Change in interannual variability of rivers and ocean impact

Upcoming Workshop: Change in interannual variability of rivers and ocean impact

Research Action: Uncertainties around oceanic and river loadings
Several areas of research have been identified depending on a better understanding of interannual variability related to future scenarios and nutrient management both short term and long term. These include:

- Natural variability: e.g. What is the variability and how does this impact nutrient availability year to year?
  Longer-term follow-up
- Climate change: e.g. What are the future conditions of the oceanic load?
- Increasing population impacts considering Climate Change and Canadian and other sources
- How do these processes drive variability?

Short-term actions to better constrain uncertainty: physical controls of natural interannual variability

- Timing and magnitude of **ocean influences** on the Salish Sea?
- Timing and magnitude of the **freshet and riverine influence**?
- Accordingly,
  - The availability of nutrients to the **euphotic zone**, first considering the role of temperature and salinity on **stratification**
  - Influence on residence time and flushing time of shallow embayments where low DO is observed (**Ocean exchange** and **riverine flushing**)

Chat

In the Chat: Who else should we engage in the next interannual variability workshop either as participants or presenters?

Nutrient Loading in the Salish Sea

Parker MacCready

Leo Maddox Endowed Professor of Oceanography

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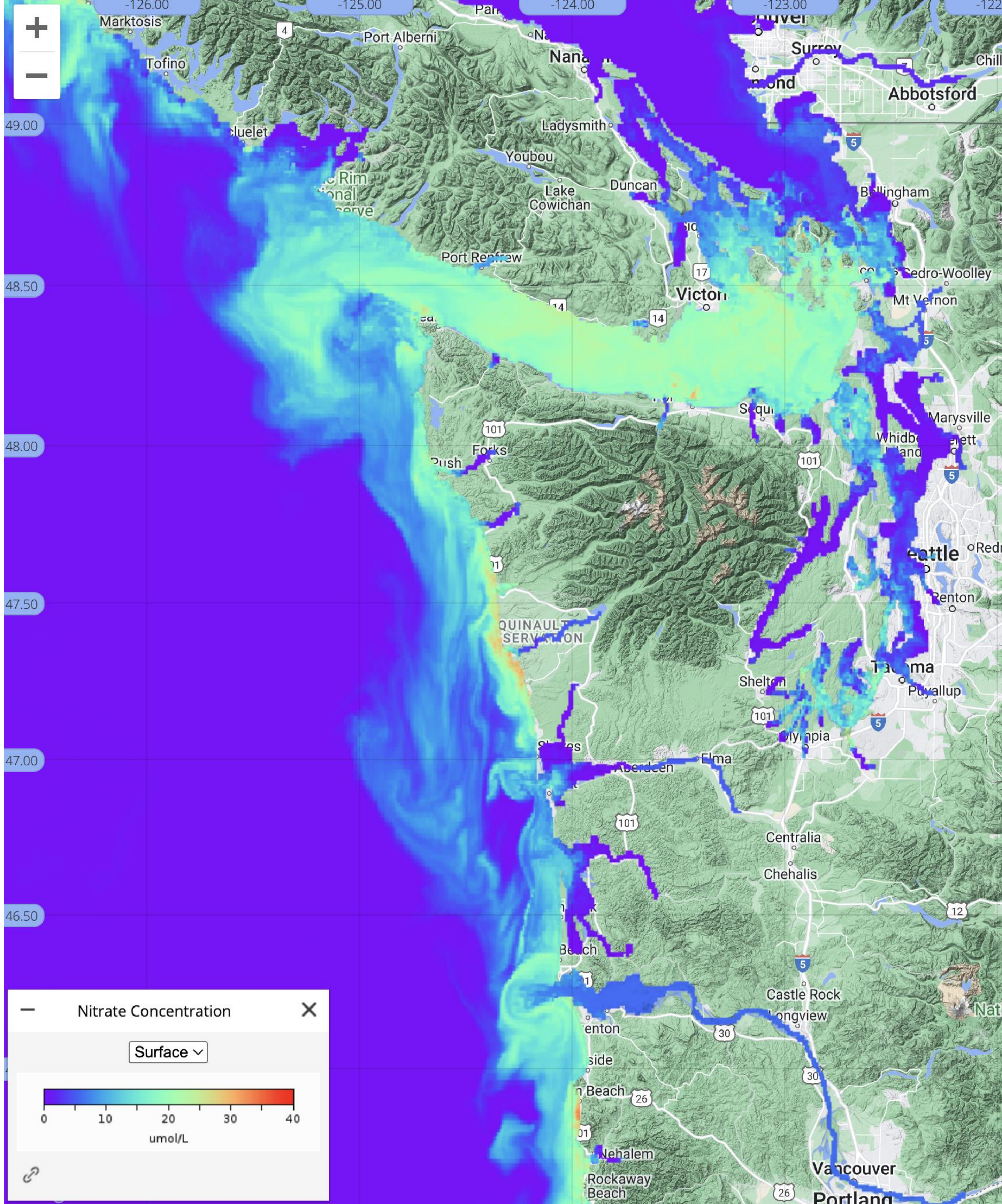
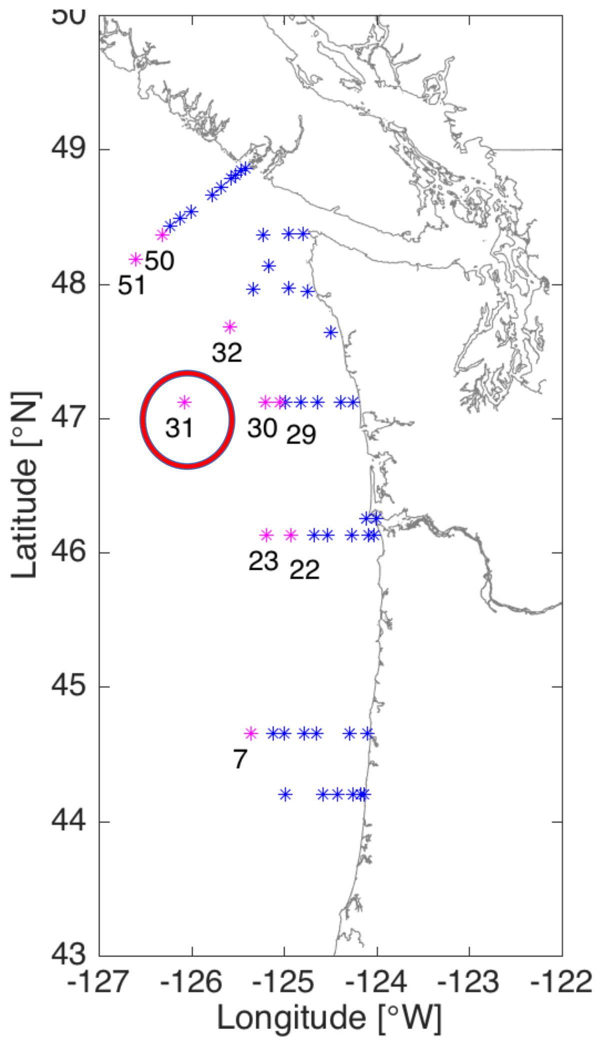
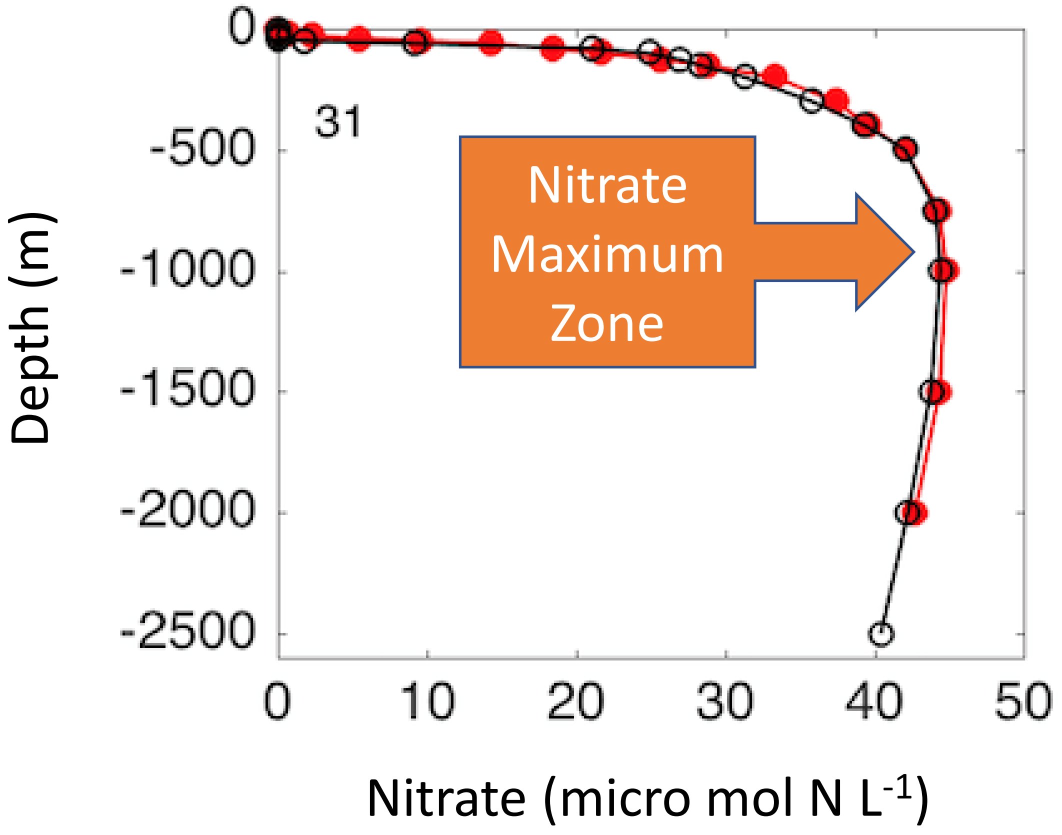


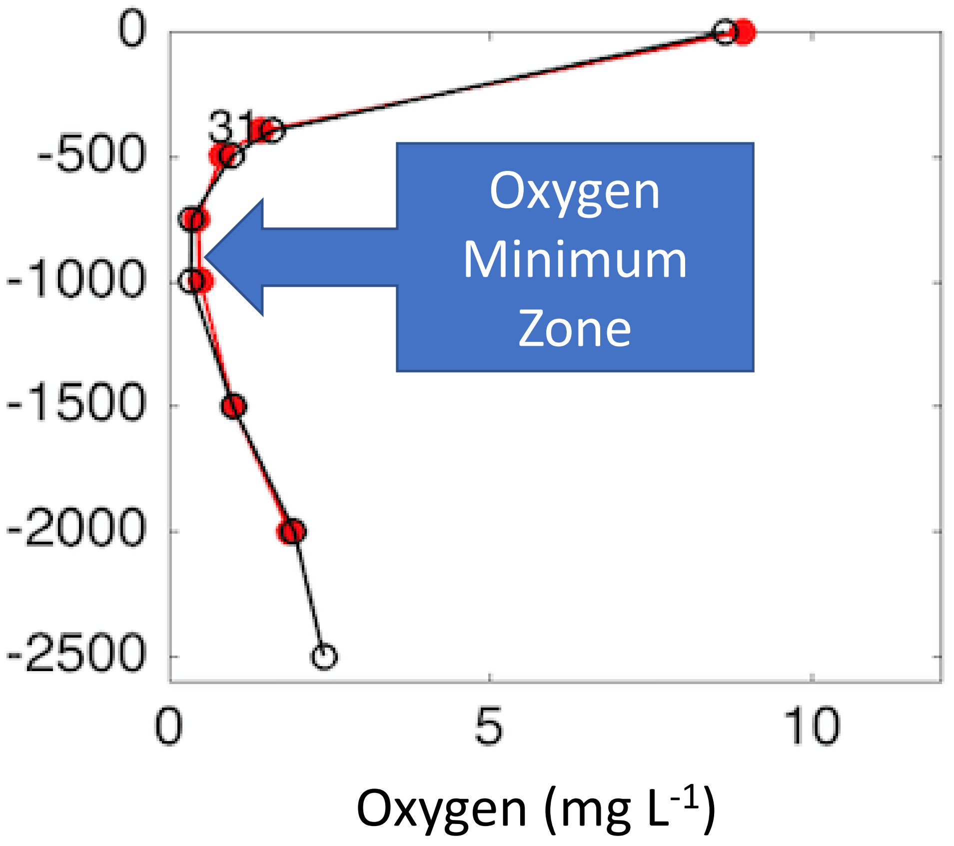
Overview and Questions

- Dissolved Inorganic Nitrogen (DIN) in the Salish Sea comes from rivers and human sources like WWTP’s, and mostly from the ocean via the estuarine exchange flow.
- How much do these sources change on monthly, annual, and longer time scales?
- How do the size and the variability of these sources affect our ability to predict consequences of actions we might take?

