

Assessment of Climate Change & Acidification Impacts to Salish Sea:

Ocean Exchange and Circulation with *Expanded Salish Sea Model*

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Historic Assessments and Understanding of Circulation in Puget Sound

► The Collias Atlas

- Atlas of physical and chemical properties of Puget Sound and its approaches: by E. E. Collias, Noel McGary, and C. A. Barnes, 1974. pp. 235. UW

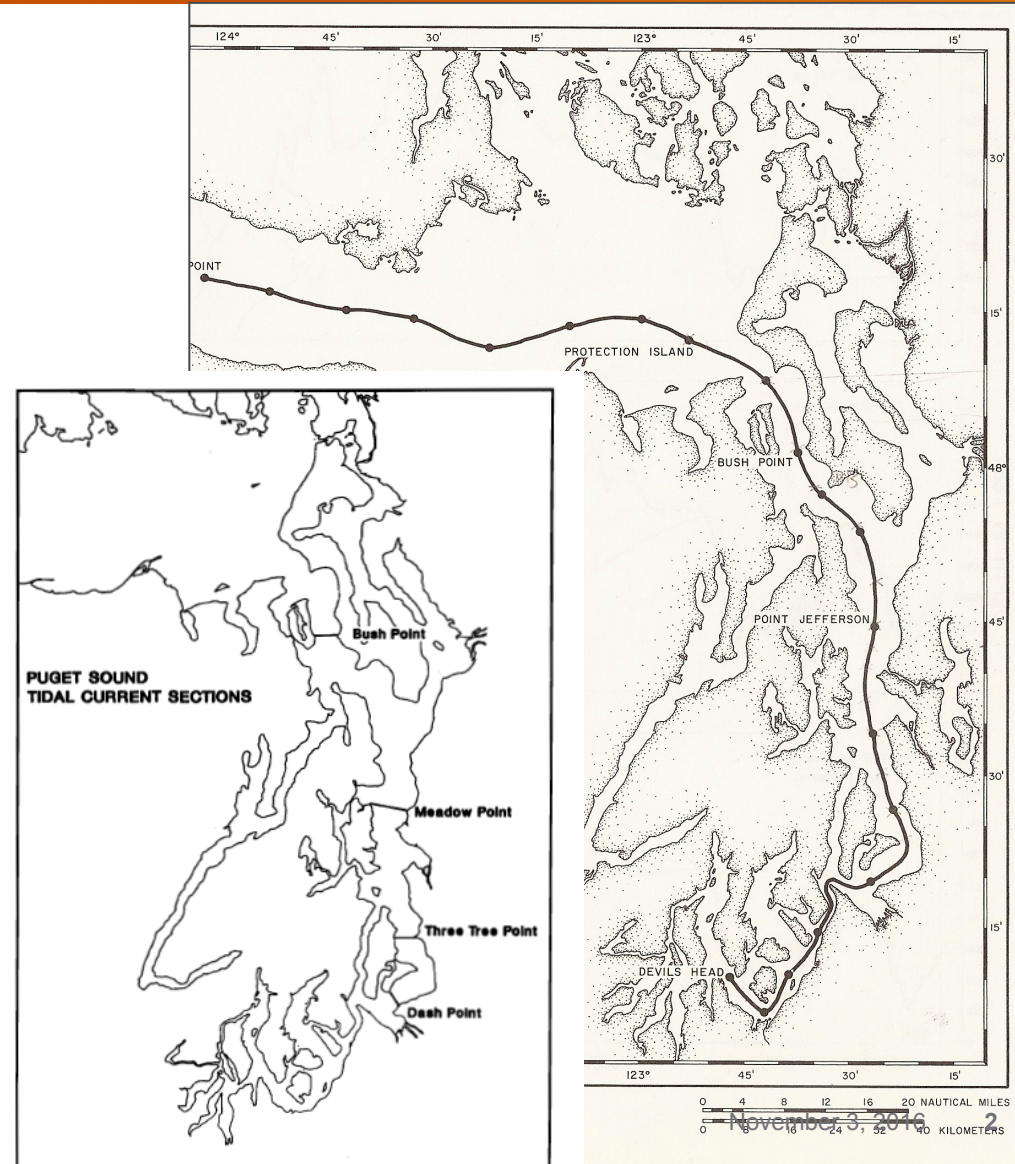
- Data collected 1952-1966

► Marine Ecosystems Analysis

- NOAA-PMEL

- Data Collected 1975-1983

- Barnes 1981, 1984
- Cox et al. 1981, 1984
- Cannon 1983
- Ebbesmeyer et al., 1980, 1984



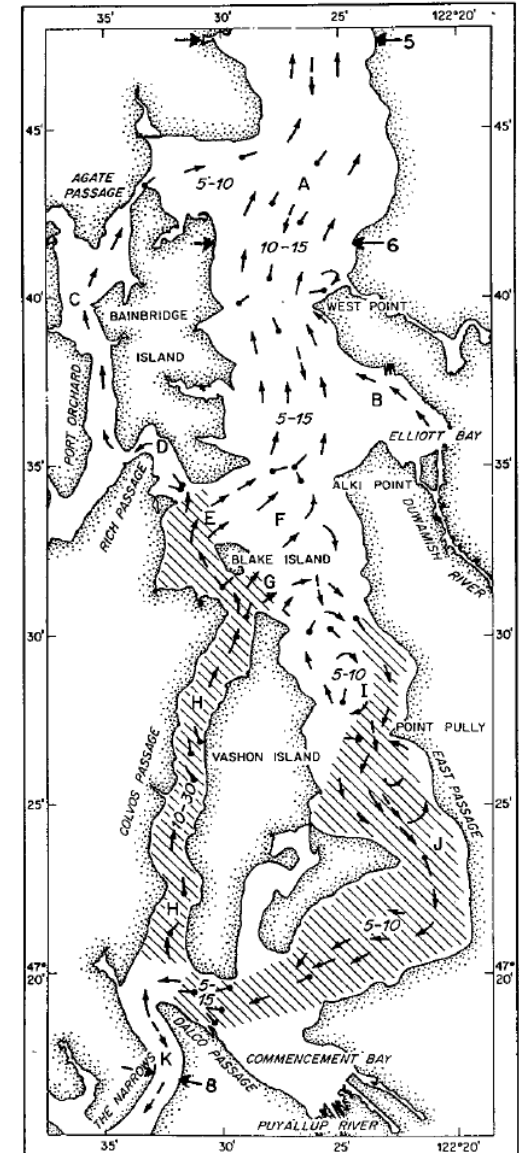
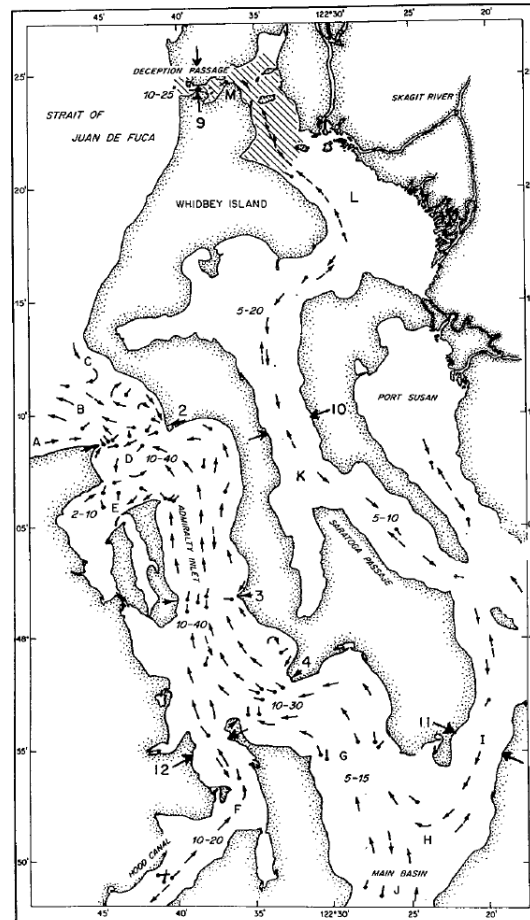
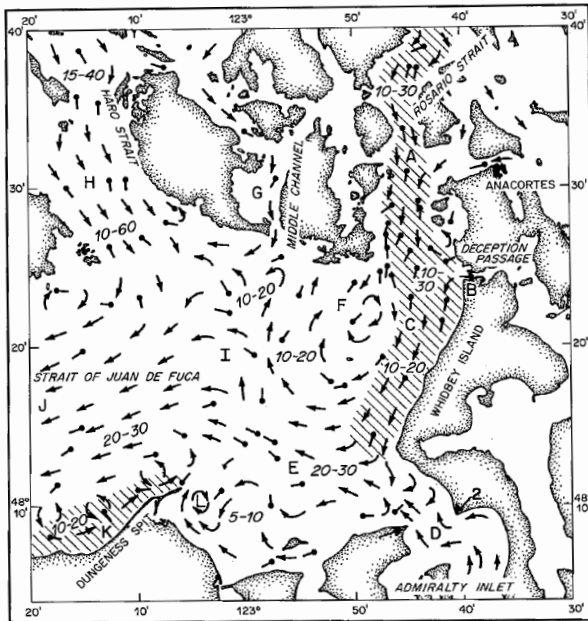
Inferred Circulation

