Biogeochemical simulation of San Francisco Bay using an unstructured-grid model

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Two papers published in Ocean Dynamics (2020) and Continental Shelf Research (2018) and a manuscript submitted to Frontiers in Marine Science

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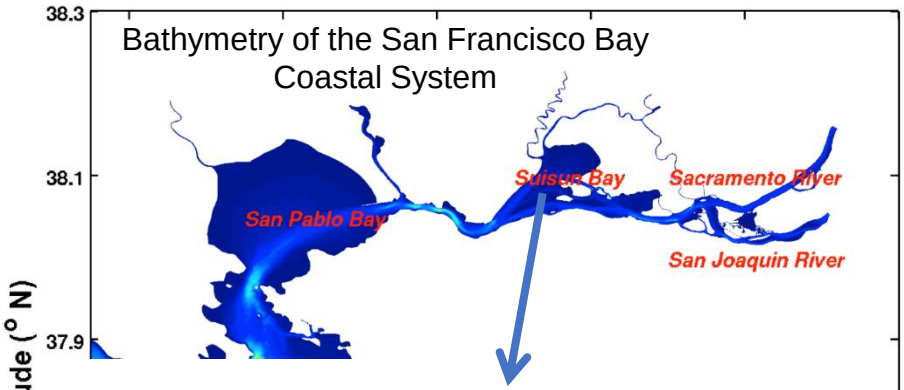
Outline

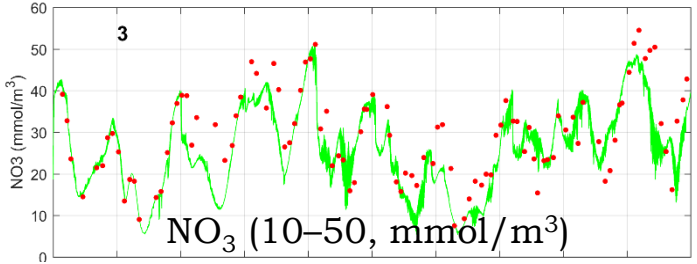
- San Francisco Bay (SFB) and SCHISM-CoSiNE model
- Model-data comparison and nitrogen export from SFB
- Nutrients and plankton response to
  - NO_3 vs. NH_4 concentration and NH_4 inhibition
  - Bottom grazing (invasive Asian clams)
  - 3D sediment transport modeling in regulating light availability and primary production
- Summary

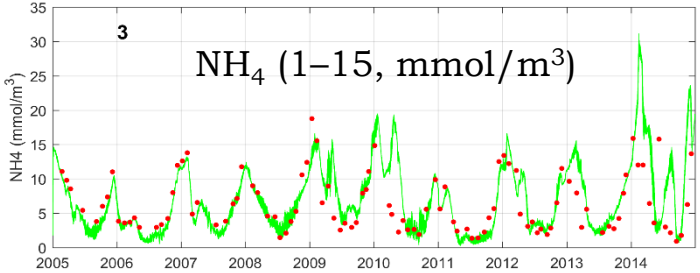
Summary

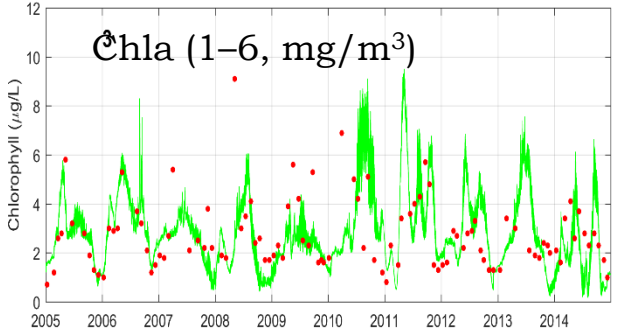
- High Nitrogen & Low Growth (HNLG) in San Francisco Bay (SFB), and ***SCHISM-CoSiNE*** captures overall nutrients and chlorophyll variability for SFB
- ***90% of DIN*** from rivers and WWTPs ***exported to the coastal ocean***, and 10% assimilated by plankton and deposited into the sediment
- ***NO_3 vs. NH_4, NH_4 inhibition*** and ***bottom grazing*** by invasive Asian clams alter nitrogen cycling (more NH_4) and regulates NO_3 uptake by phytoplankton
- **Sediment transport modeling for better SPM simulation** is crucial for improving primary production and phytoplankton dynamics.

Background & Motivation







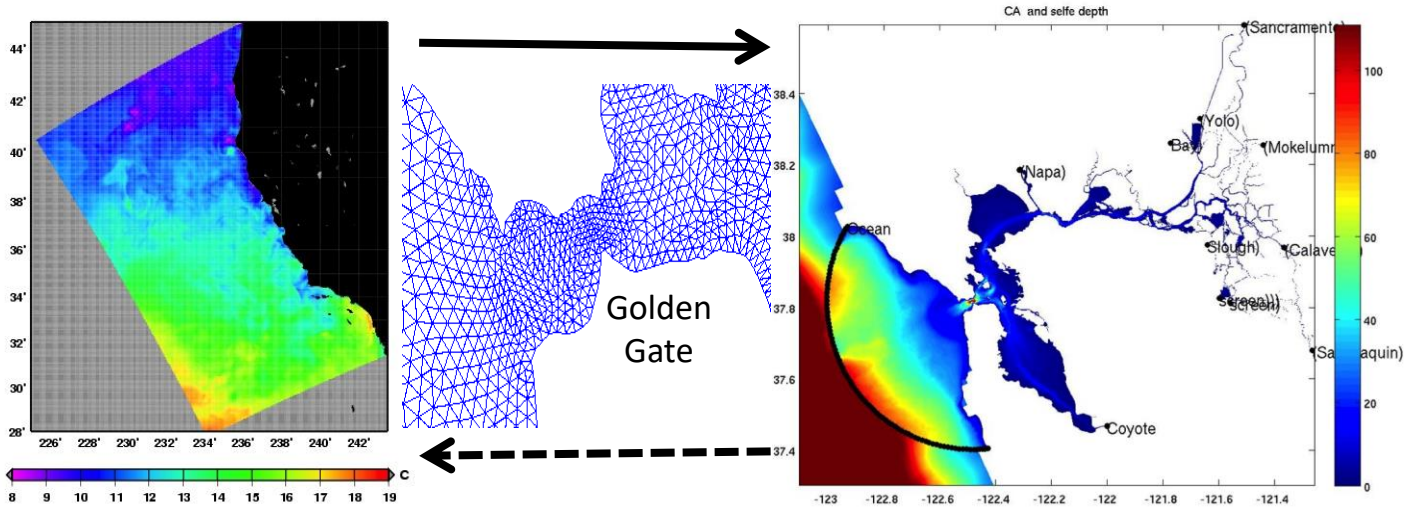


- Population growth (8 millions people)
- High NO_3 and NH_4 input from 18 WWTPs
- ***High Nitrogen and Low Growth (HNLG)***
- Sediment loading
- Invasive species – Asian clams

Modeling San Francisco Bay/Estuary

SCHISM: 3D Semi-implicit Eulerian–Lagrangian Finite-Element,
horizontal resolution from 10m to 1000m, wet/dry, 23 vertical levels
NCEP/NAM atmospheric forcing (9-km), 3-km ROMS coastal ocean boundary conditions

Linking California coastal ocean model with San Francisco Bay/Estuary & lower Sacramento River



Carbo**n**, **Si**licate, **N**itrogen **E**cosystem (**CoSiNE-13**)

(Chai et al., 2002; Dugdale et al., 2002;
Xiu and Chai, 2014; Liu and Chai et al., 2018)

