capturing the dynamics of ocean-estuarine interactions across multiple spatial and temporal scales

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Collaborators

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ocean/estuarine interactions

(why you want freshwater in your model!)

Introduction
- motivation

Freshwater influence along and across-shore
- buoyancy and heat delivery to the shelf
- nutrient delivery and productivity
- along-coast estuarine interactions

Influence of a changing climate
- spatial distribution of freshwater inputs
- timing of freshwater input

Summary & food for thought
- estuarine circulation and mixing impact physical transport pathways and biogeochemical processes along-coast and far offshore
- estuaries and their offshore impacts will change in response to a changing climate (spatially and temporally)
- can these processes be better represented in global and regional climate models?

motivation

Why do we care about estuarine/coastal interactions?

- delivery of terrigenous material to the coastal ocean (sediment, pollutants, etc.)

- ocean/estuary exchange and delivery of nutrients, primary productivity, low pH, and O_2 deplete water

(e.g. Roegner et al. 2011, Monteiro and Largier 1999, Newton and Horner 2003, O'Callaghan et al. 2007)

- delivery of heat and buoyancy to the coastal ocean

- transport processes (including Harmful Algae Blooms (HABs), larval connectivity, etc.)

(e.g., Banas et al. 2009, Yamada and Kosro 2010, McConnaughey et al. 1994)

- how will these systems respond to a changing climate?

motivation

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Tijuana River plume in Imperial Beach, CA courtesy of WILDCOAST

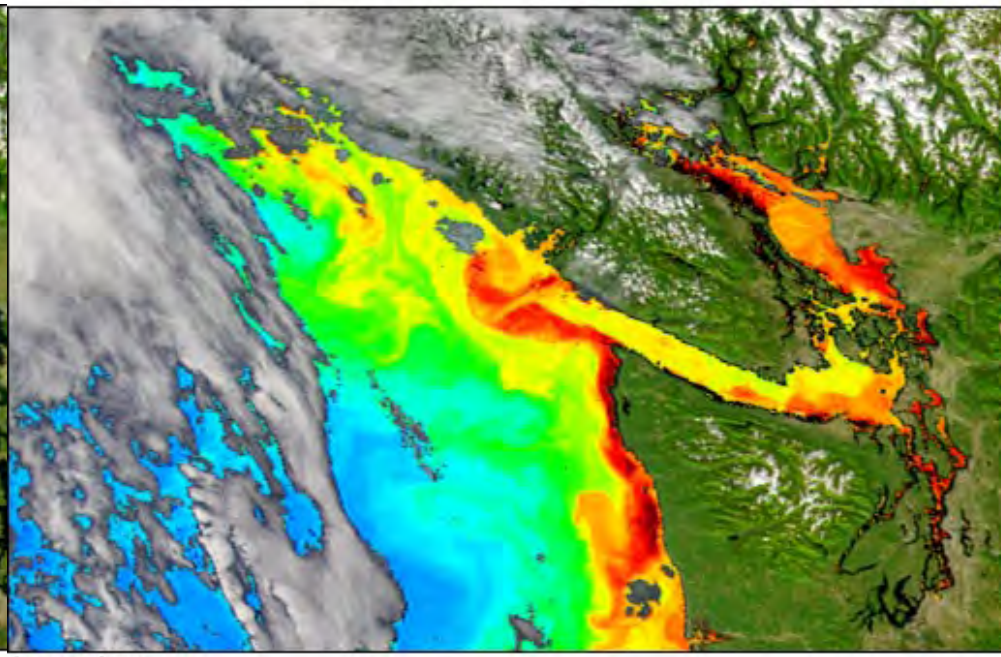
Columbia and Salish Sea River plumes image from SeaWiFS, NASA

motivation

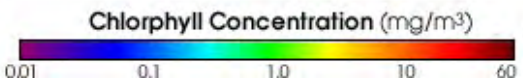
Ganges Delta, India
http://www.redorbit.com/media/gallery/earth/1_23425bc3820cd972c628e8835f4eb102.jpg

motivation

True Color

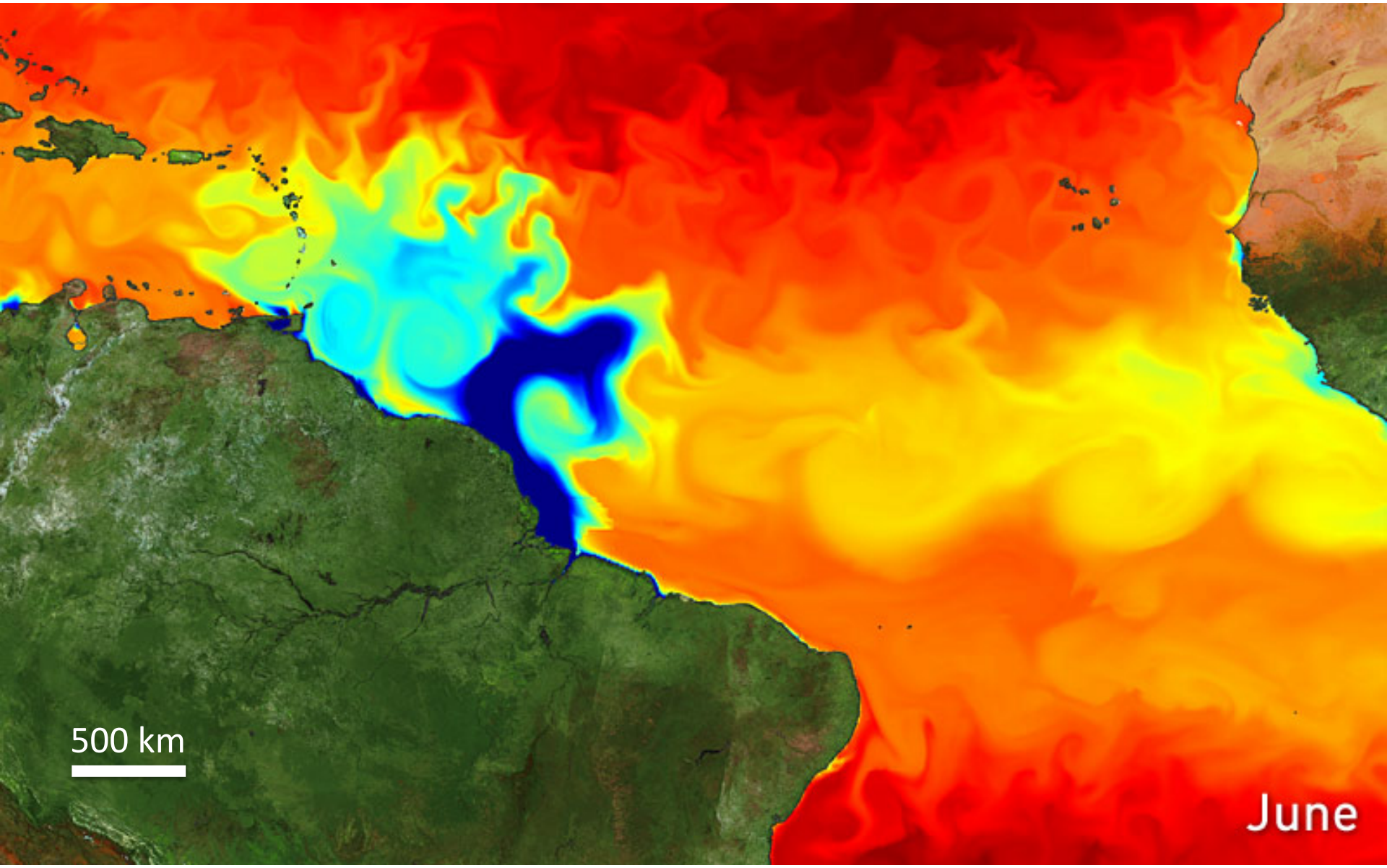


Ocean Color



Chlorophyll in the Salish Sea http://eoimages.gsfc.nasa.gov/images/imagerecords/3000/3613/S2003190210100.jpg

motivation

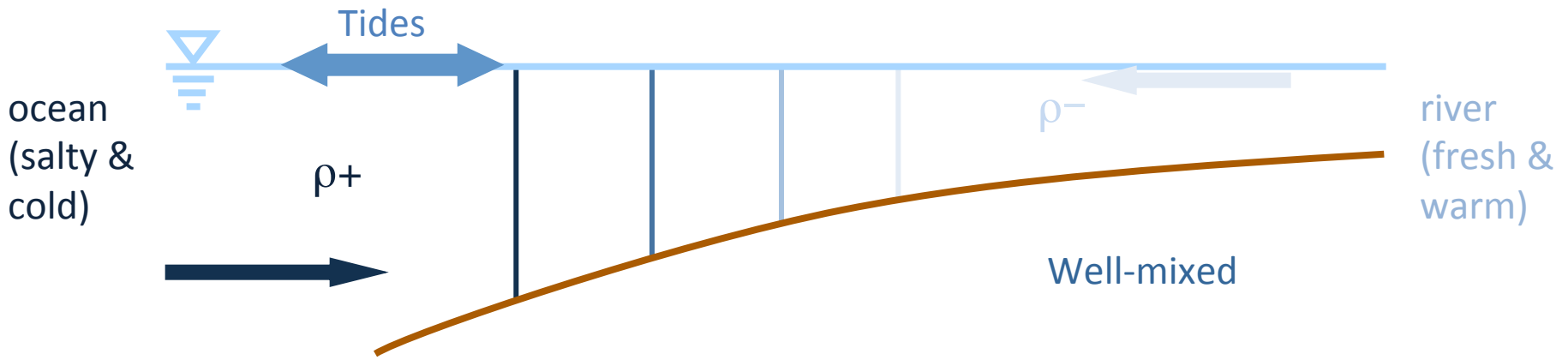


Aquarius sea surface salinity at the Amazon River Plume Image from
http://www.myocean.eu/automne_modules_files/pmedia/public/r2_9_200911_amazon_june-4.jpg

residual estuarine circulation - theory

Basic estuarine dynamics

- longitudinal density gradients
- tides generate mixing via bottom friction
- the amount of mixing (i.e., strength of the tides) and the strength of the river flow determine if the estuary is well-mixed, partially mixed, or strongly stratified and determine the river plume buoyancy and momentum



