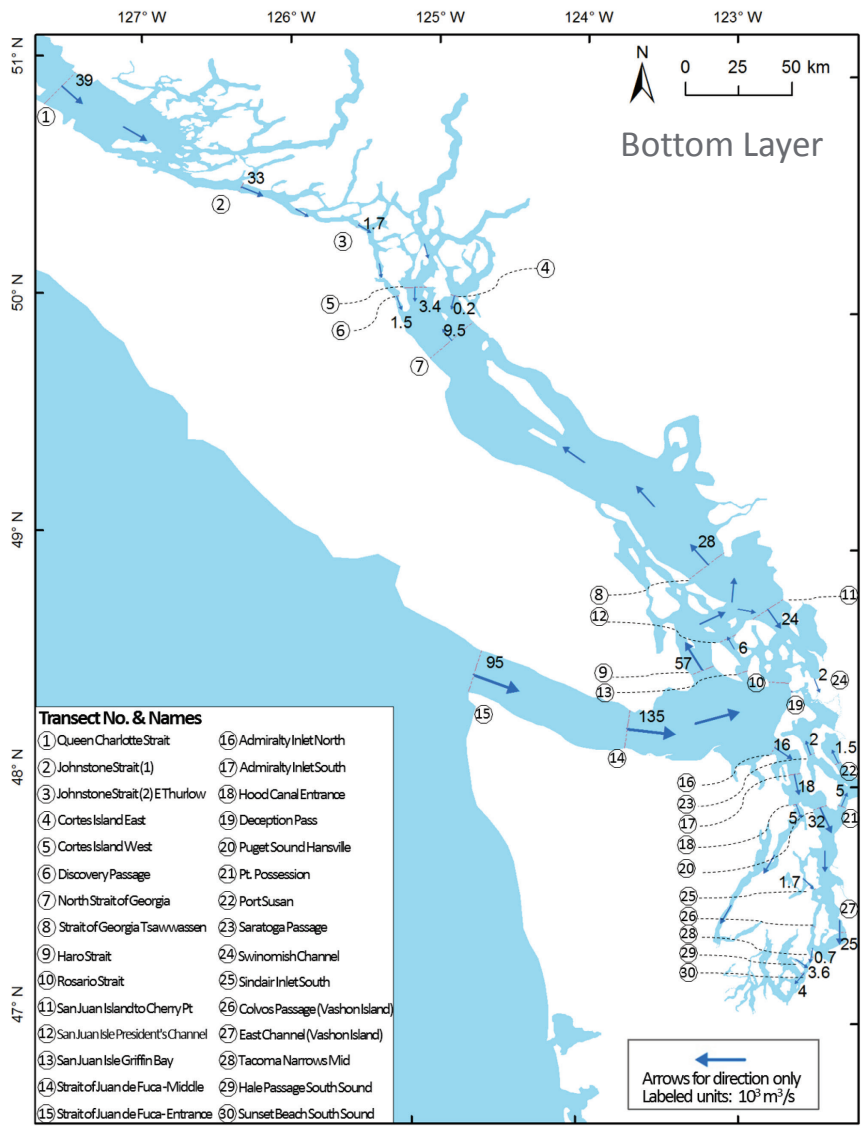
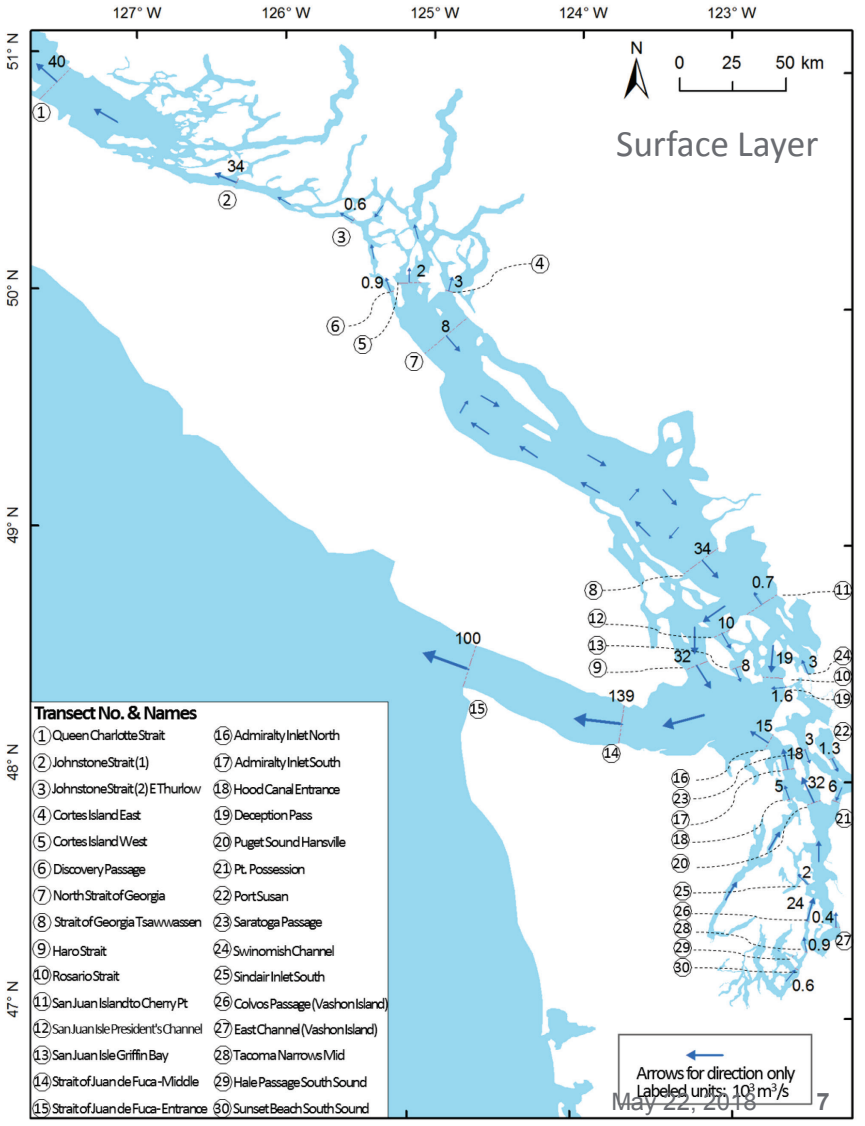