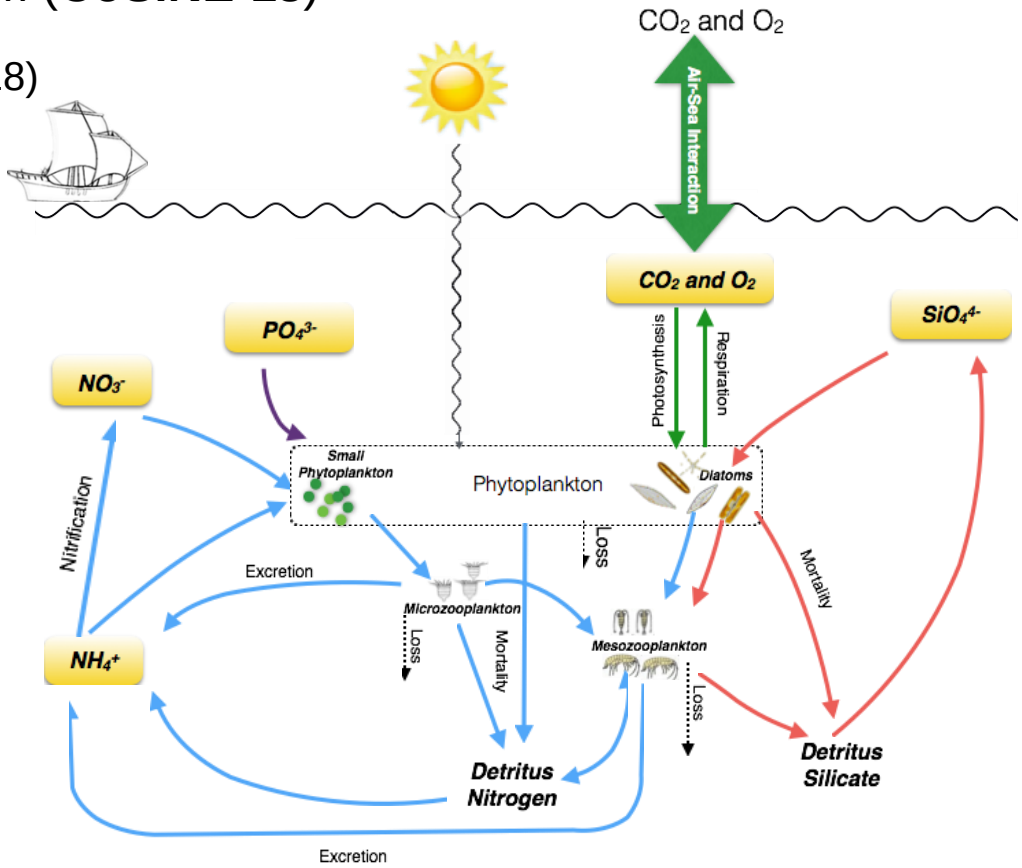
Nutrient:
Nitrate (NO3)
Ammonium (NH4)
Silicate (SiO4)
Phosphate (PO4)

Phytoplankton:
Small Phytoplankton (S1)
Diatom (S2)

Zooplankton:
Microzooplankton (Z1)
Mesozooplankton (Z2)

Detritus:
Detritus Nitrogen (DN)
Detritus Silicon (DSi)

Oxygen and Carbon
Dissolved Oxygen (DOX)
Carbon Dioxide (CO2)
Alkalinity (ALK)

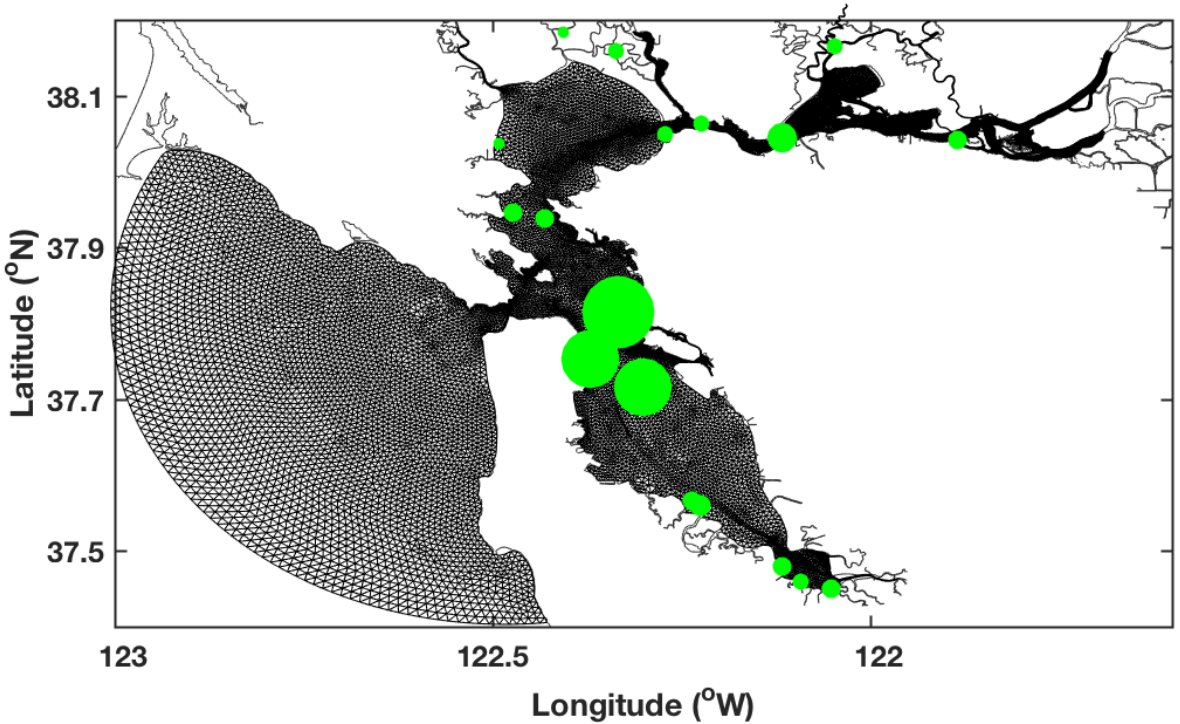


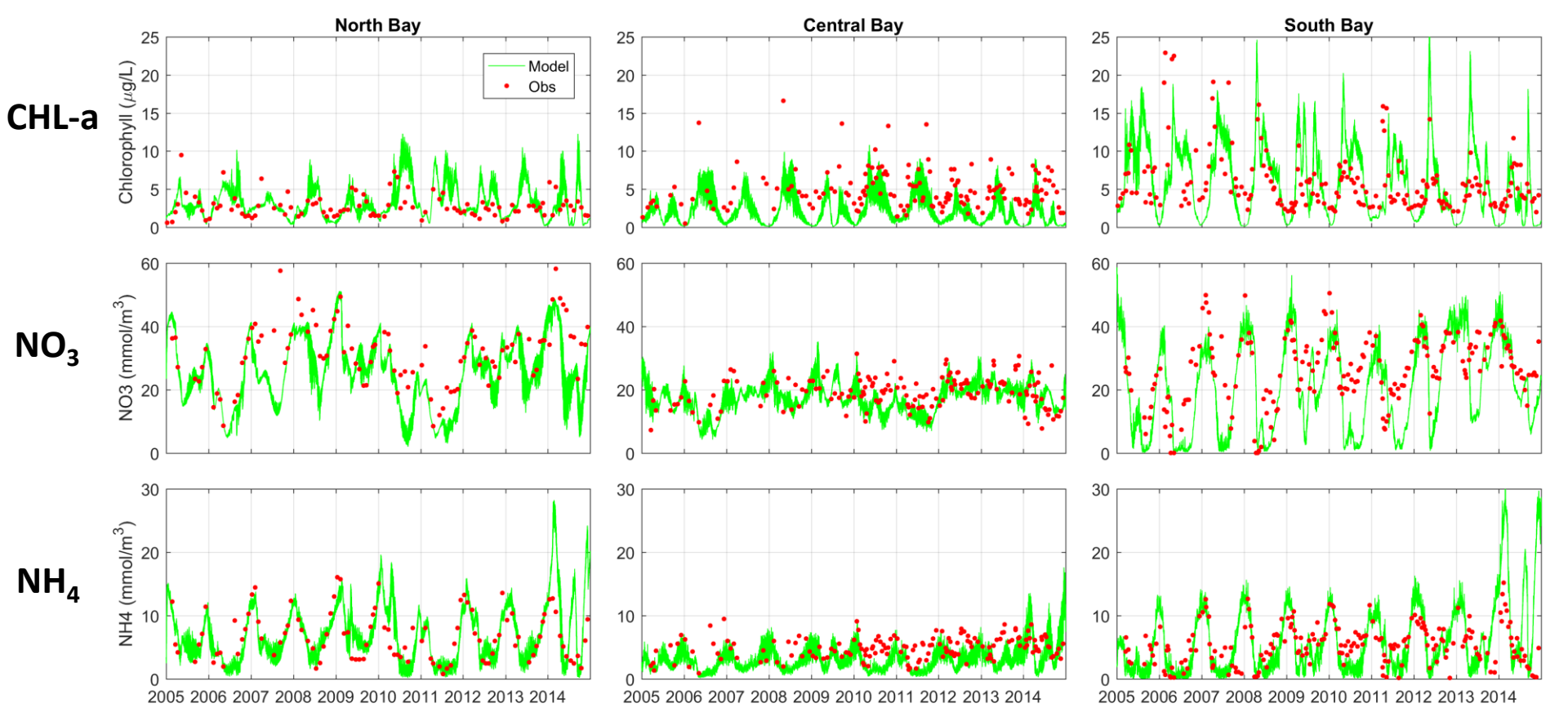
Liu and Chai et al., 2018
Continental Shelf Research