Excellent review papers: MacCready & Geyer 2010, Geyer & MacCready 2014

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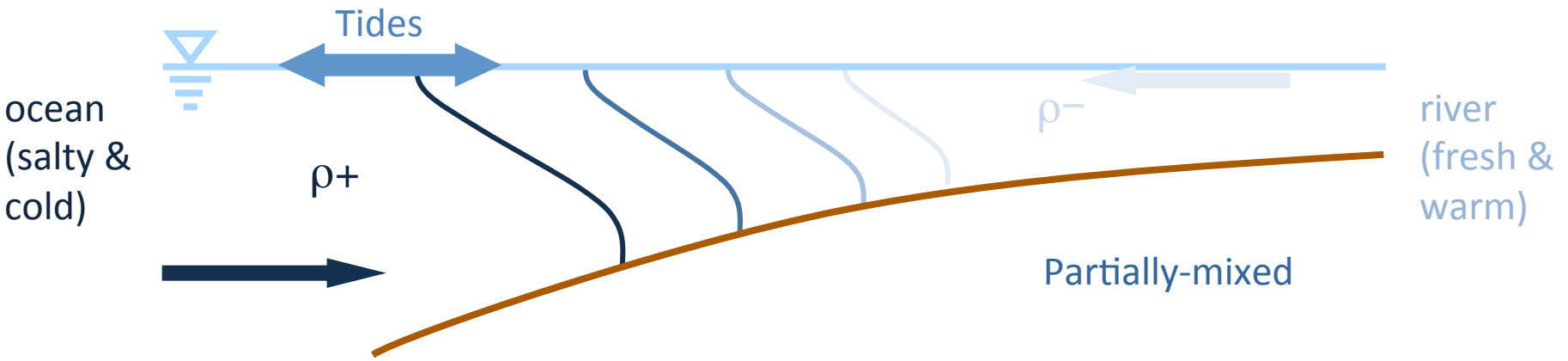

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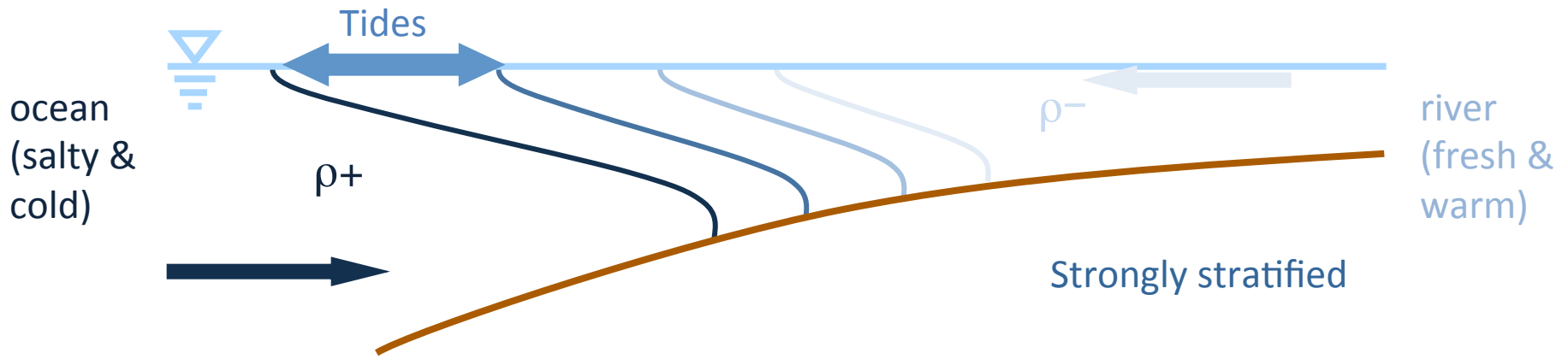

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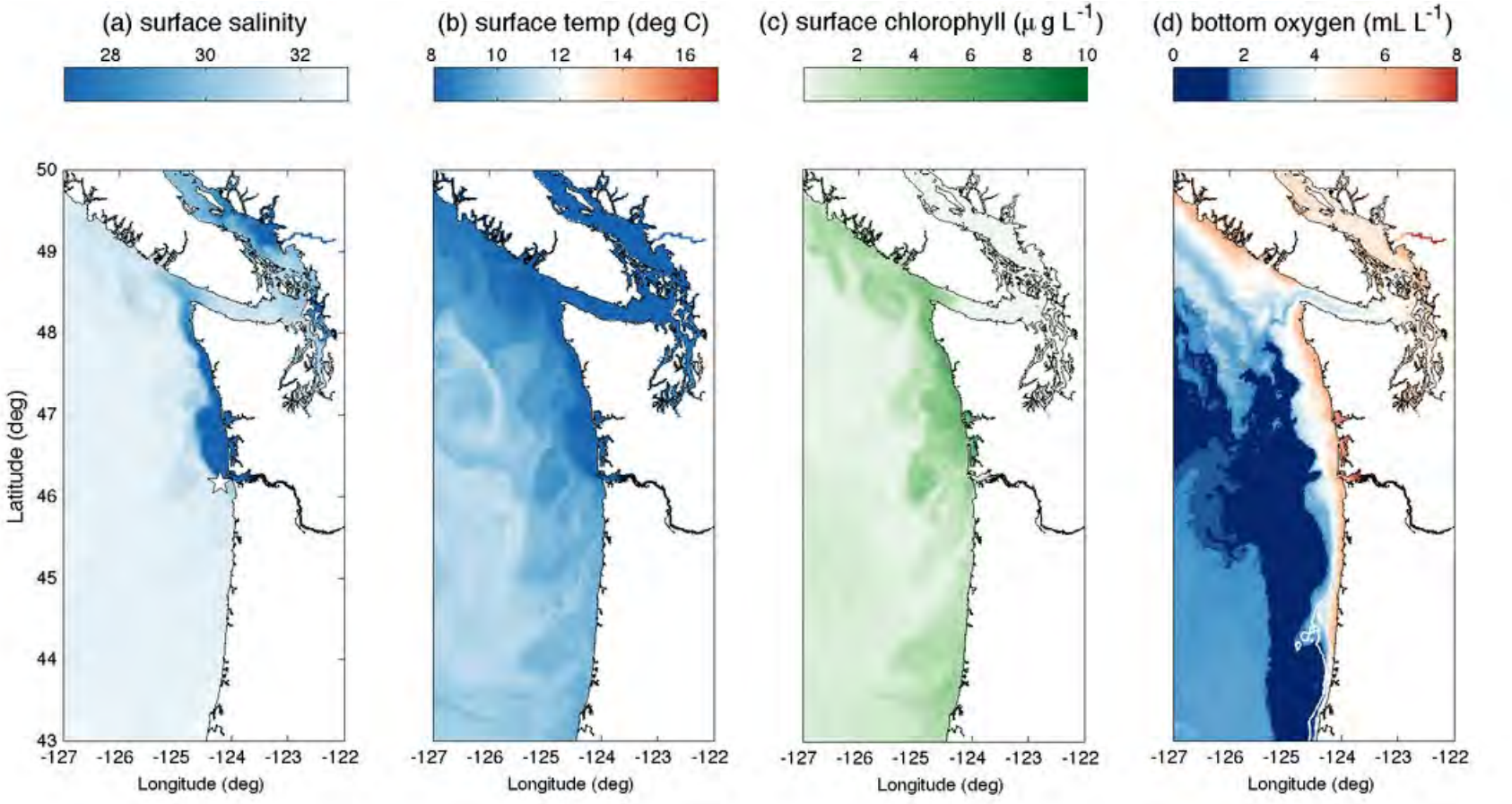
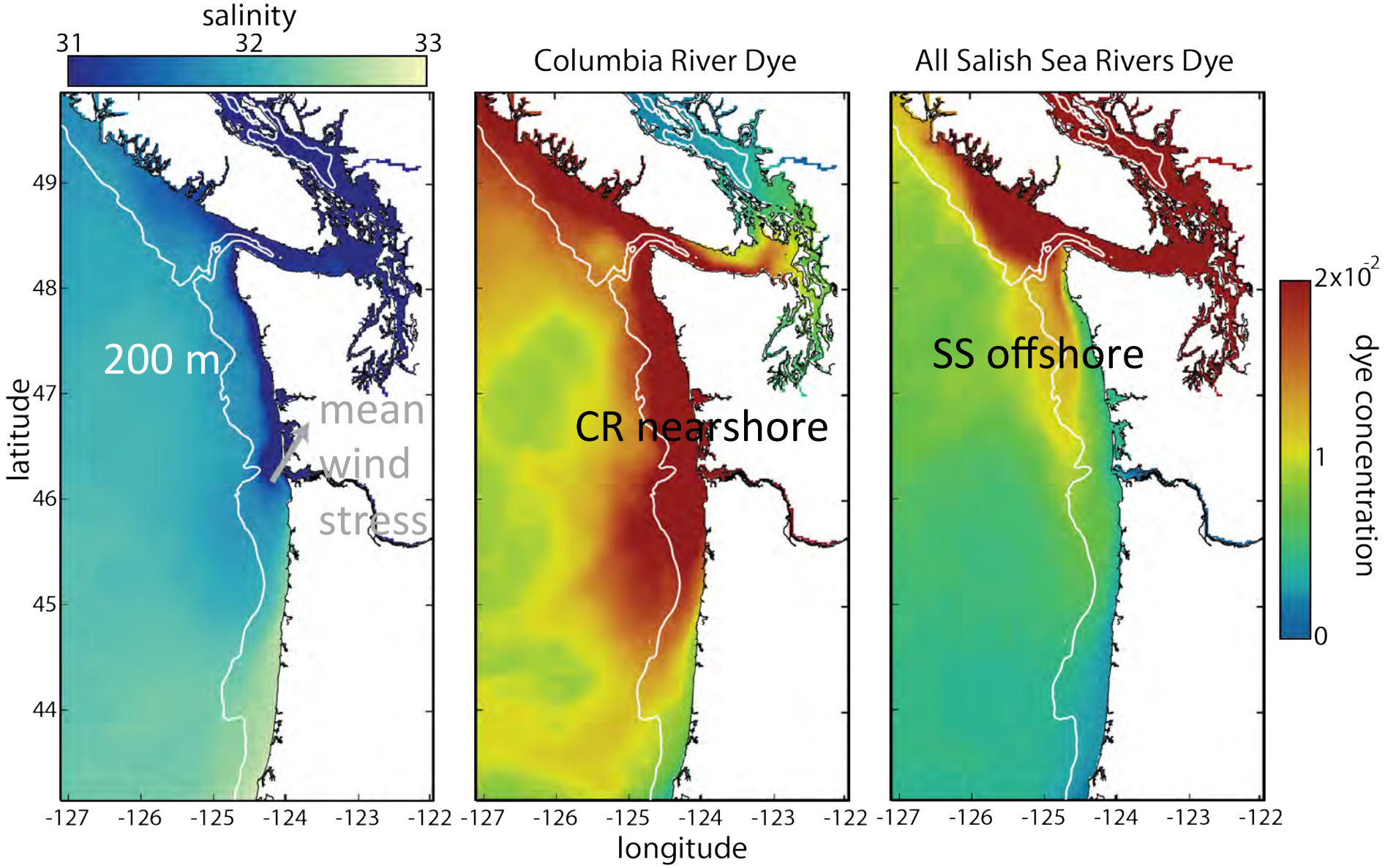
physical-biogeochemical simulations