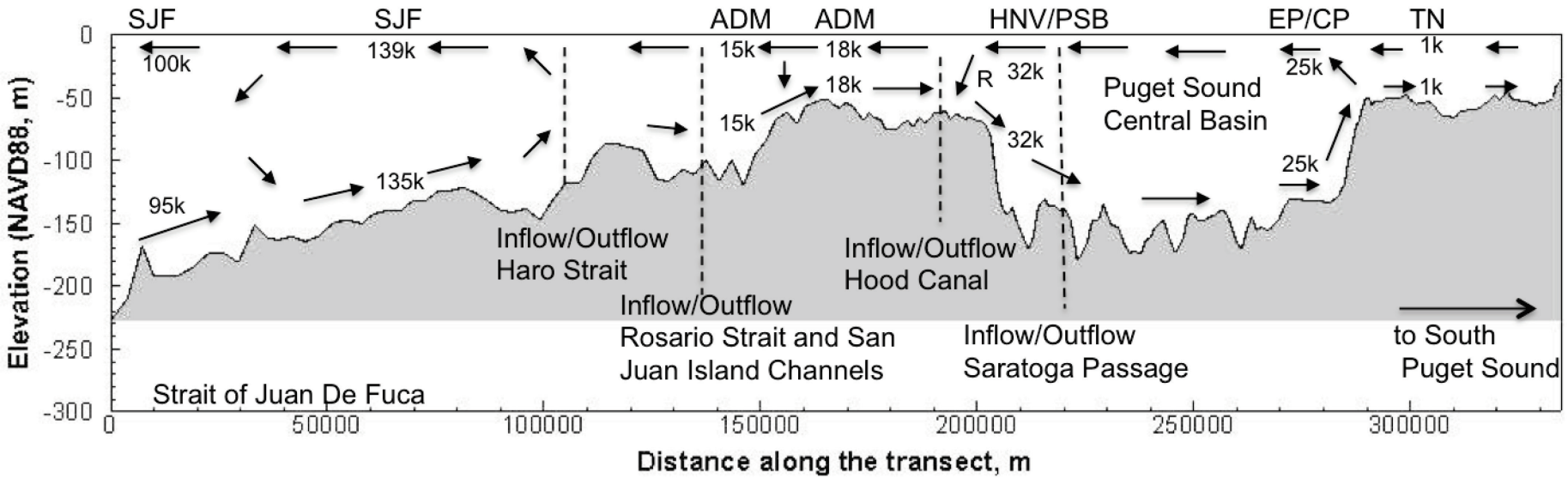