There is a lot of High-Nitrate, Nearly-Anoxic water offshore below the shelf break (NOAA Casts 2016)



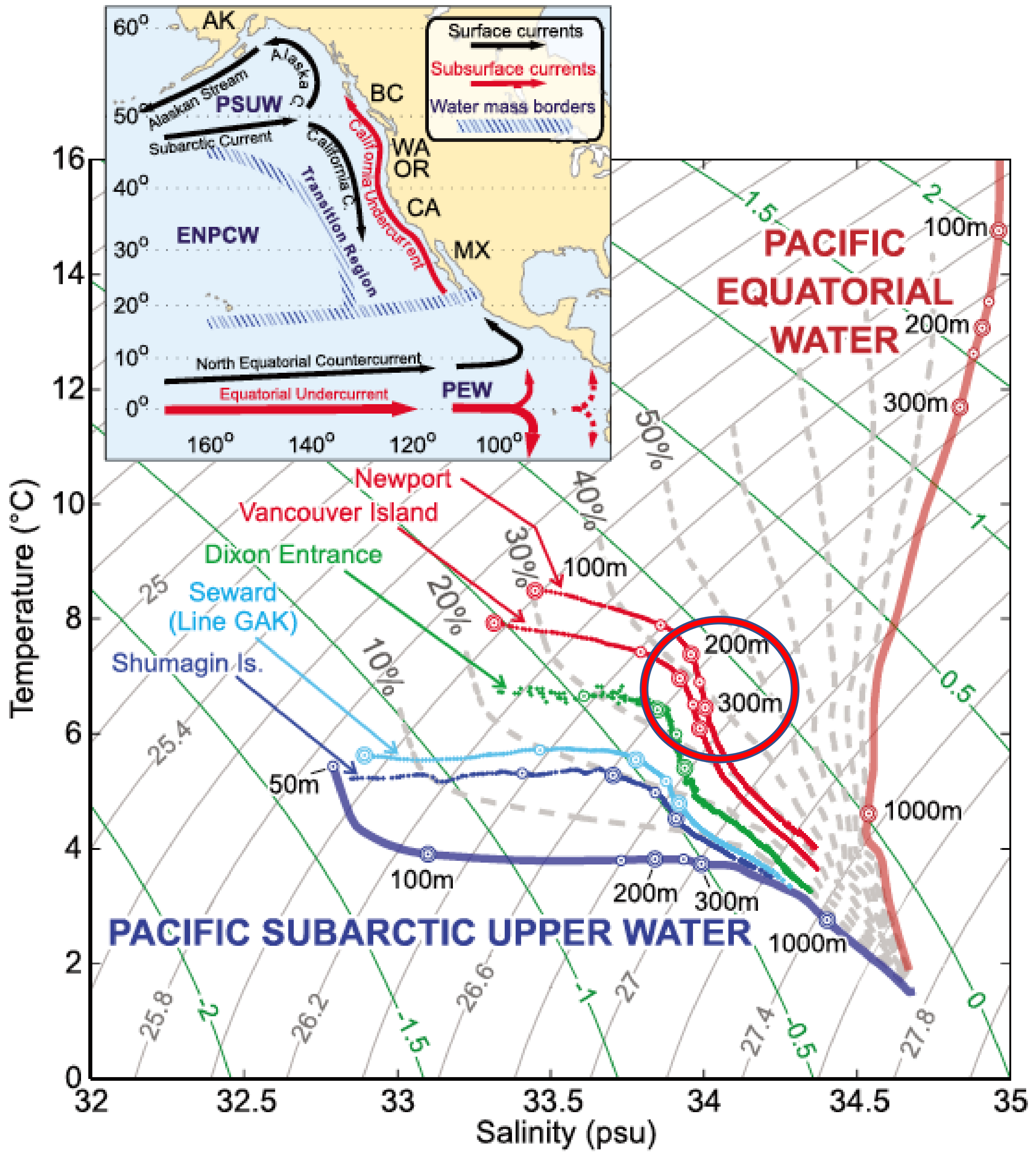




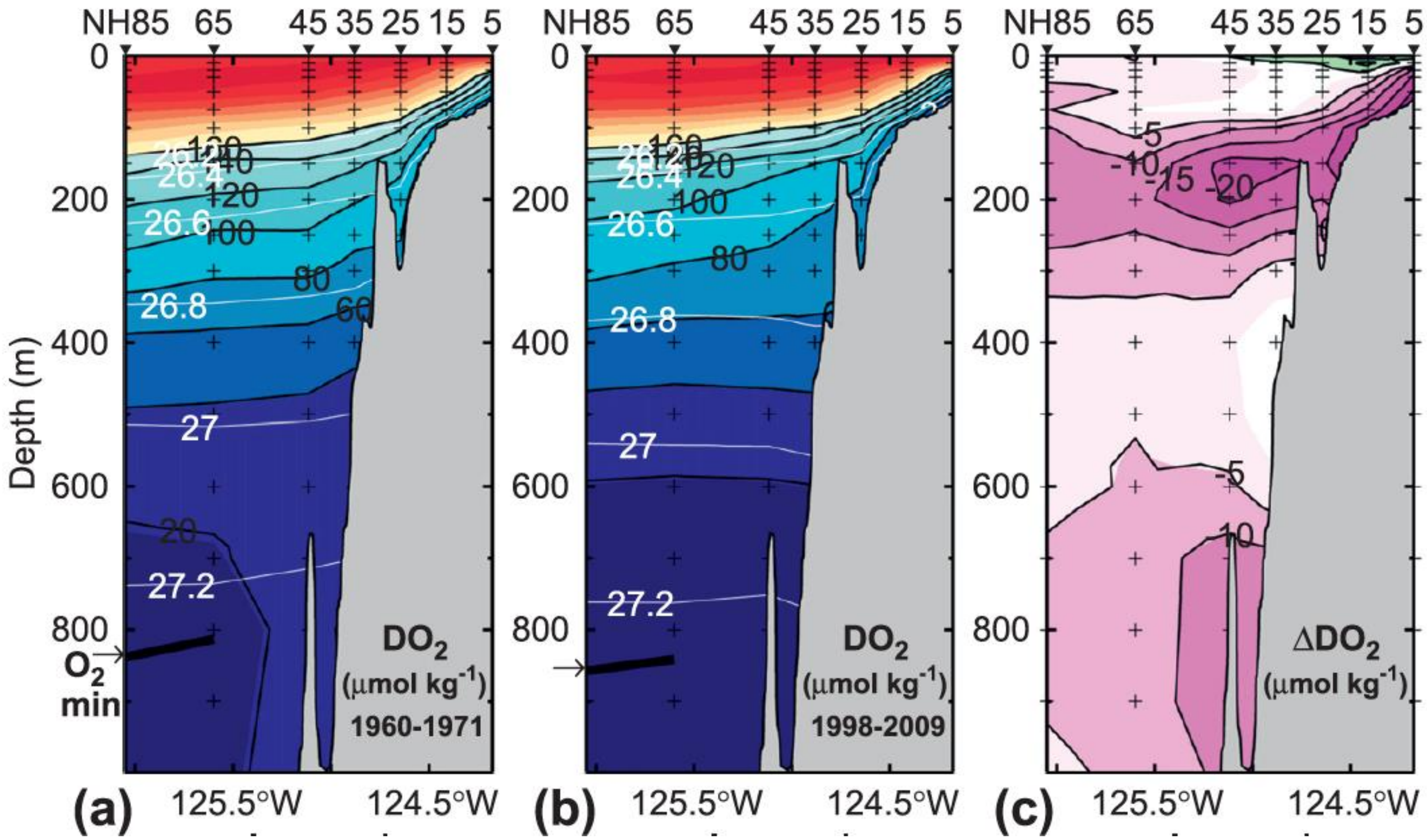
Hypoxia = 2 (mg L^{-1})

Reflects the accumulated remineralization of organic matter in the global ocean circulation

The incoming water at the mouth of Juan de Fuca is a 40:60 mixture of Pacific Equatorial Water coming north in the California Undercurrent, and Pacific Subarctic Upper Water from the NW Pacific



Thomson & Krassovski (2010 JGR) Poleward reach of the California Undercurrent extension



DO decreased by about 20% at the depth of the shelf break over 40 years.

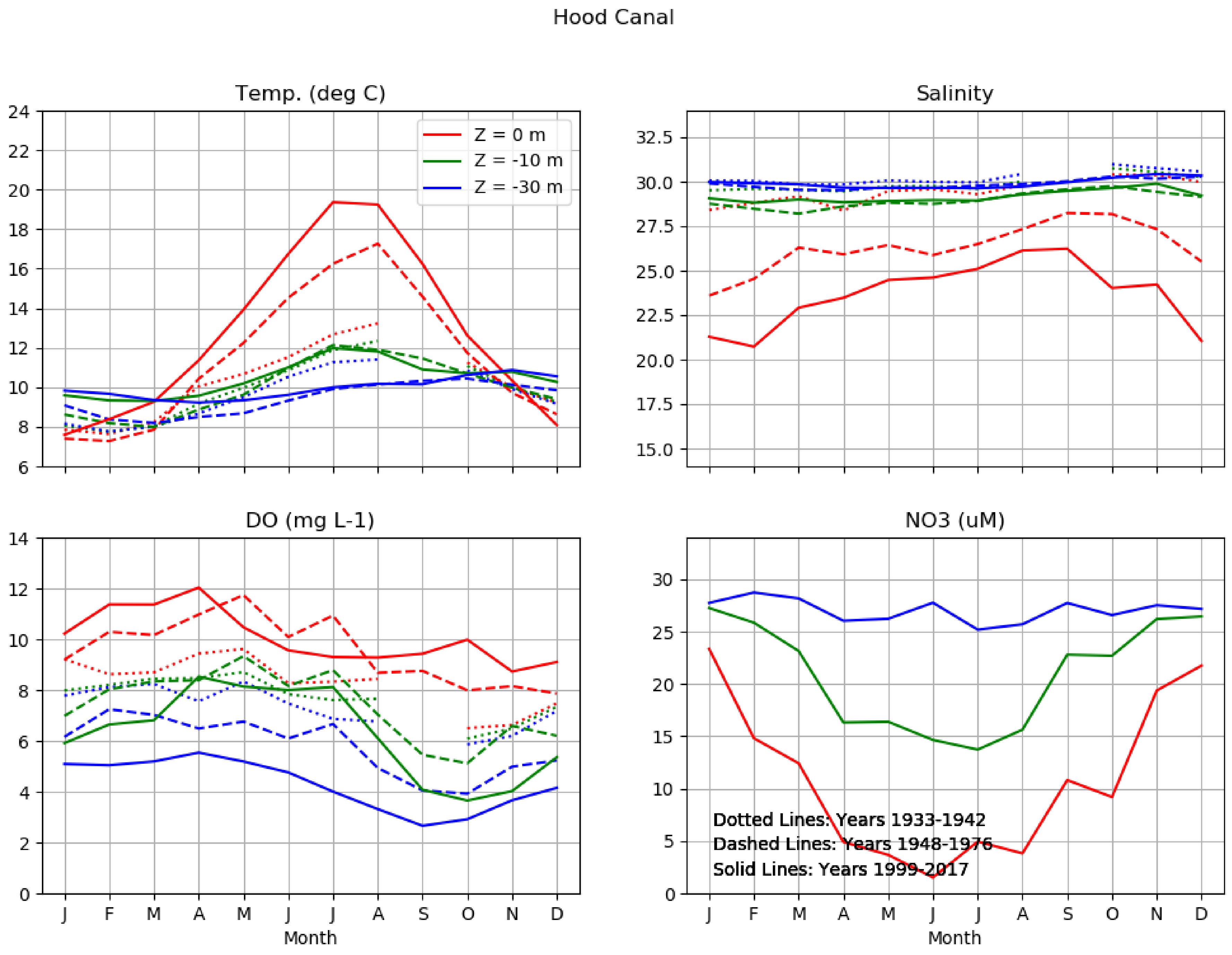
Because the vertical gradients are strong, any change in the depth of the ocean source of the exchange flow could also be very important.