UW Coastal Modeling Group
Cascadia simulations

Movie avail at: iod.ucsd.edu/~sgiddings/PNWTOX/resultsHypoxia.html

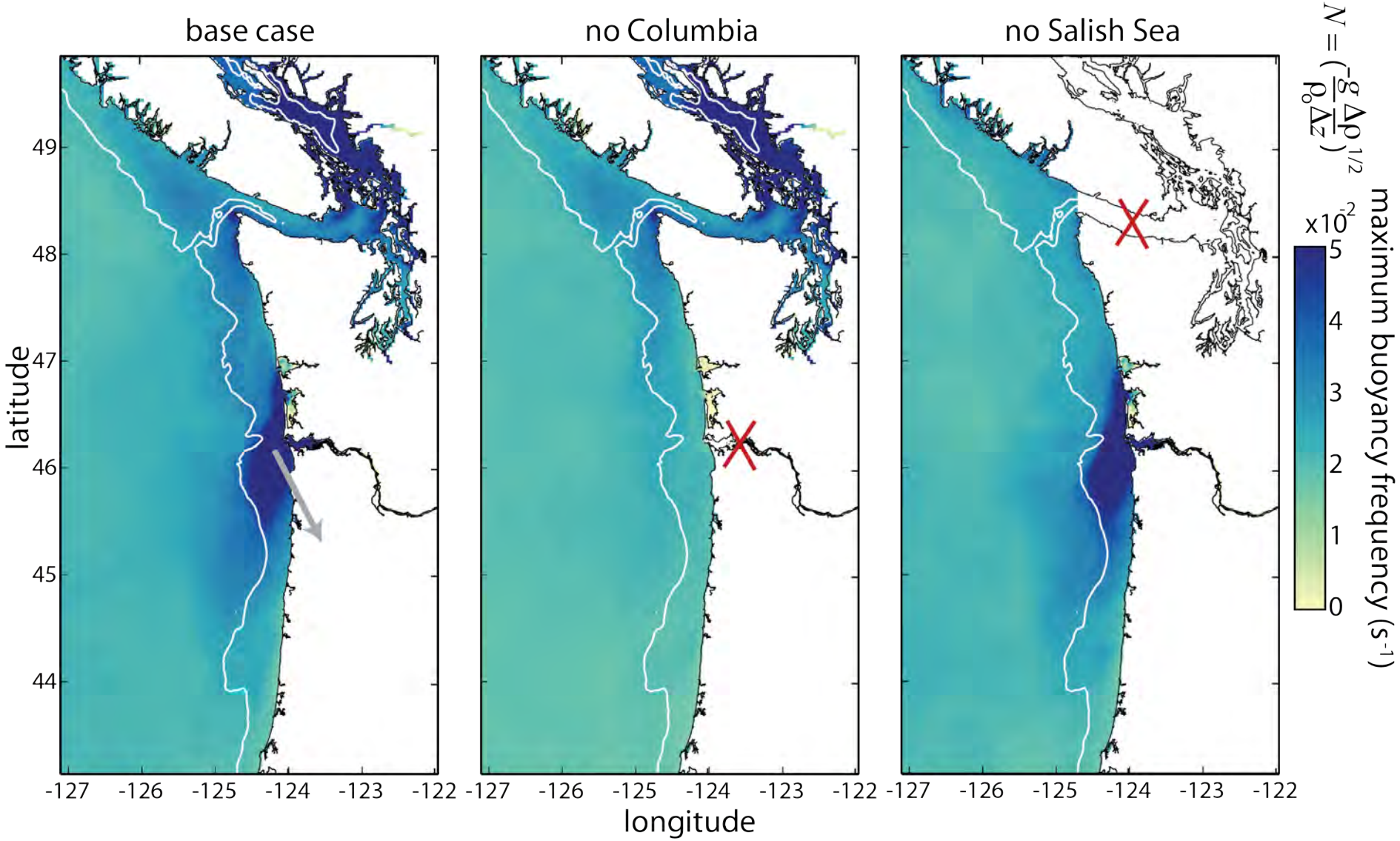
freshwater input: annual average



Cross shelf banding of freshwater sources, impact beyond shelf

SN Giddings, SIO, 15 Oct 2015

buoyancy input: upwelling

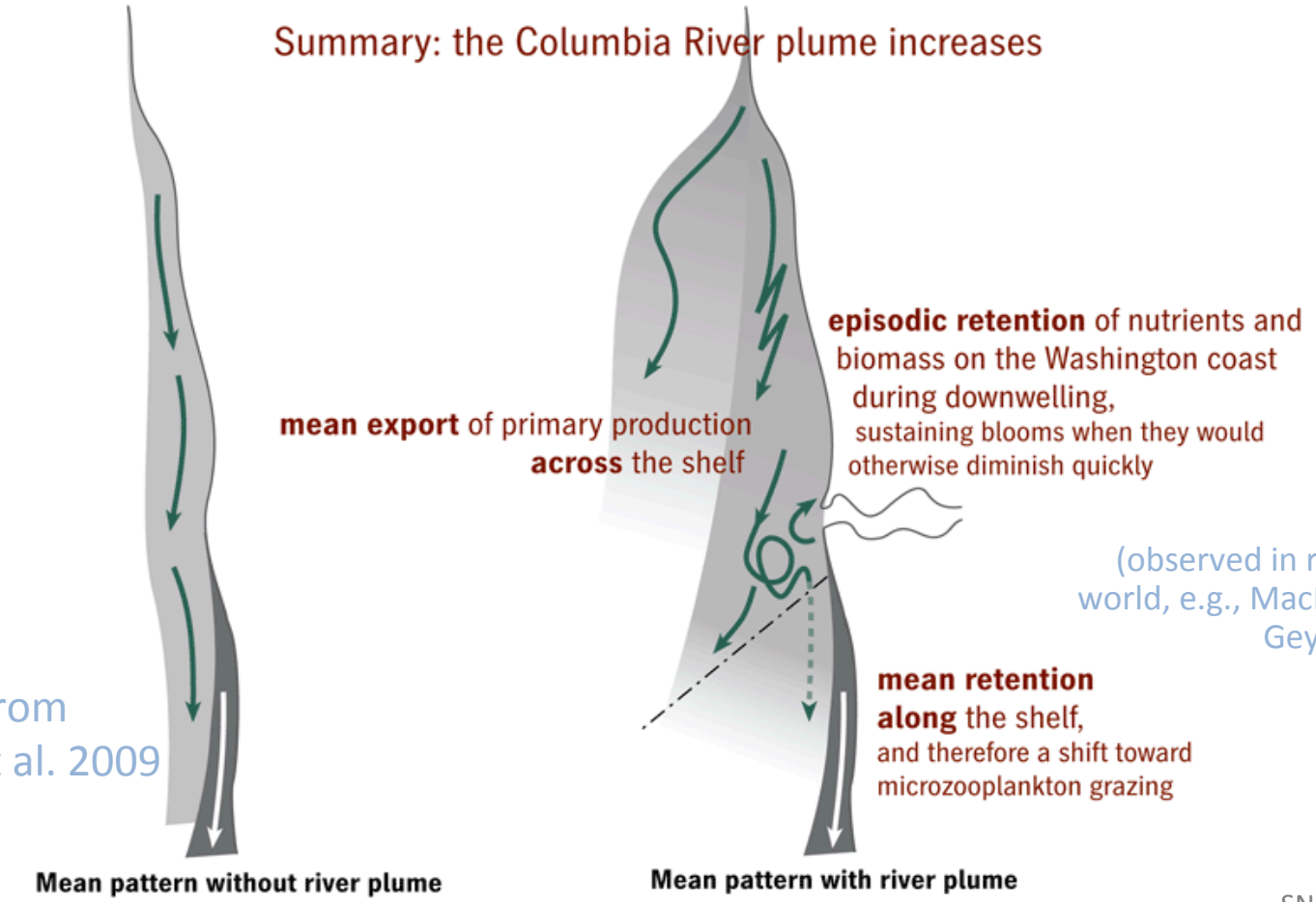


CR delivers warmer water AND caps upwelling

impact on coastal physical transport

The Columbia River impacts buoyancy forcing and heat input on the shelf much more strongly than the Salish Sea. This implies a significant role for the CR on the shelf in terms of physical transport processes.