[Khangaonkar et al. (2017) – *Ocean Modelling*]

Circulation in the Salish Sea

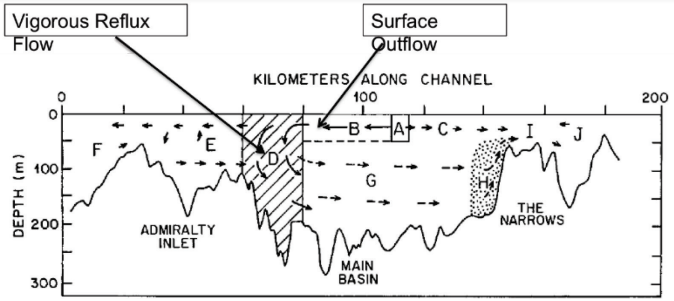
Puget Sound – Reflux flows



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

[Khangaonkar et al. (2017) – *Ocean Modelling*]



Reflux Flow ≈ 2/3rd Surface Outflow

"Circulation in Embracing Sills"
- Ebbesmeyer et al. 1984

Biogeochemical Model Simulation

WQ - 2014

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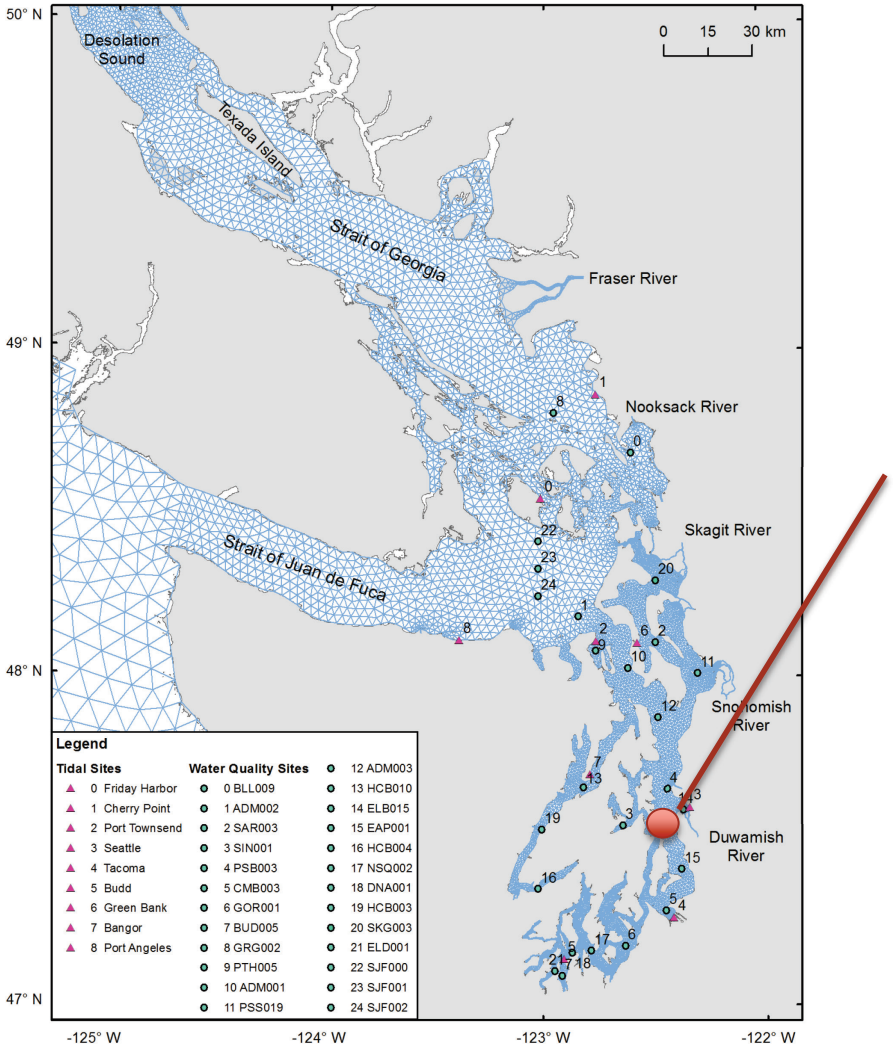