- Ebbesmeyer et al. 1984



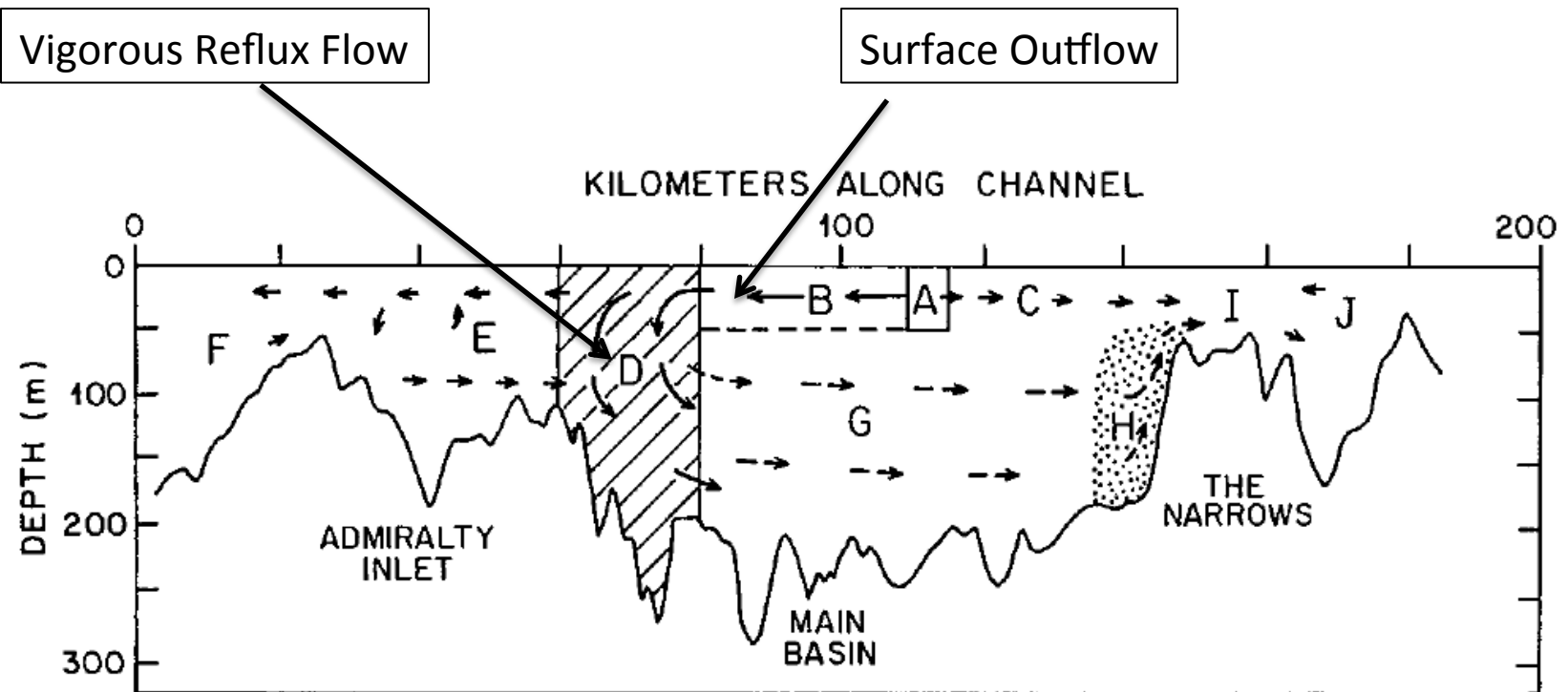
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“Circulation in Embracing Sills”

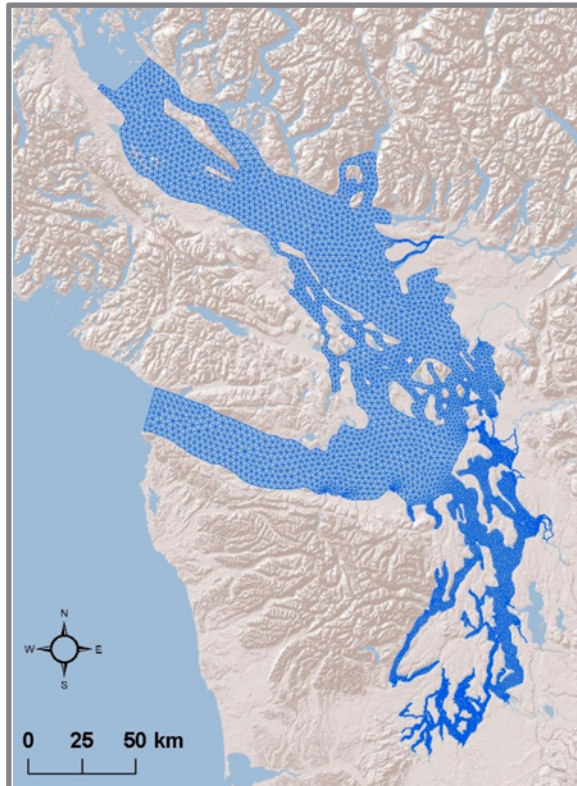
- Ebbesmeyer et al. 1984



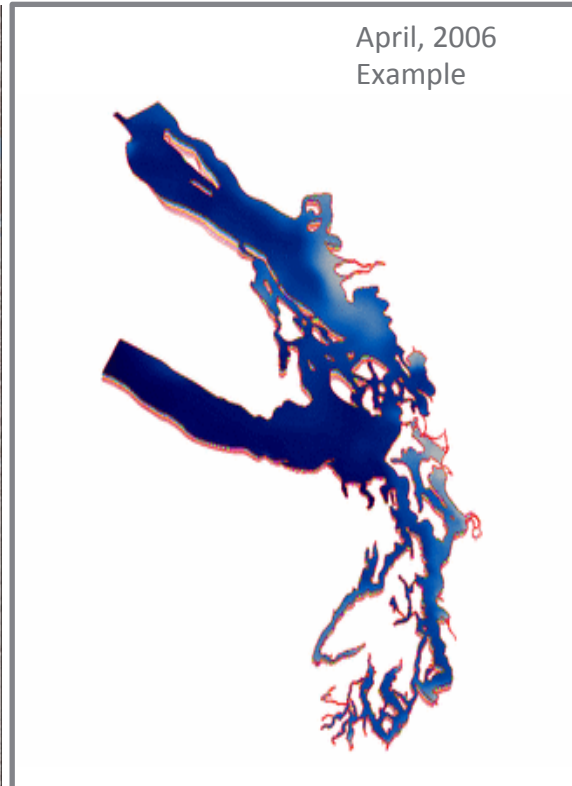
Reflux Flow $\approx 2/3^{\text{rd}}$ Surface Outflow

Salish Sea Model – PNNL / Ecology / EPA

Salish Sea Model (SSM) - Grid



Surface salinity, 24-hr simulation



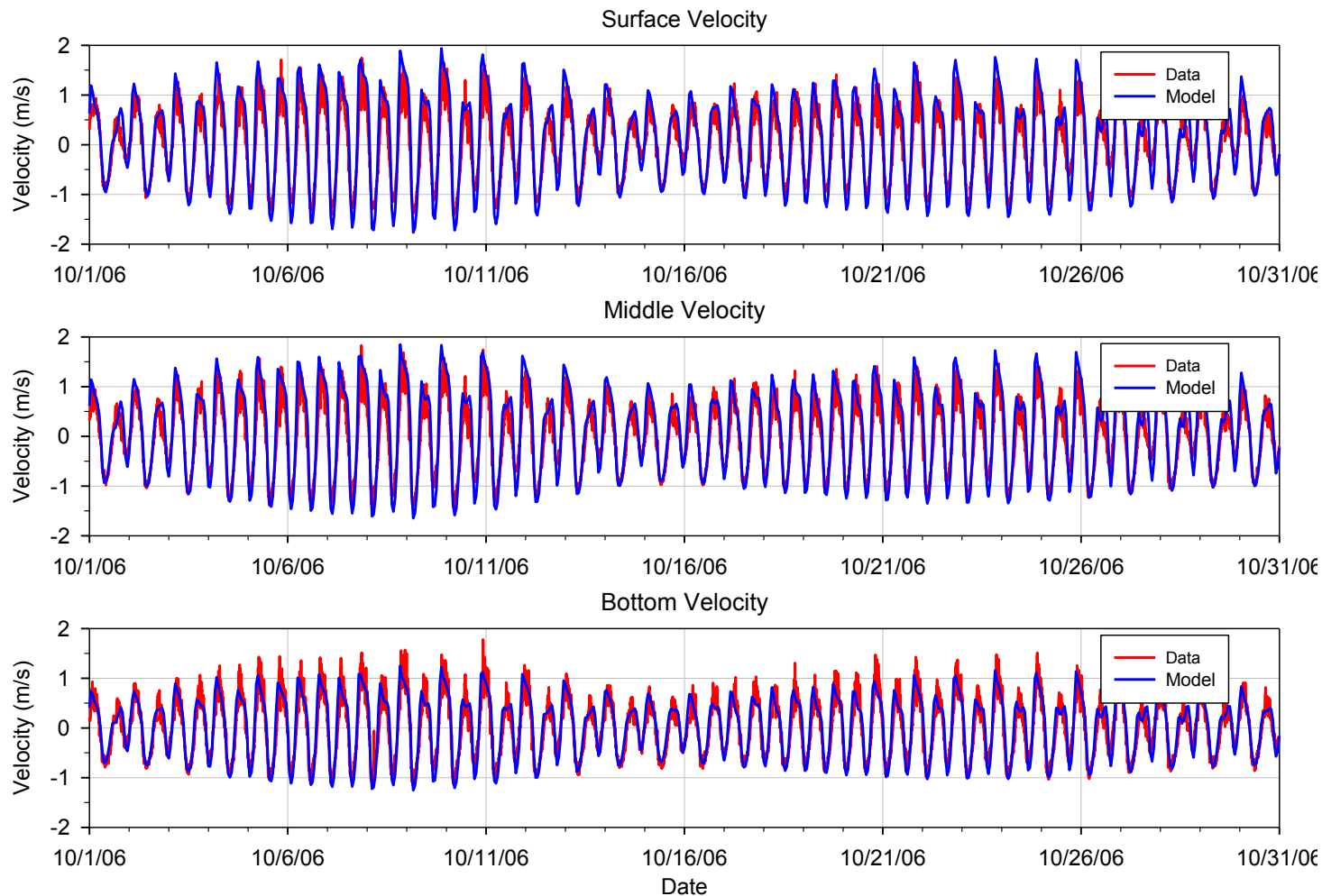
Model Specifications

- ▶ **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
 - Boundary loads based on DFO monitoring data
 - Point source loads ...