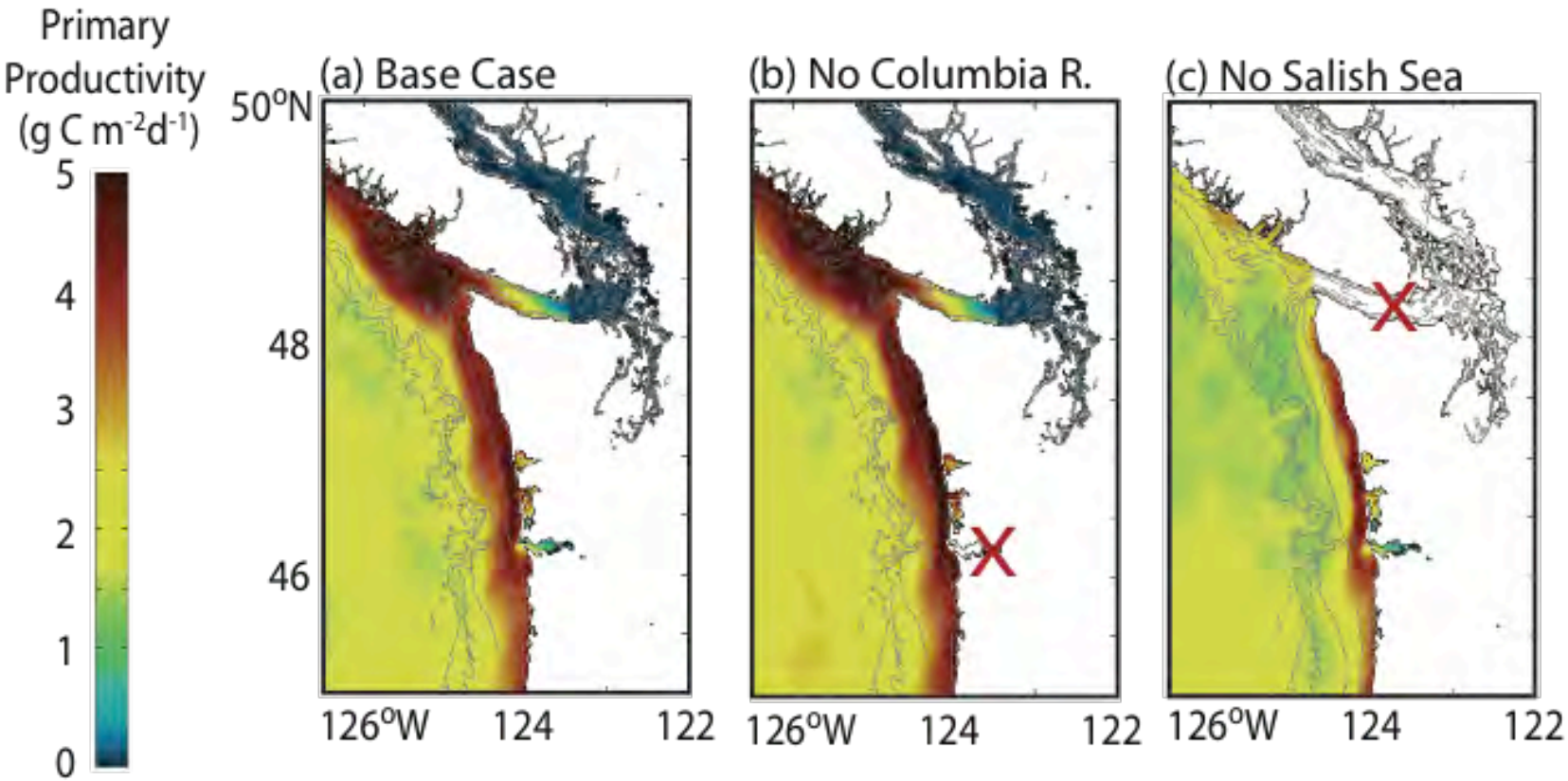
(see Banas et al. 2009, Hickey et al. 2009, Kudela et al. 2010, Giddings et al. 2014)



Sketch from Banas et al. 2009

(observed in river plumes around the world, e.g., MacDonald, Horner-Devine, Geyer, Largier, O'Donnel…)

contribution to primary productivity



Despite the CR dominating buoyancy input, the Salish Sea contributes most to PNW primary productivity due to its strong estuarine exchange returning significant nutrients to the ocean surface

Figure from Davis et al. 2014. This is just the tip of the iceberg, excellent recent work by Siedlecki, Feely, Hill, Baptista and others looking at other biogeochemical impacts (pH, alkalinity, DIC, etc.)

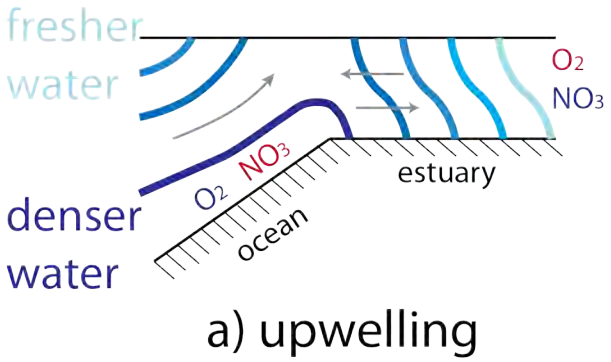
contribution to primary productivity

$$Q_E \propto \frac{s_2 + s_1}{s_2 - s_1} Q_r$$

(Knudsen, 1900)

$$u_E \propto \frac{gH^3}{\rho_o \nu_t} \frac{\partial \rho}{\partial x}$$

(Hansen & Rattray, 1965)



a) upwelling

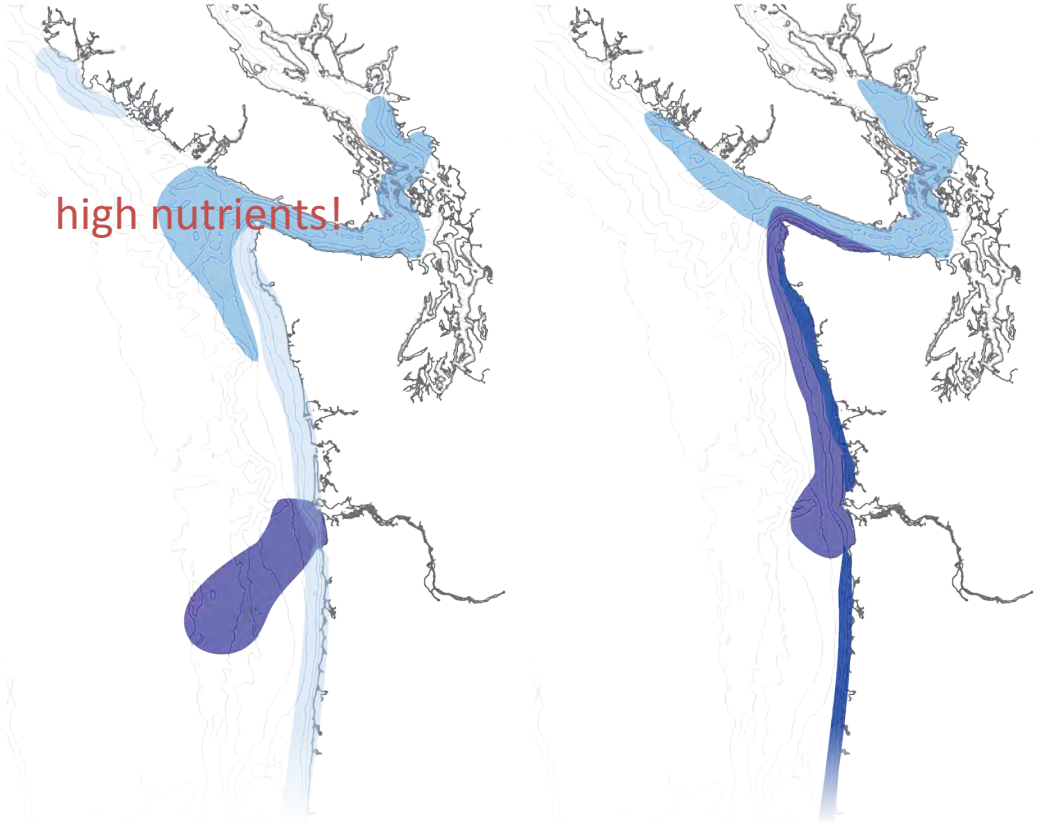
Despite the CR dominating buoyancy input, the Salish Sea contributes most to PNW primary productivity due to its strong estuarine exchange returning significant nutrients to the ocean surface

conclusions – shelf influence

the CR dominates buoyancy input and physical transport

however, the Salish Sea contributes most to PNW primary productivity due to its strong estuarine exchange returning significant nutrients to the ocean surface

As Parker MacCready refers to these: estuarine "batteries of energy"



- > estuarine influence on the shelf in terms of transport and biogeochemical processes depends on upstream (river) and downstream (ocean) conditions AND dynamics inside of the estuary!

