Three-Dimensional Modeling of Eutrophication and Cyanobacteria Growth in Two Shallow Bays of Lake Champlain

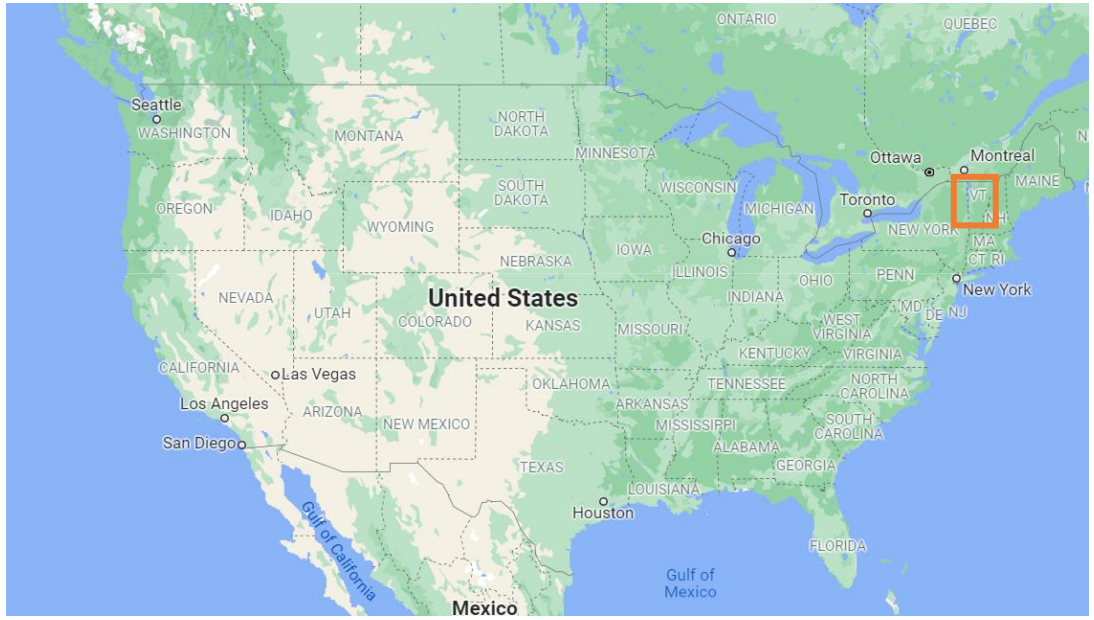
Kareem I. Hannoun[1], Imad Hannoun[1], Xing Qi[1], Andrew Schroth[2], Asim Zia[2], Scott Turnbull[2], Patrick J. Clemins[2]

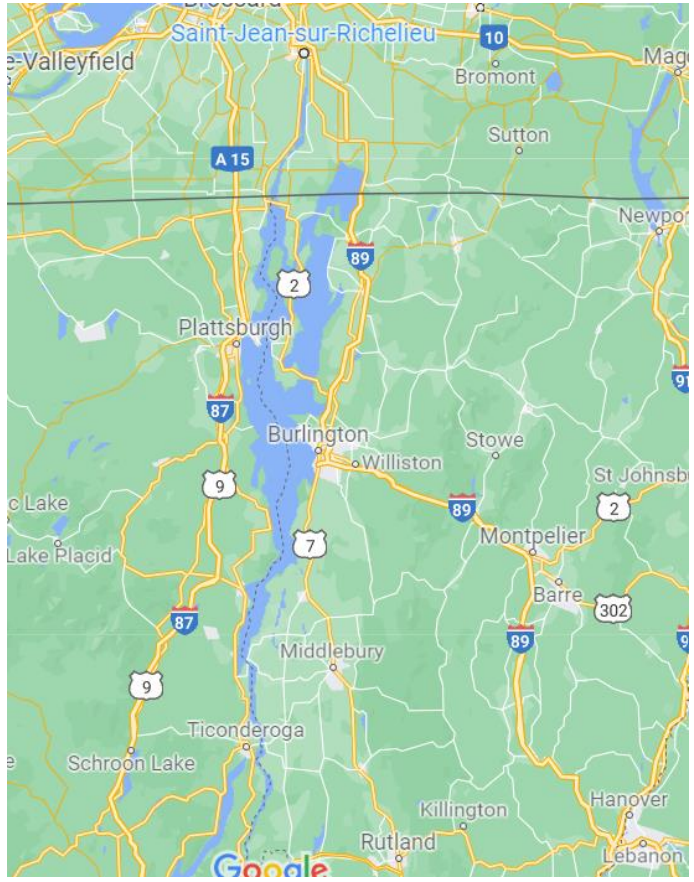
[1]Water Quality Solutions
[2]University of Vermont

This material is based upon work supported by the National Science Foundation under Grant No. OIA-1556770.

Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

Lake Champlain





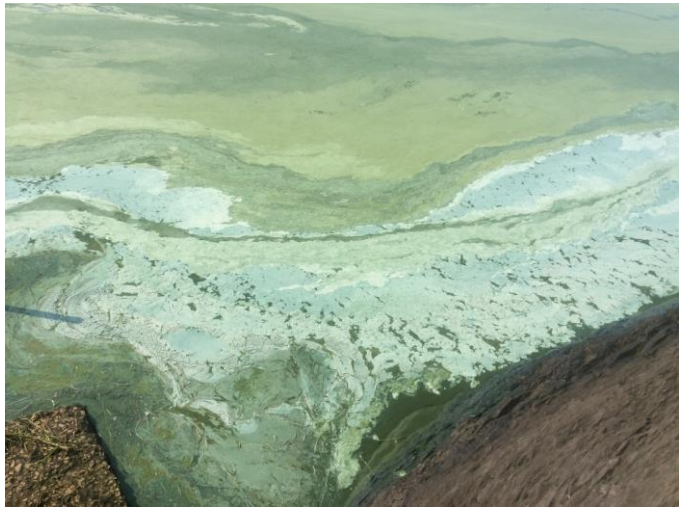
- Volume of 21 million acre-feet
- Water supply for 200,000 people
- Tremendous recreational value reliant on high water quality

Water Quality Concerns in Lake Champlain

High P loading and increasing air temperature have led to eutrophication across Lake Champlain

Eastern Bays of Lake Champlain have experienced increasingly problematic cyanobacteria blooms

- Significant economic and recreational impacts
- Future outlook concerning as air temperatures continue to rise