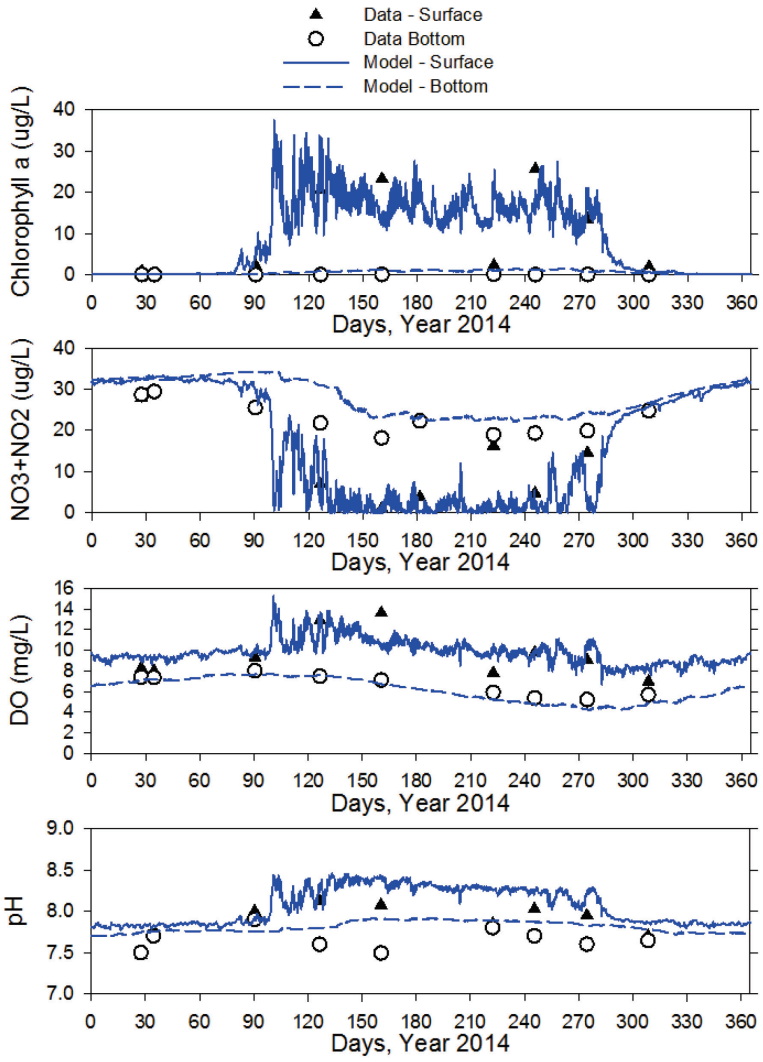

Progression DO

Neah Bay to South Puget Sound