(see Giddings et al. 2014, Banas et al. 2009, Siedlecki et al. 2015, Davis et al. 2015)

conclusions – estuarine exchange

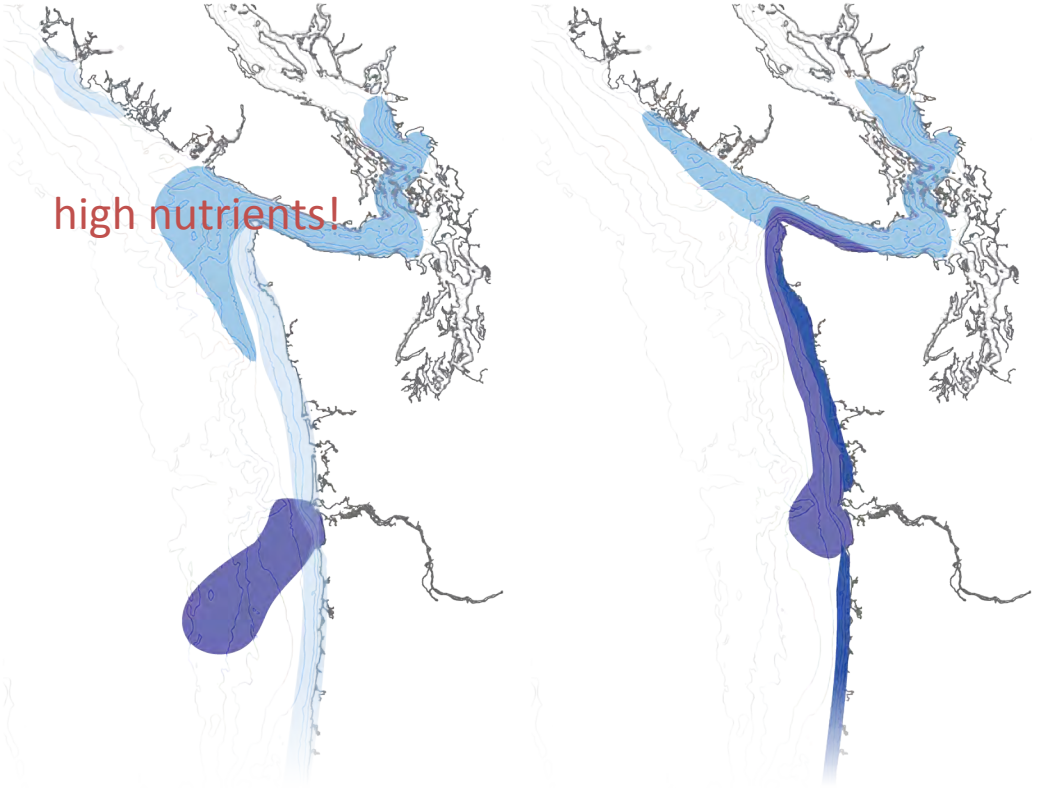
Interacting plumes: Columbia River plume frequently intrudes into the Salish Sea during winter downwelling & exchange reverses

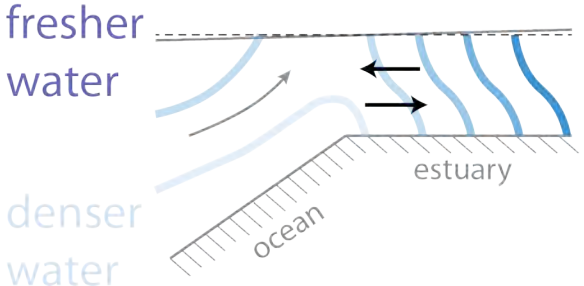
- > strong connectivity between along-coast estuaries that depends on the season

This can be very hard to represent in regional models if they are not in the boundary conditions (i.e., global models)

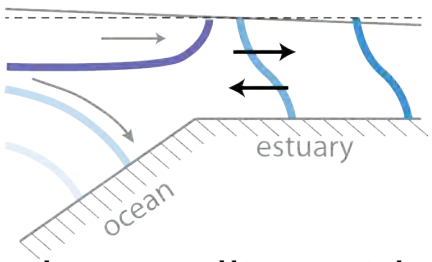
Similar observations from around the world: Monteiro and Largier 1999, Li et al. 2011, Wong and Lu 1994, Hickey et al. 2002, Hickey and Banas 2003, Banas et al. 2004, Brown and Ozretich 2009, Thomson et al. 2007

after Hickey et al. 2009





upwelling



downwelling with offshore plume

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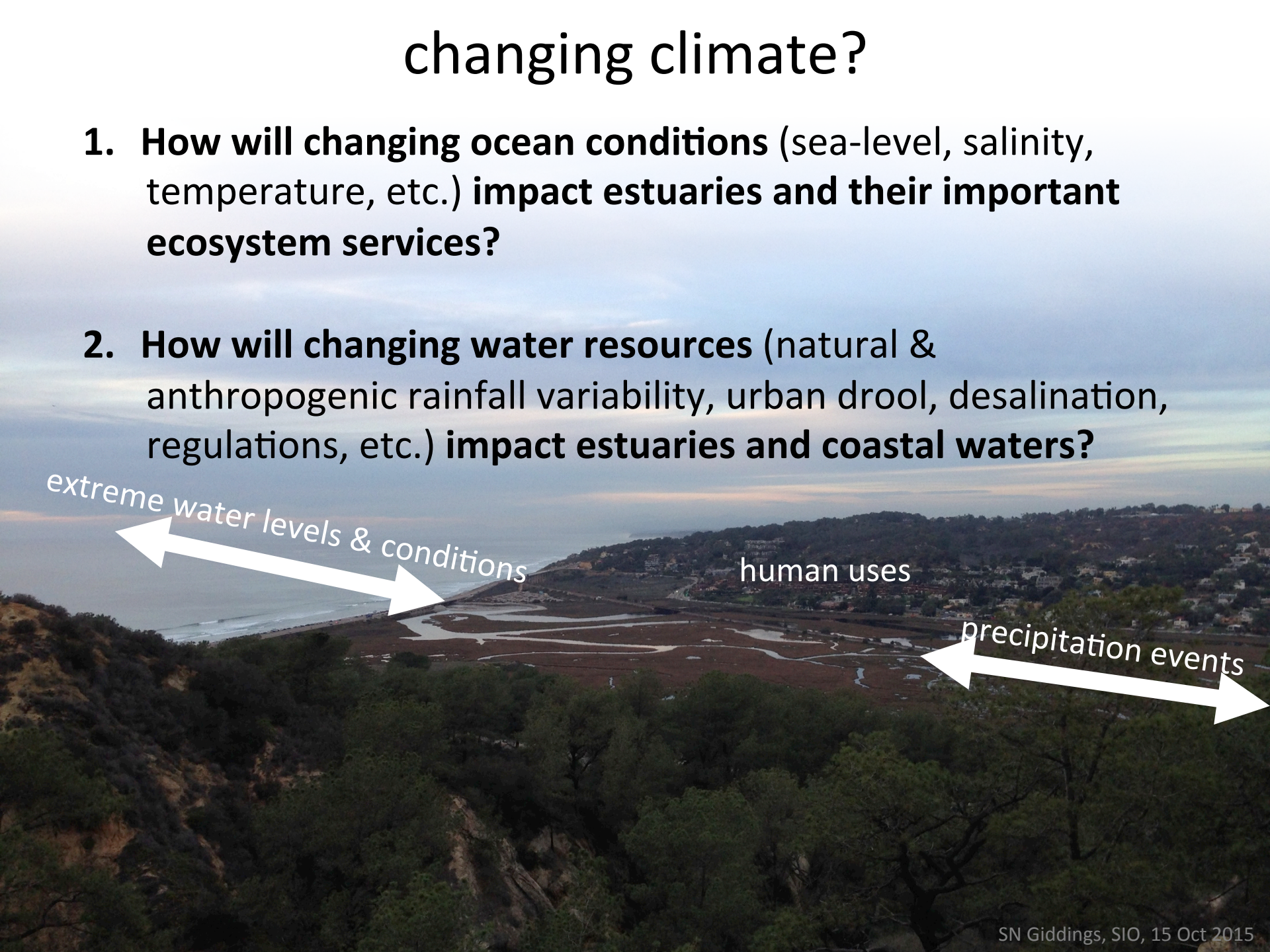
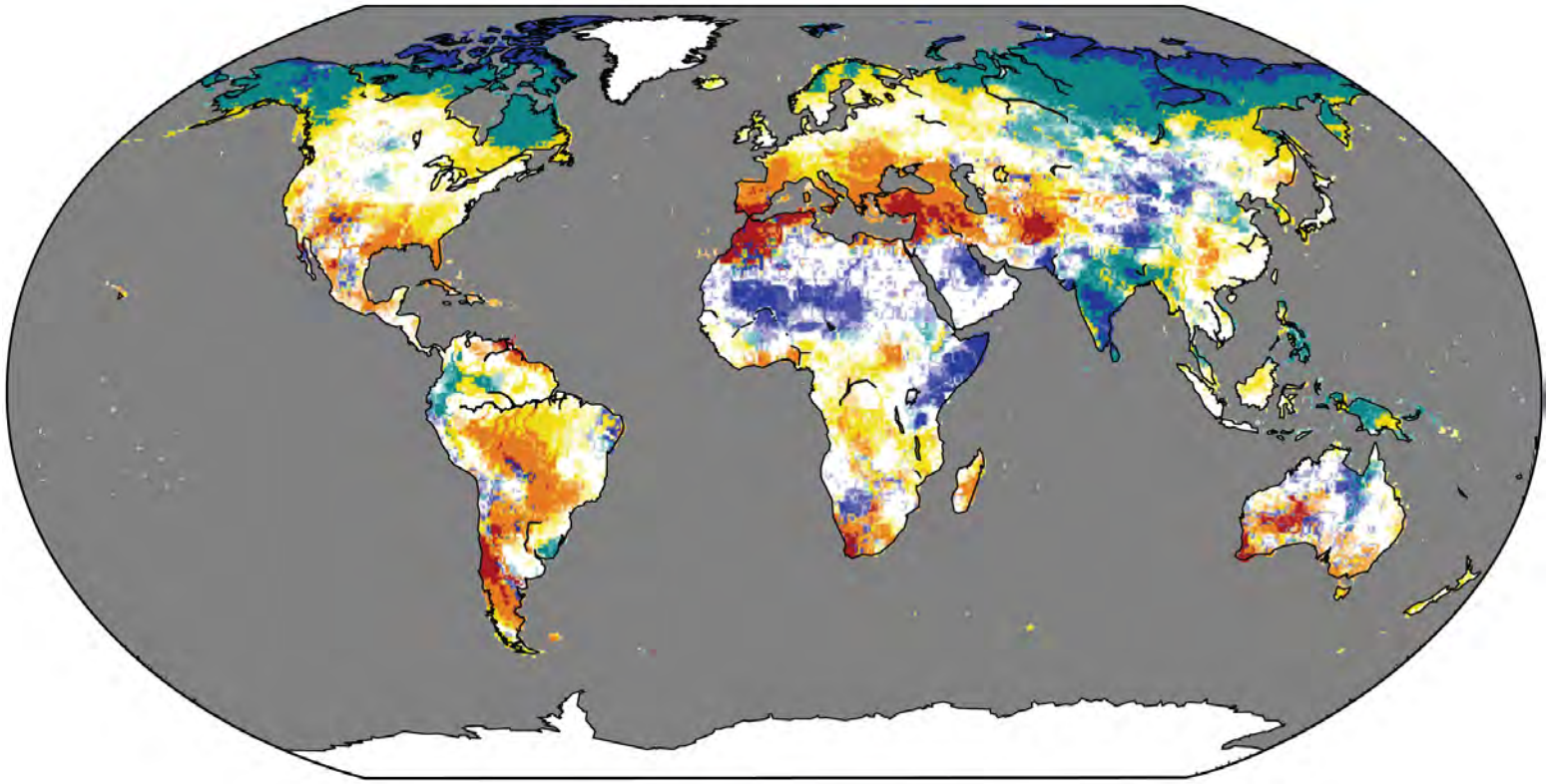
changing climate?