Wang and Chai et al., 2020
Ocean Dynamics

Coupled SCHISM-CoSiNE Model

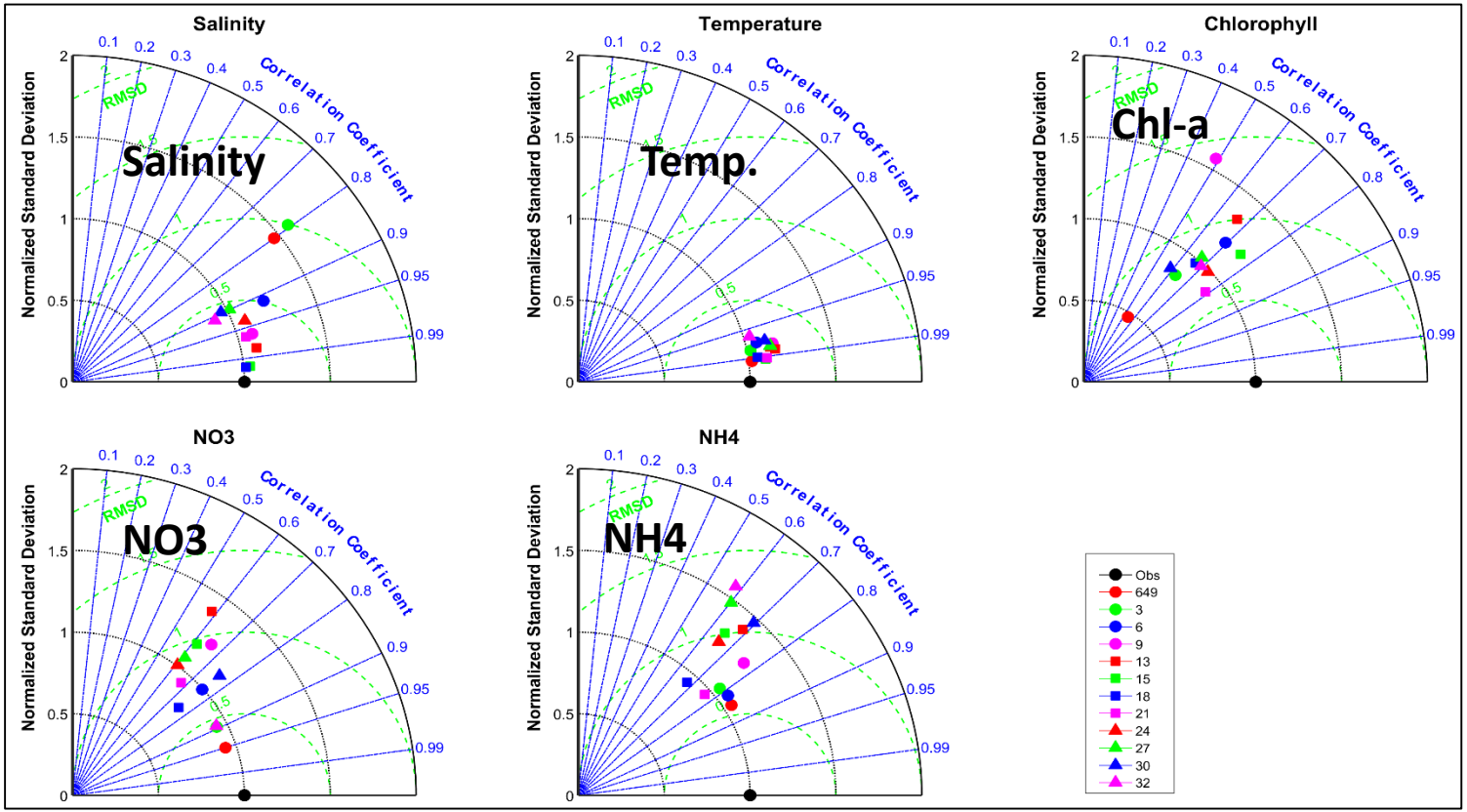
- **Boundary Conditions:** 3-km California ROMS-CoSiNE;
  4 Rivers with discharge (USGS), dissolved inorganic nutrients;
- **Sources:** NO_3 and NH_4 from 18 WWTPS



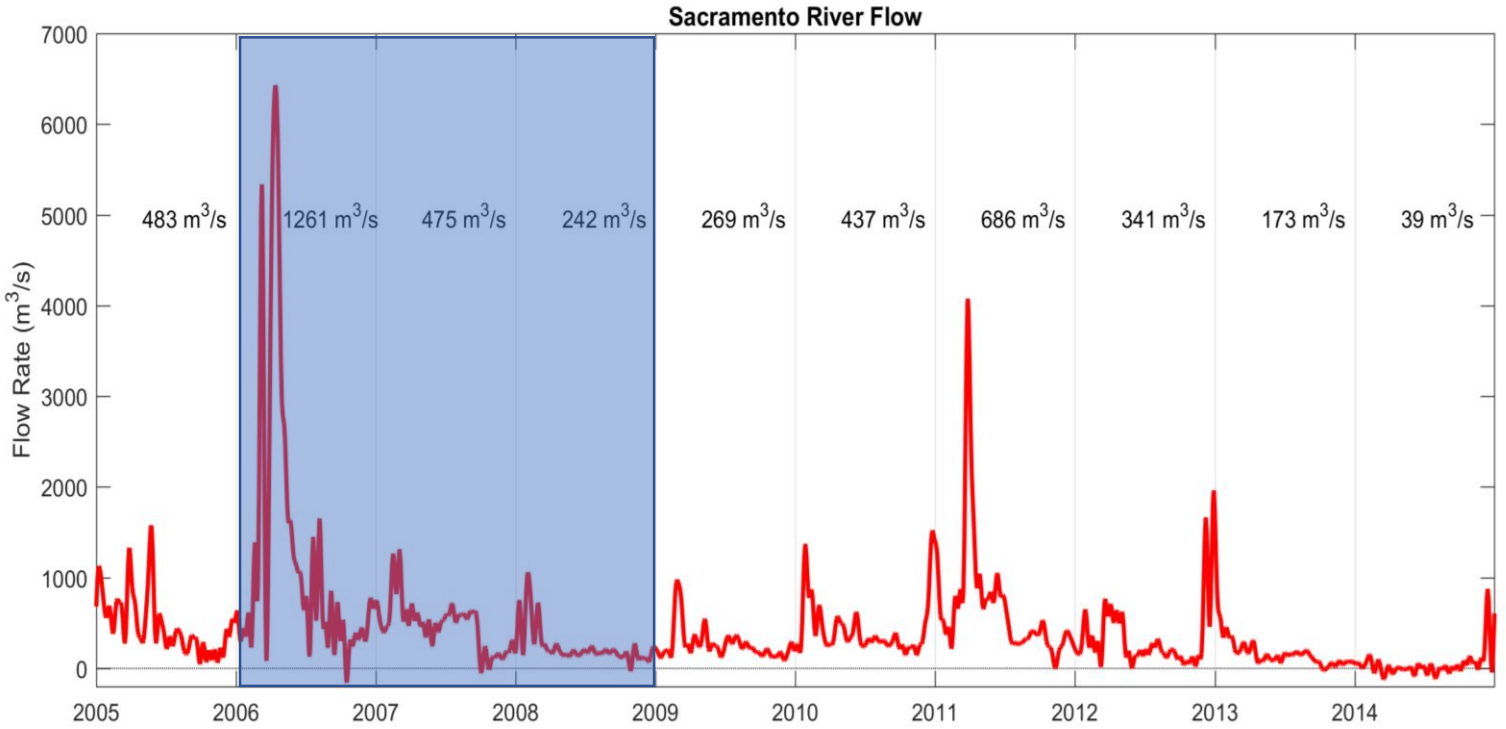


- Time series of simulated chlorophyll generally match measurements from USGS
- The interannual variation of nutrients (NO_3 and NH_4) were well captured by CoSiNE model