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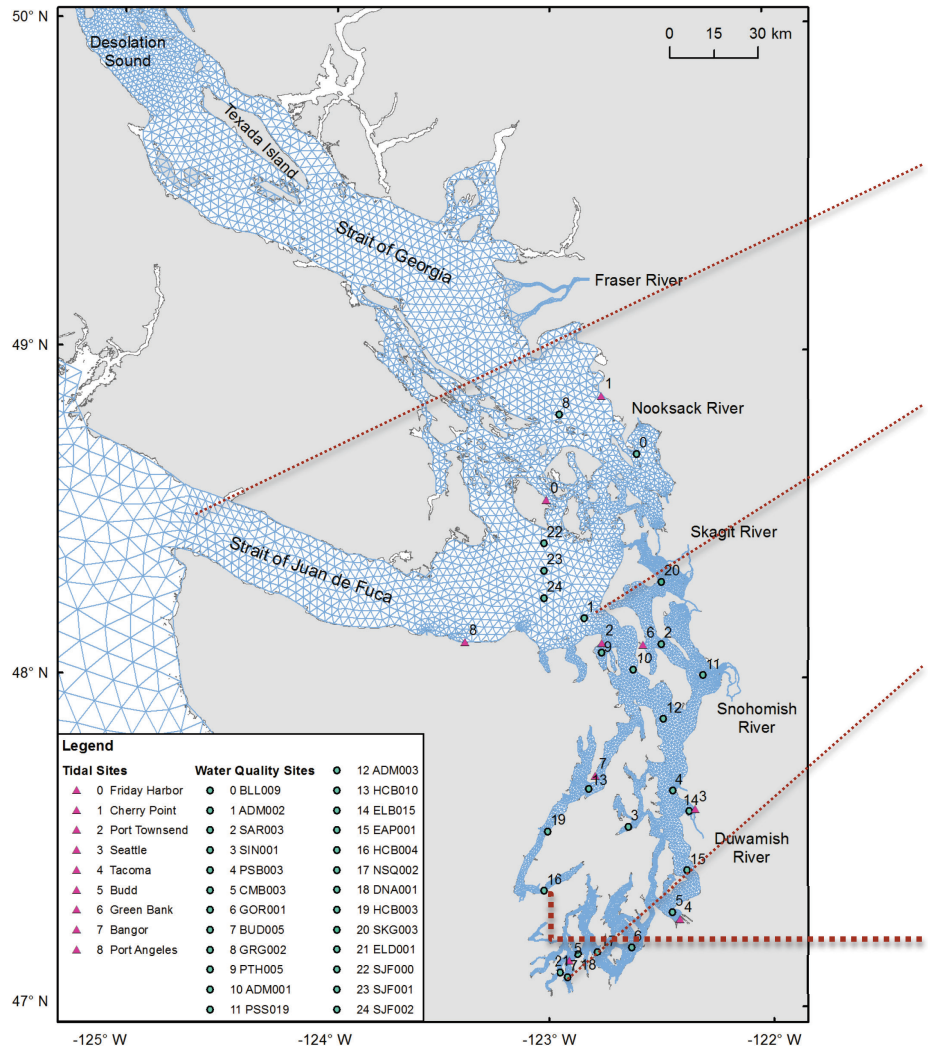