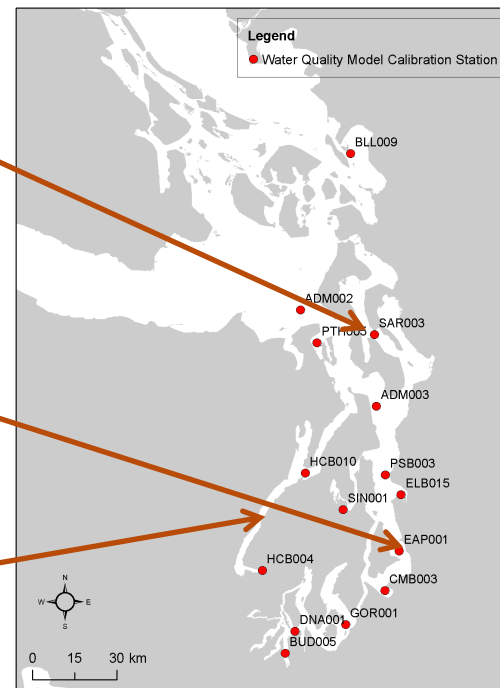
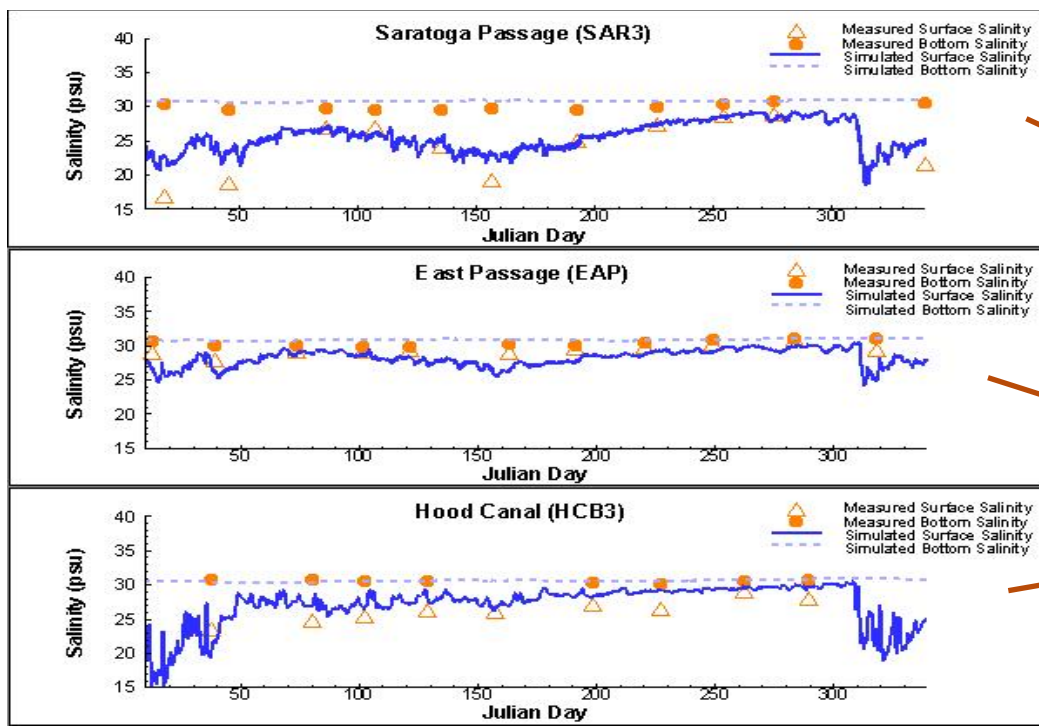
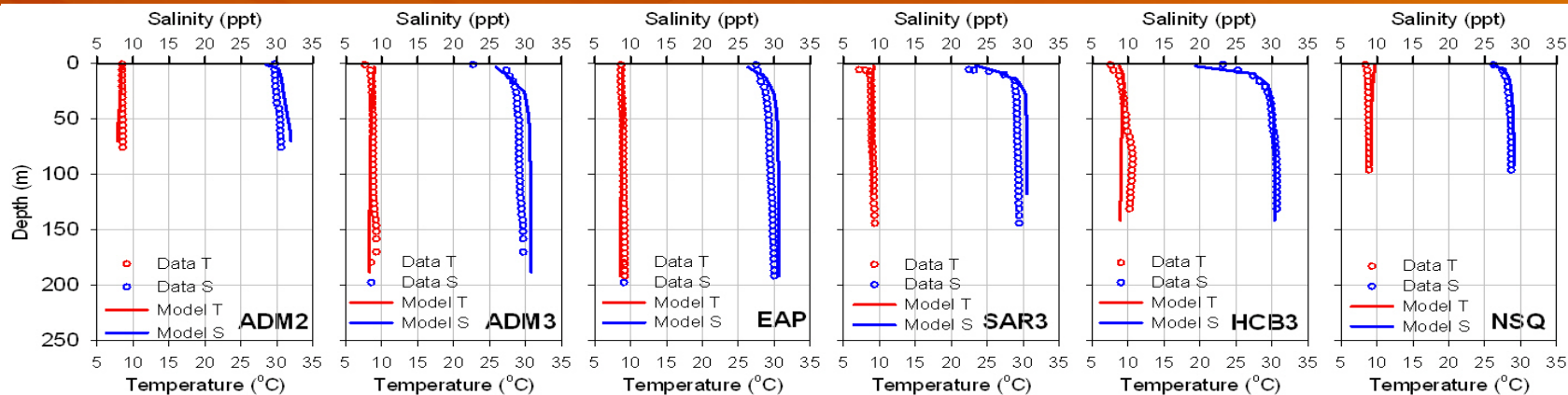
Salish Sea Model (Khangaonkar et al. 2011, 2012) – <http://salish-sea.pnnl.gov/>

Calibration: Velocity

Dana Passage (example)



Calibration: Salinity and Temperature



Simulated Surface Constituents (2006)



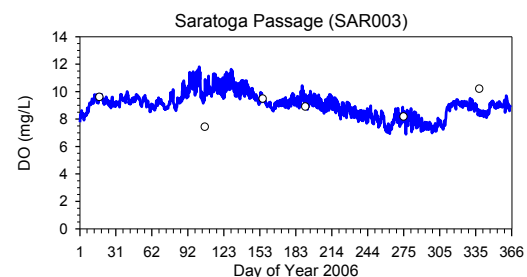
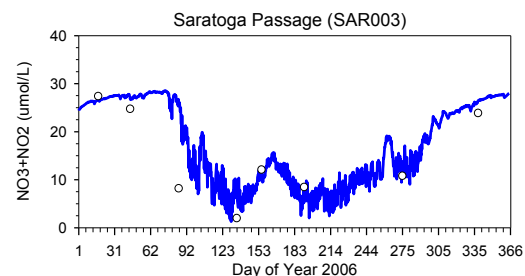
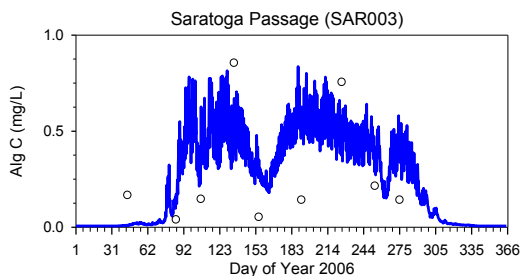
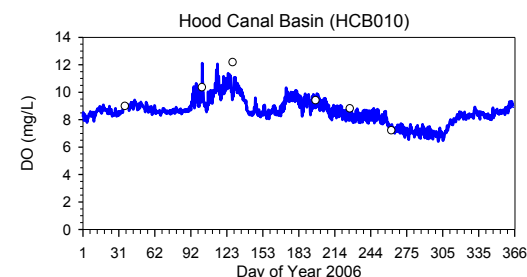
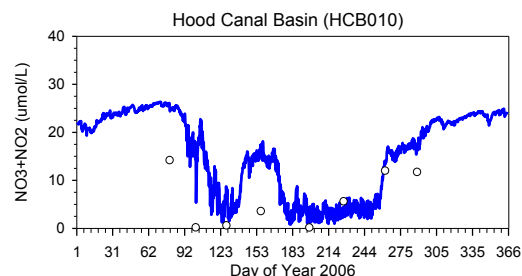
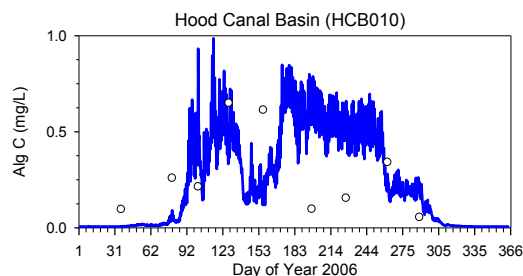
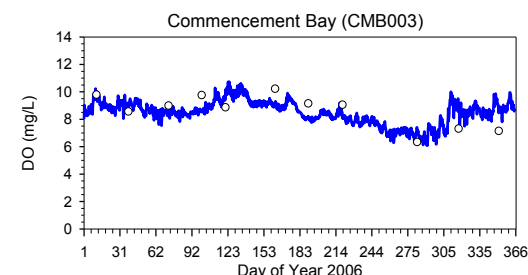
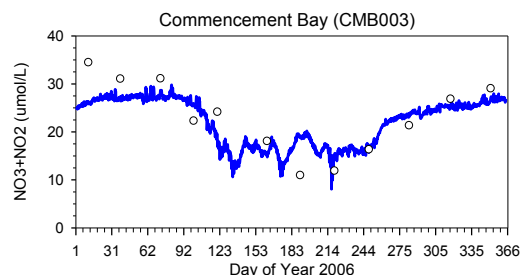
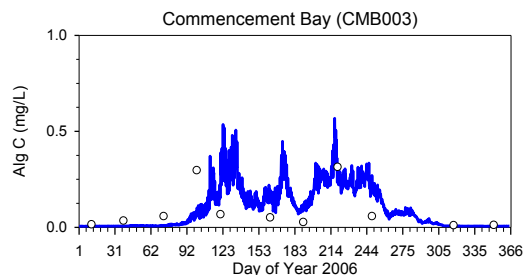
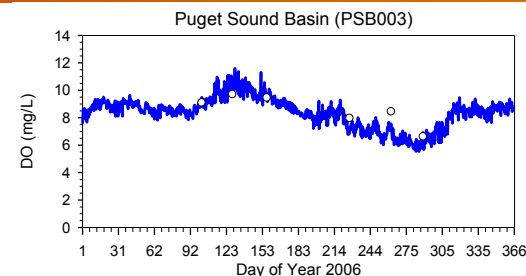
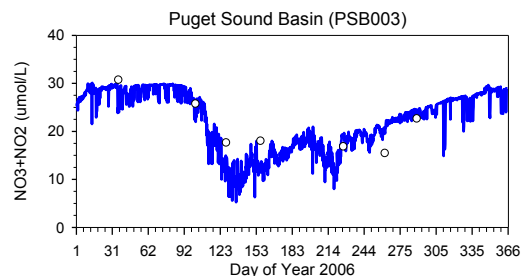
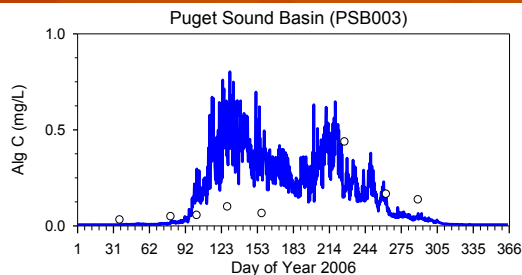
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Algae