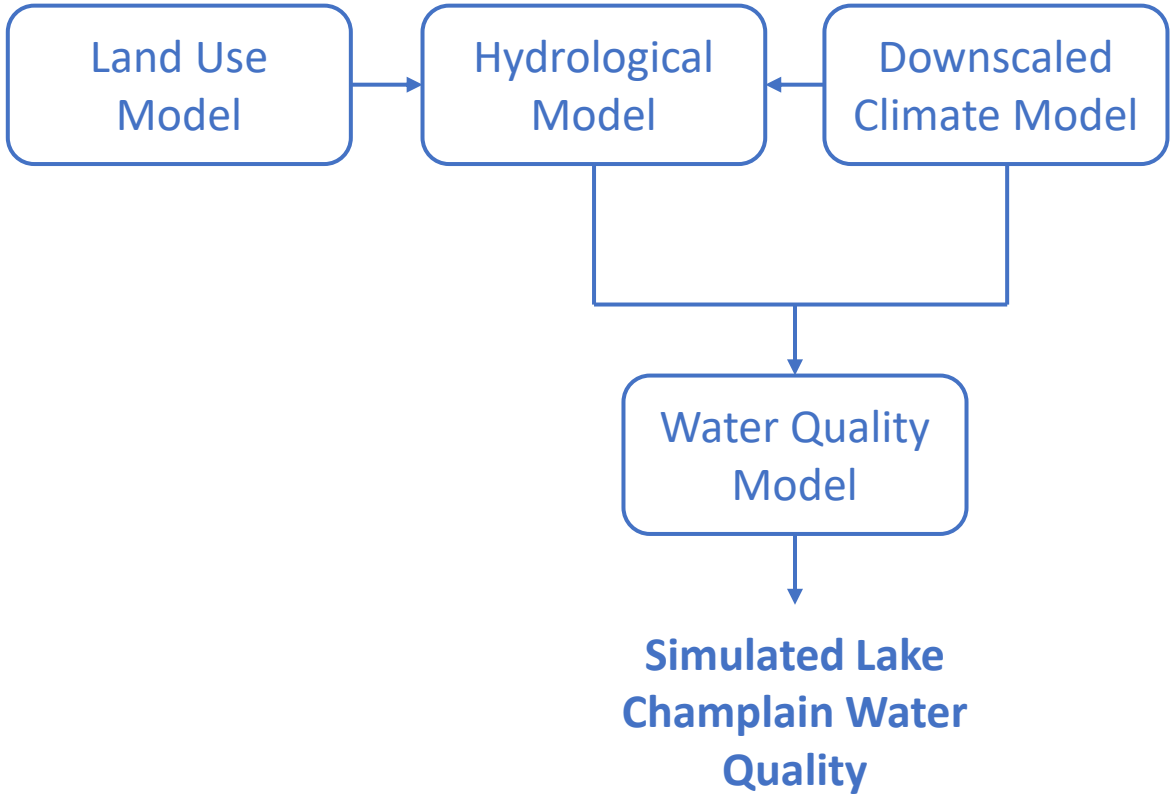
Missisquoi Bay August 2021

St. Albans Bay August 2021

Images via Vermont Cyanobacteria Tracker

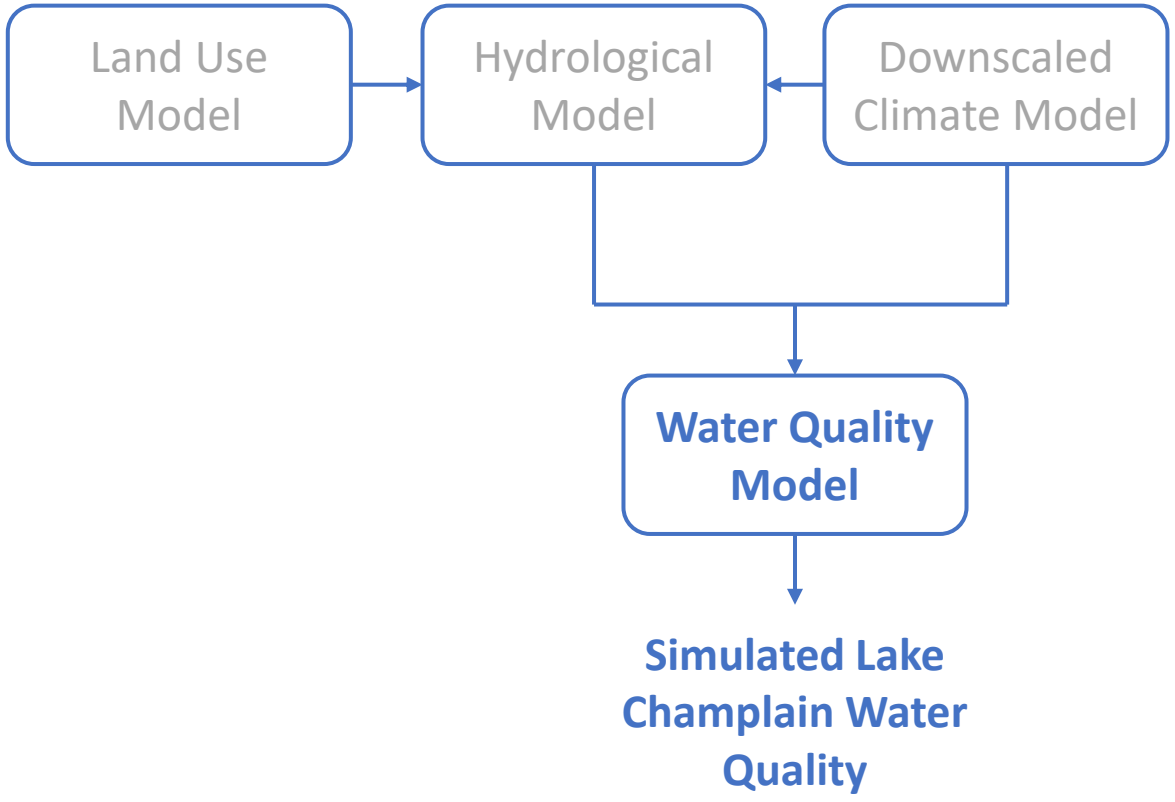
Integrated Assessment Model (IAM)

Integrated Assessment Model (IAM) seeks to simulate the effects of climate change in Lake Champlain under various land use and climate scenarios



Integrated Assessment Model (IAM)

Integrated Assessment Model (IAM) seeks to simulate the effects of climate change in Lake Champlain under various land use and climate scenarios



Water Quality Model Calibration

Objective:

Calibrate and validate a 3D water quality model of Missisquoi Bay and St. Albans Bay

- Model will interface with hydrological and climate models for 100-year simulations of in-lake water quality under various basin land-use scenarios and climate

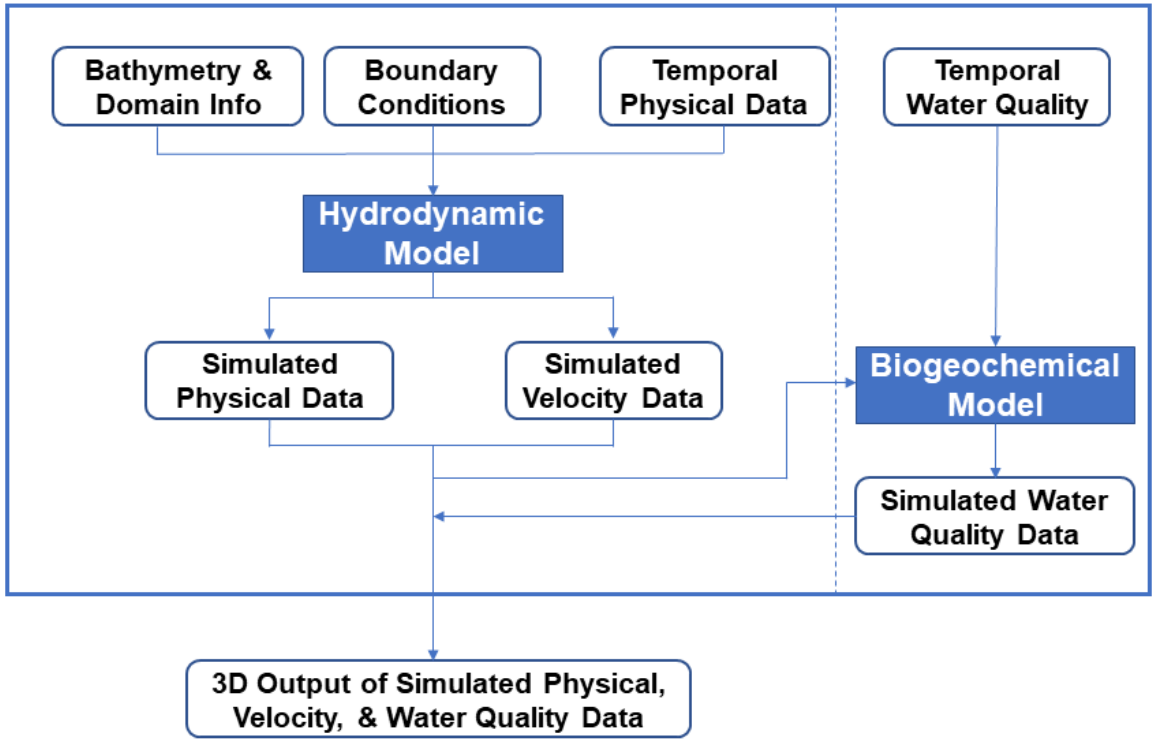
Previous work:

3D water quality model of Missisquoi Bay was calibrated for years 2017-2018 (Marti et al.)

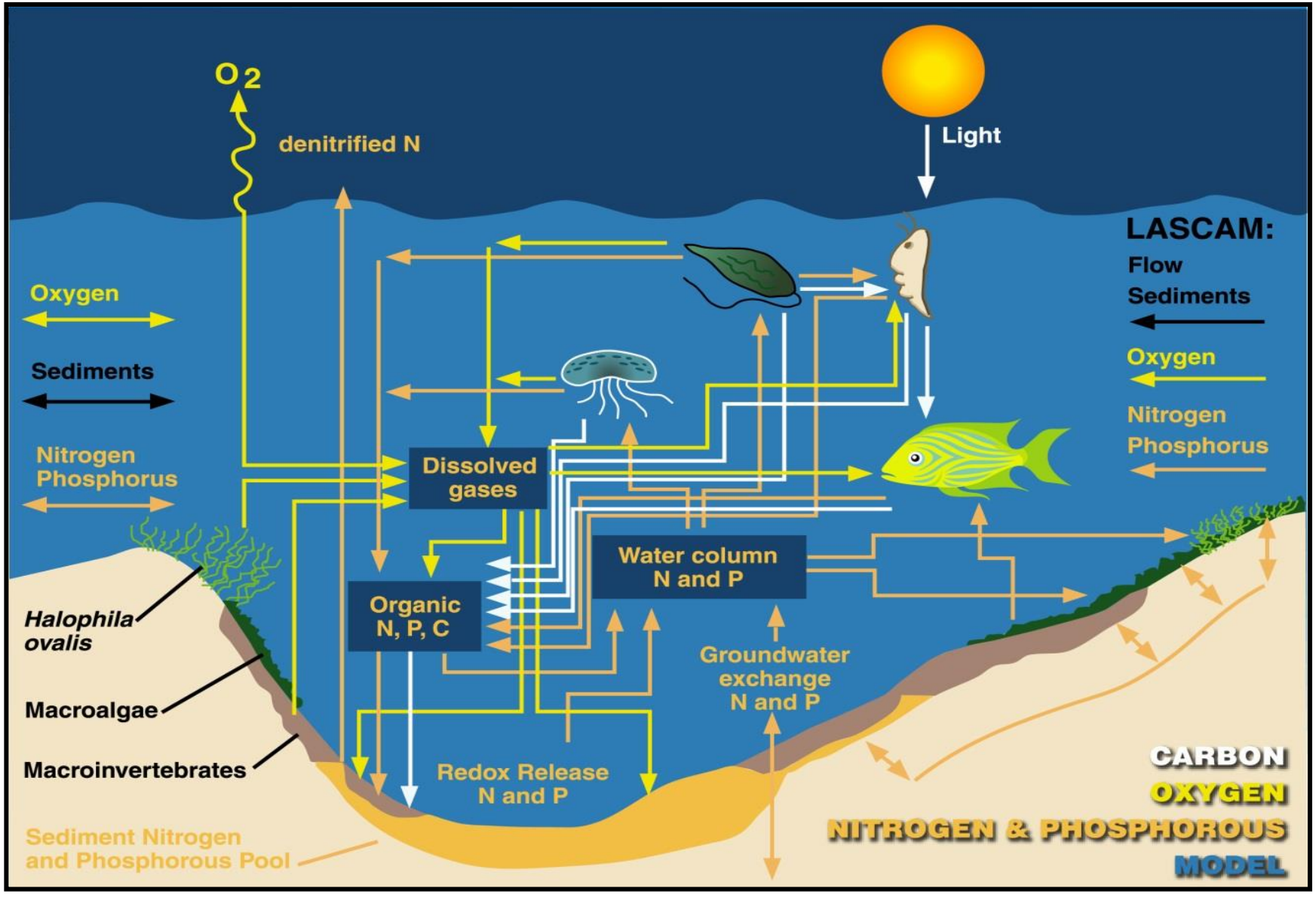
Marti, C. L.; Schroth, A. W.; Zia, A.
American Geophysical Union, Fall Meeting 2019