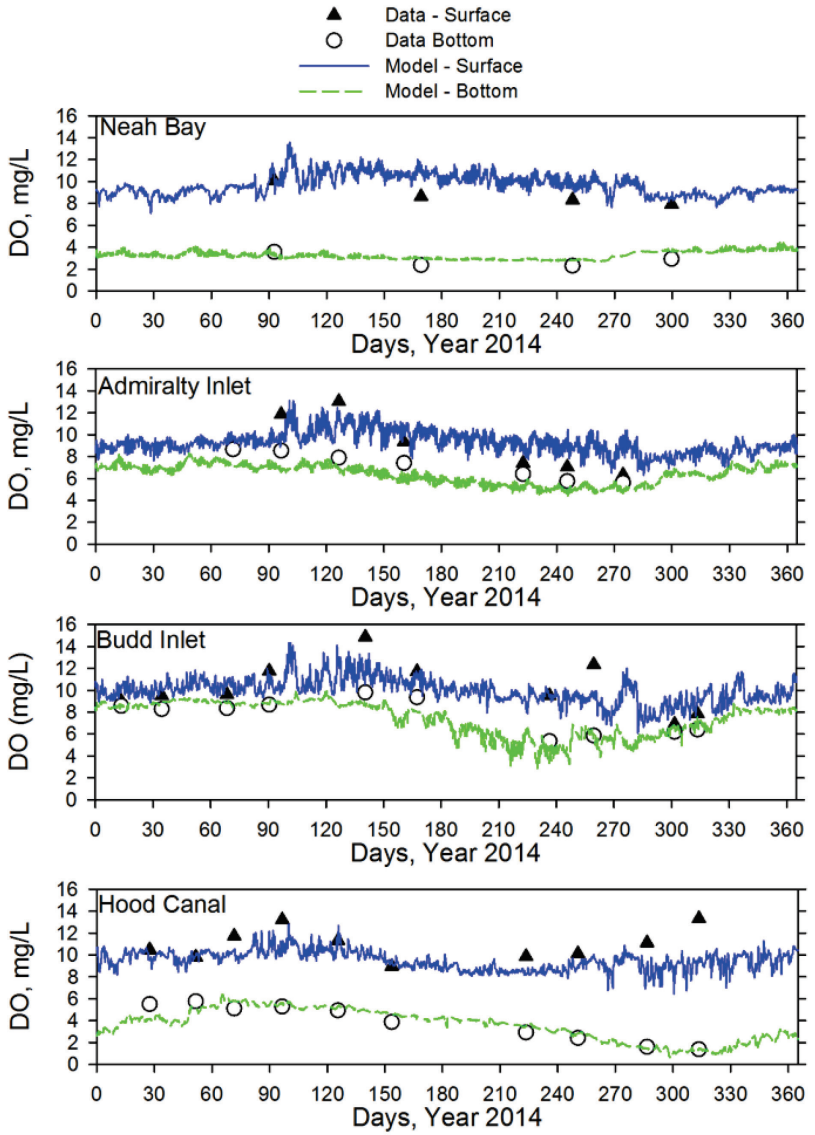
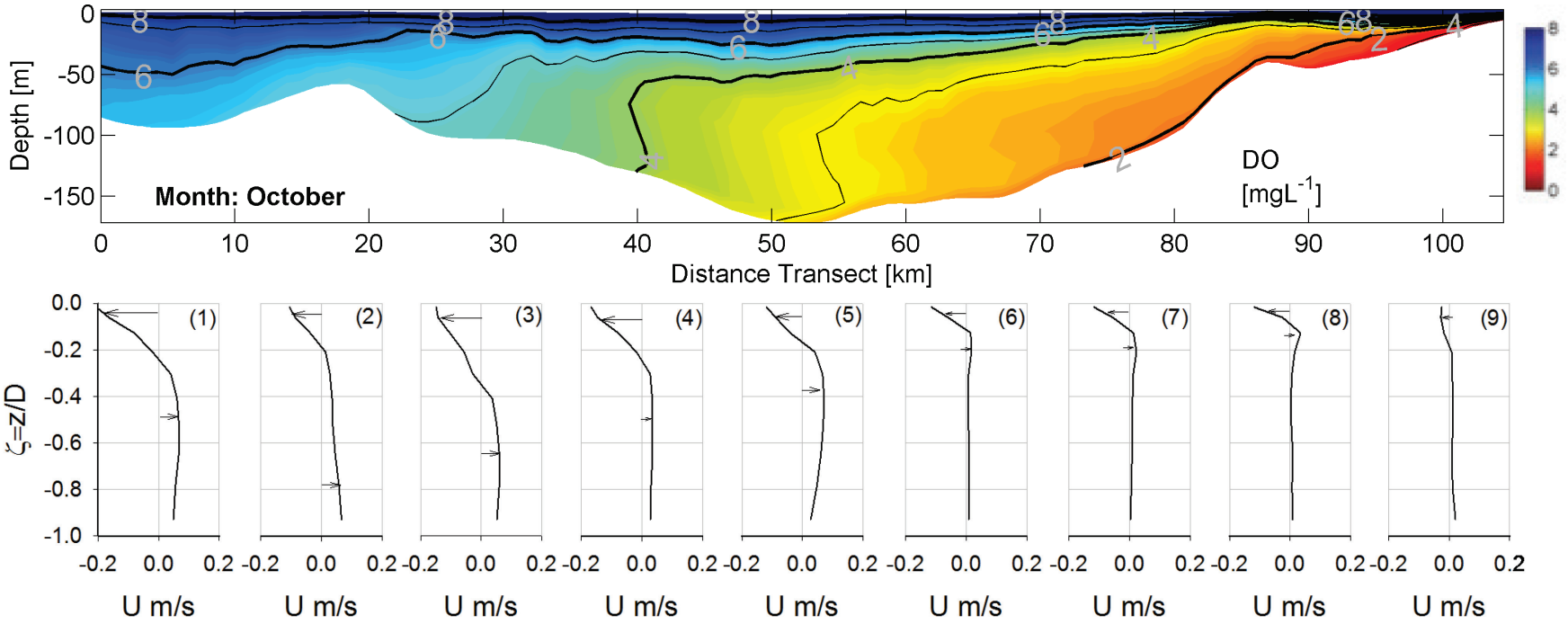