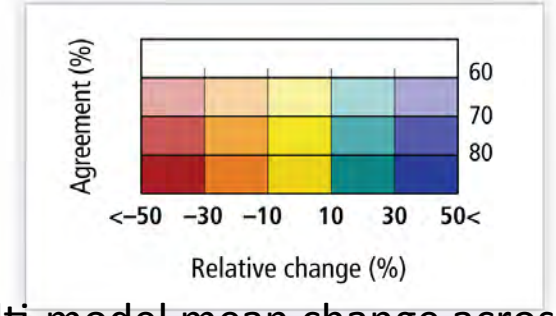
1. **How will changing ocean conditions** (sea-level, salinity, temperature, etc.) **impact estuaries and their important ecosystem services?**

2. **How will changing water resources** (natural & anthropogenic rainfall variability, urban drool, desalination, regulations, etc.) **impact estuaries and coastal waters?**



spatial & temporal distribution of Q





Percentage change of mean annual streamflow for a global mean temperature rise of 2°C above 1980–2010 (2.7°C above pre-industrial).

multi-model mean change across 5 GCMs and 11 GHMs

IPCC5 WGII AR5 Chapter 3, Figure 3-4, from Schewe et al., 2013

sea level rise and extreme events

San Francisco near Golden Gate, NOAA observations and GFDL model (Vermeer and Rahmstorf 2009)

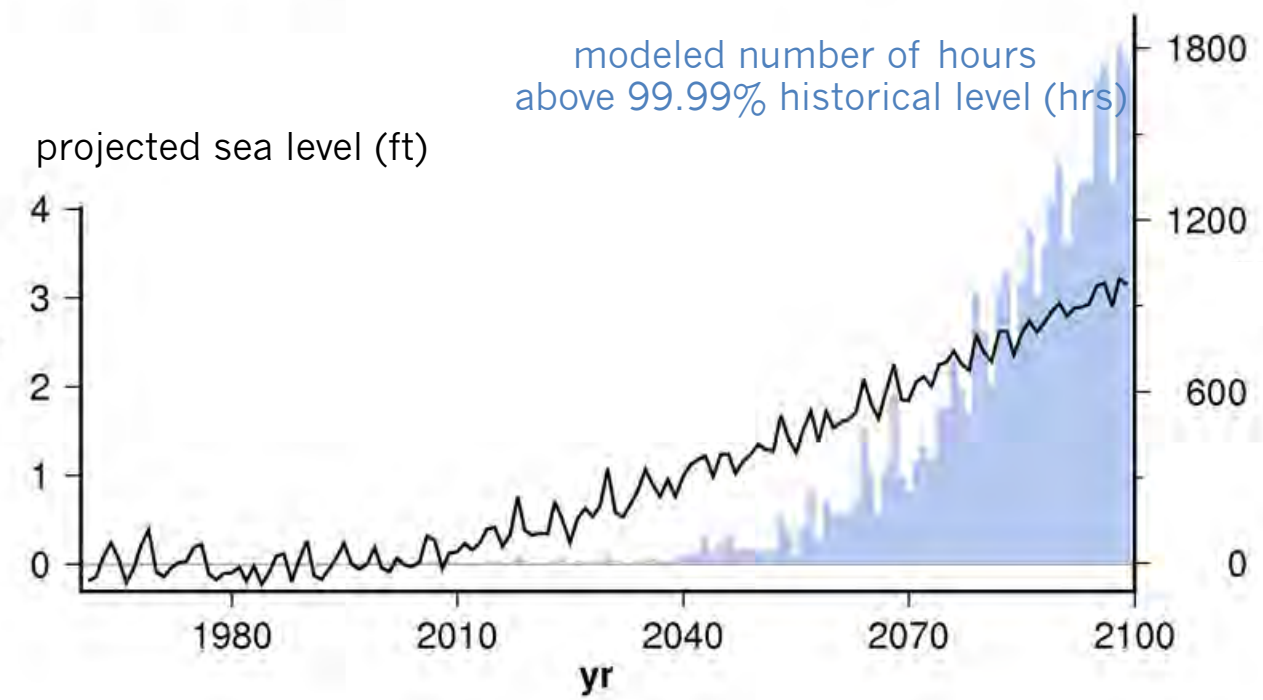


Figure courtesy of Dan Cayan, SIO, NRC West Coast SLR Study 2012

as mean sea level rises projections indicate a marked **increase** in the likelihood of exceeding historical extremes (Cayan et al., 2008)

similarly, storms and thus flood magnitudes while potentially less frequent are expected to become larger (Das et al., 2013)

How will estuaries respond to sea level rise & extreme events?

- morphological changes (e.g., Reeve & Karunarathna 2009, Zedler 2010)
- changes in salt-water intrusion distance (tied into Q) (e.g., Cloern et al. 2011)
- changes in tidal response (e.g., Friedrichs)

food for thought…

Freshwater input to the Arctic Ocean…

- stratification
- ice cover
- heat

(e.g., Dean et al. 1994, Wood et al. 2013)

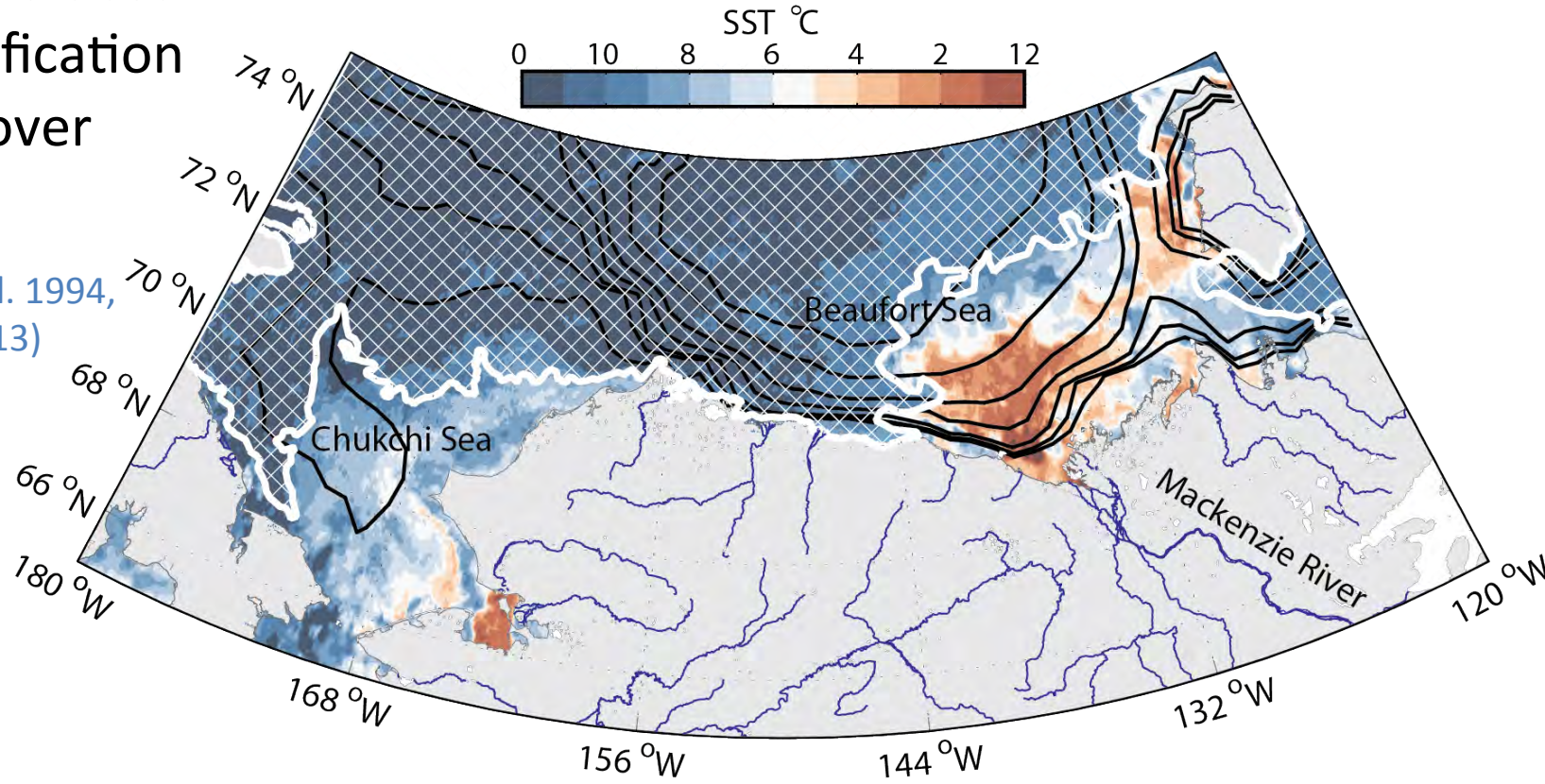


Figure created by SN Giddings. SST image taken on 5 July 2012 from the JPL Our Ocean project shows the warm Mackenzie River plume extending far into the Beaufort Sea during upwelling (e.g., Nghiem et al., 2014). White outline with hashing indicates the marginal ice zone from the Naval Ice Center. Depth contours at 4000, 3000, 2000, 1000, 500, 200, 100, and 50 m.