NO₃+NO₂

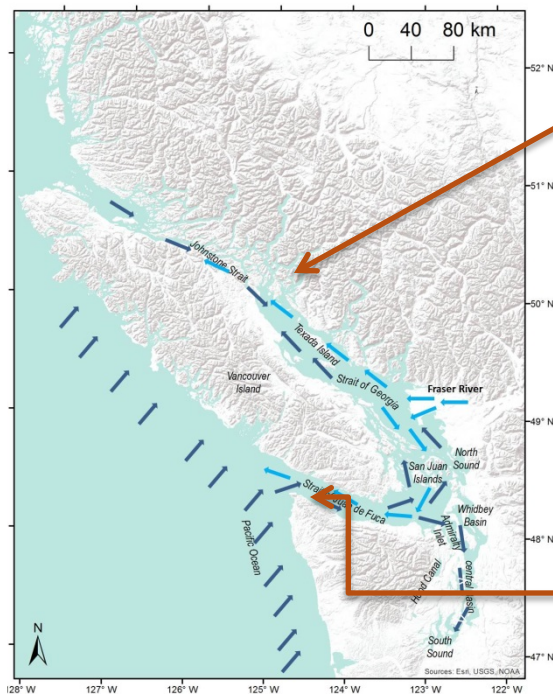
DO



Future Impacts to Salish Sea Circulation and Water Quality

► Assessment of impacts from future stresses

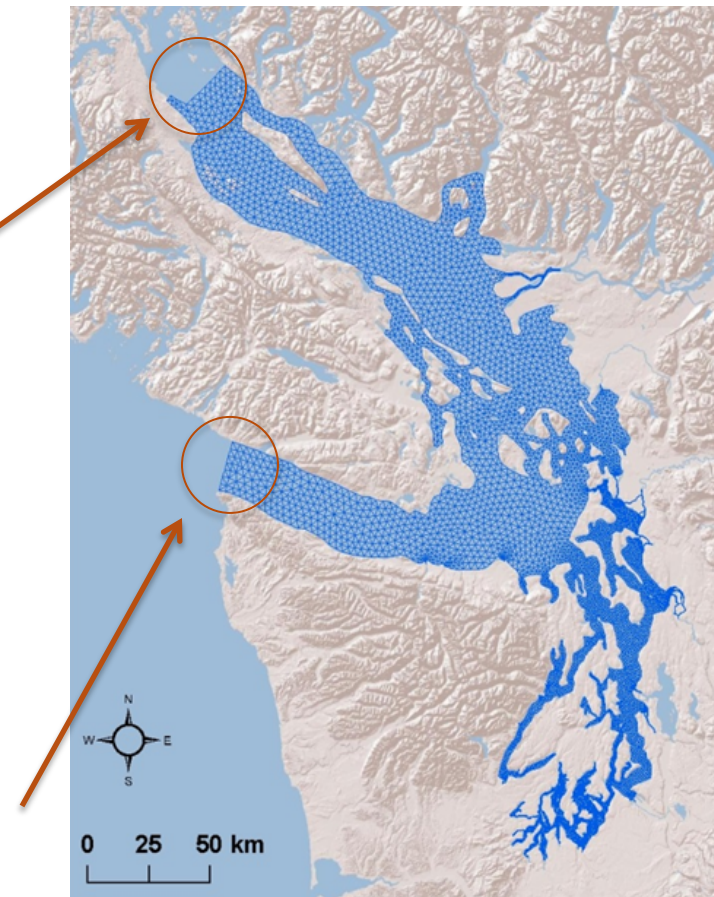
- Sea Level Rise
- Climate Change
- Ocean Acidification



Georgia Strait
Boundary
(Johnstone Strait)