Hypoxia in Hood Canal

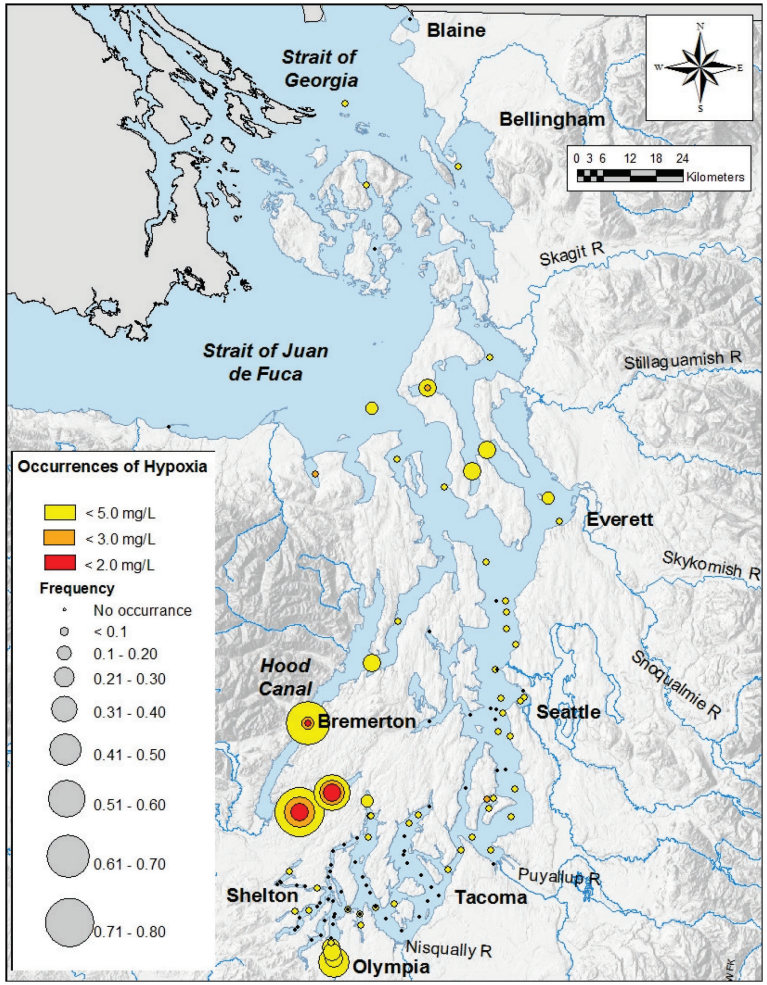
Effect of Fjordal Circulation & Residence