AEM3D Model Principles

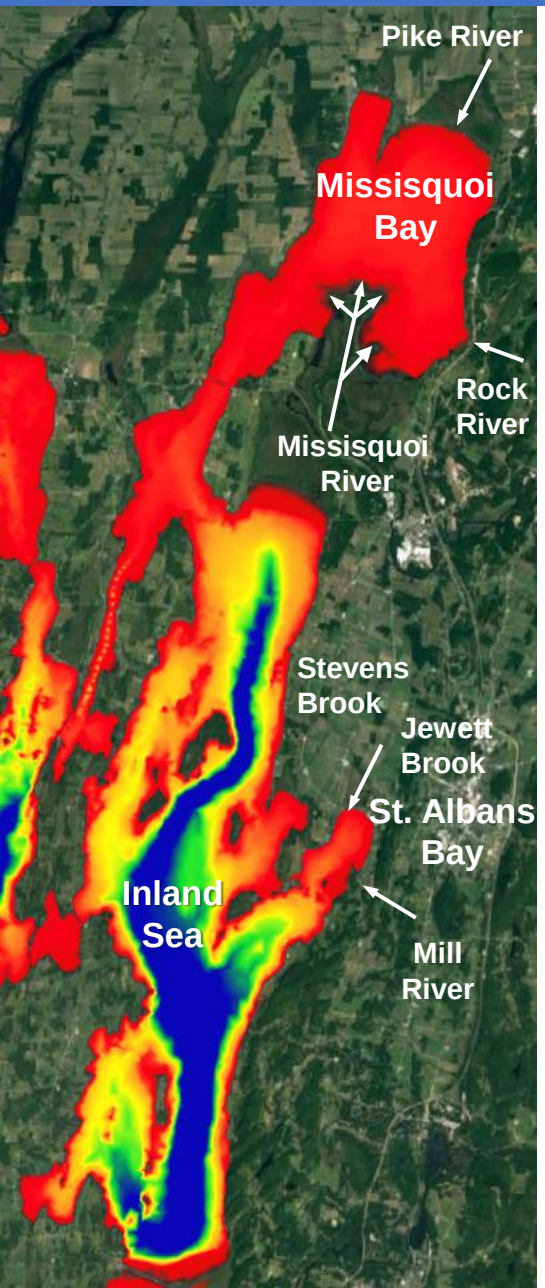
- AEM3D takes bathymetric, meteorological, and hydrological data to simulate lake hydrodynamics
- Lake hydrodynamics are coupled to biogeochemical model
- Model output parameters include:
  - Temperature
  - Dissolved oxygen concentration
  - Nutrient concentrations
  - Chlorophyll *a* concentration



AEM3D Model: Water Quality

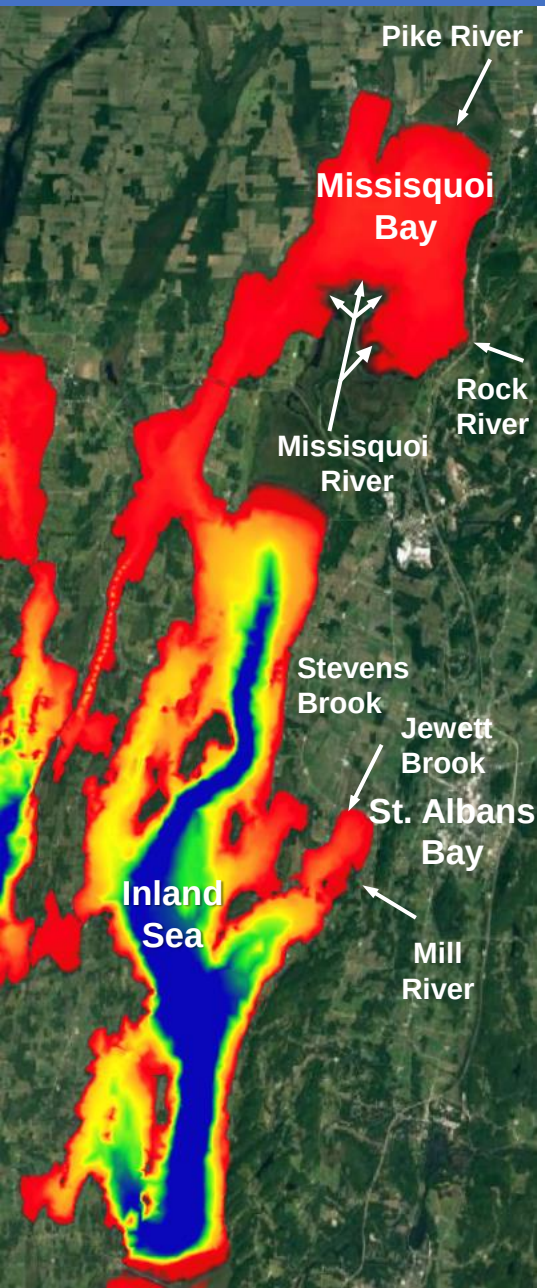


Inland Sea (IS) Model Setup: Water Quality Model

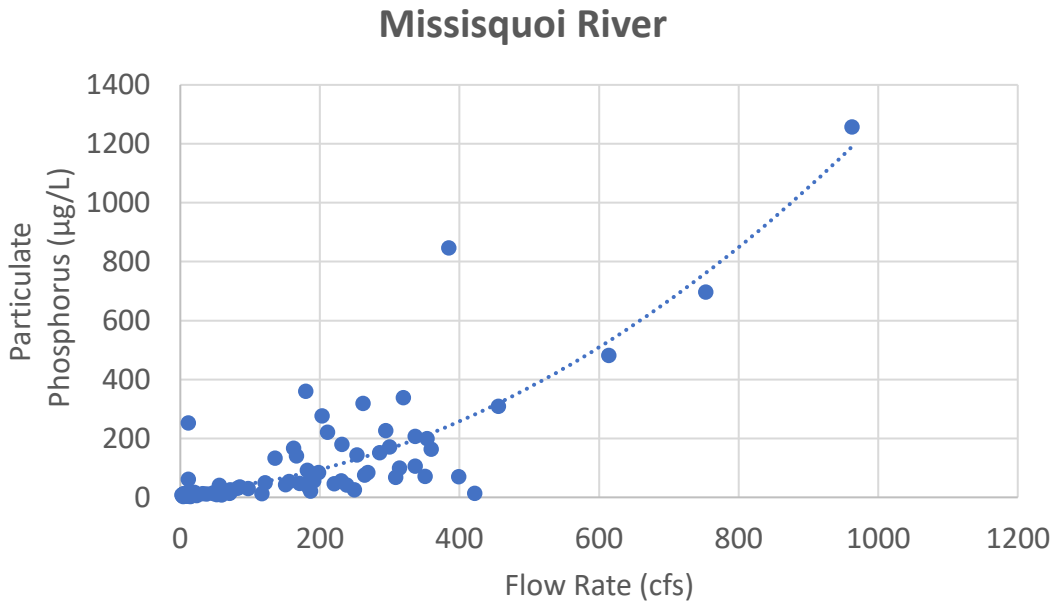


1. Inland Sea (IS) domain defined
    - Four open boundaries defined
    - Five major inflows modeled
    - Inland Sea domain provides results for Missisquoi Bay (MB) and St. Albans Bay (SAB)
2. Implemented spatially varying parameters:
    - Air temperature
    - Solar radiation
    - Wind speed
    - Sediment oxygen demand
    - Sediment nutrient release rates
3. Modeled two phytoplankton groups:
    - Freshwater diatoms
    - Cyanobacteria
4. Extended calibration period to years 2017-2019