Ocean Exchange

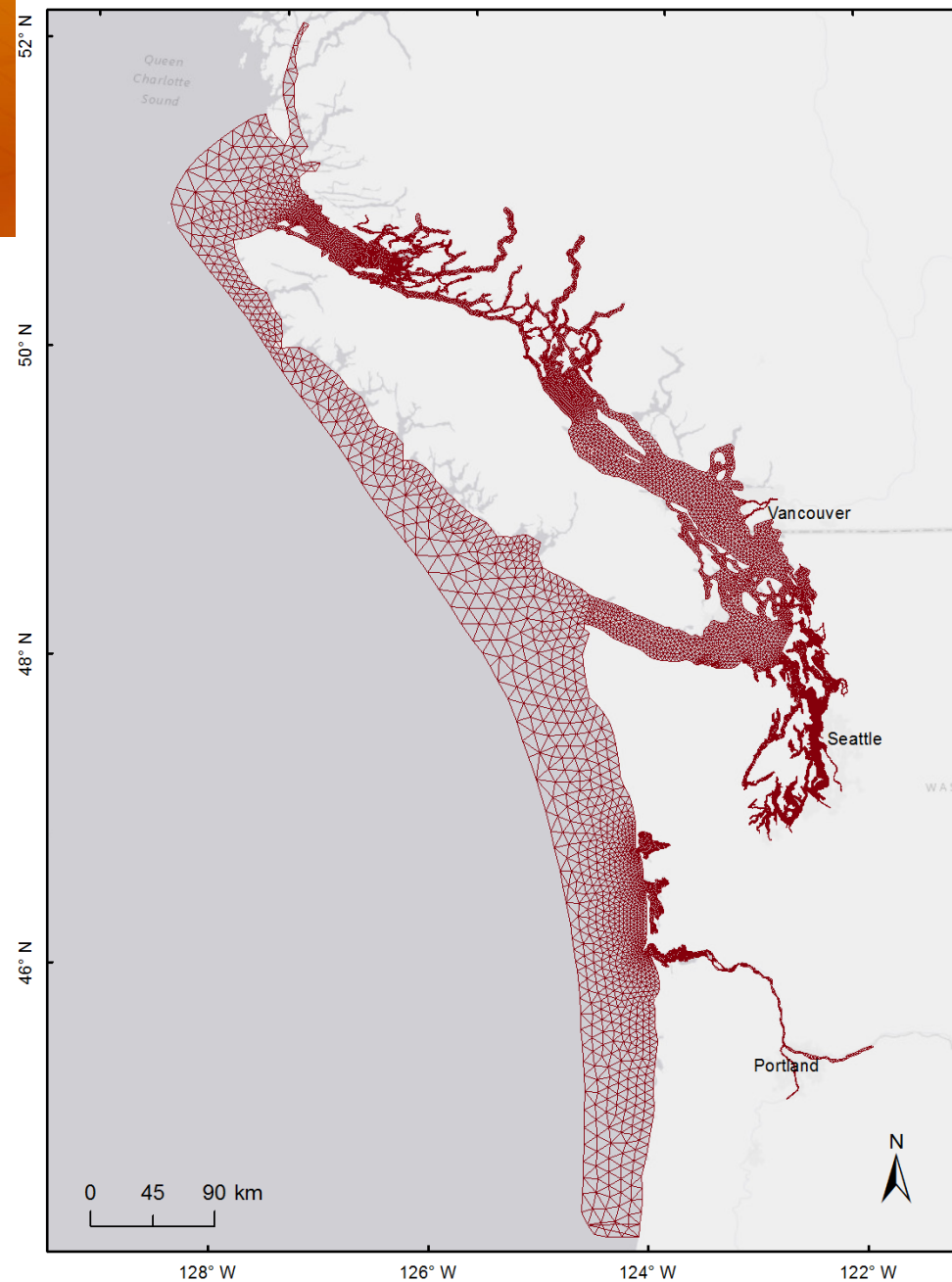
Strait of Juan de Fuca
Boundary



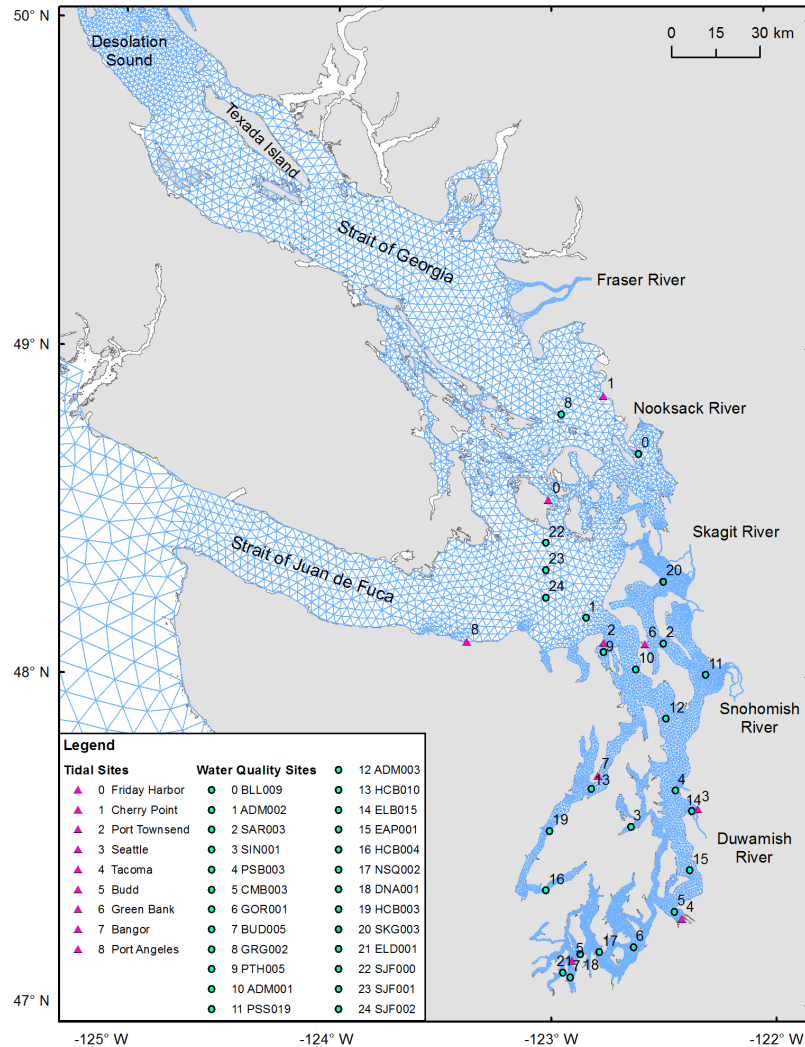
Salish Sea Model
(Khangaonkar et al. 2011, 2012)
– <http://salish-sea.pnnl.gov//>

Salish Sea Model Expanded Domain

- ▶ Expanded Salish Sea Model
 - Discovery Passage
 - Johnstone Strait
 - Queen Charlotte Strait
 - Shorelines
 - Vancouver Island
 - Washington
 - Oregon
 - Additional Rivers (Pacific Ocean)
 - Columbia / Willamette Rivers
 - Chehalis River
 - Willapa River
 - Tidal Constituents
 - ENPAC 2003 Tidal Constituents database (USACE 2004)
 - Meteorology
 - UW / WRF Model (12 Km Grid)



Model Calibration – Tides, S, & T Year 2014



► Tides

ME (m)	MAE (m)	RMSE (m)	RME (%)
-0.08	0.30	0.36	8.0%

► Salinity

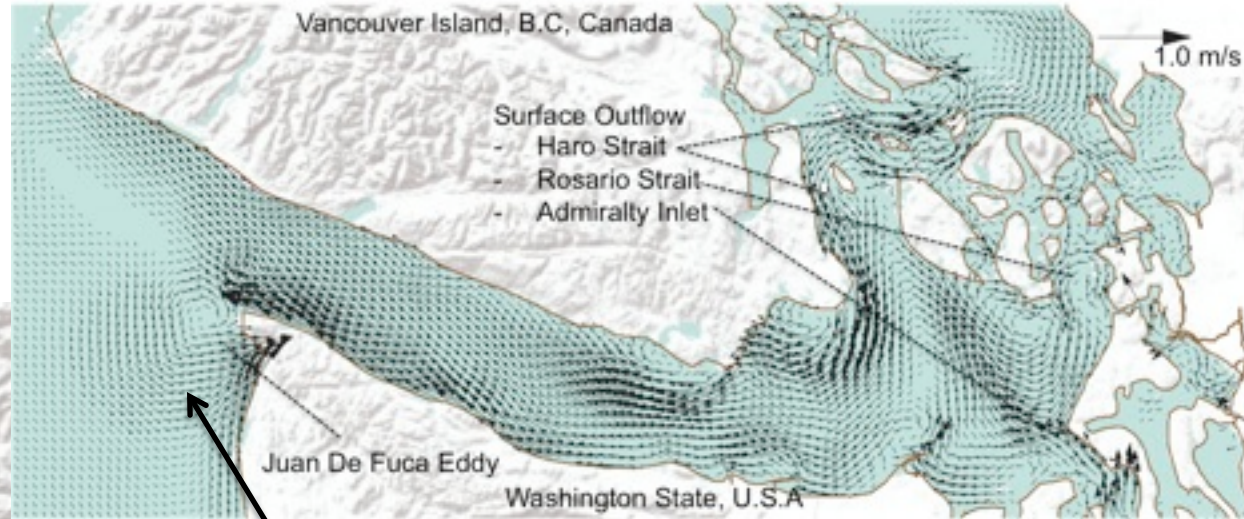
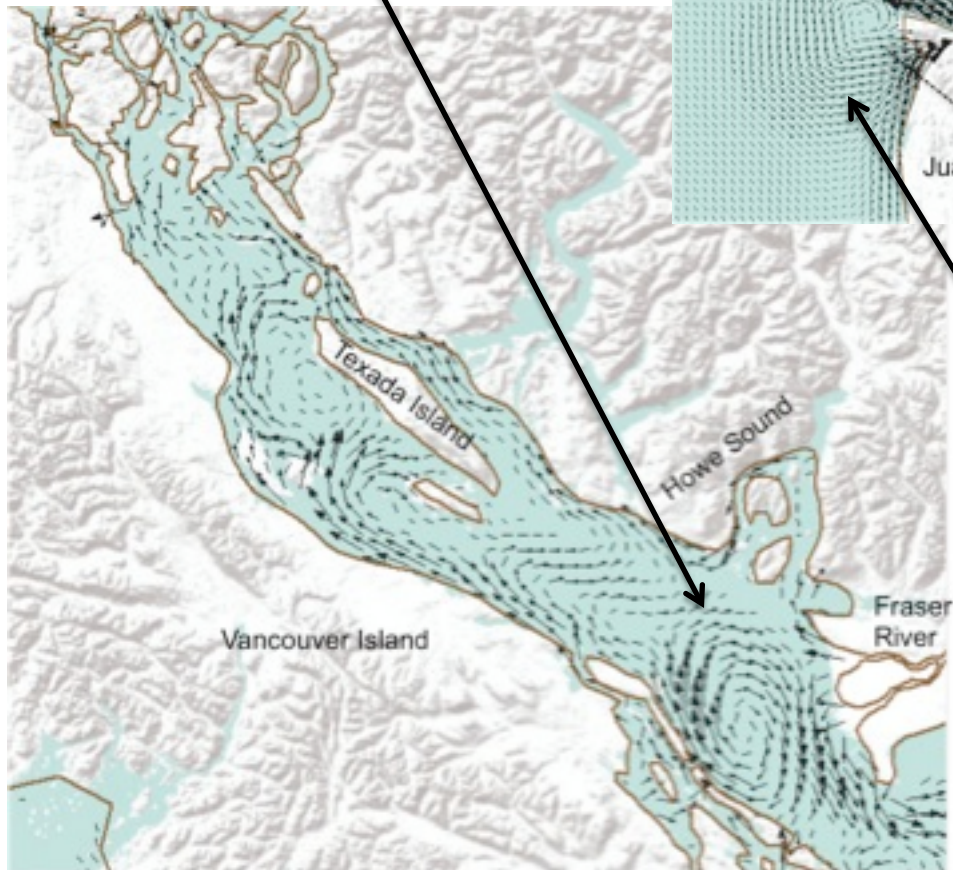
ME (ppt)	RMSE (ppt)	R ²
0.34	1.12	0.62