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food for thought…

frontal strength?
(e.g., Horner-Devine, MacDonald, Geyer, etc.)

waves?
(e.g., Gerbi et al. 2013, Gilory ongoing)

remote internal waves?
(e.g., Alford et al. 2012)

ice/plume interactions?
(e.g., Dean et al. 1994, Wood et al. 2013)

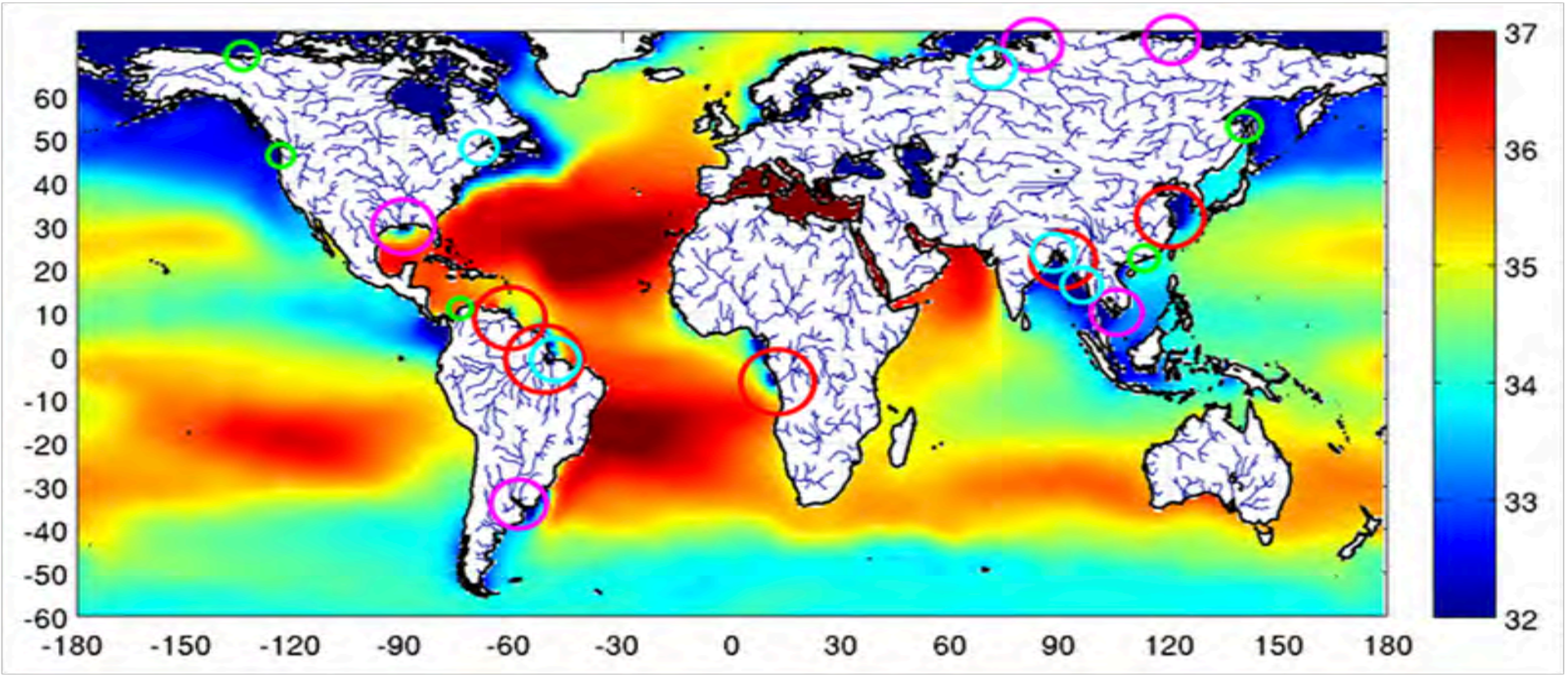
how to best represent estuaries & plumes?

- which Q?
- 2-way nesting?
- modified salinity?

CSIDE project, NSF,
scripps.ucsd.edu/projects/cside/
photo by N Statom and S Holleman

how to add estuaries?

SciDAC project: Improving the Representation of Coastal and Estuarine Processes in Earth System Models



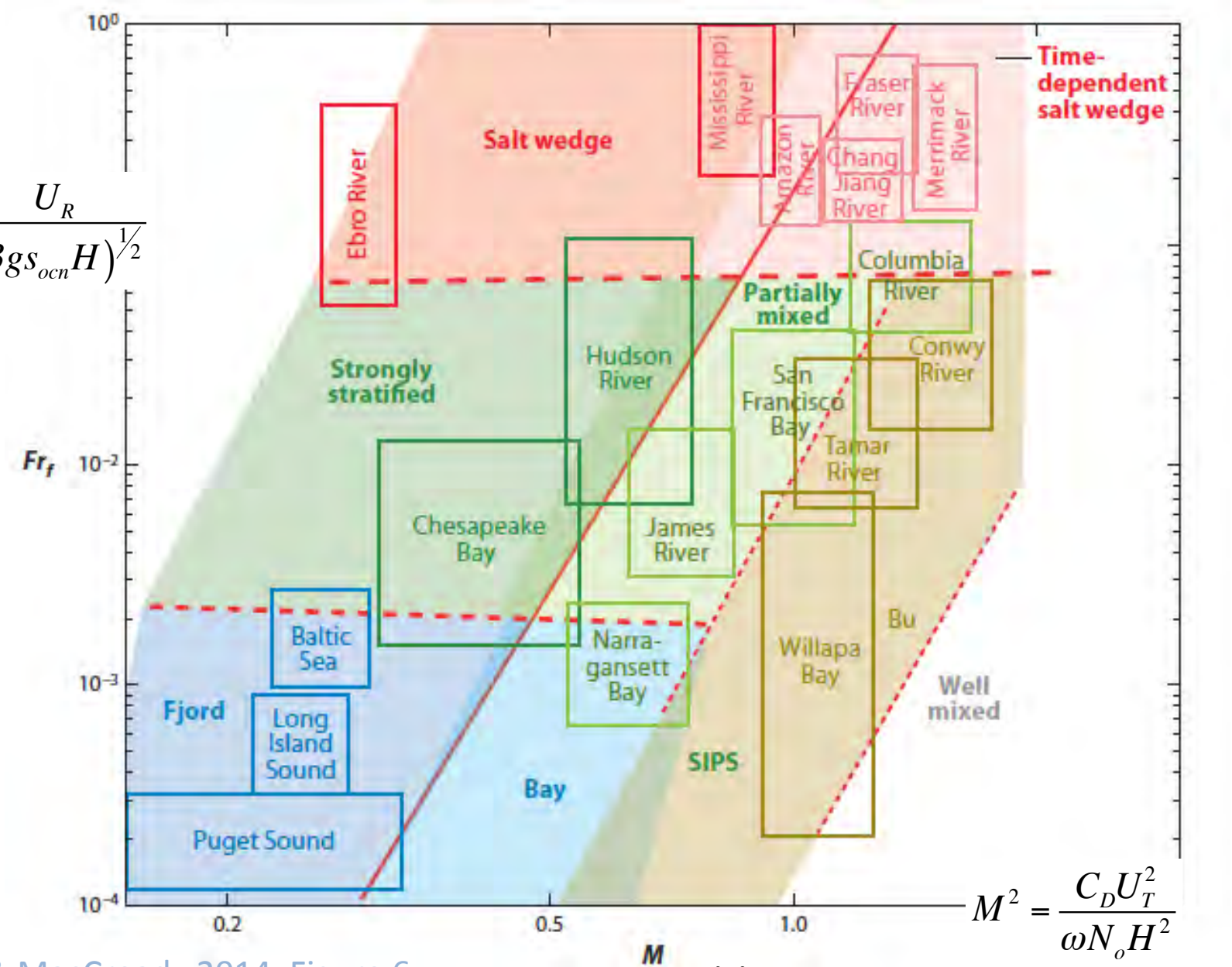
Participants (figure from their project website)
NCAR: Frank Bryan, Yu-heng Tseng, John Dennis, Allison Baker
U. Washington: Parker MacCready, David Darr
U. Connecticut: Michael Whitley

Estuary-shelf Box model
Preliminary results show significant global circulation changes!

how to add estuaries?

$$Fr_f = \frac{U_R}{(\beta g s_{ocn} H)^{1/2}}$$

riverine Froude #



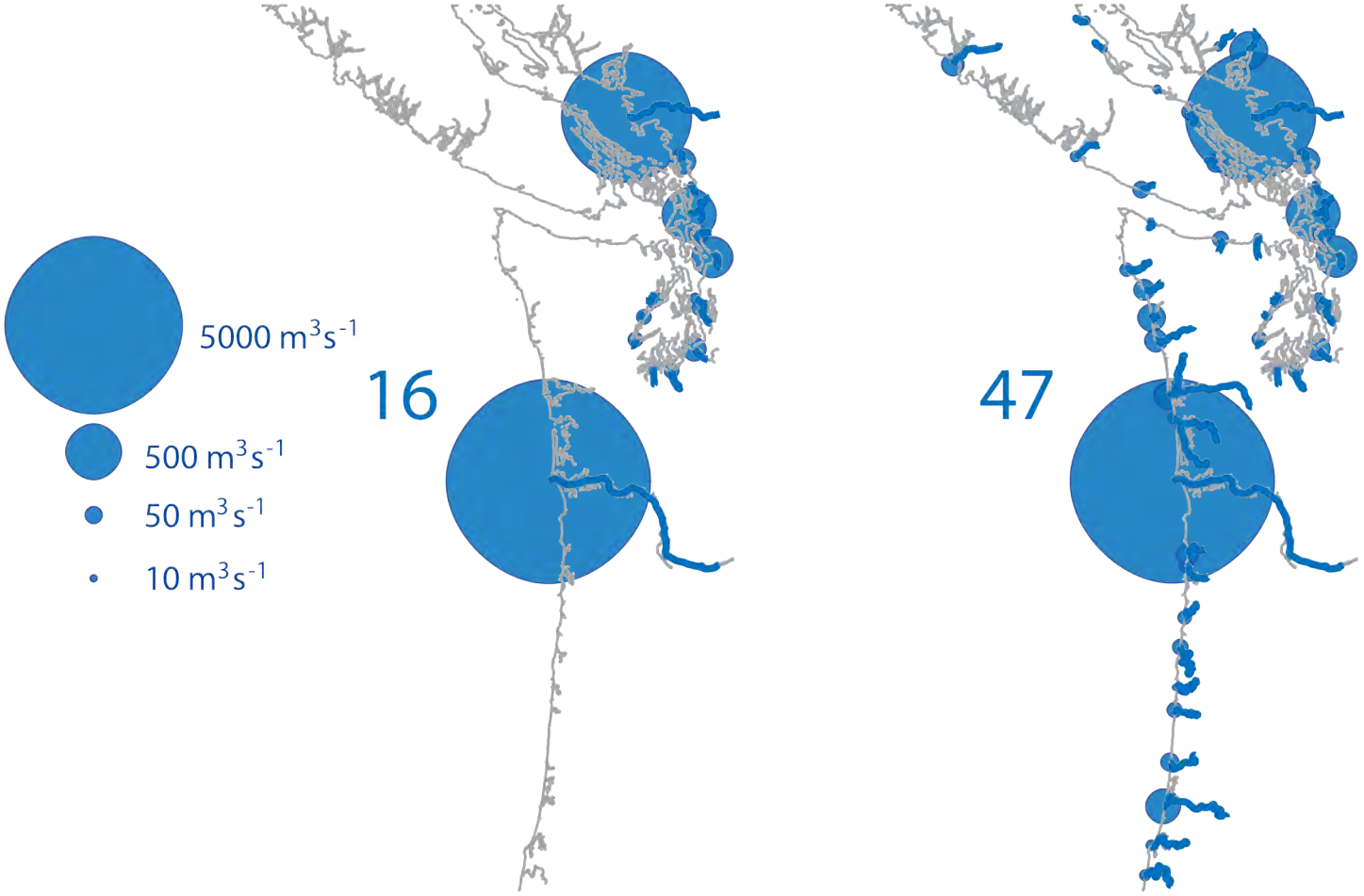
$$M^2 = \frac{C_D U_T^2}{\omega N_o H^2}$$