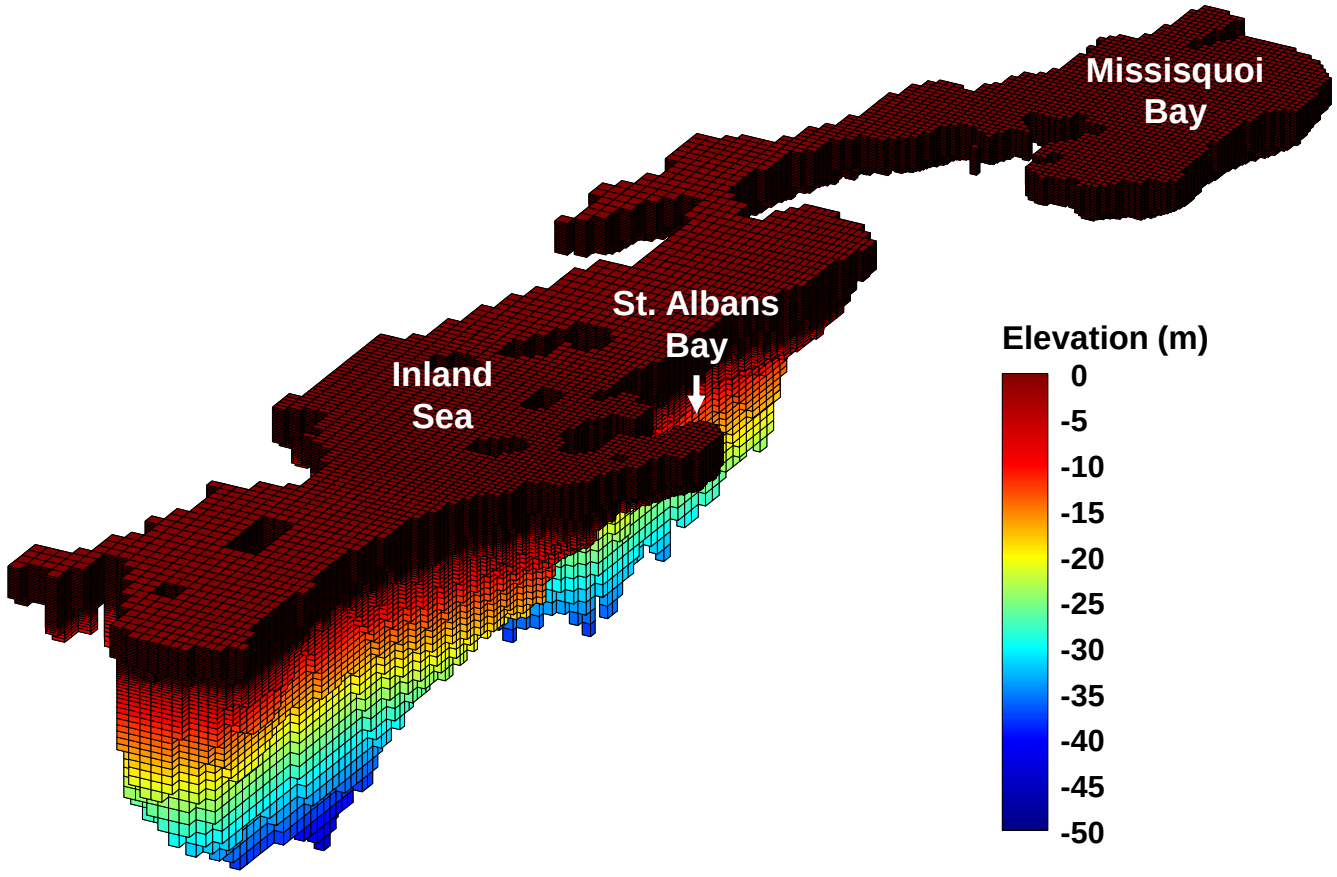
Inflows and External Loading



- High-frequency flow data obtained from USGS for all five inflows
- Inflow nutrient concentrations were determined base on concentration-discharge (C-Q) relationships
  - Flow rate and low-frequency nutrient data fit to determine a C-Q relationship
  - C-Q relationships used to generate high-frequency nutrient input



IS Model Setup: Grid



Horizontal Grid:

200 m x 200 m in bays

Up to 400 m x 400 m in Inland Sea

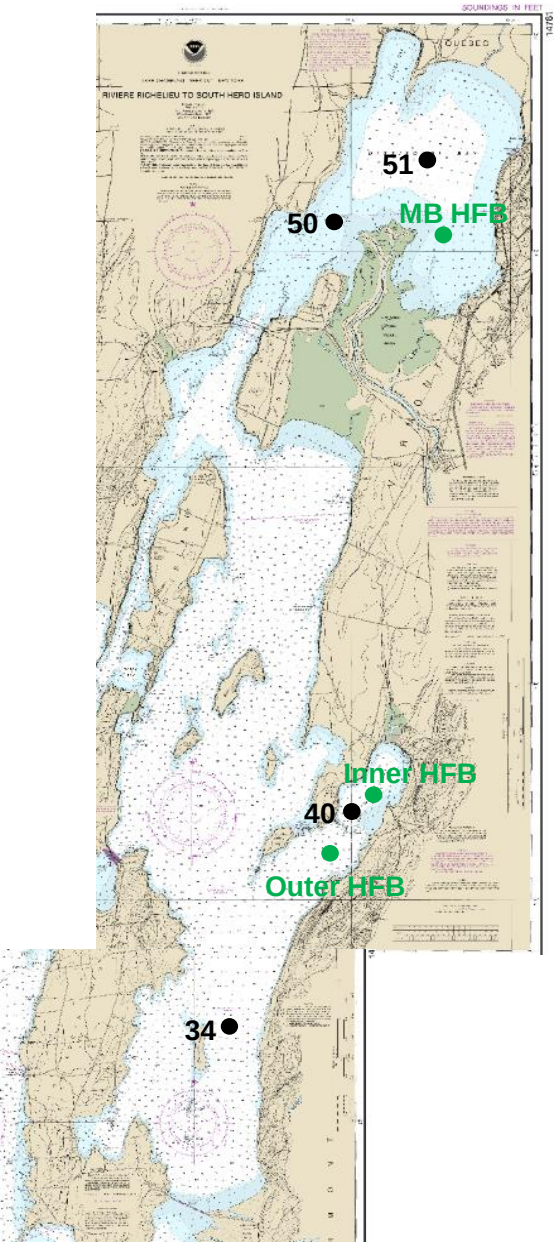
Vertical Grid:

0.25 m at surface and epilimnion

Up to 2.0 m at depth in Inland Sea

Grid stretching retains accuracy while providing run times compatible with long-term simulations

IS Model Calibration: Water Quality Model

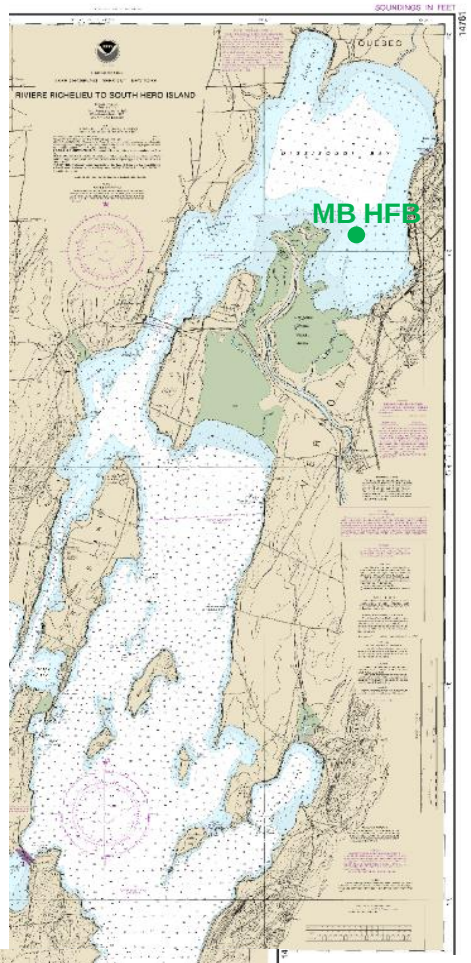


Model Calibration:

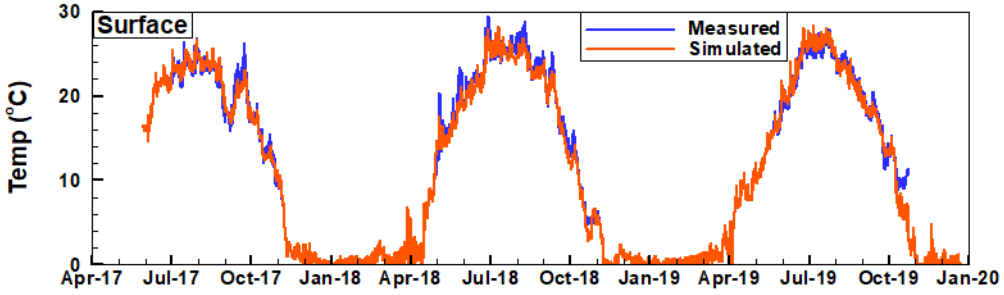
1. Adjusted ice cover parameters (better temperature comparisons in the spring)
2. Adjusted DO parameters including oxygen production and sediment oxygen demand– good agreement at all three locations
3. Improved sediment nutrient release parameters
4. Adjusted phytoplankton parameters to match growth, nutrient uptake, and chlorophyll *a* production

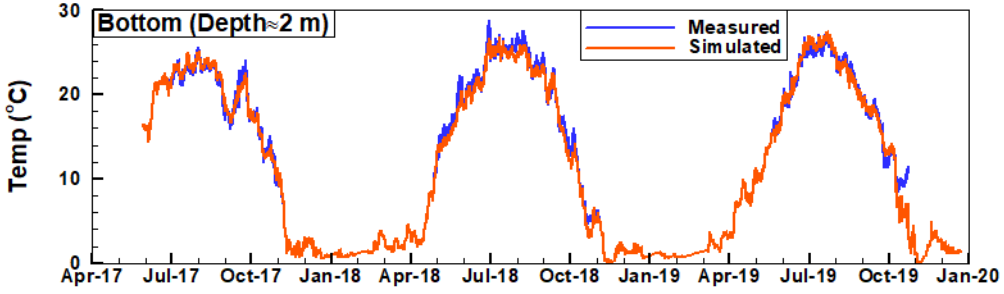
Water quality model calibration was based on previous Missisquoi Bay model calibration (Marti et al.)