► Temperature

ME (°C)	RMSE (°C)	R ²
0.39	0.87	0.53

Surface Currents

Fraser River Eddy



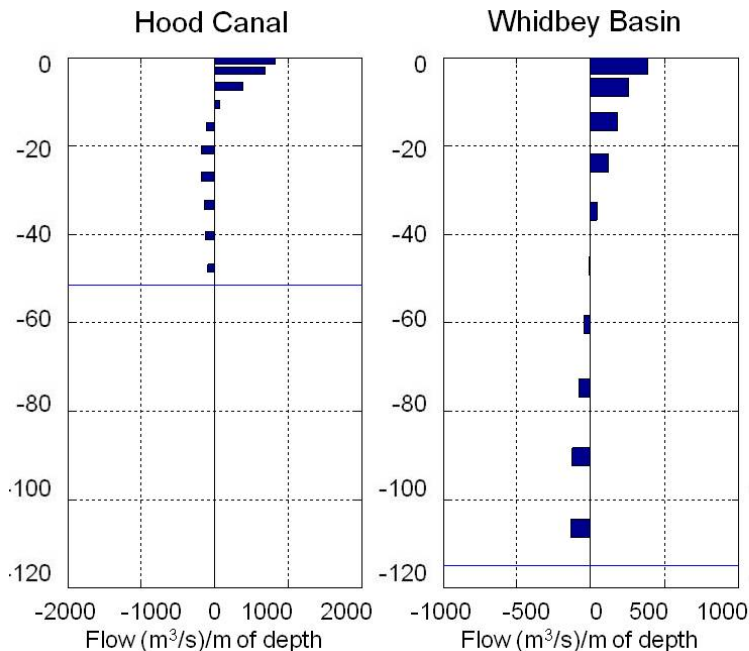
Juan De Fuca Eddy

Tidally averaged flows in Salish Sea

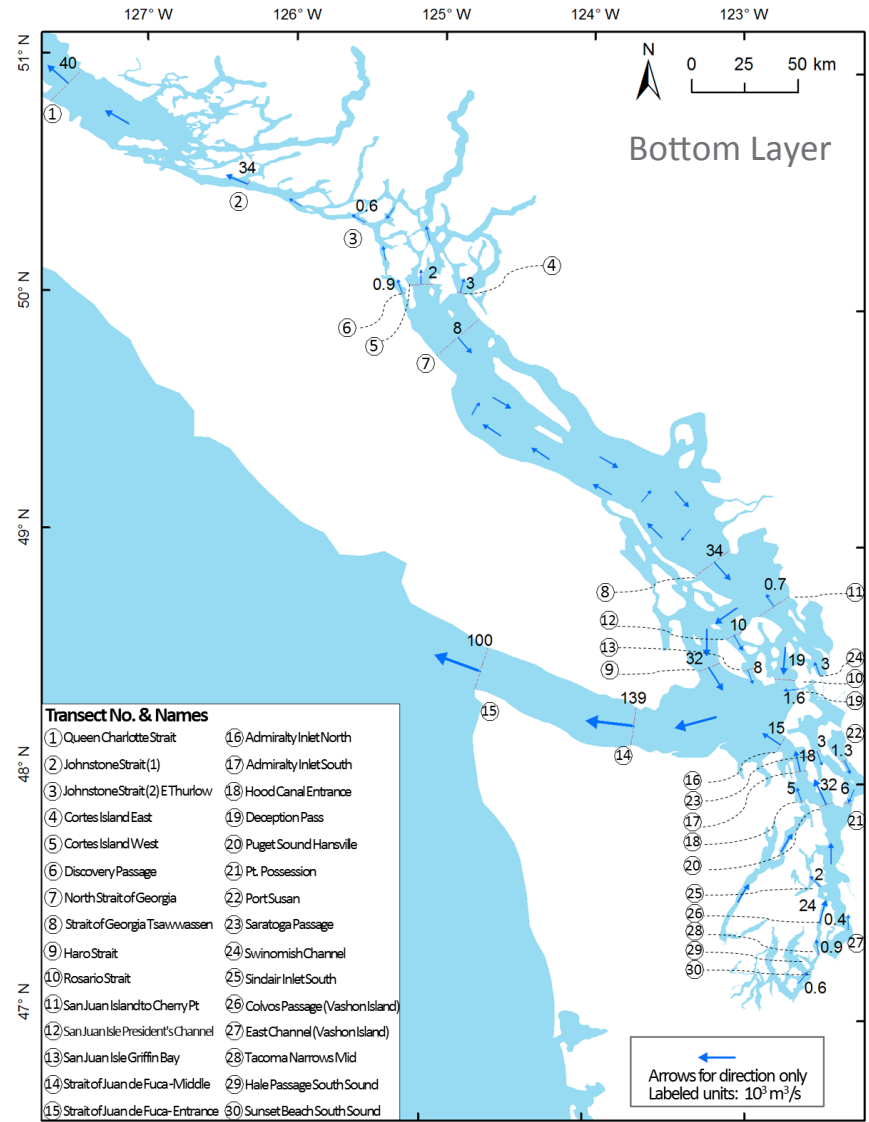
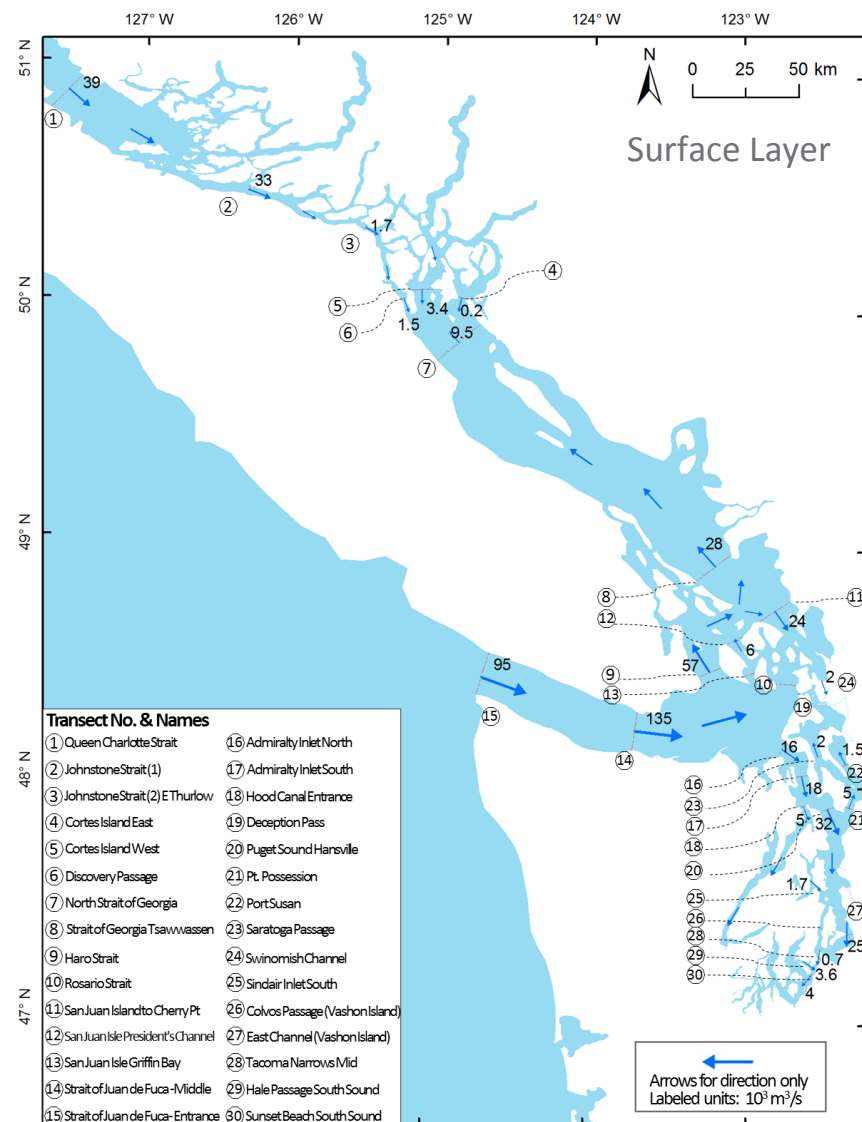
Year 2006

- ▶ Bottom Layer Flow
 - Saline inflow below depth of zero mean flow
- ▶ Surface Layer Flow
 - Brackish outflow above depth of zero mean flow

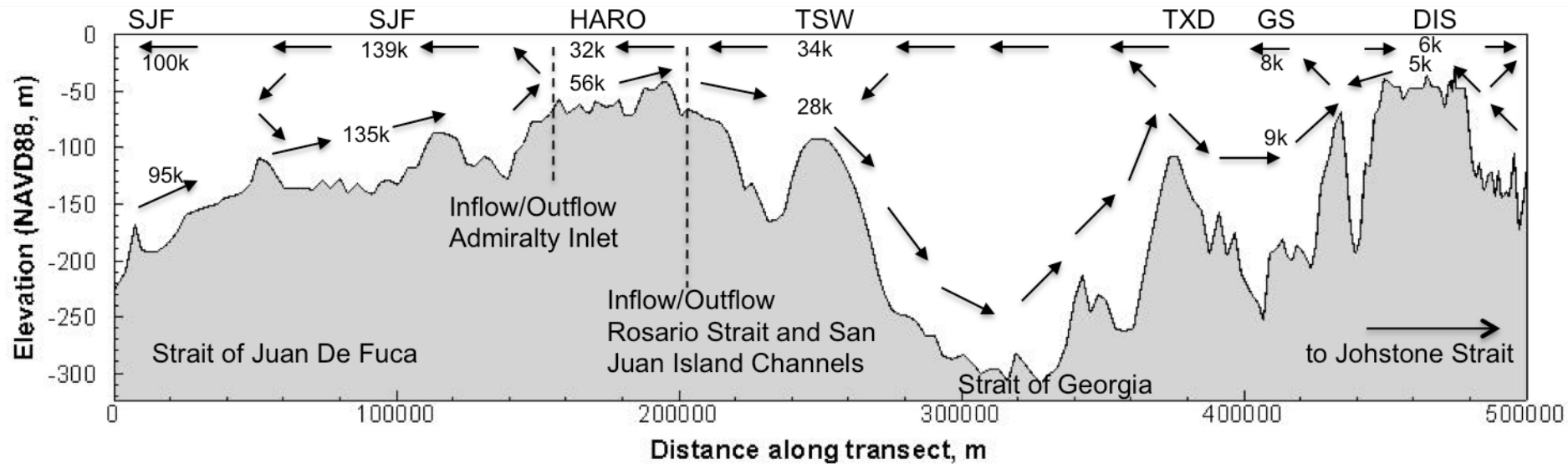
- ▶ 34 - Transects for Flux Calculations