Declining Oxygen in the Northeast Pacific*, S. D. Pierce, J. A. Barth, R. K. Shearman and A. Y. Erofeev, Journal of Physical Oceanography 2012 Vol. 42 Pages 495-501, DOI: 10.1175/JPO-D-11-0170.1

There are also long-term changes in Puget Sound

Using Collias CTD data from 1932-1975, and Ecology data for recent decades, we find that Hood Canal surface water has gotten warmer and fresher, and the deeper water has less DO.

The largest signal in Main Basin is that it is warmer by about 1 °C (top to bottom, all seasons).

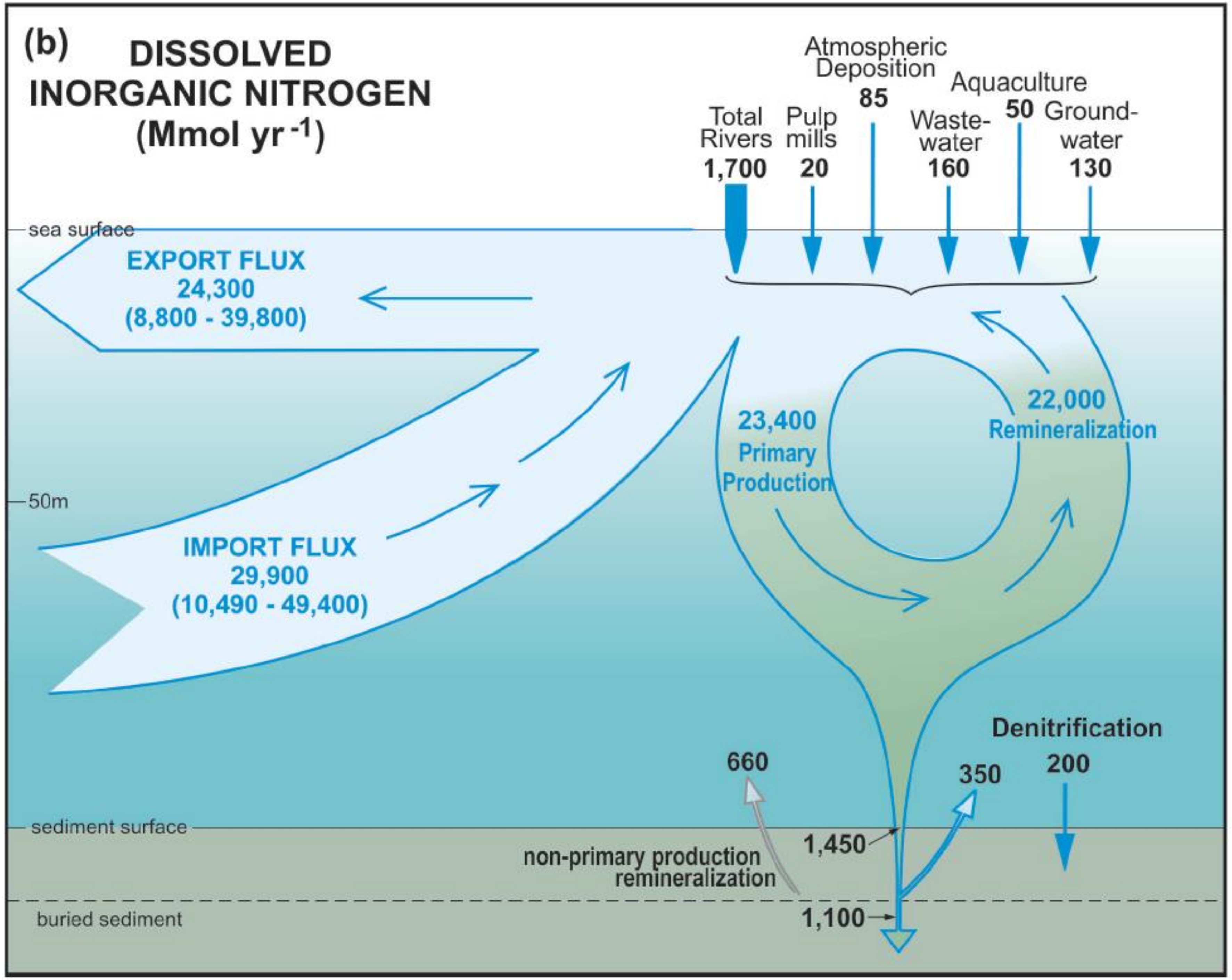


Strait of Georgia DIN Budget

The estuarine exchange flow is the biggest DIN source and sink, and the net ocean source is about 60% of the total sources.

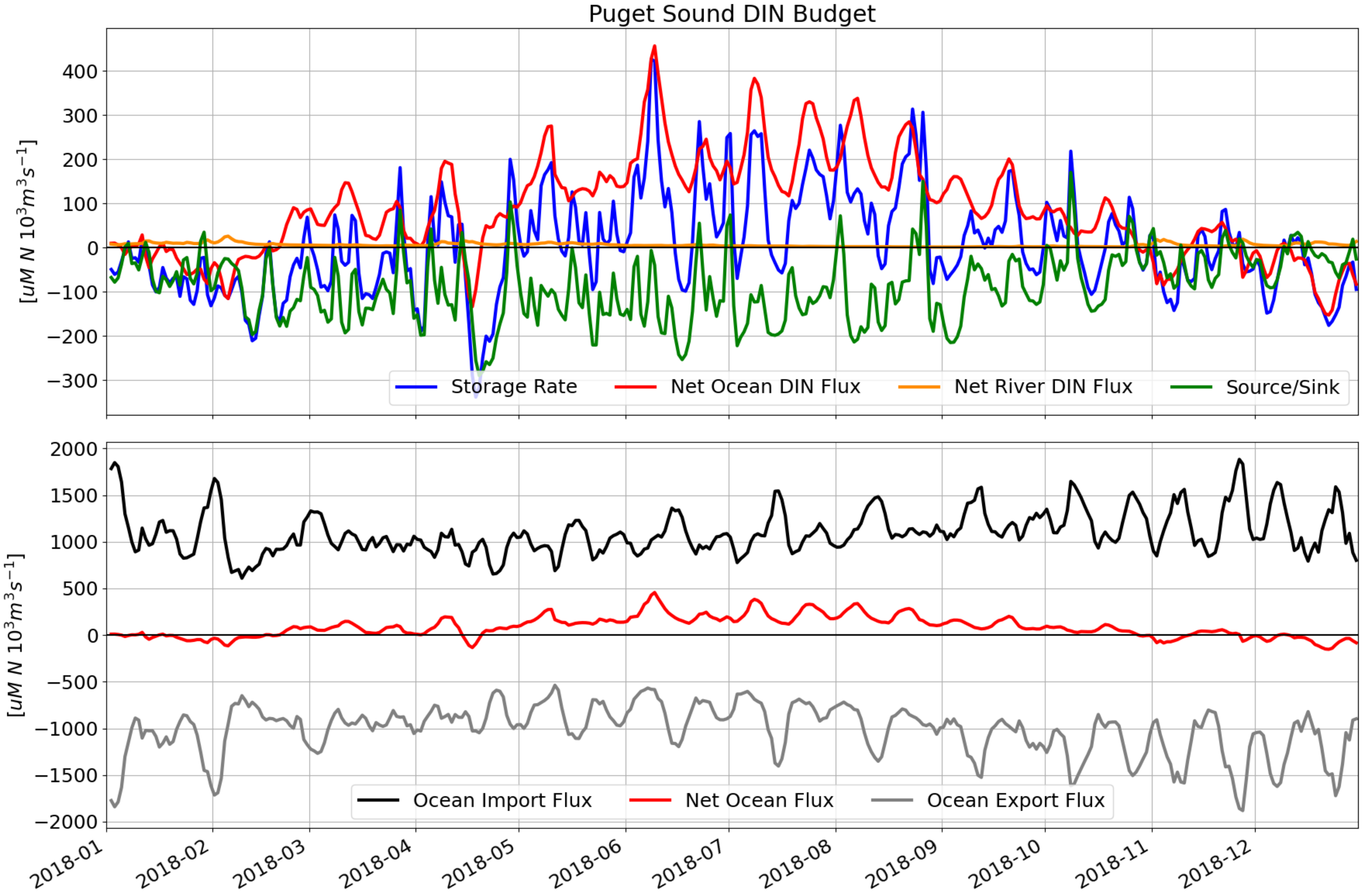
Import – Export = 5000 Mmol/yr

Note the large variability of the ocean exchange.



A nitrogen budget for the Strait of Georgia, British Columbia, with emphasis on particulate nitrogen and dissolved inorganic nitrogen, J. N. Sutton, S. C. Johannessen and R. W. Macdonald, Biogeosciences 2013 Vol. 10 Pages 7179-7194, DOI: 10.5194/bg-10-7179-2013

Model DIN Budget of Puget Sound



The Net Ocean DIN Flux through Admiralty Inlet and Deception Pass is the small difference of two large numbers.

Net = Import - Export

Estuarine Circulation, Mixing, and Residence Times in the Salish Sea, P. MacCready, R. M. McCabe, S. A. Siedlecki, M. Lorenz, S. N. Giddings, J. Bos, et al., Journal of Geophysical Research: Oceans 2021 Vol. 126 Issue 2 , DOI: 10.1029/2020jc016738

Why the Size of the Ocean DIN Import Flux Matters

- In the Mohamedali et al. (2011) Report the Net DIN Loading from Rivers+WWTP's is estimated to be about 50% of the Net from the ocean. Thus, we expect that changing human loading may matter.
- However, the River+WWTP load is only 4% of the Ocean Import, and WWTP's are only 2.5%.
- Using the Ocean Import a more meaningful measure of the ocean influence on the system.