Temperature and DO Comparison: MB HFB

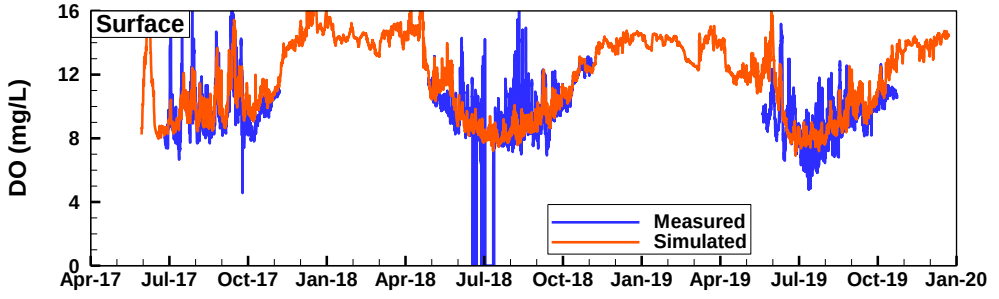


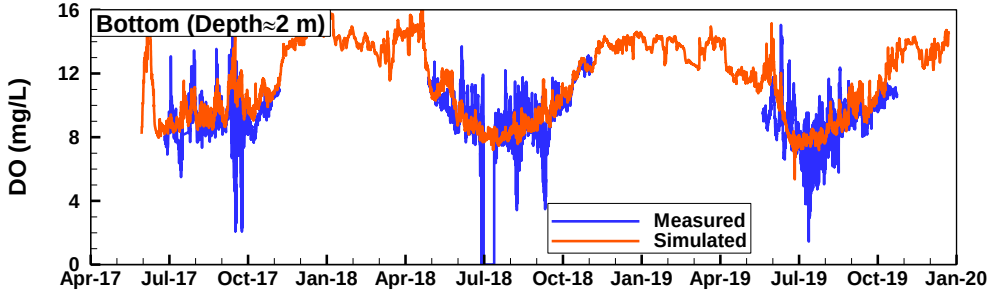
Temperature



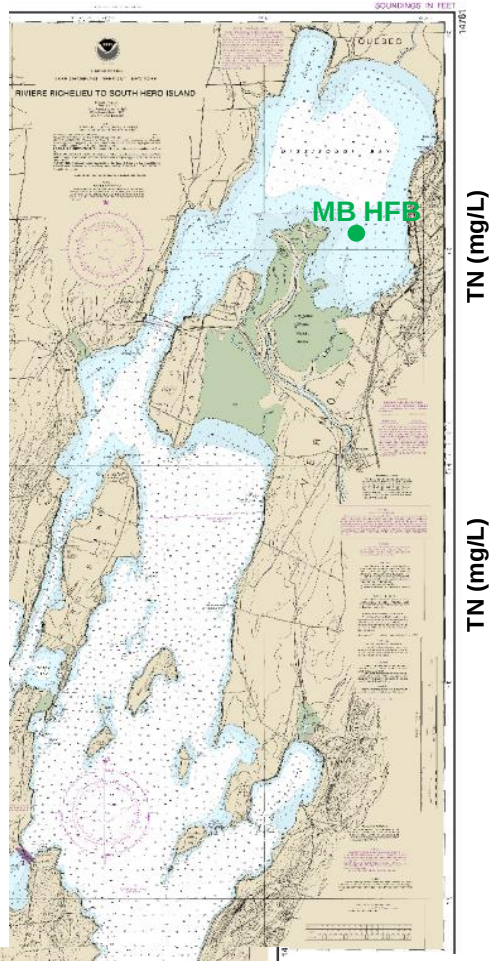


Dissolved Oxygen

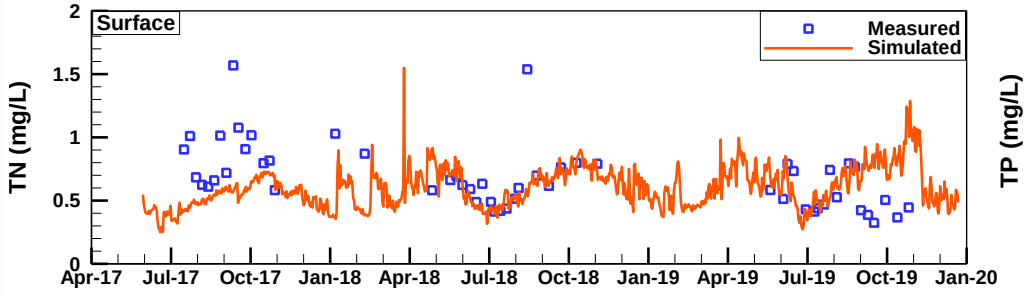


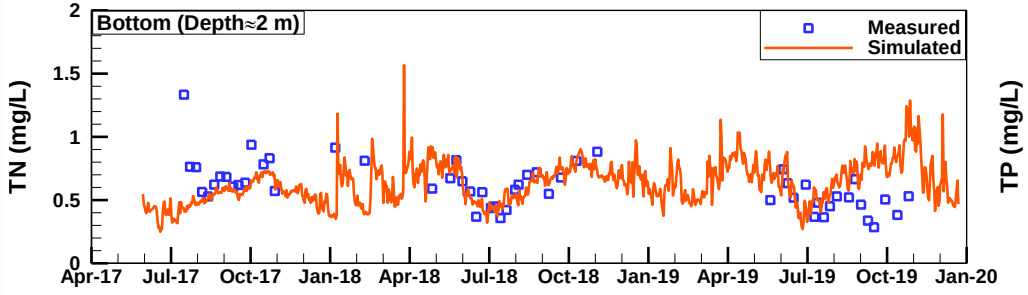


TN, TP Comparison: MB HFB

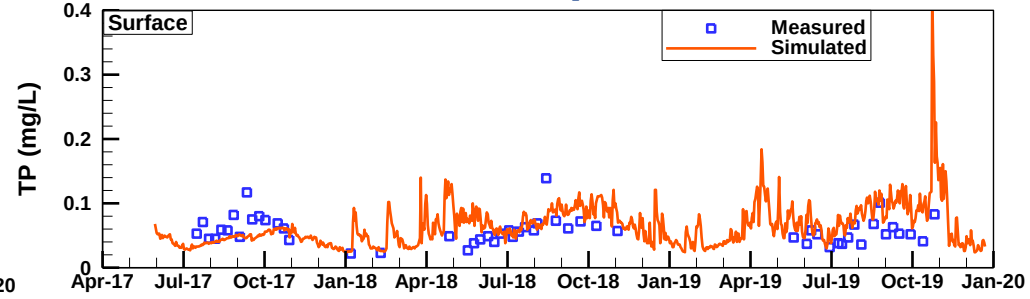