Circulation in the Salish Sea Northwest Straits

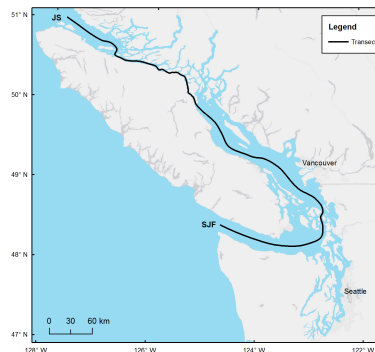


Circulation in the Salish Sea Northwest Straits

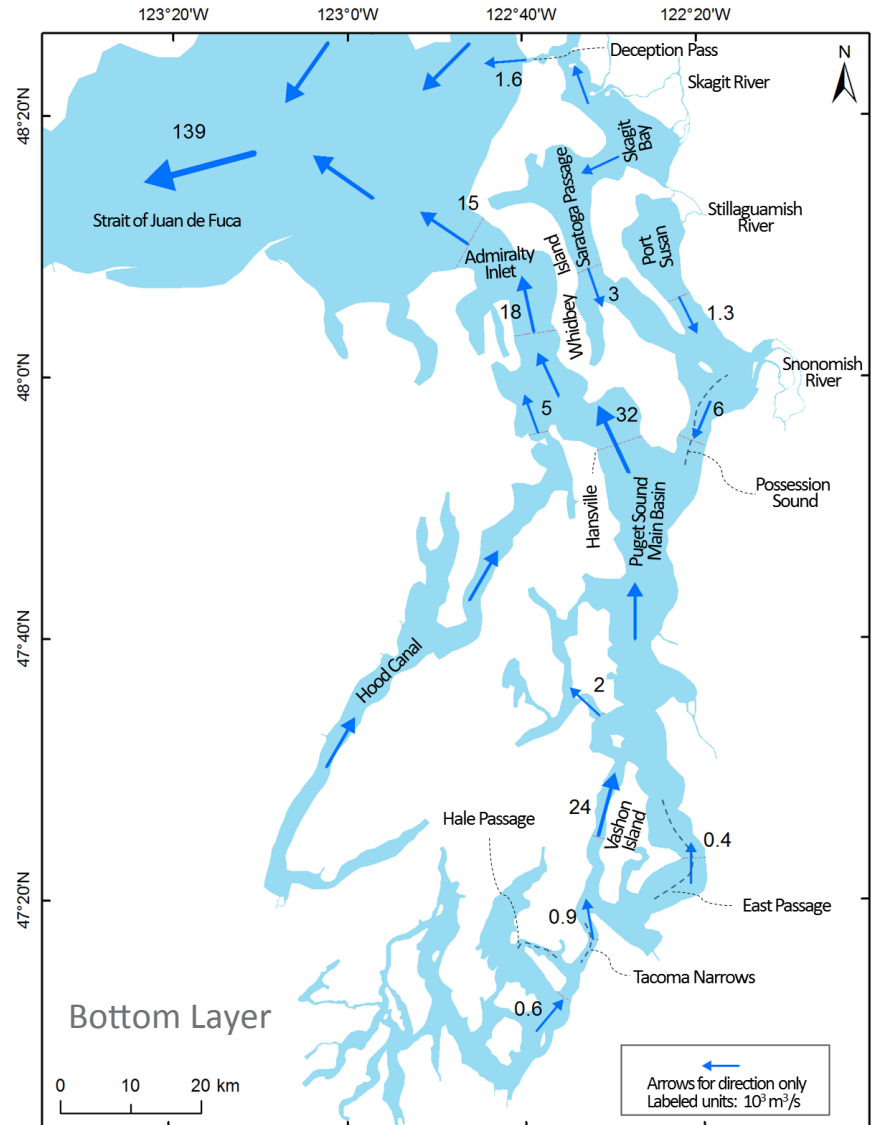
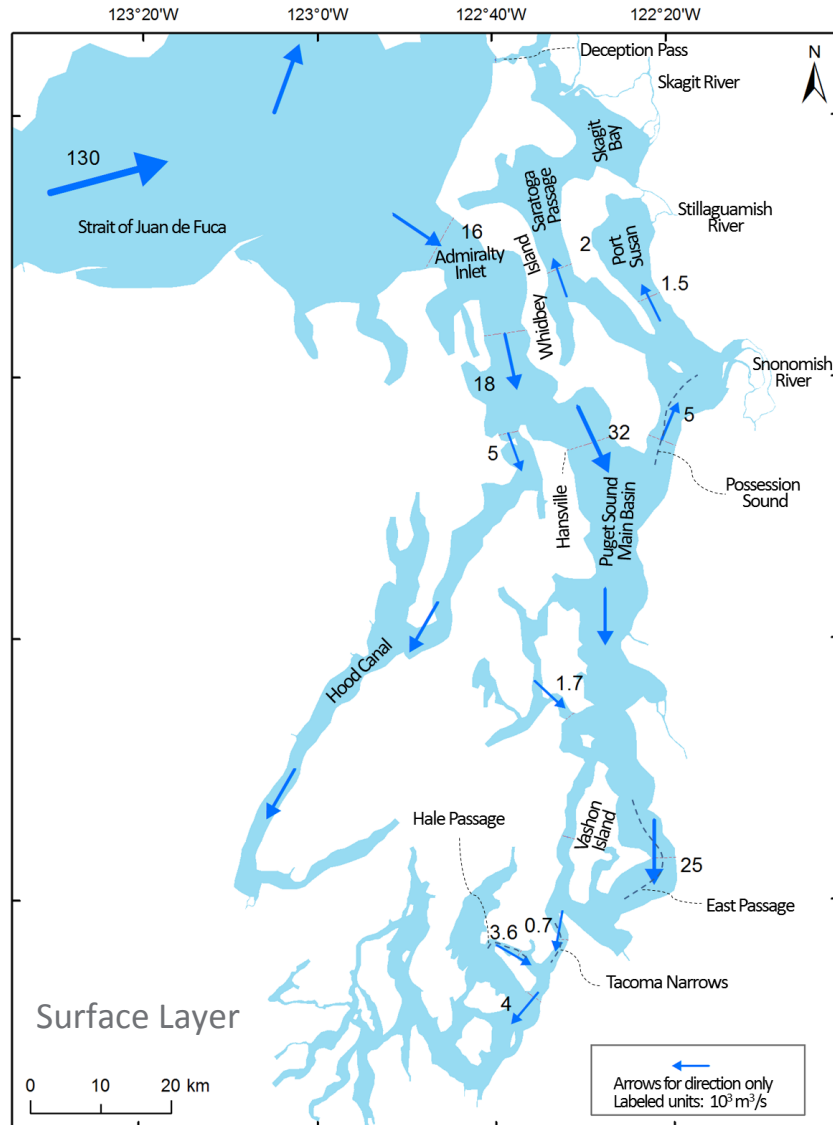


SJF = Strait of Juan De Fuca
HARO = Haro Strait
GS = North boundary of Georgia Strait

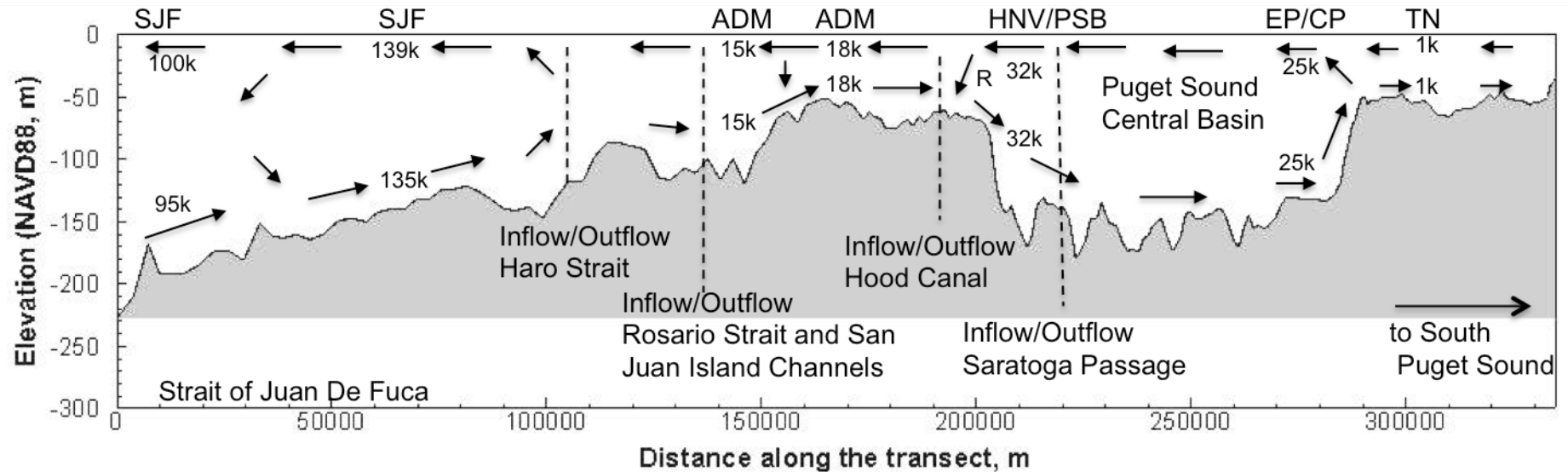
TSW = Tsawwassen
TXD = Texada Island
DIS = Discovery Passage