Model Skill - Taylor Diagram

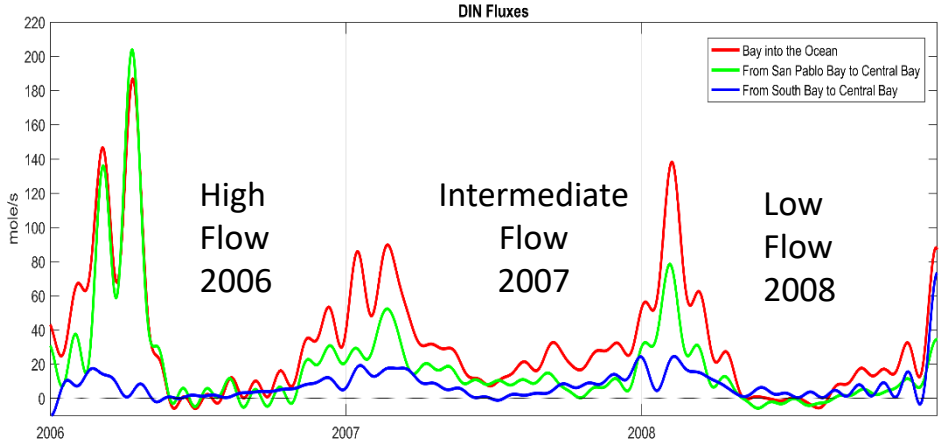


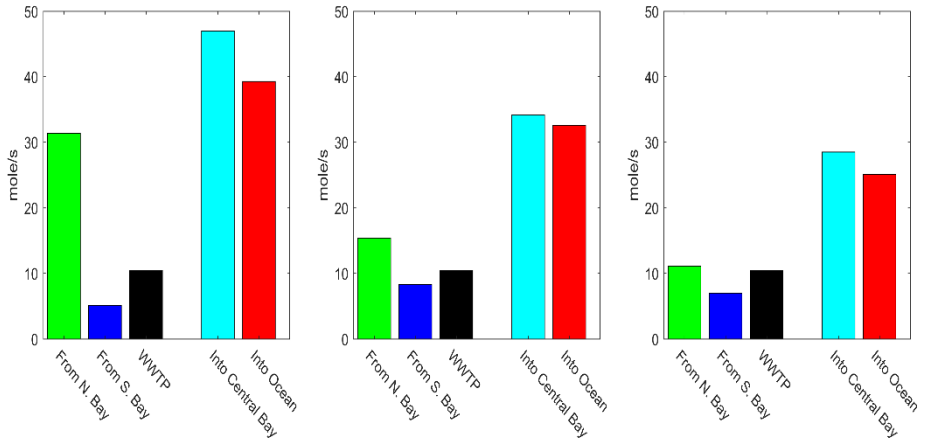
Wang and Chai et al., Ocean Dynamics, July 2020

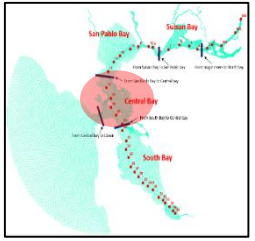


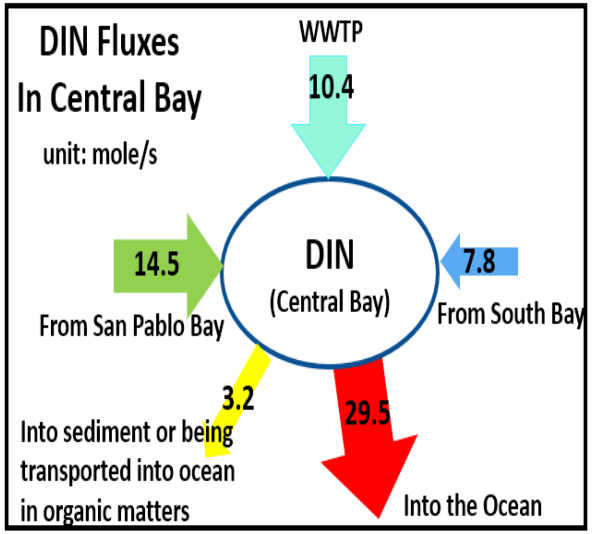
Three years from 2006 to 2008 are selected for analyzing model results under different river flow conditions.

DIN (NO_3 + NH_4) Fluxes in Central Bay









Most of nutrient loads (**90%**) into the Bay are transported out, while only 10% are assimilated by plankton or into the sediment.