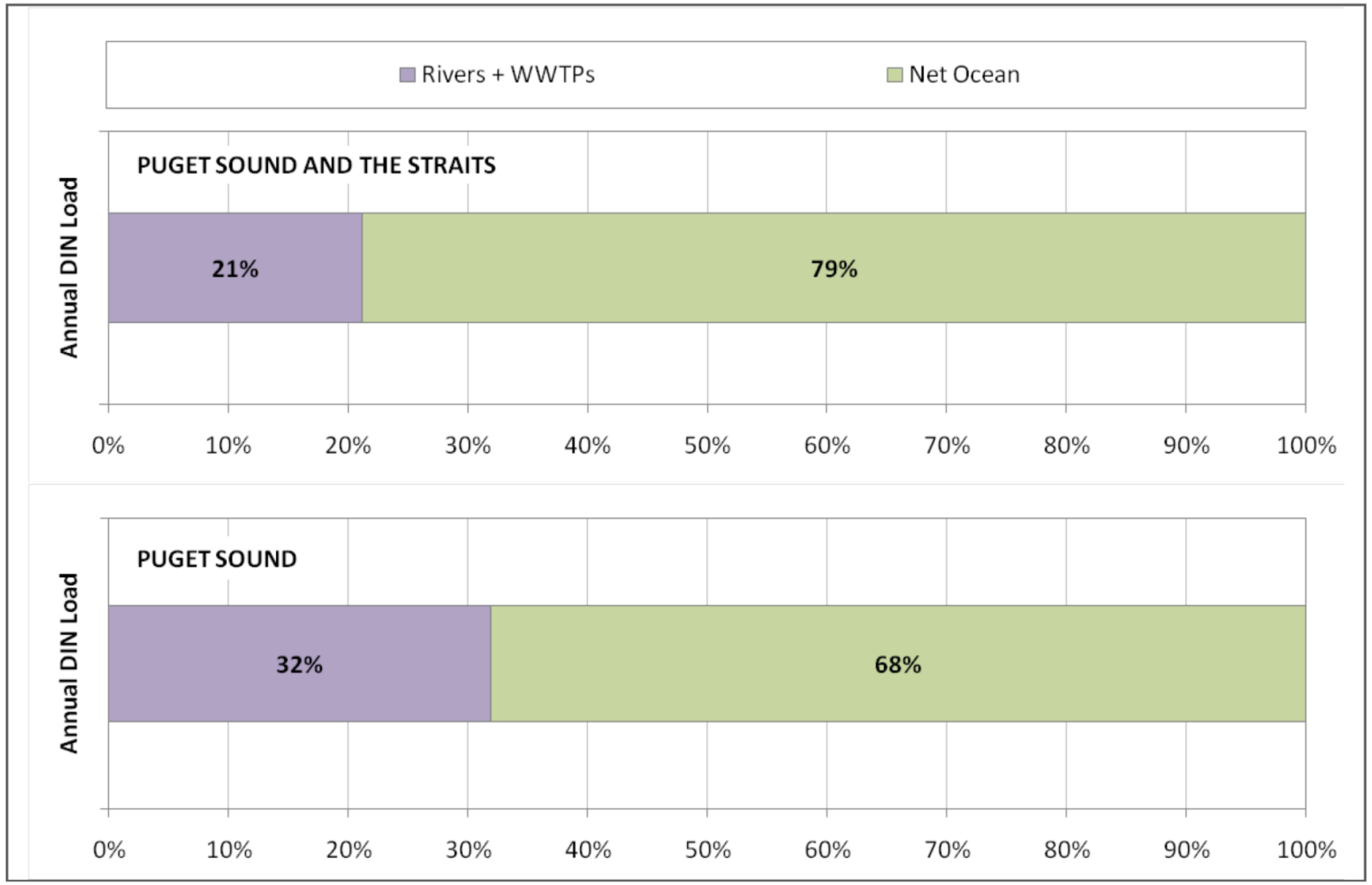


Figure 31. Comparison of DIN load contributions to Puget Sound and the Straits from rivers, WWTPs, and the oceanic loads from Mackas and Harrison (1997).

Puget Sound Dissolved Oxygen Model Nutrient Load Summary for 1999-2008, T. Mohamedali, M. Roberts, B. Sackmann and A. Kolosseus, 2011 Report Number: 8778336341

Important Hypotheses and Research Directions

- Variability of Ocean Source water is likely to be very important to the ecosystem.
- Is Variability of Ocean Source water important for uncertainty estimates?
- For Biogeochemical Modeling we would greatly benefit from more observations of:
  - Phytoplankton growth rates
  - Zooplankton grazing rates
  - PAR (Photosynthetically active radiation)
  - Organic Particle Fluxes
  - Benthic Fluxes

Salish Sea response to interannual variations during the marine heat wave years (2013-2017)

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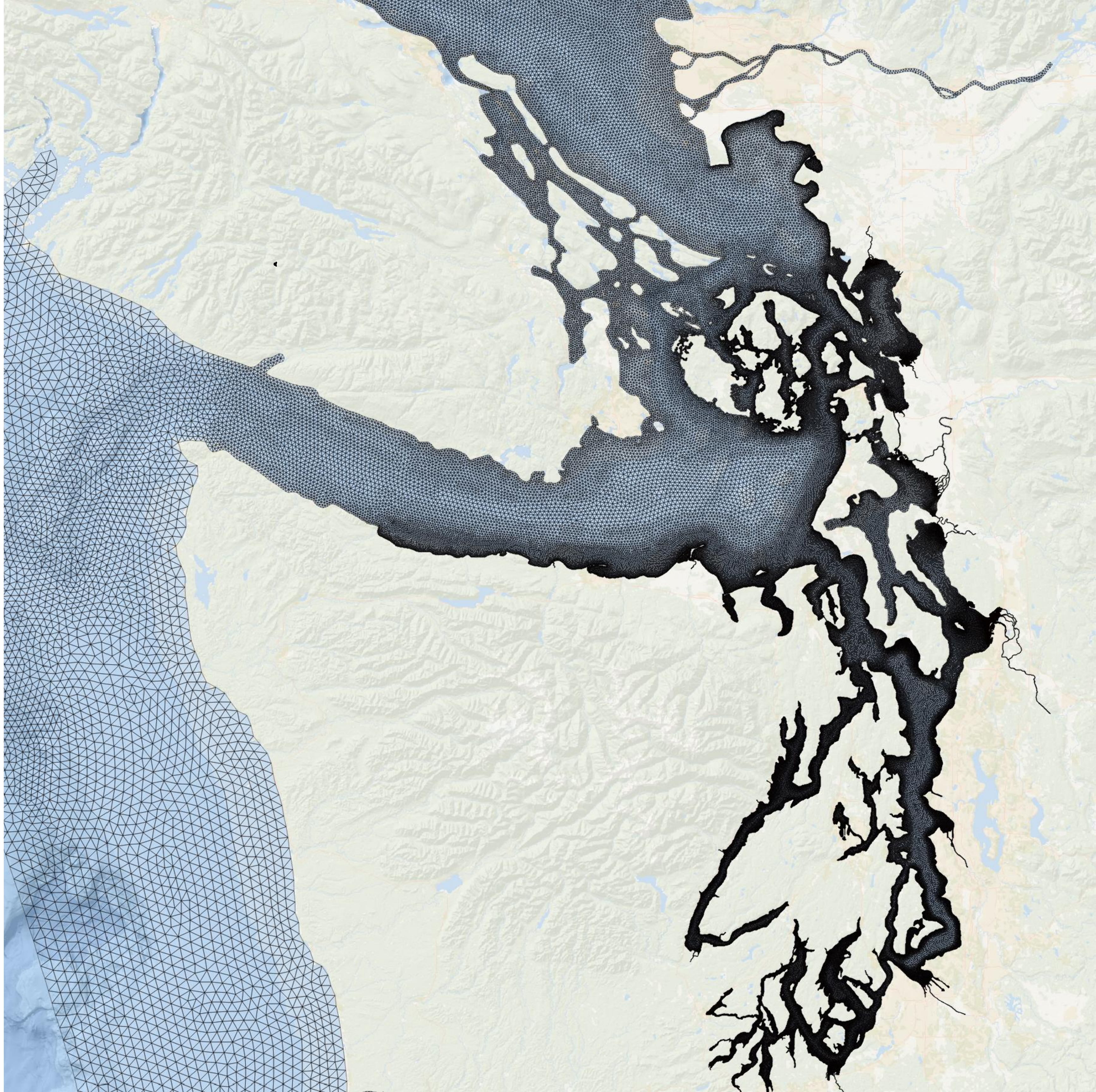
Kickoff: Science supporting decision-making workshop
UW Puget Sound Institute