mixing parameter

Geyer & MacCready 2014, Figure 6

missing rivers??

these results were from 16 river inputs, but there are MANY more of different scales in the region… add more!



Mazzini et al. 2014, Wetz et al. 2006

conclusions

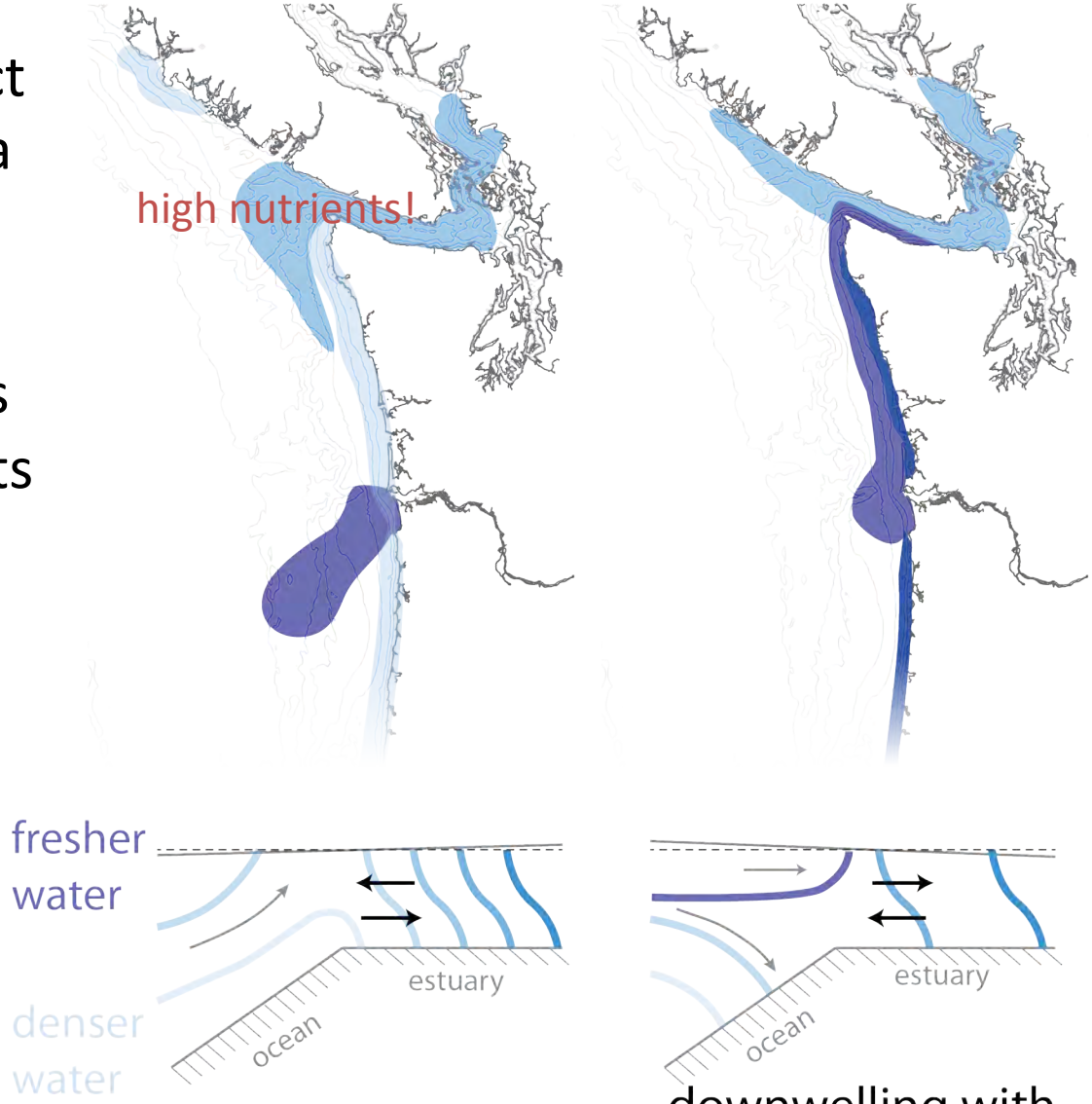
ocean can strongly impact the estuaries & vice versa

along-coast estuaries

dynamics inside estuaries determine coastal impacts

- > choice of Q and S?

changing climate will influence the spatial and temporal distribution of these impacts



thank you! questions?

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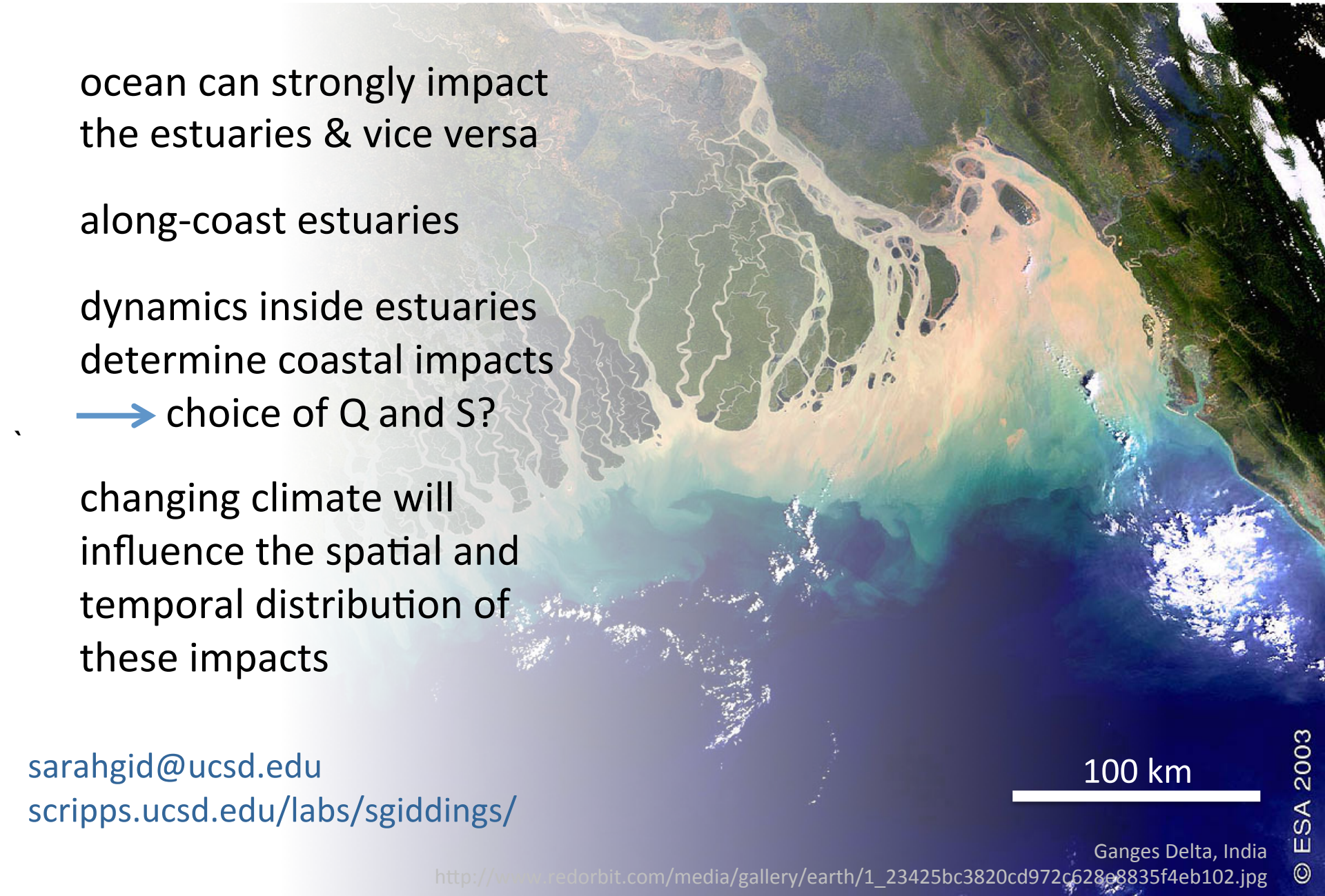

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Ganges Delta, India
http://www.redorbit.com/media/gallery/earth/1_23425bc3820cd972c628e8835f4eb102.jpg