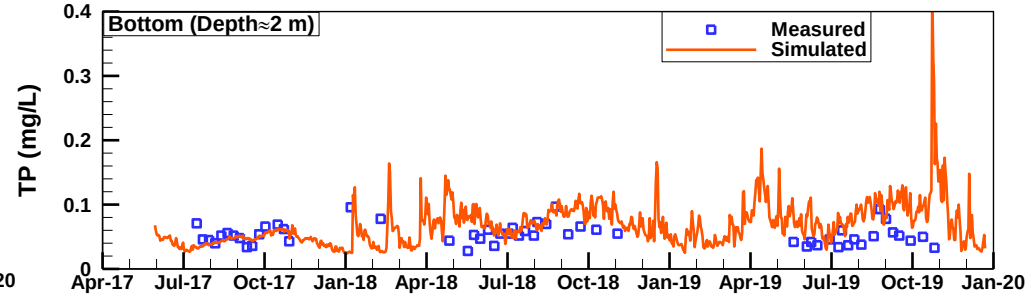
Total Nitrogen



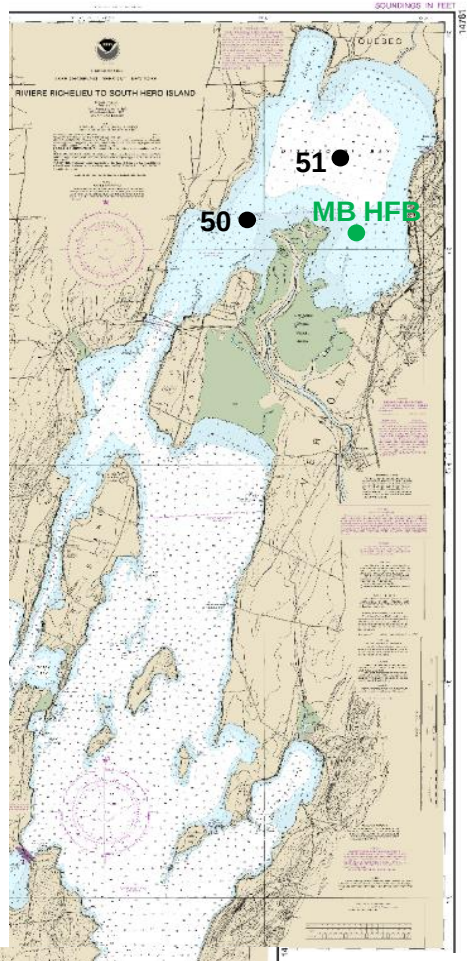


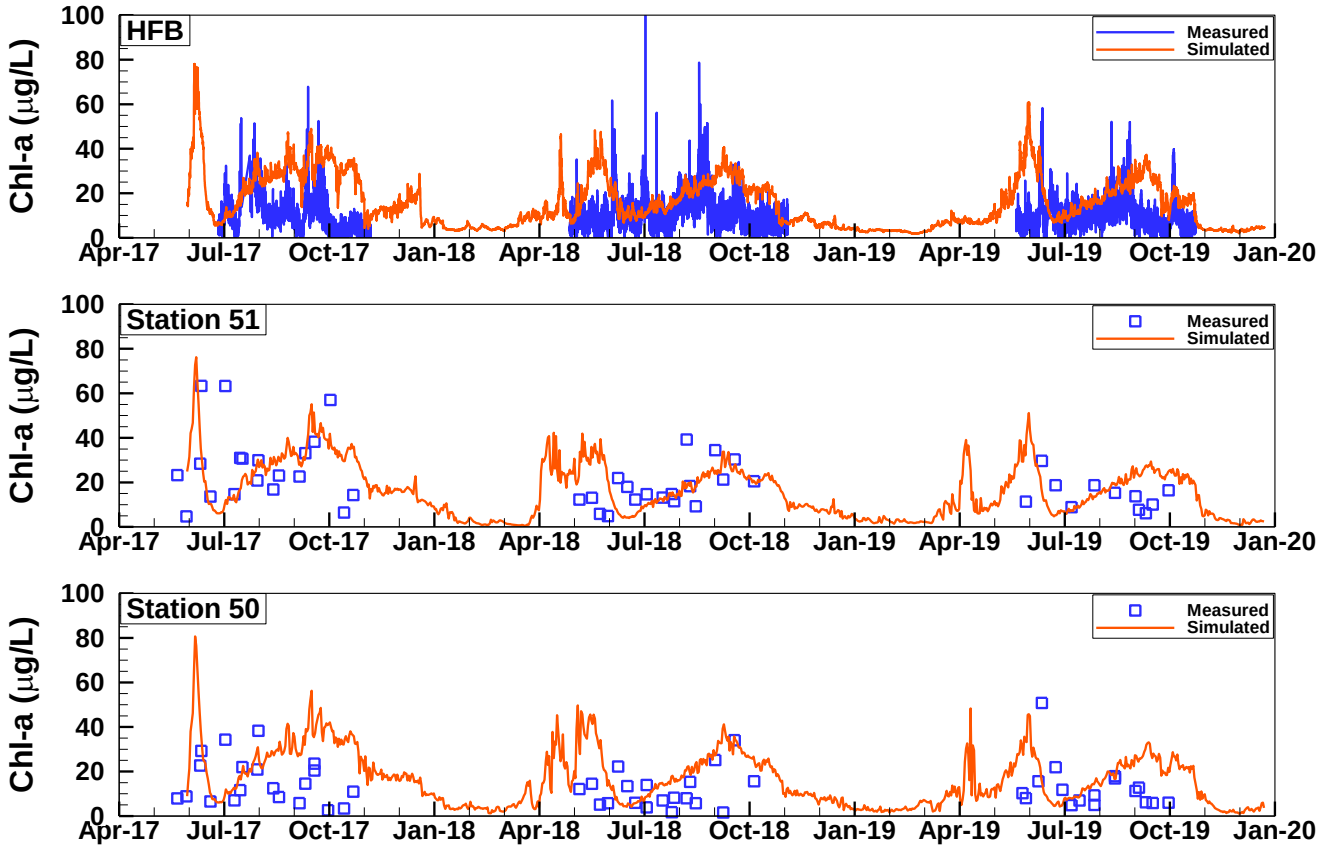
Total Phosphorus



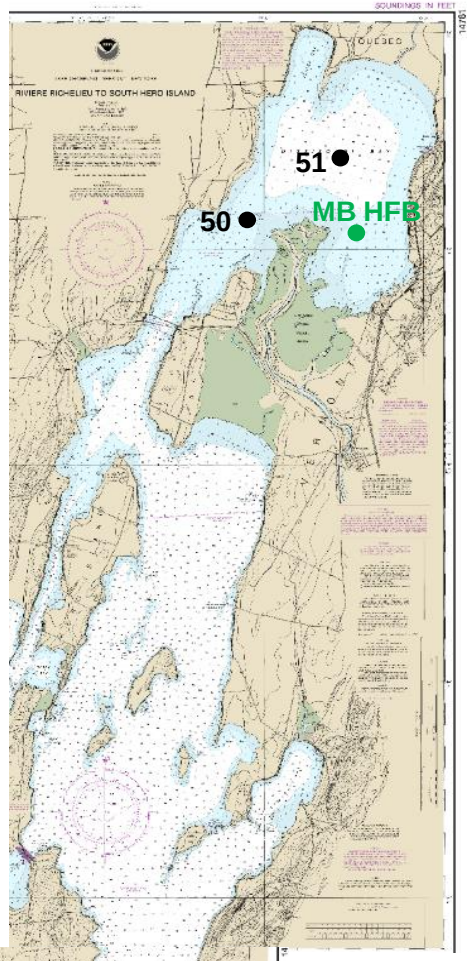


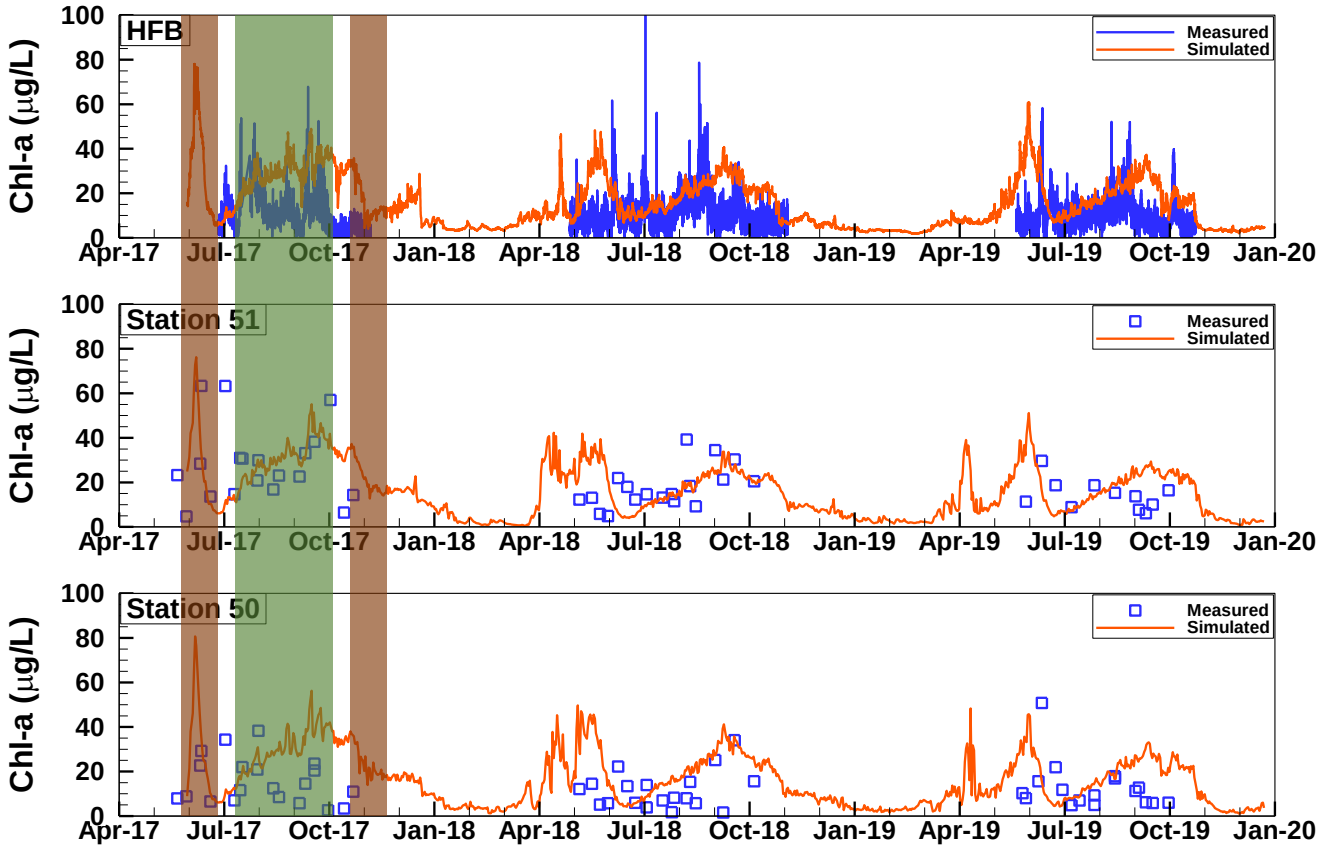
CHLA COMPARISON: MB VARIOUS STATIONS





CHLA COMPARISON: MB VARIOUS STATIONS