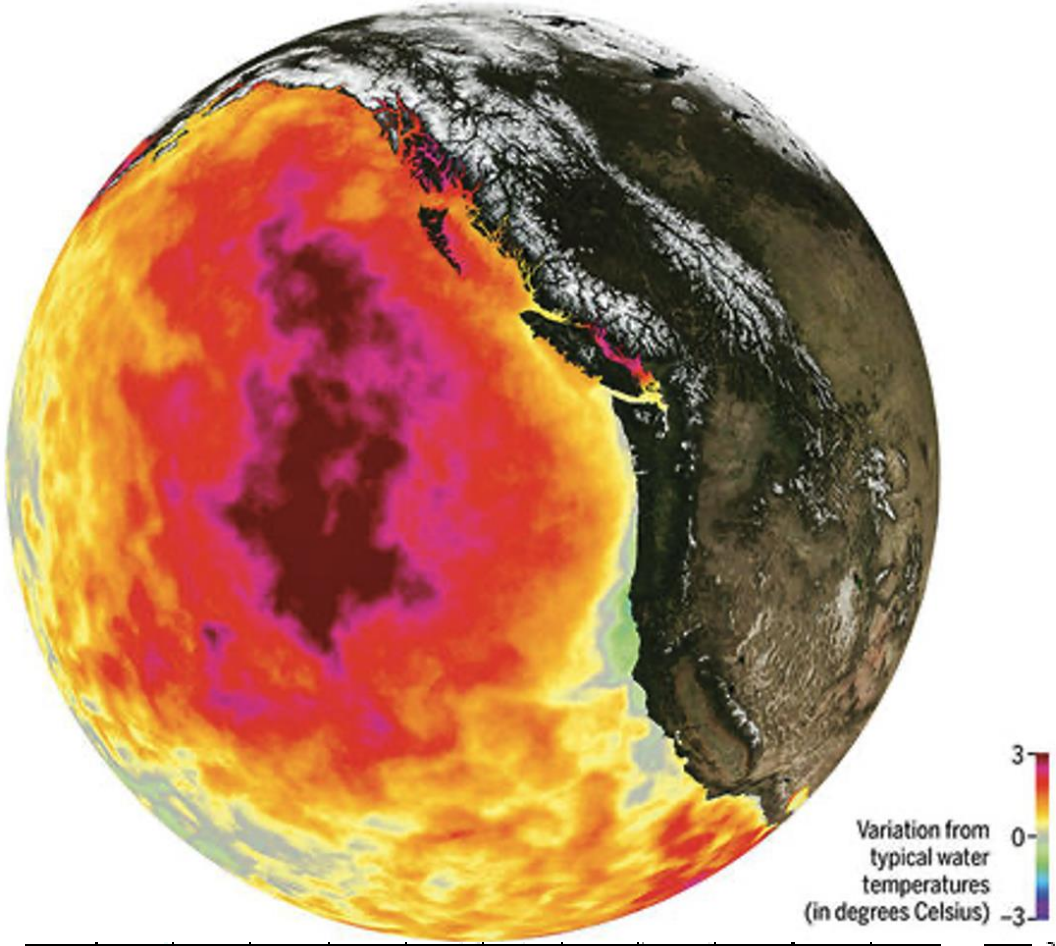
July 26, 2022

PNNL is operated by Battelle for the U.S. Department of Energy



Pacific Northwest
NATIONAL LABORATORY

Source: Gentemann et. al JGR Letters 2017 issue Cover

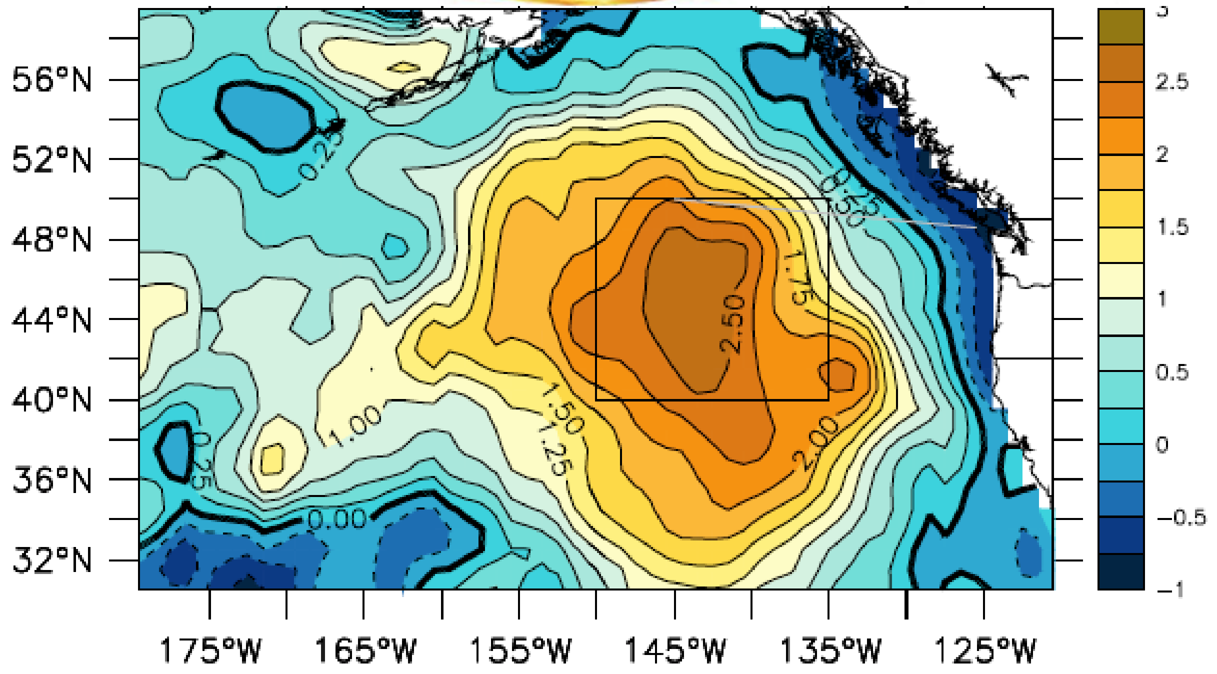


Background/Motivation

Concern over climate change impacts

Northeast Pacific Marine Heatwave of 2014-2016

- Sea surface temperatures exceeded 90th percentile bounds of seasonal variation
  - Arrival - winter of 2013- 2014
  - 2014 – ΔT > 2.5℃
  - 2015 – Coastal impingement
  - 2016 – Persistent through winter
- Lack of cooling as opposed to added warming



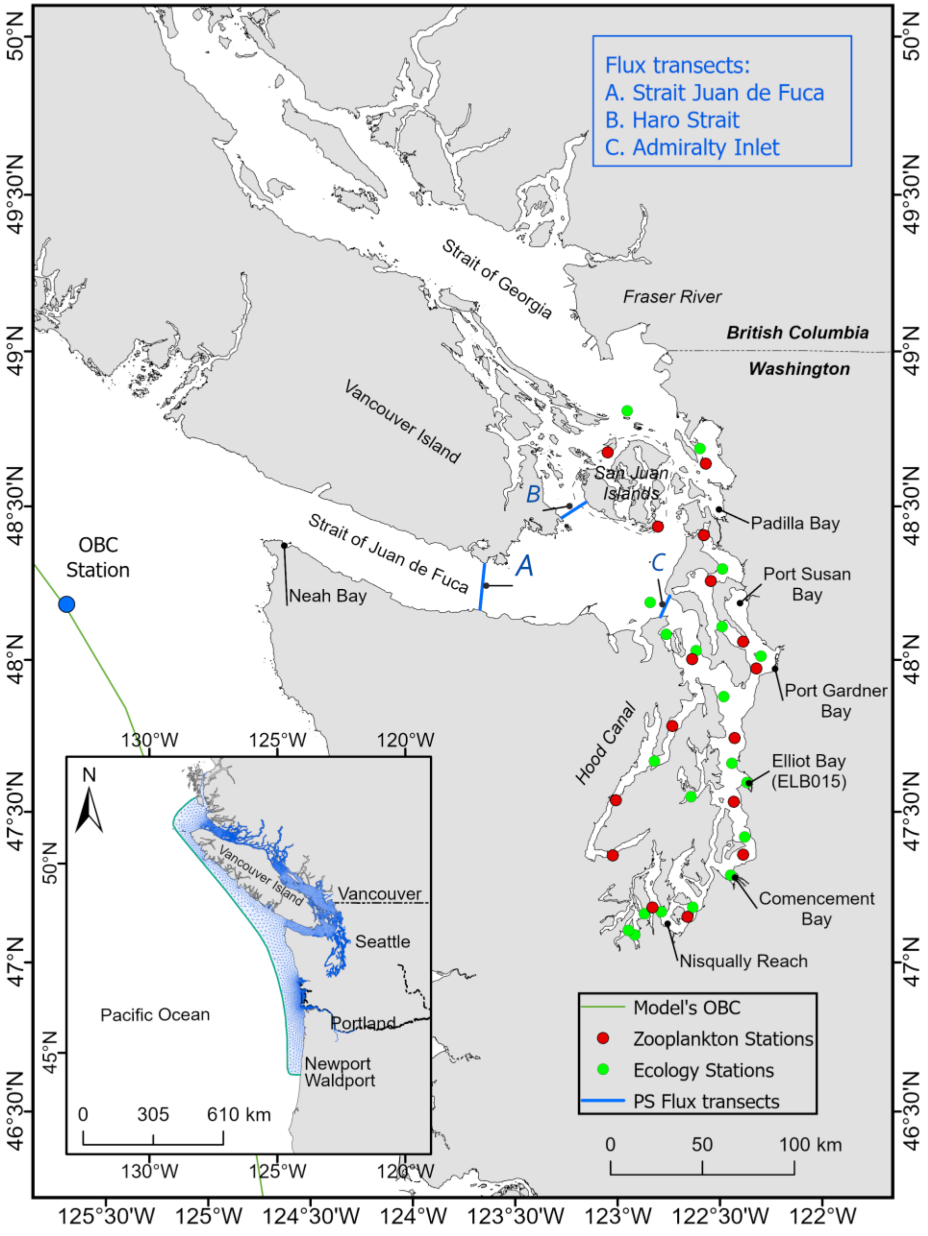
Source: Bond et. al JGR Oceans 2015

SALISH SEA MODELING CENTER

Objective: Characterize and quantify impacts

Focus on inner estuarine waters of the Salish Sea

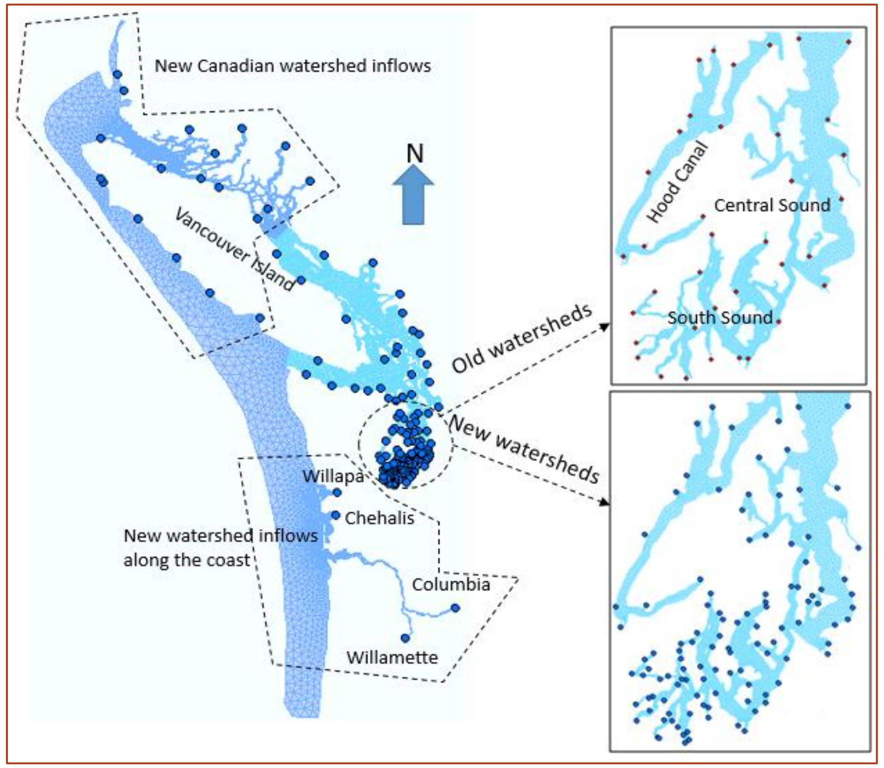
- Coastal impact documented based on field studies
  - Nearshore SST – ΔT as high as 6.2℃ (Southern California) (Gentemann et al. 2017)
  - Decrease in phytoplankton biomass - *induced by anomalous winds* (Whitney et al. 2015)
  - Coastwide Pseudo-nitzschia bloom in spring 2015 - *due to warmer waters* (McCabe et al. 2016)
  - Overall drop in copepod biomass - *potential collapse of the food chain* (Peterson et al. 2017)
  - Massive mortality of planktivorous seabirds (Jones et al. 2018)
- Any inner estuarine impacts? Impacts to the *Salish Sea?*
  - Noted increase in primary production (monitoring data)
  - Impacts - Largely unquantified, inconclusive, and somewhat speculative …