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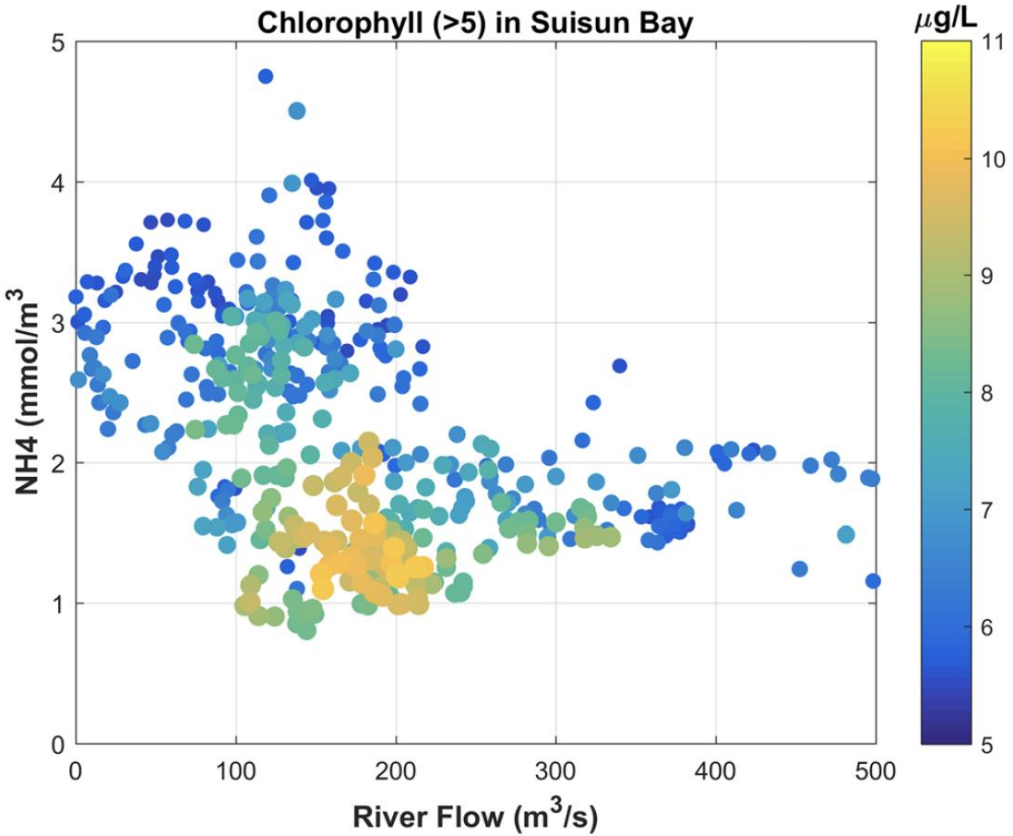
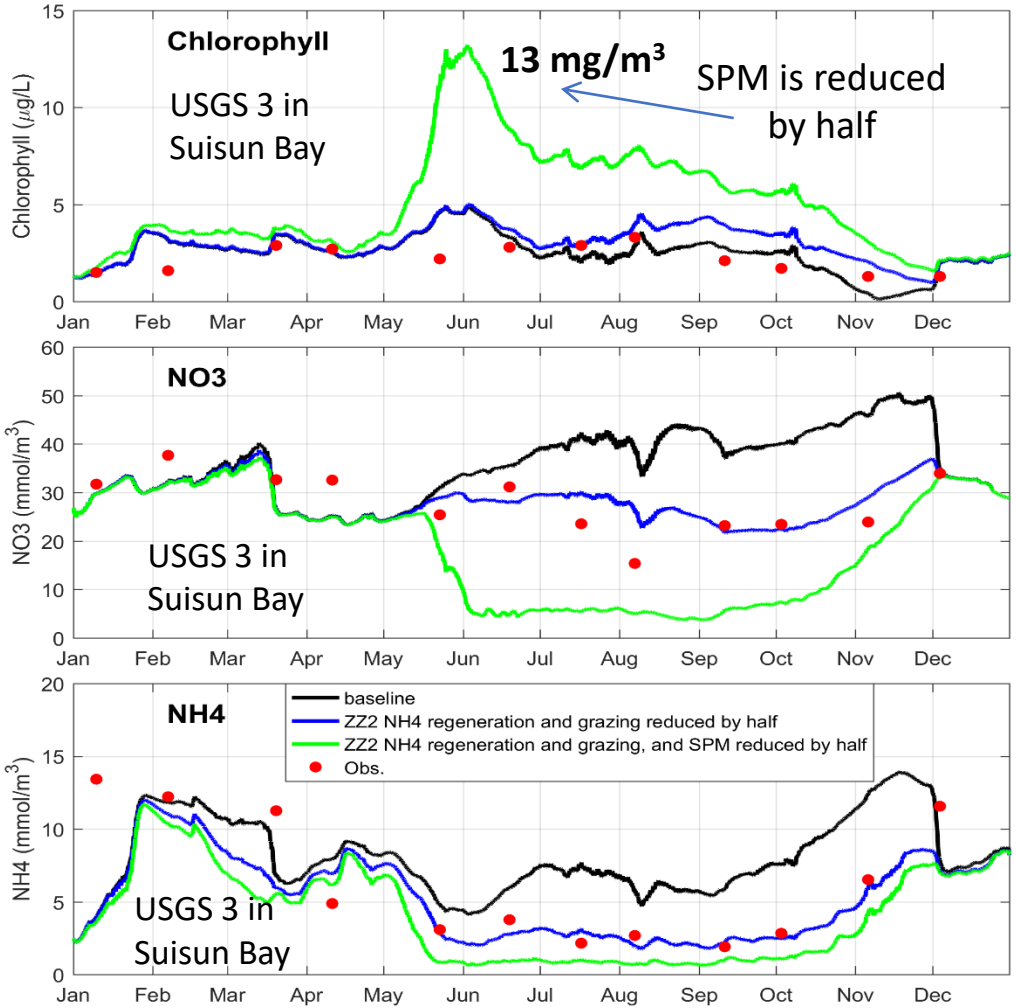


Fig. 12 Scatter plot for chlorophyll (> 5 μg/L) in Suisun Bay. Ten-year model results are used for this analysis. The *x*-axis represents the flow rate from major rivers, while the *y*-axis represents NH_4 concentration. For each chlorophyll point, the corresponding flow rate is obtained by averaging the river flow over the past 2 weeks

Flow rate, NH_4 concentration, and Chlorophyll

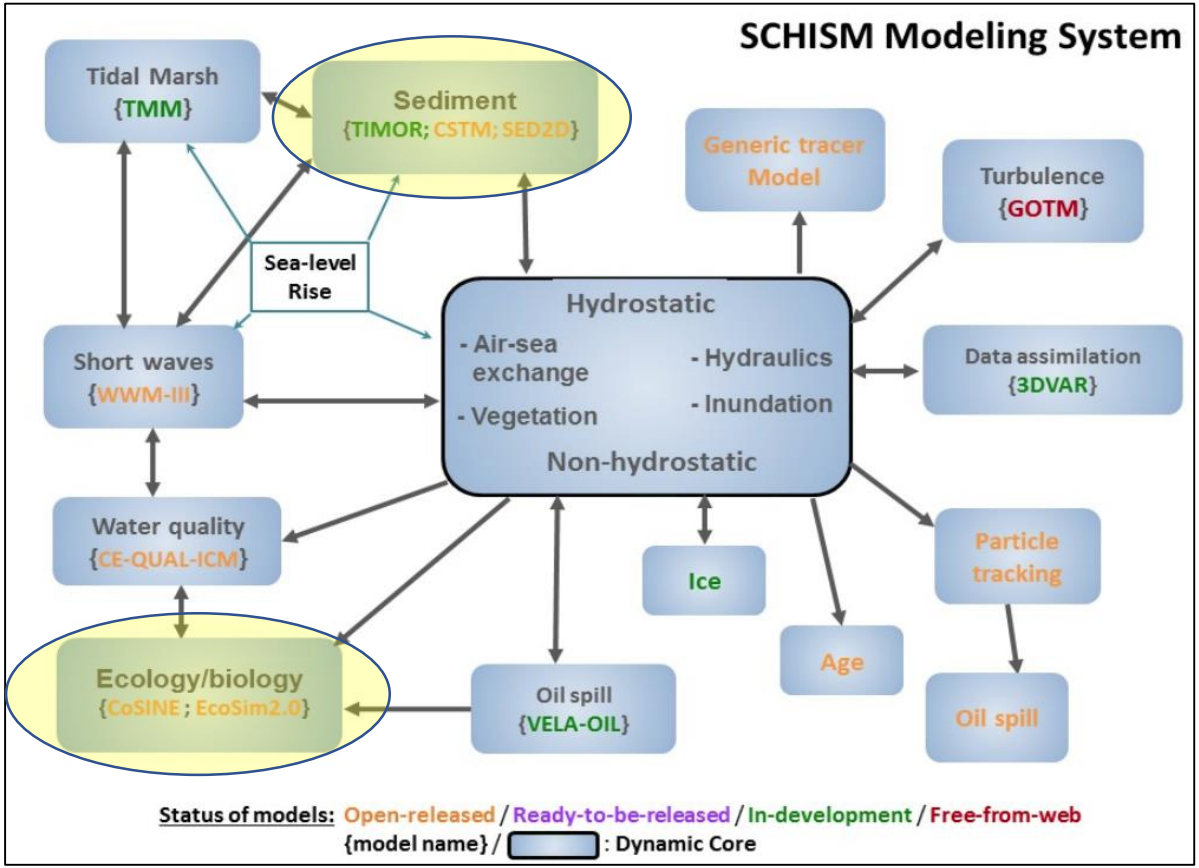
Wang and Chai et al.,
Ocean Dynamics, July 2020



Role of SPM and Light in Regulating Phytoplankton Bloom

It shows that SPM concentration can largely influence the phytoplankton growth.