Circulation in the Salish Sea Puget Sound



Circulation in the Salish Sea Puget Sound



SJF = Strait of Juan De Fuca

ADM = Admiralty Inlet

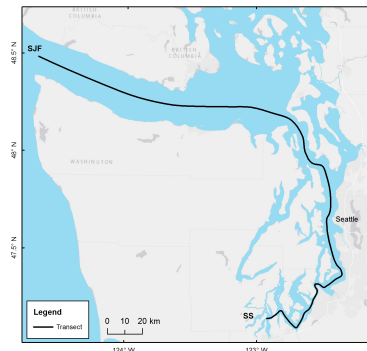
HARO = Haro Strait

R = Reflux Flow at Admiralty Sill (estimated at 19 k, $\approx$ 60% of surface outflow)

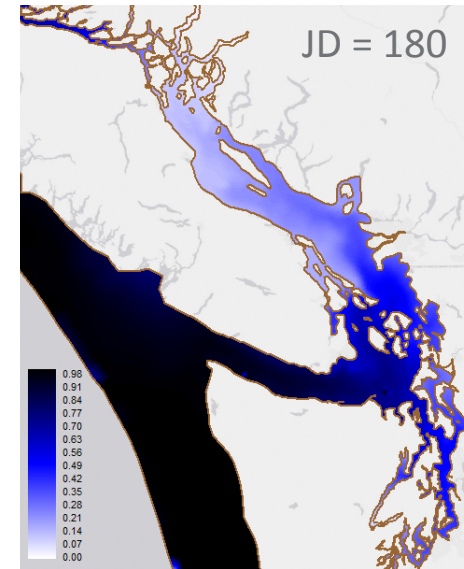
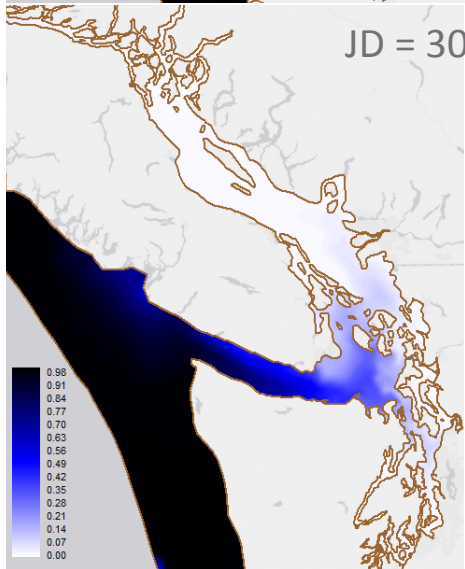
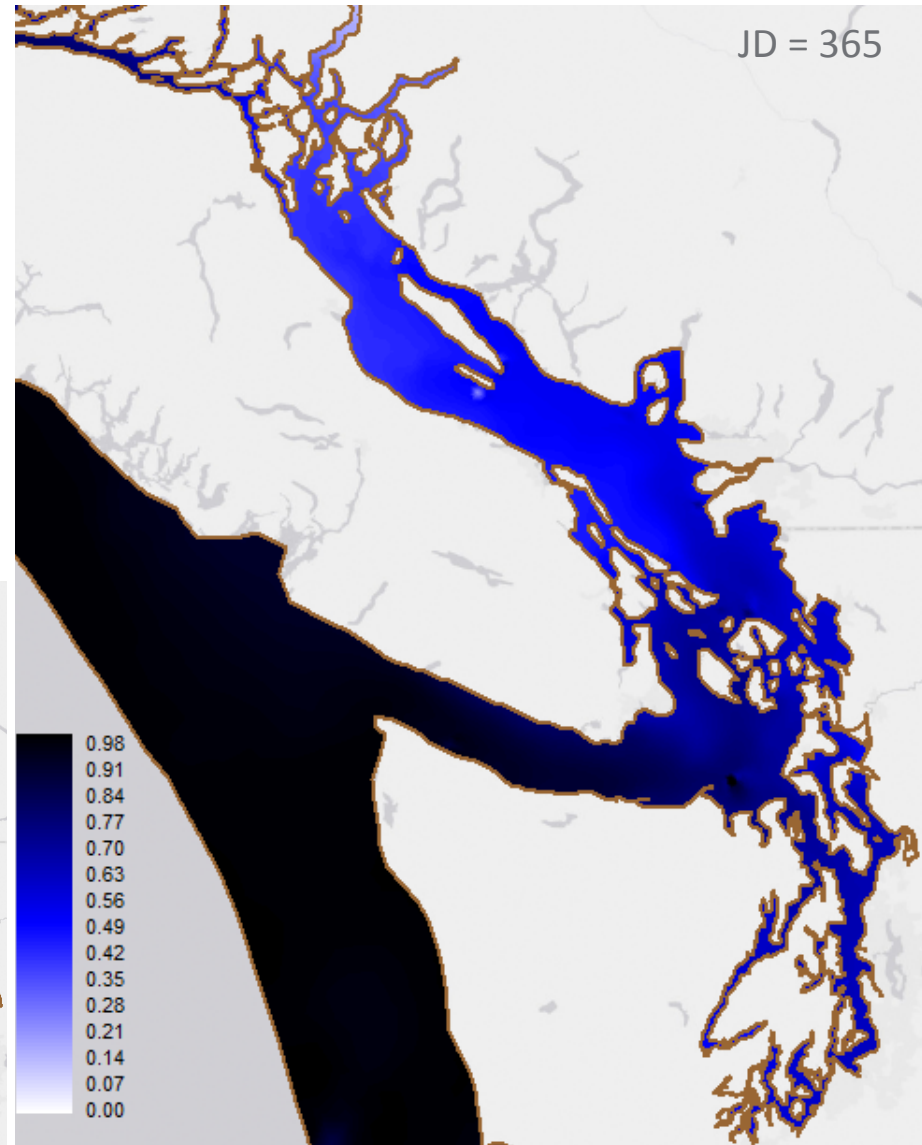
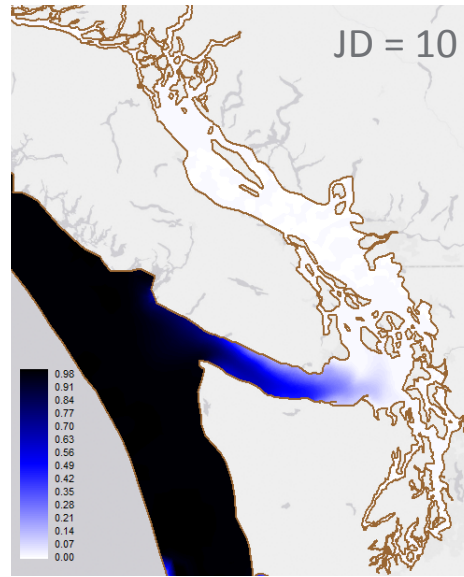
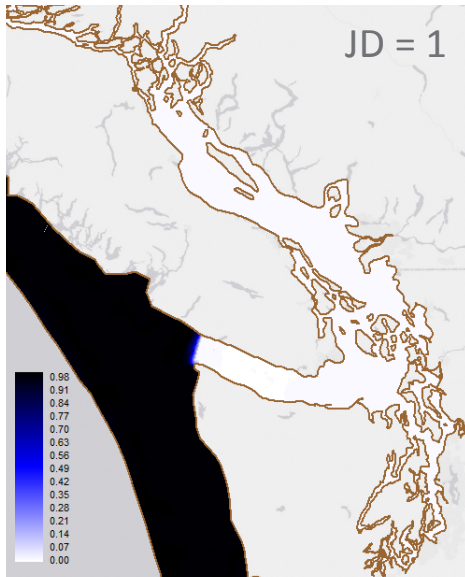
HNV/PSB = Hansville, Puget Sound

EP/CP = East Passage / Colvos Passage

TN = Tacoma Narrows



Intrusion of Upwelled Shelf Waters into Salish Sea and Puget Sound





Summary / Preliminary Conclusions

- ▶ The *Salish Sea Model* successfully reproduces
 - Exchange of upwelled Pacific Ocean water with the Salish Sea
 - Transport and distribution of flows between Puget Sound and Georgia Basin
 - Inter-basin transport within Puget Sound sub-basins
- ▶ Validation of the *Circulation in Embracing Sills* concepts proposed by Ebbesmeyer and Barnes (1980)
 - Nearly 2/3rd of surface outflow is refluxed back to Puget Sound near the Admiralty Inlet sill
- ▶ Influence of Johnstone Strait pathway on Salish Sea
 - Inlet for a fraction of bottom layer flow entering Georgia Basin
 - $\approx 12\%$ of inflow from Georgia Basin is north through Johnstone Strait
 - Outlet for a portion of Fraser and Georgia Basin freshwater
 - 17% of freshwater outflow estimate (Thomson 1994, Crean 1988)

Questions or Comments?



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