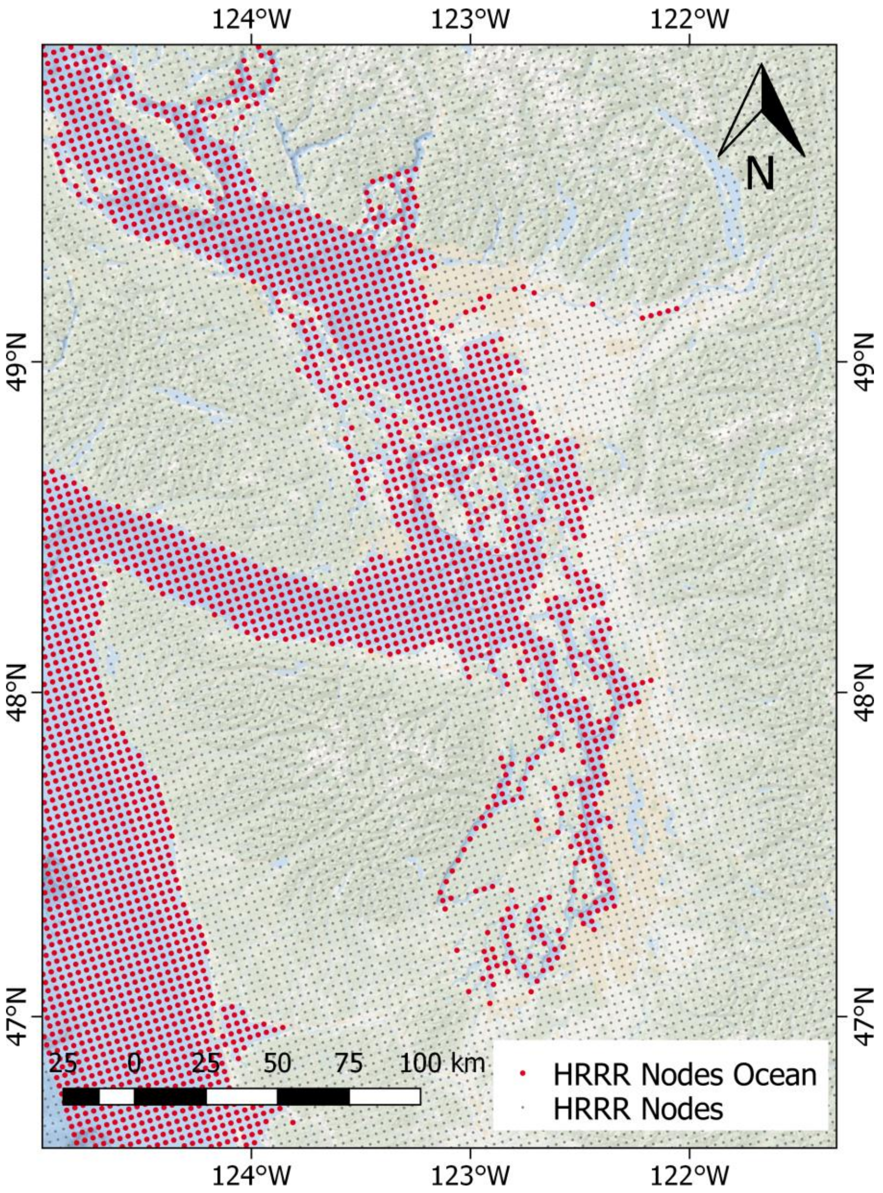
Approach: modeling-based quantification

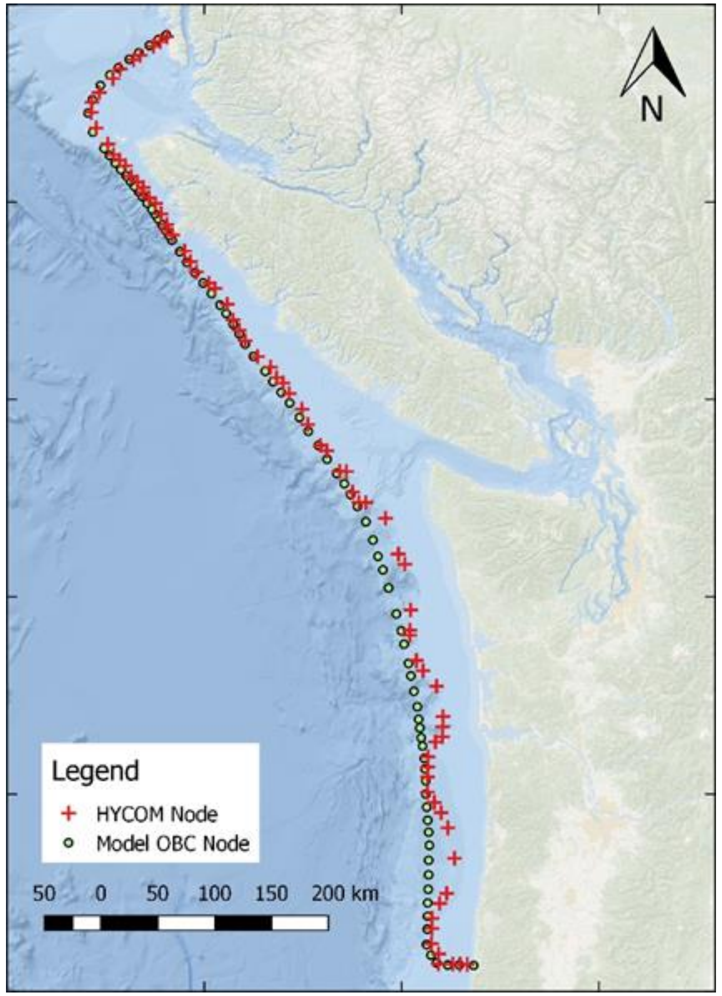
Multi-year validation & sensitivity test

- ***Salish Sea Model*** Setup and validation 2013 - 2017
  - Hydrodynamics (FVCOM)
  - Biogeochemistry (FVCOM-ICM)



[Khangaonkar et al. 2018, 2019, 2021]



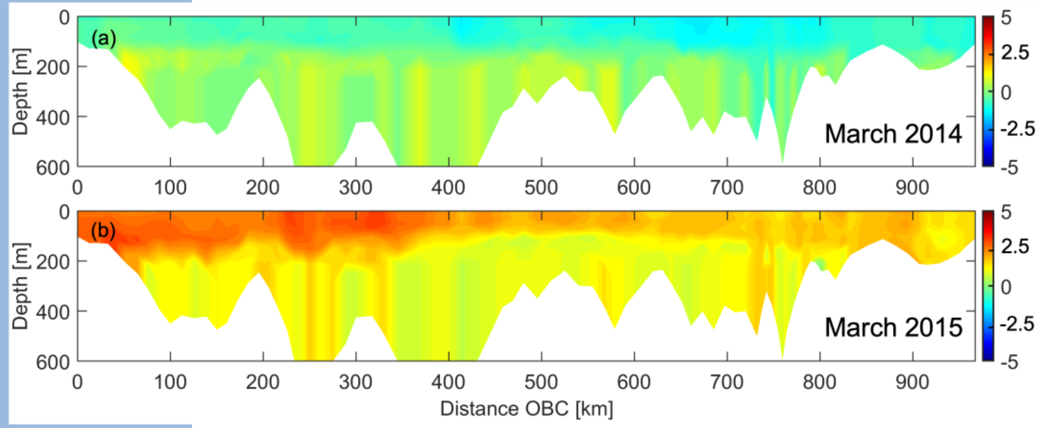


Approach: modeling-based quantification (2 scenarios)

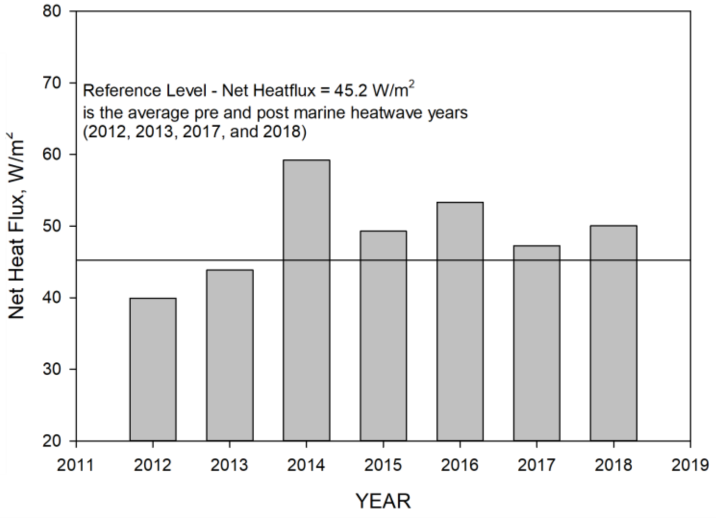
(a) Existing condition - validation
(Marine heatwave included)

(b) Reference condition - no warming

Climatological ocean boundary
(1999-2009 average)