SCHISM and Sediment Transport Model (SED3D)



Open-released Ready-to-be-released In-development Free-from-web

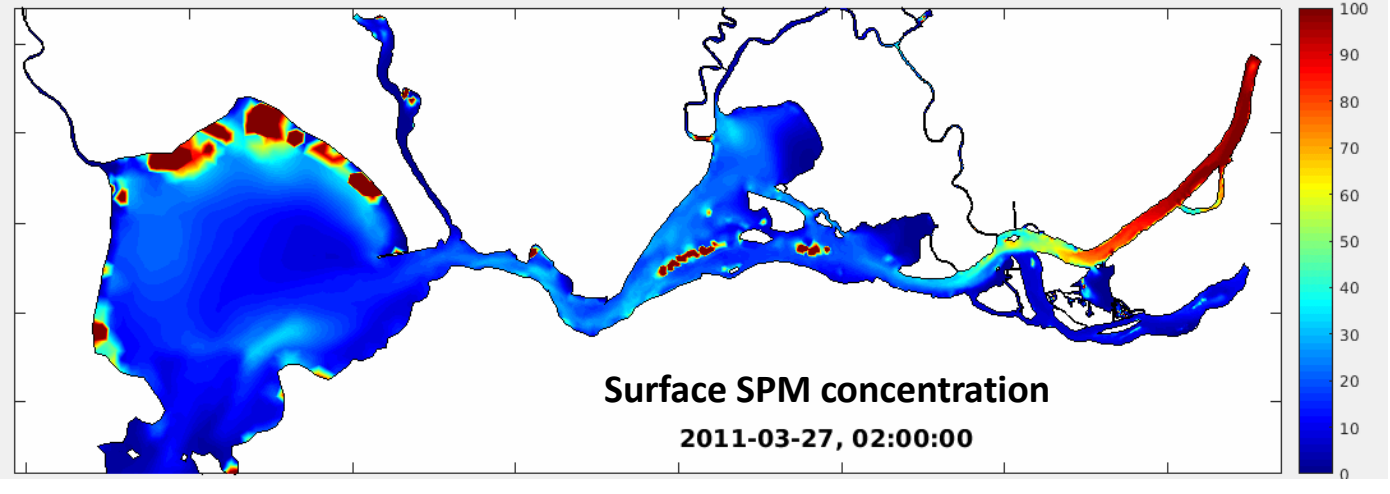
Sediment Transport Model Configuration in SF Bay

- **3 Type of Sediment Grains**

- **Initial Condition**
  - Sediment bed fraction
  - Sediment bed thickness
  - SPM concentrations in water

- **Boundary Condition**
  - Open Ocean boundary: SPM=10 mg/L
  - River Boundaries: Turbidity data

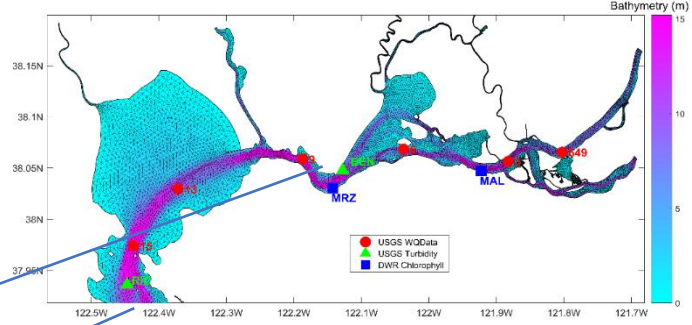
- **Sensitive Parameters**
  - Grain size
  - Erosion rate

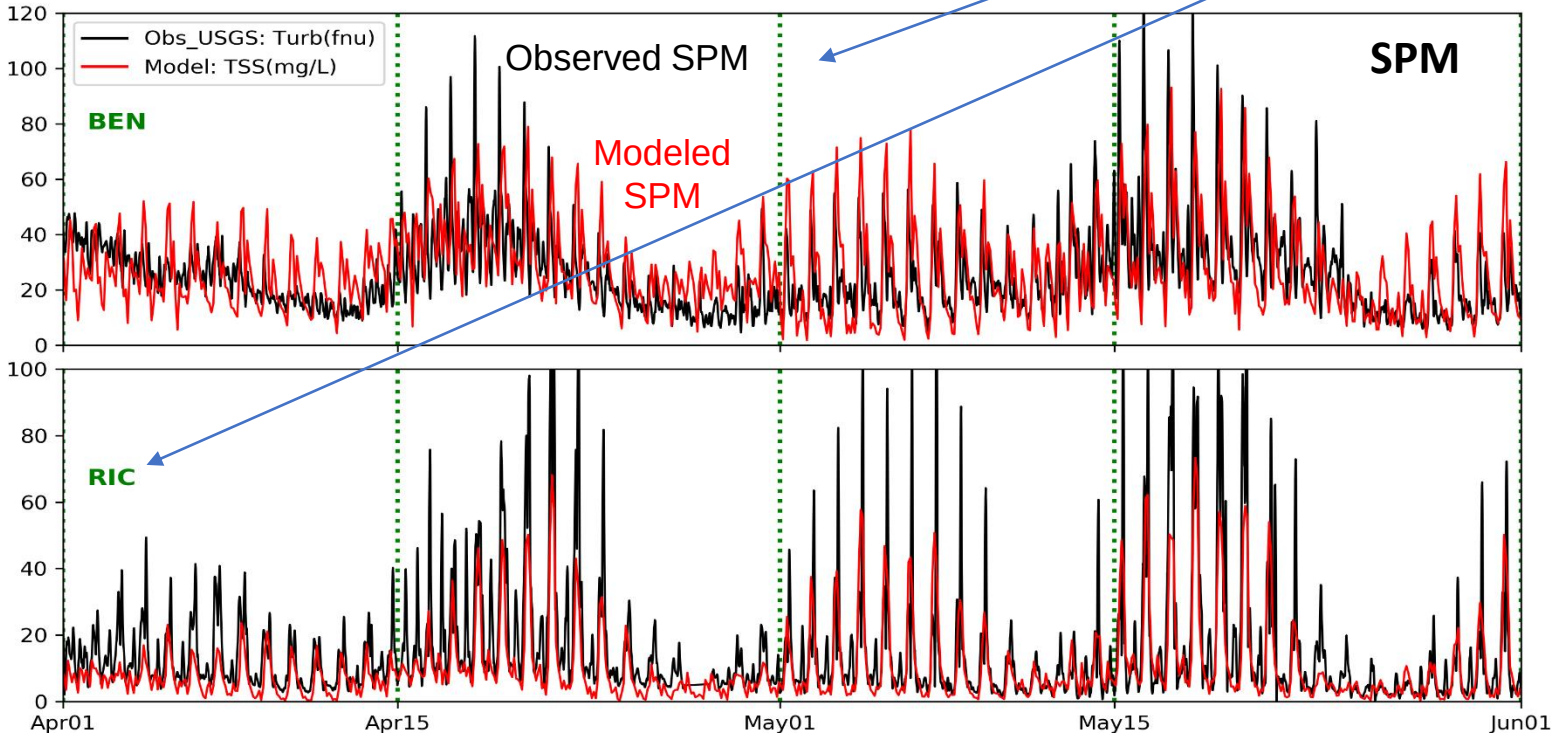


Wang and Chai et al., submitted.

Model Calibration: SED3D

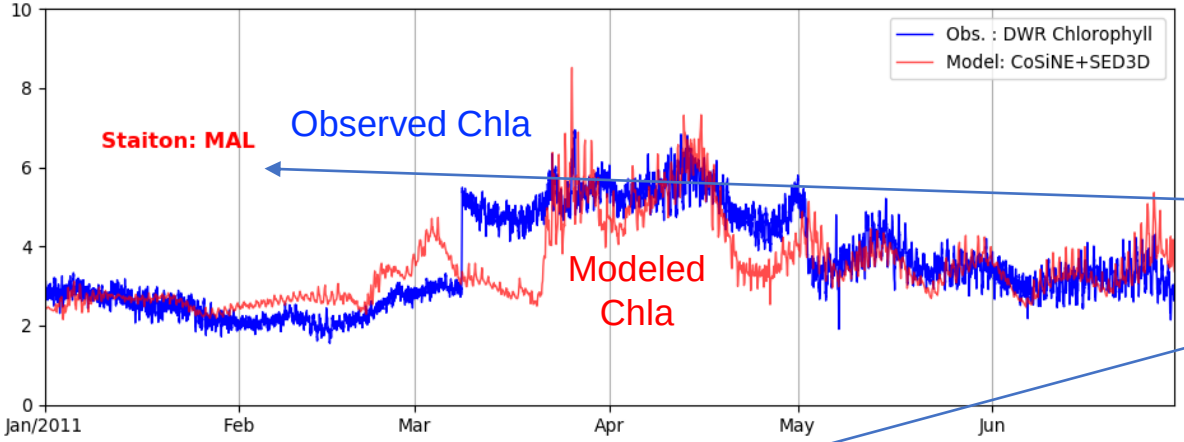
- SPM (or TSS) is compared with turbidity data from USGS
- Model well captures the diel cycle (1 day) and spring-neap tide cycle (14 day)