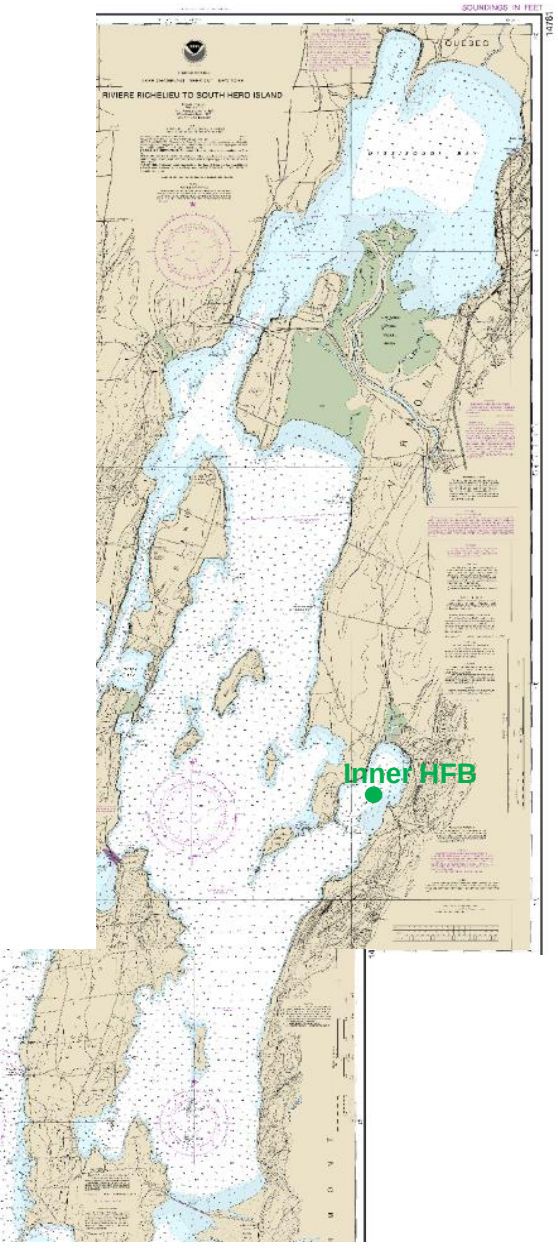


Spring Diatom

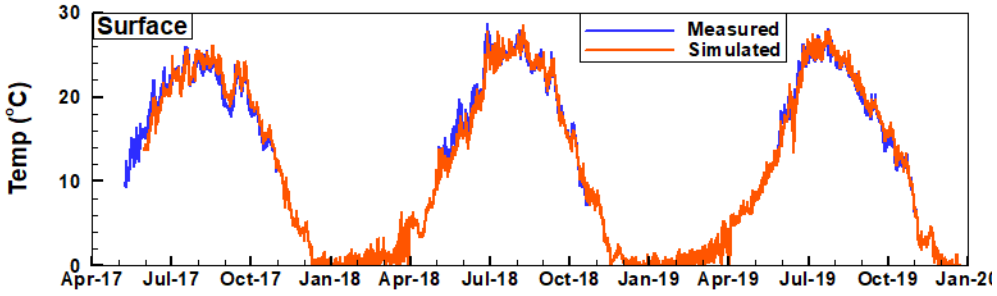
Cyanobacteria

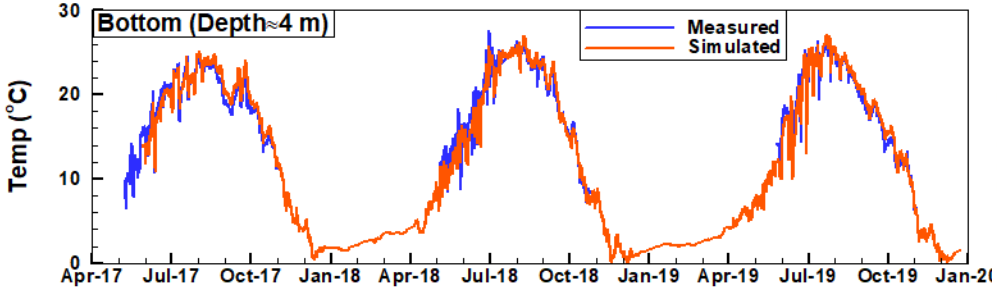
Fall Diatom

Temperature and DO Comparison: Inner SAB HFB

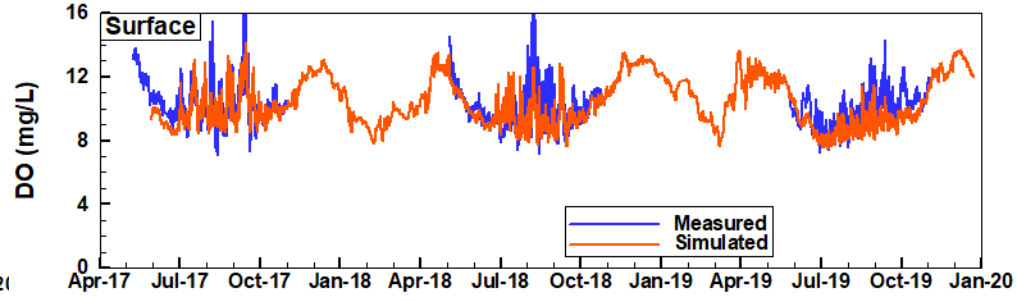


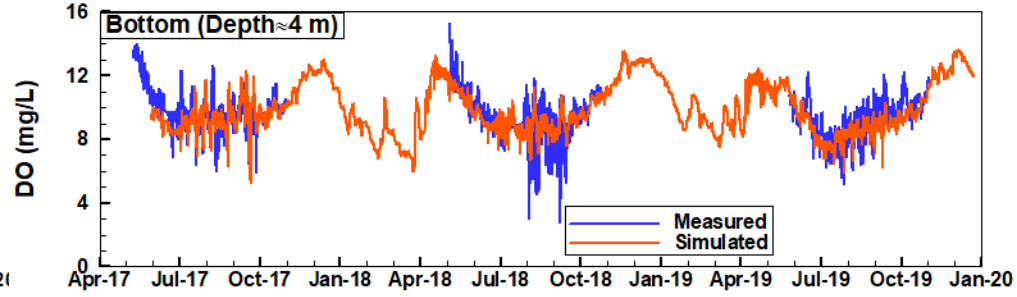
Temperature



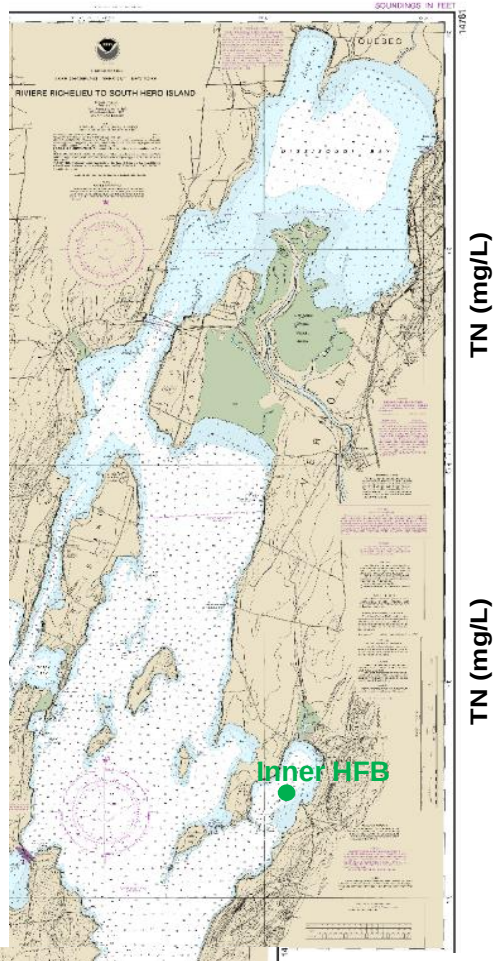