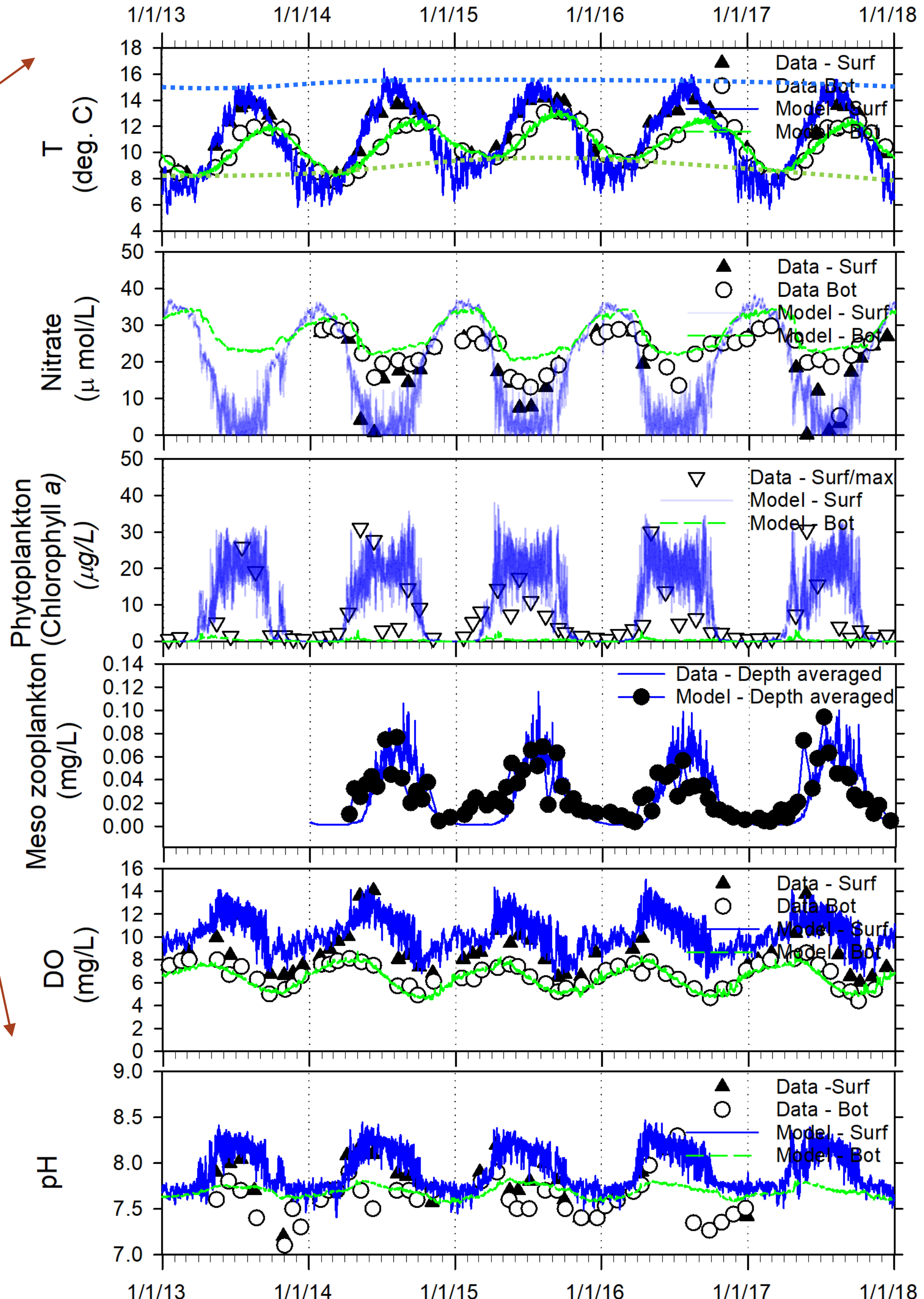


Average net heatflux



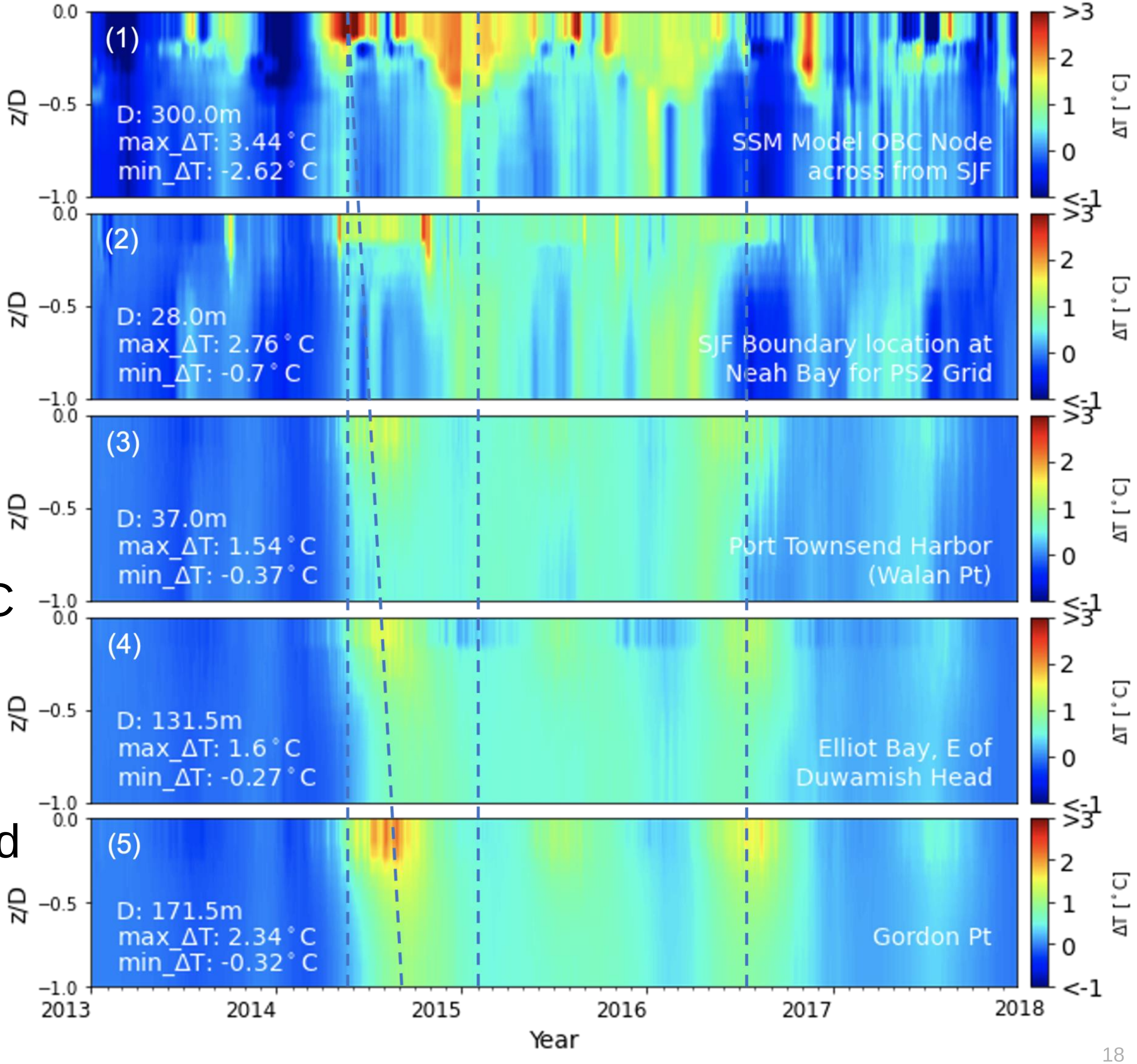
Average atmospheric net heat flux during the marine heatwave years (2014–2016) was (≈+19%)

Elliot Bay station Example



Results: Propagation of the MHW into Salish Sea

- Maximum ΔT 3-4 ℃ at OBC
- Inner Salish Sea
  - Max ΔT 2-3 ℃ at surface during impingement period
- Sustained average elevated temperatures 2015-2016
  - ΔT ≈ 0.4-0.6 ℃

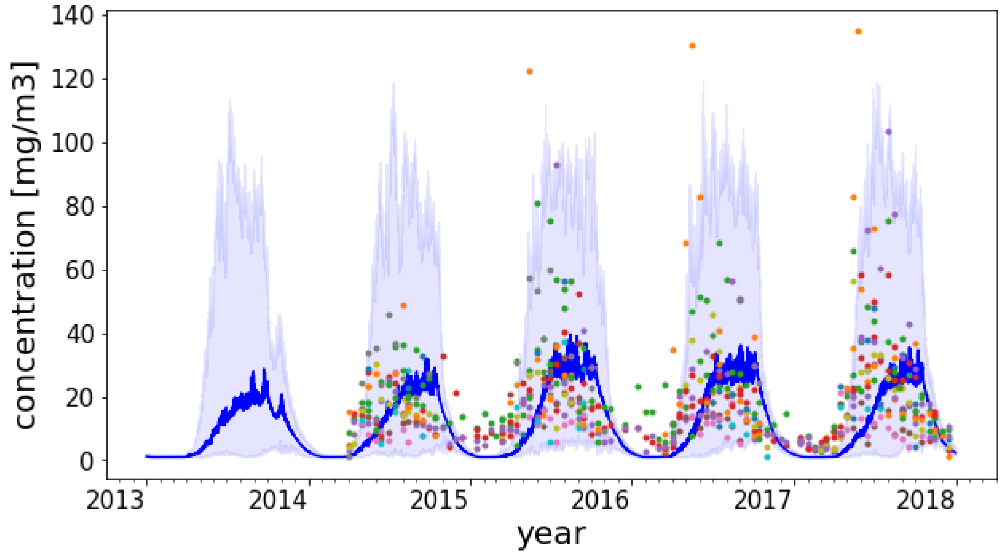


Salish Sea Monitoring Data 2014-2017

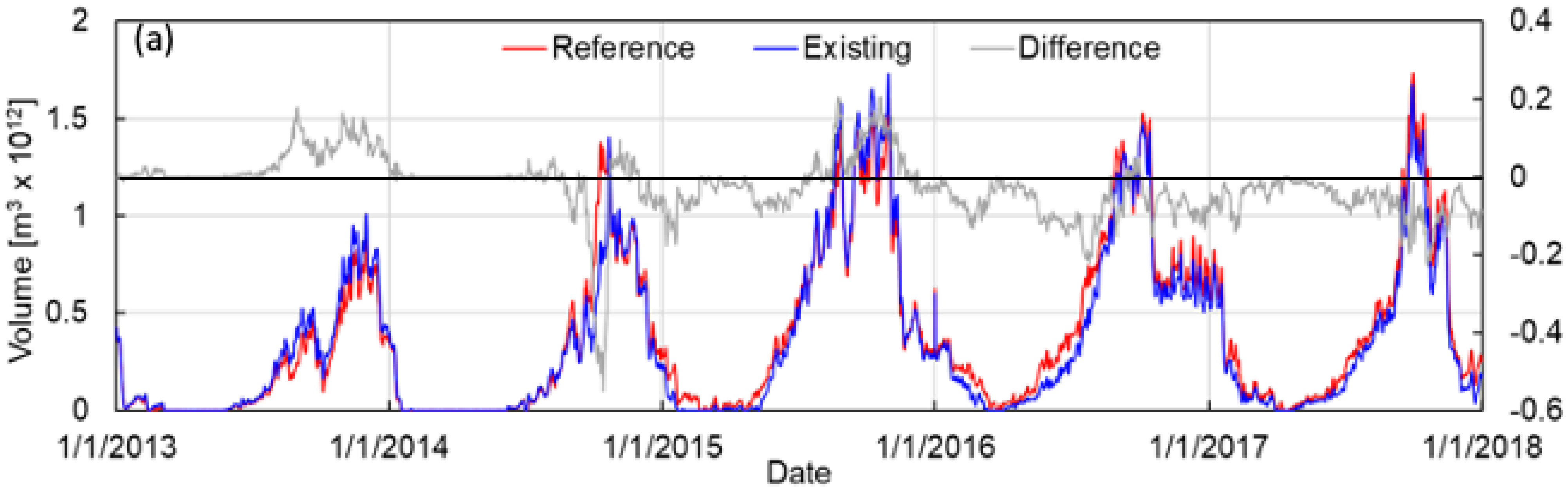
Primary production increased during the heatwave

- Increase in 2015 and 2016 relative to 2014
  - +9%, and 2% Δ phytoplankton biomass
  - + 10%, + 8% Δ zooplankton biomass

Mesozooplankton biomass



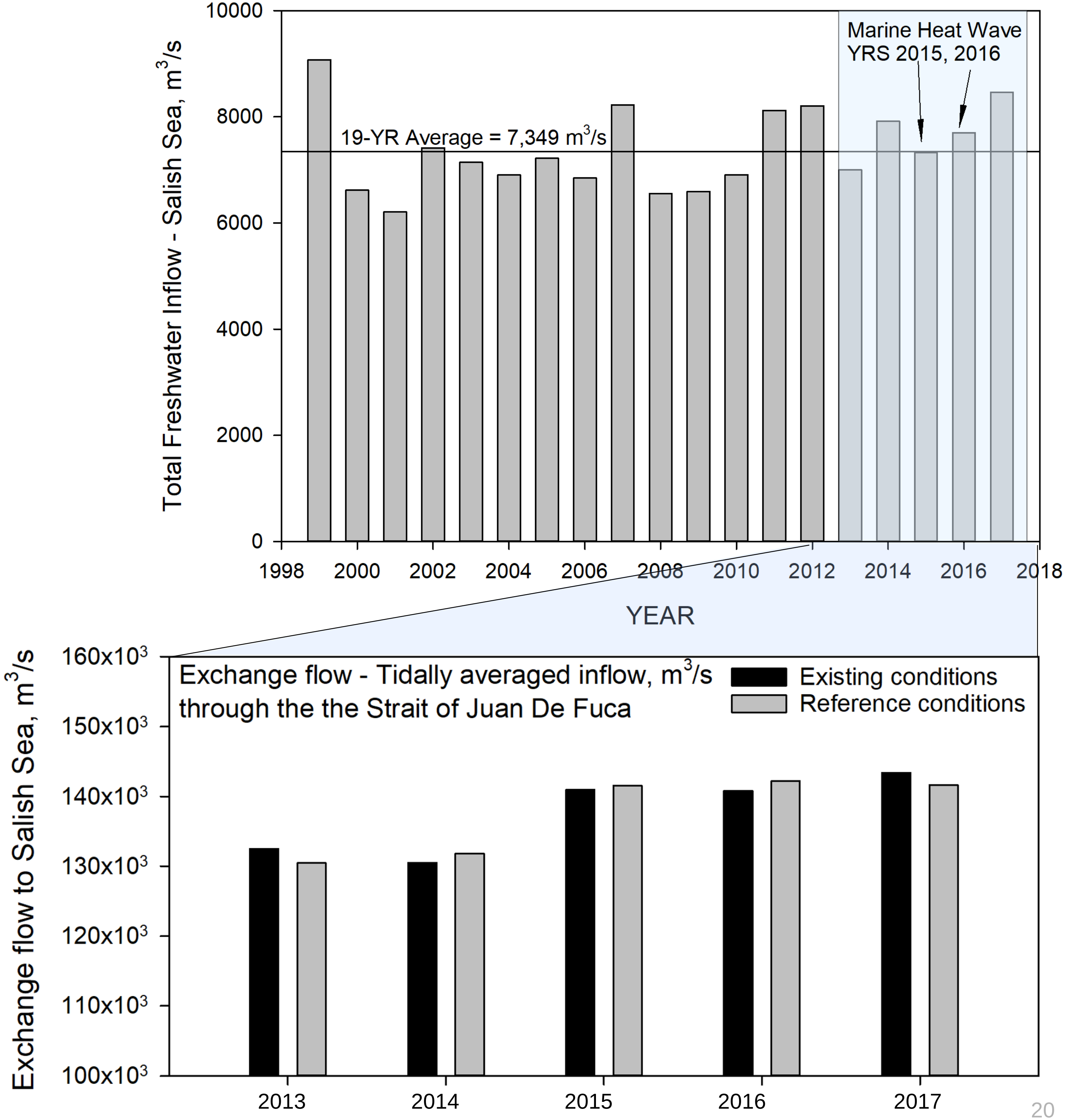
Hypoxic volume



Hypoxic volume – with marine heatwave (Existing) and without (Reference)

Influence of interannual variability in freshwater loading

- Affects salinity gradients
  - Impacts annual exchange with the Pacific Ocean
  - Indirect influence on oceanic nutrients availability to the photic zone
- Direct influence on nutrient loads to the photic zone