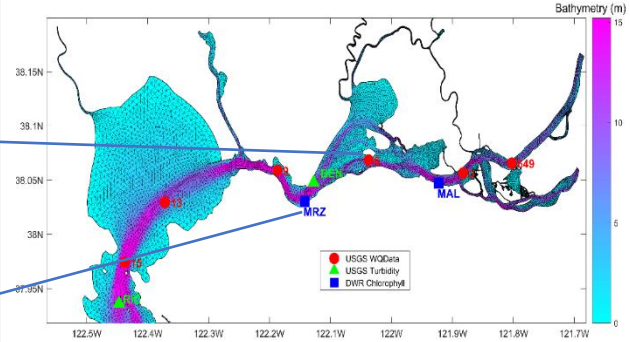


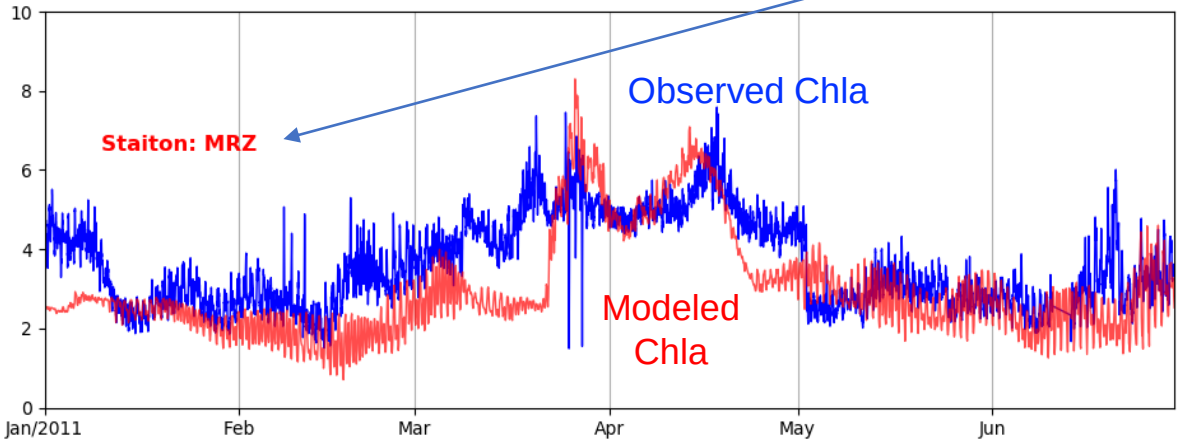


Wang and Chai et al., submitted.

Modeled *chlorophyll* also compares well with continuously monitoring data

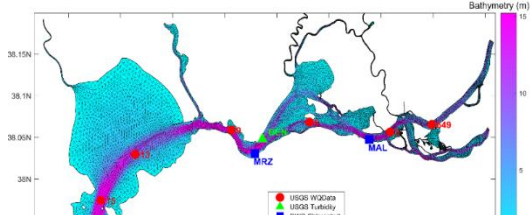






Wang and Chai et al., submitted.

Chlorophyll Simulation with SED3D



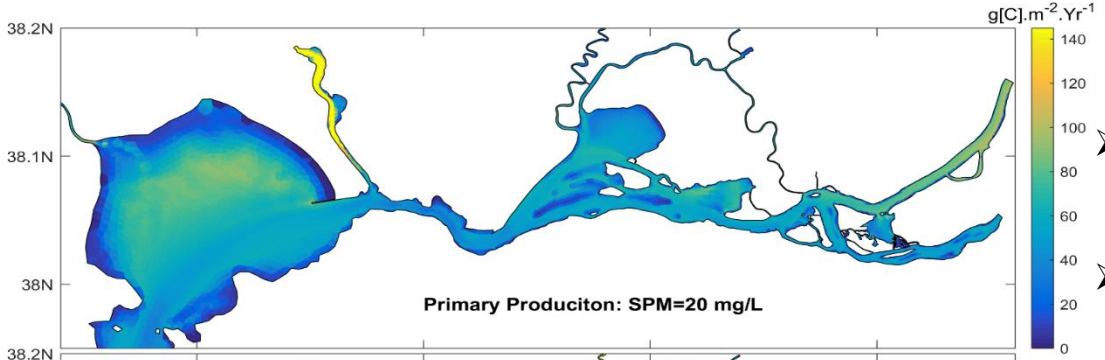
- With SED3D, simulated chlorophyll matches the observation better visually

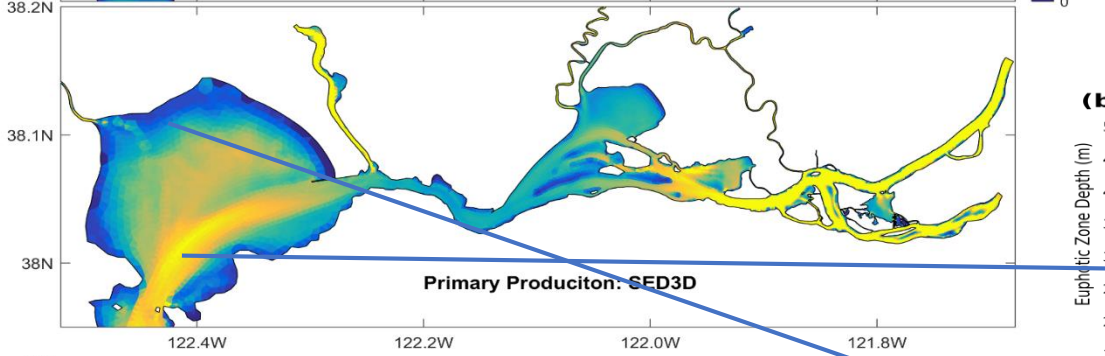
Table 1. Statistics for chlorophyll results including R, MAE and ME for the six stations in northern SFB. They are based on the best matches in +/- 3 days around the observation times. The numbers in parentheses are the improvement (percentage) of the chlorophyll in SPM_SED3D relative to that in SPM_20. The last column is the averaged improvement.

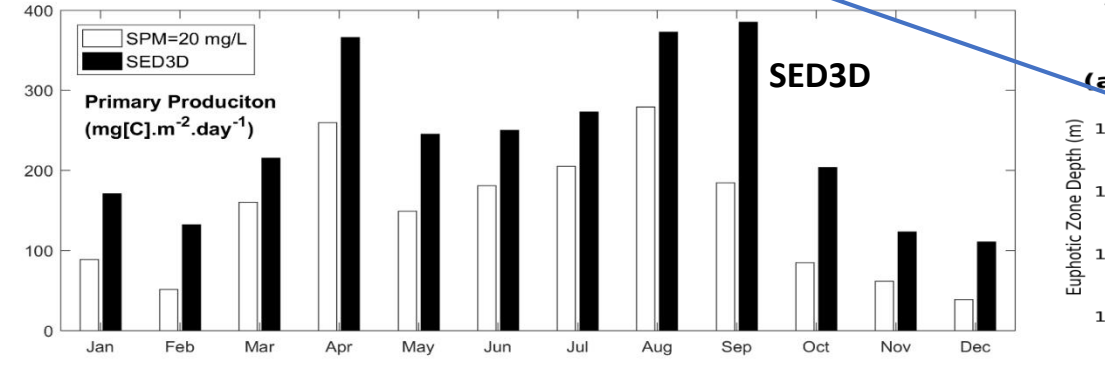
Chlorophyll ($\mu g \cdot L^{-1}$)		649	3	6	9	13	15	Improvement
R	SPM_20	0.43	0.19	0.68	0.32	0.39	0.52	
	SPM_SED3D	0.95	0.77	0.85	0.63	0.79	0.85	0.38
MAE	SPM_20	2.46	1.40	0.84	1.34	2.42	3.47	
	SPM_SED3D	1.18 (52%)	0.57 (59%)	0.37 (56%)	0.74 (44%)	1.59 (34%)	2.11 (39%)	0.90 (48%)
ME	SPM_20	-1.71	-0.58	-0.52	-0.60	-1.73	-2.89	
	SPM_SED3D	-0.31 (81%)	0.41 (30%)	0.04 (91%)	0.05 (91%)	-0.88 (49%)	-1.49 (48%)	0.80 (65%)