October 2014

Bottom Water Hypoxia in Salish Sea

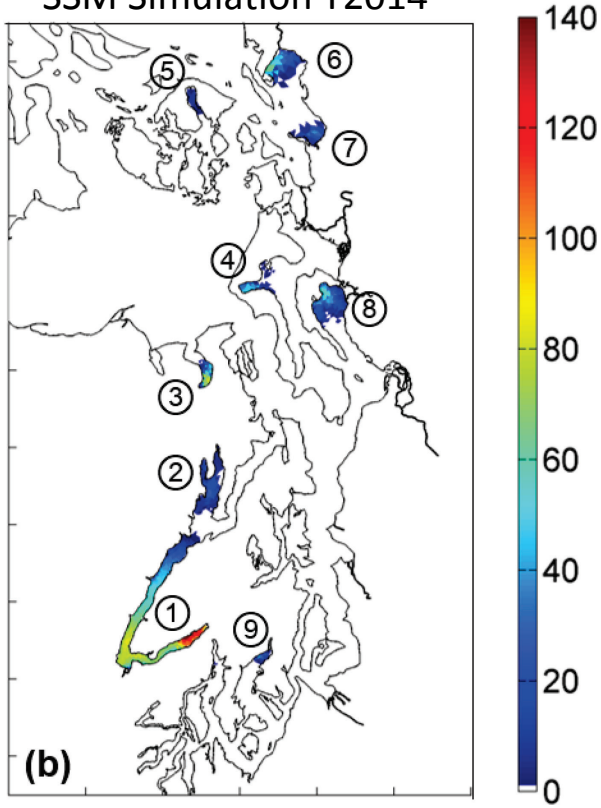
Occurrences of Hypoxia in Puget Sound



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



Y2014 Baseline

Source: Puget Sound Partnership
2009 *State of the Sound*

Salish Sea Model - Summary

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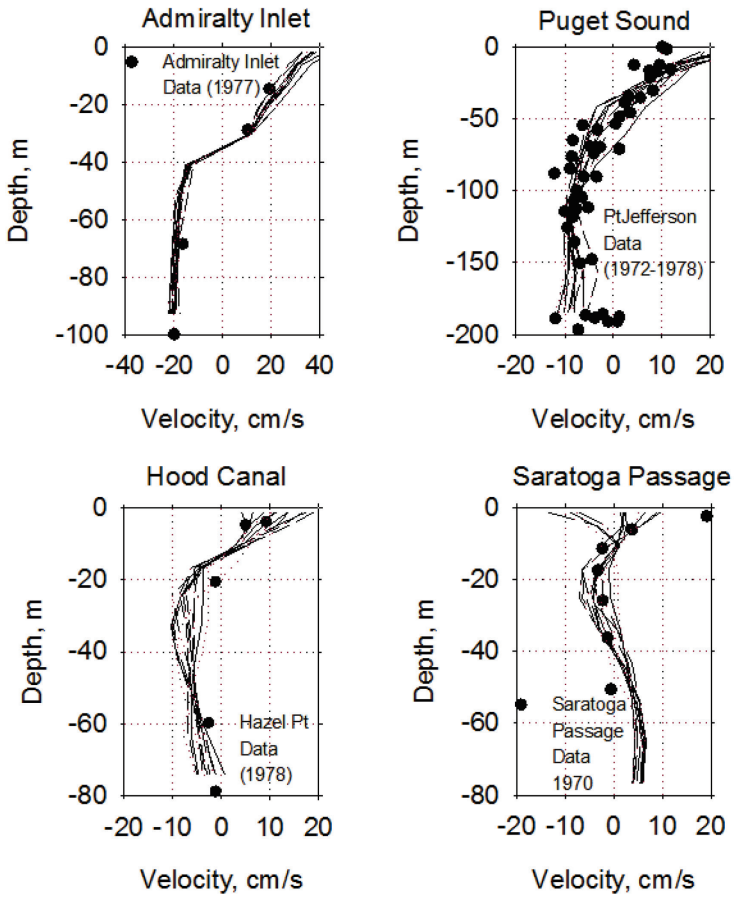
- Salish Sea Model – Puget Sound and Northwest Straits
  - http://salish-sea.pnnl.gov/
- Hydrodynamic Model (Expanded Domain)
  - Validation of the Circulation in Embracing Sills
    - Nearly 2/3rd of surface outflow is refluxed back to Puget Sound near the Admiralty Inlet sill [Khangaonkar et al. (2017) – *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 [Bianucci et al. (2018) – *Elementa Sci Anth*]
  - Hypoxia – sensitive to Nutrient Loads [Khangaonkar et al. (2018) – *JGR Oceans (under review)*]

EPA United States Environmental Protection Agency
DEPARTMENT OF ECOLOGY State of Washington
UNIVERSITY OF WASHINGTON 1861
NOAA NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION U.S. DEPARTMENT OF COMMERCE
US Army Corps of Engineers
Fisheries and Oceans Canada
USGS science for a changing world

Comparison to Historical Measurements

Tidally averaged currents data



(Data source: Cokelet [1990] - PMEL).

Representative Model Error Statistics (2014)

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Hydrodynamics

Tides

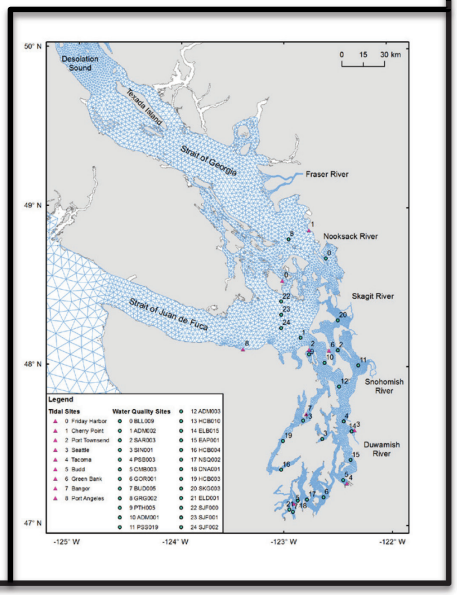
ME (m)	MAE (m)	RMSE (m)	RME (%)
-0.03	0.29	0.35	**7.8%**

Salinity

ME (ppt)	RMSE (ppt)
-0.12	**0.97**

Temperature

ME (°C)	RMSE (°C)
-0.28	**0.76**



Water Quality

DO

ME (mg/L)	RMSE (mg/L)
-0.24	**0.99**

Nitrate

ME (ug/L)	RMSE (uM/L)
0.96	**6.49**

Algae (Chl – *a*)

ME (ug/L)	RMSE (ug/L)
0.83	**4.37**

Phosphate

ME (mg/L)	RMSE (mg/L)
-0.67	**0.93**

pH

ME	RMSE
0.12	**0.21**