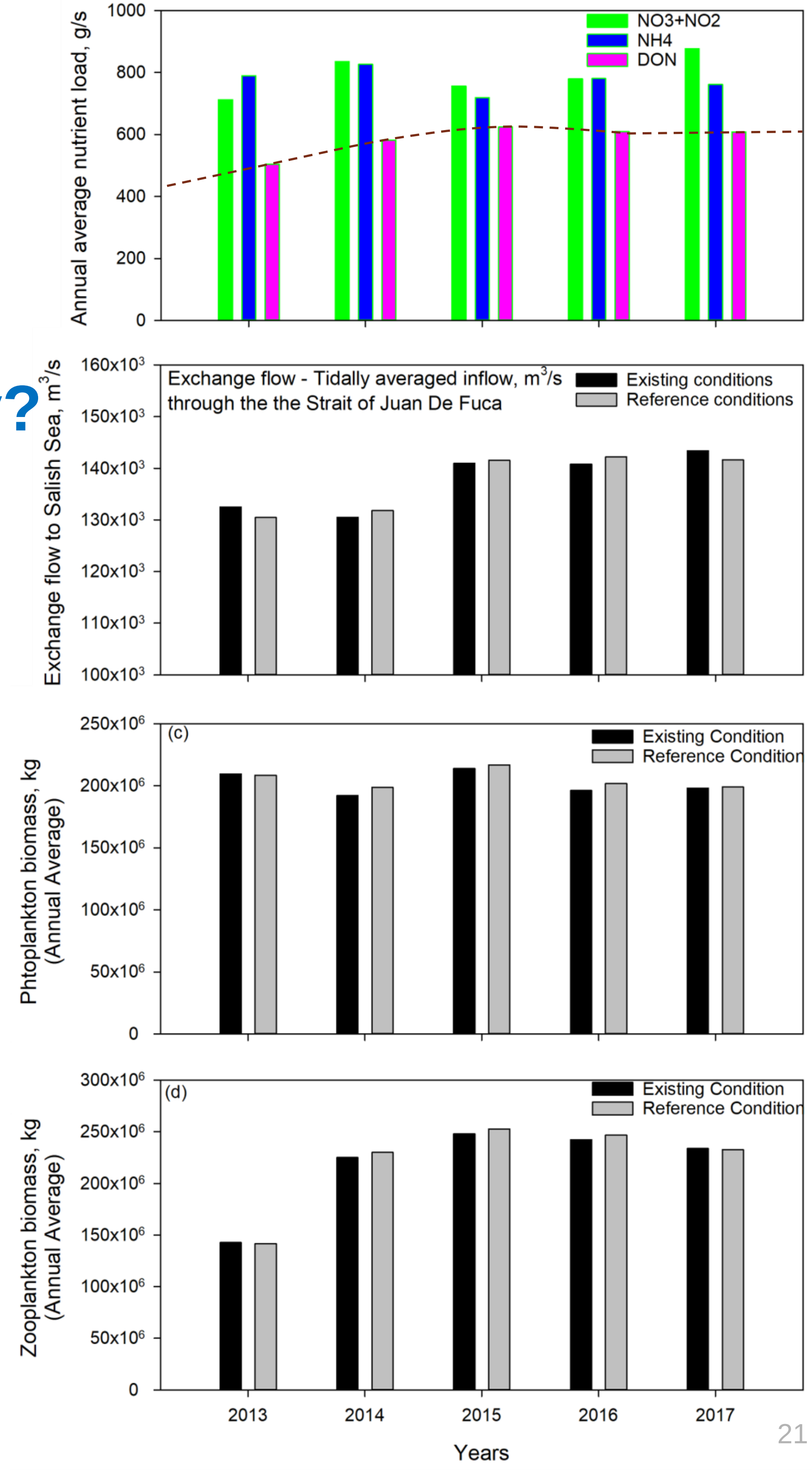


Summary / Discussion

Observed interannual variation (2013-2017)

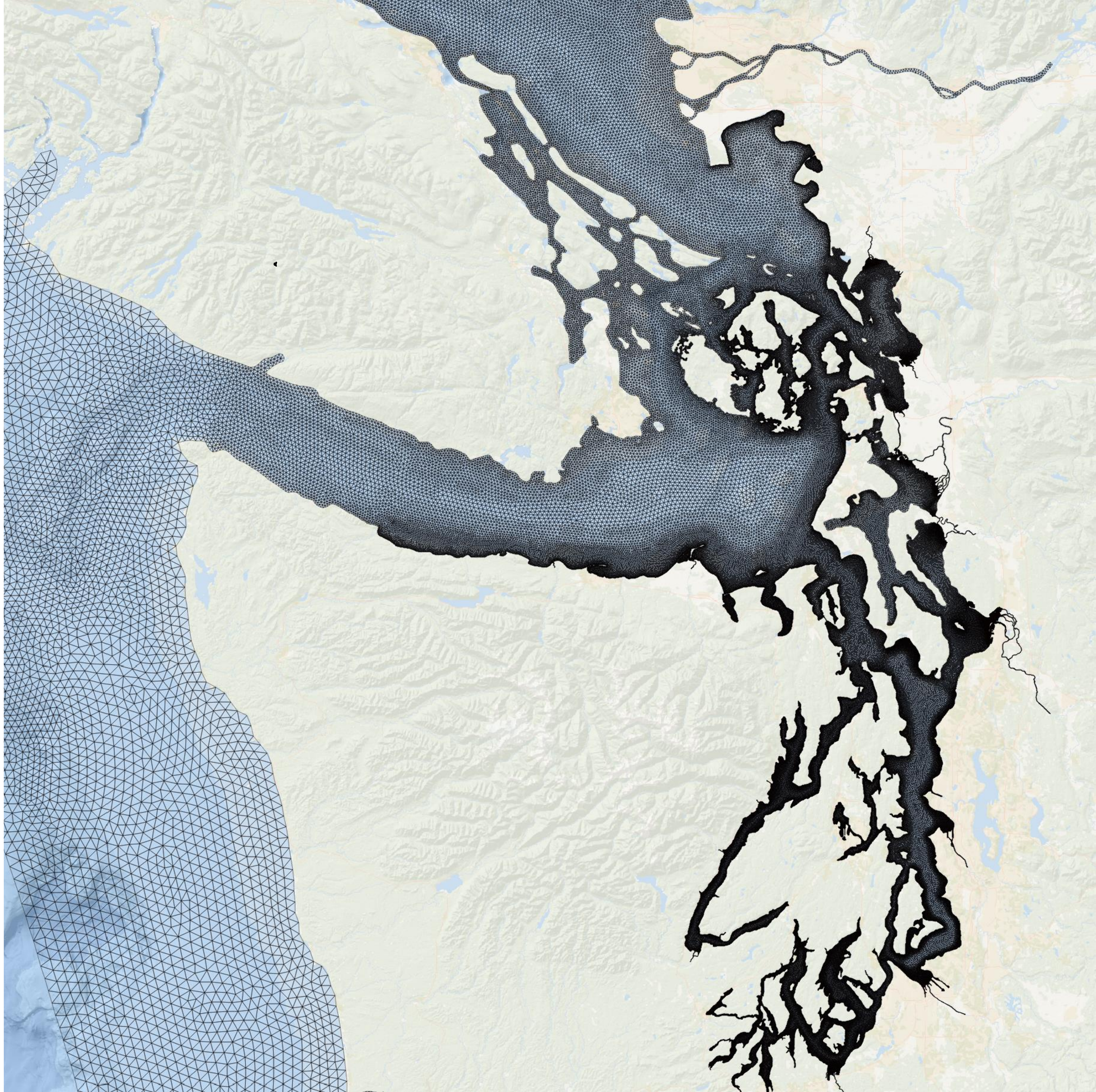
- Impact of the marine heatwave? Or
- Marine heatwave effect on hydrology? Or
- Interannual variability - meteorology & hydrology?

- Concurrent with the marine heatwave
  - Fresh water inflow/loads increased from 2013 by ≈ 7%
  - Net heat flux increased by ≈ 19%
  - Exchange flow strength increased ≈ 8%
- Overall higher biomass ≈ + 10% (2015-2107)
  - *Likely unrelated to marine heatwave*
  - Attributed primarily to interannual variability
- Relative to conditions without marine heatwave
  - Reduced estuarine exchange (<1%)
  - Reduced primary production was (<4%)



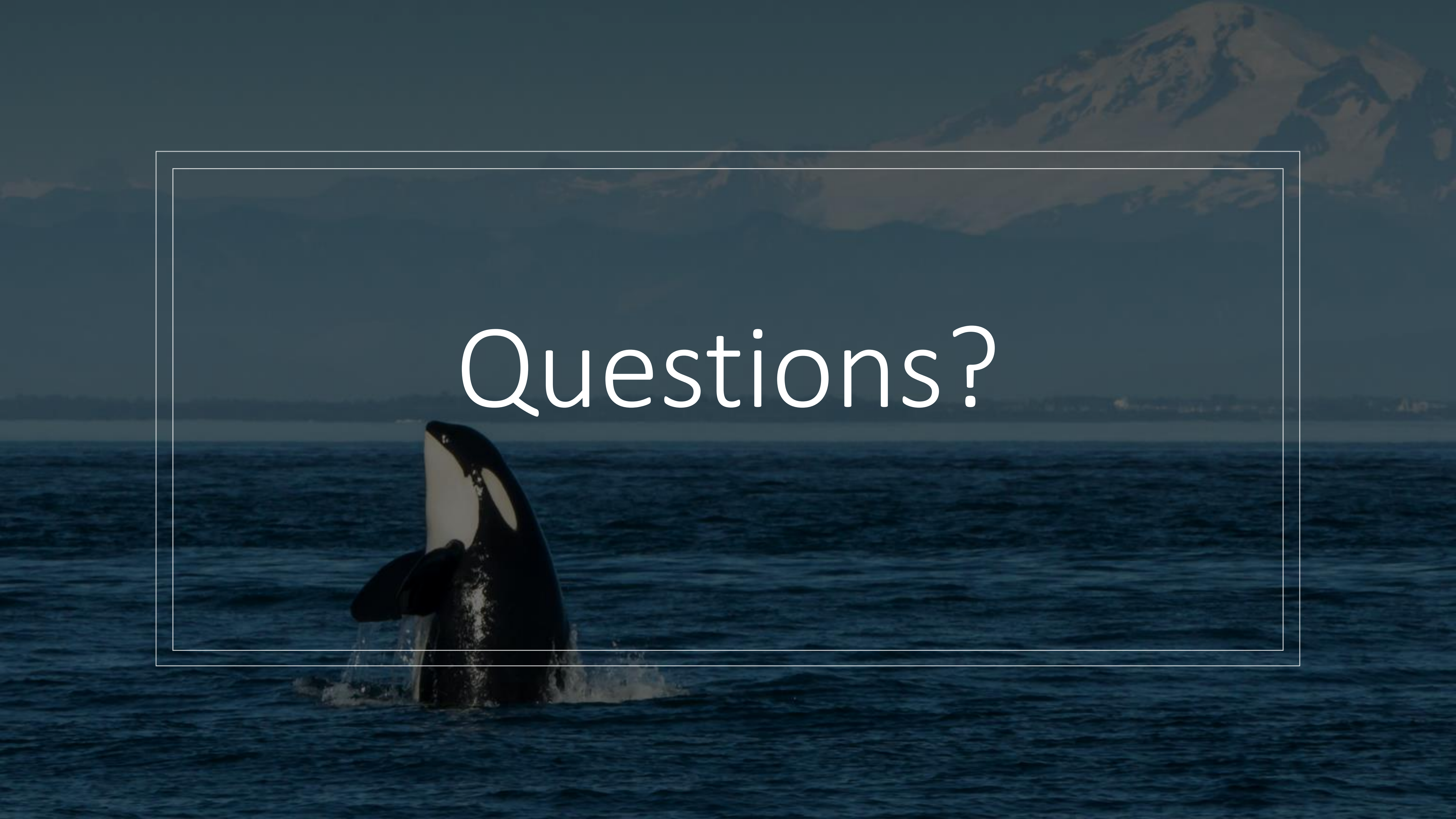
Model limitations and uncertainties

- Definition of **reference conditions**
  - Pre-Marine heatwave vs long-term average
- Assumption that MHW did not affect hydrology and loading to SSM
- Accuracy of global models HYCOM and WRF in capturing MHW
- Model parameters and constituents based on limited years of calibration
  - Required an adjustment / relaxation of prior calibration parameter values
- Improvement needed in some of the sub-basins
  - Increase in resolution
  - Improve wind-effects on mixing



https://ssmc-uw.org//

https://salish-sea.pnnl.gov



Questions?