Primary Production

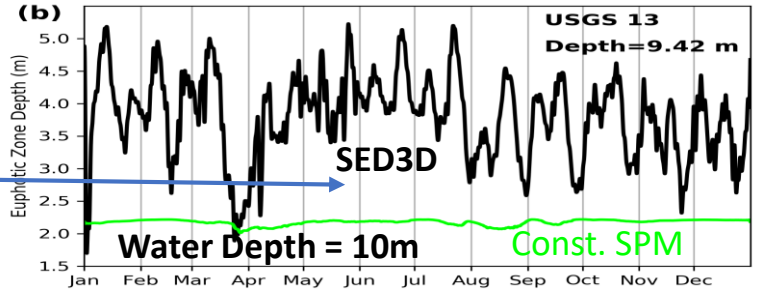
- Primary production is significantly increased (15%) in CoSiNE model with SED3D compared to the case with constant SPM.
- The difference is larger along the bay channel where the water depth is deeper.

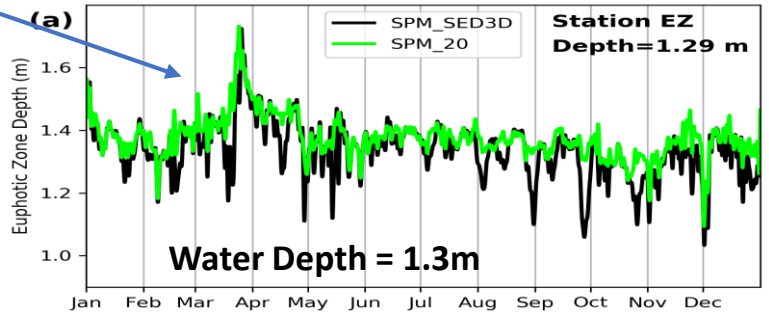






Euphotic Zone Depth at different location





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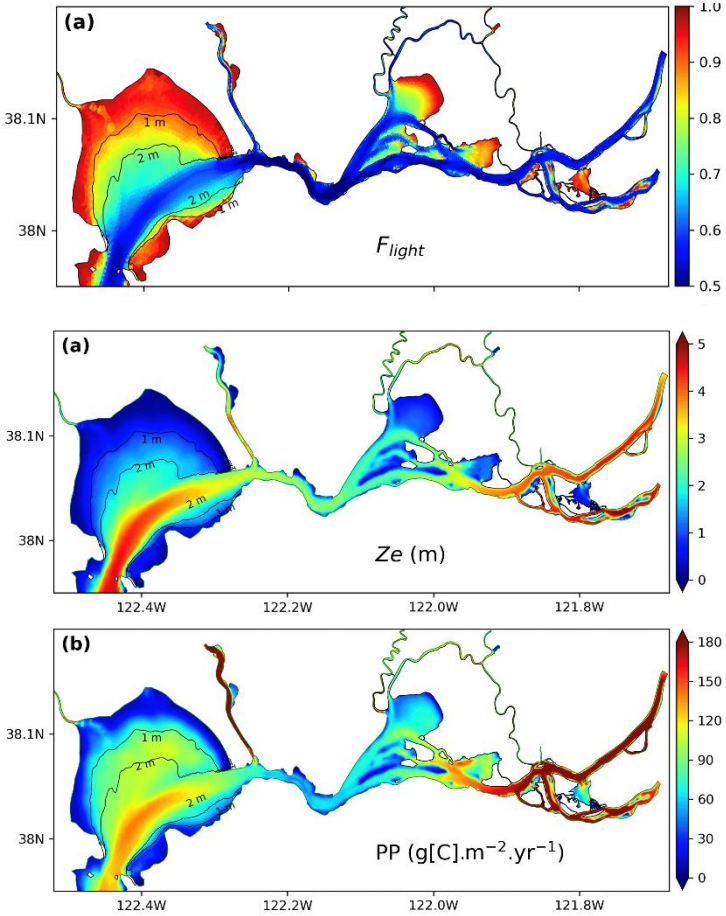
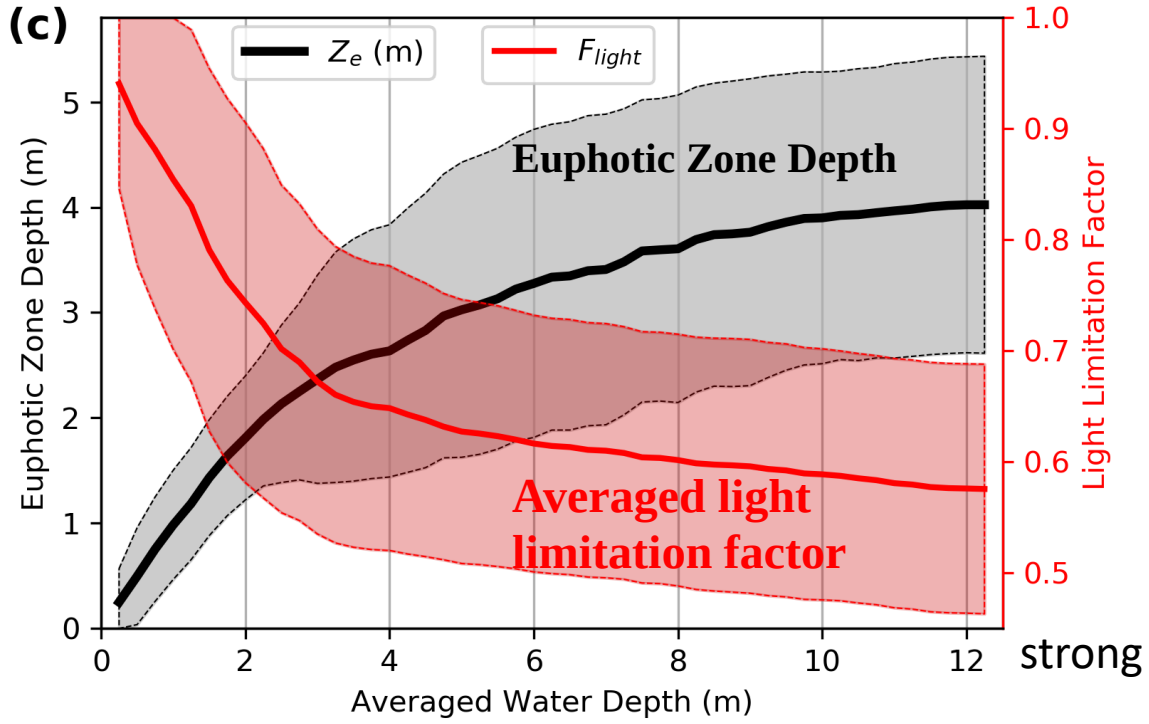


Figure 10. Comparison of Euphotic Depth (a) and vertically integrated primary production (b) in northern SFB for 2011. All the data are from SPM_SED3D.



Ze :Euphotic Zone Depth

Wang and Chai et al., submitted.

F_{light} : Averaged light limitation for phytoplankton

$$F_{light} = \frac{1}{Ze}\int_{-Ze}^{0} \phi(z)\cdot dz \qquad \phi(z) = \left(1 - e^{\frac{-\alpha}{\mu_{\max}}\cdot I}\right)\cdot e^{\frac{-\beta}{\mu_{\max}}\cdot I}$$

is light calculation