Dissolved Oxygen

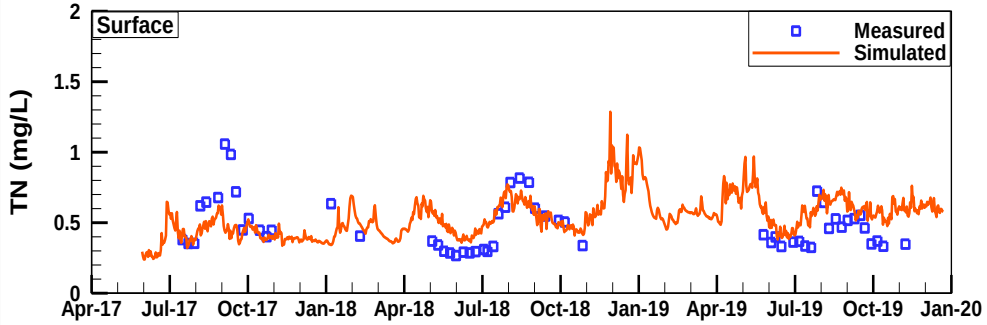


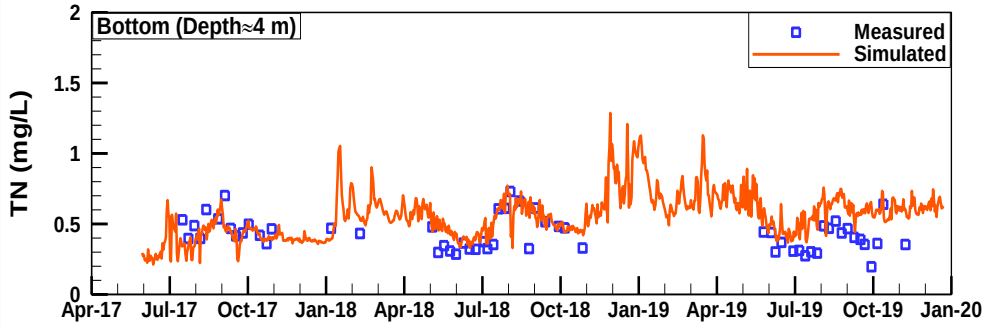


TN, TP Comparison: Inner SAB HFB

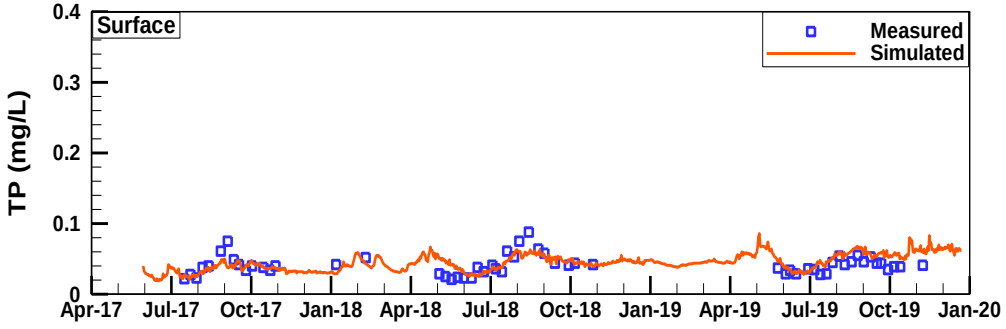


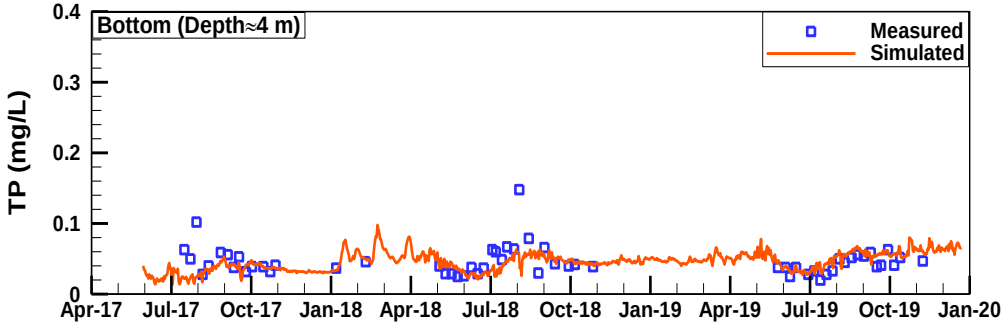
Total Nitrogen



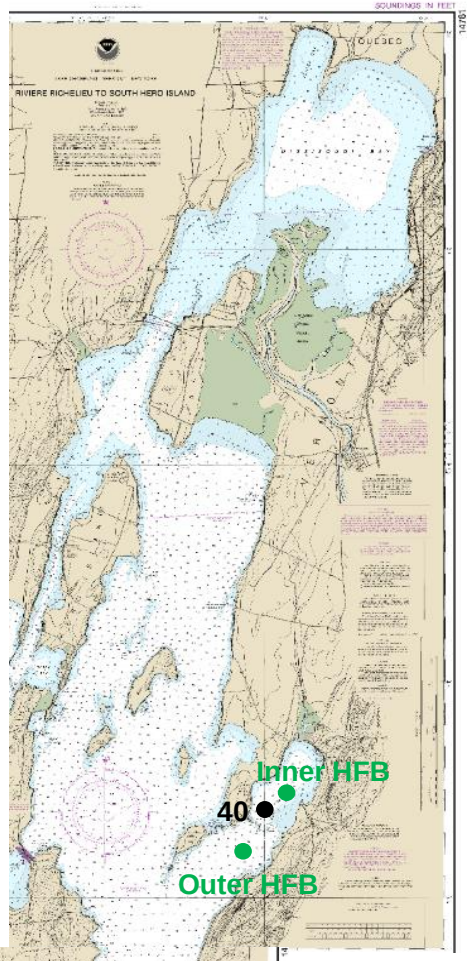


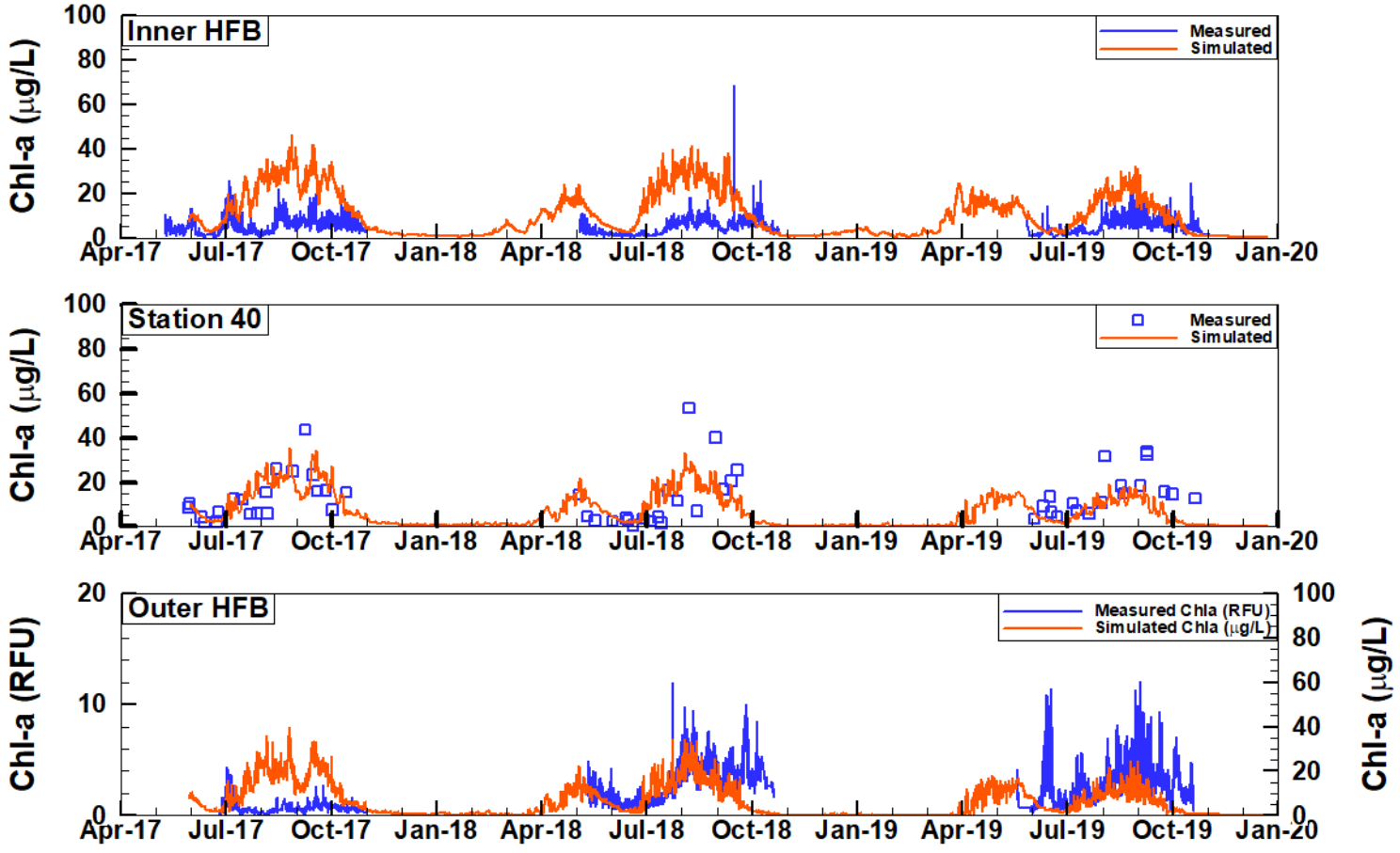
Total Phosphorus



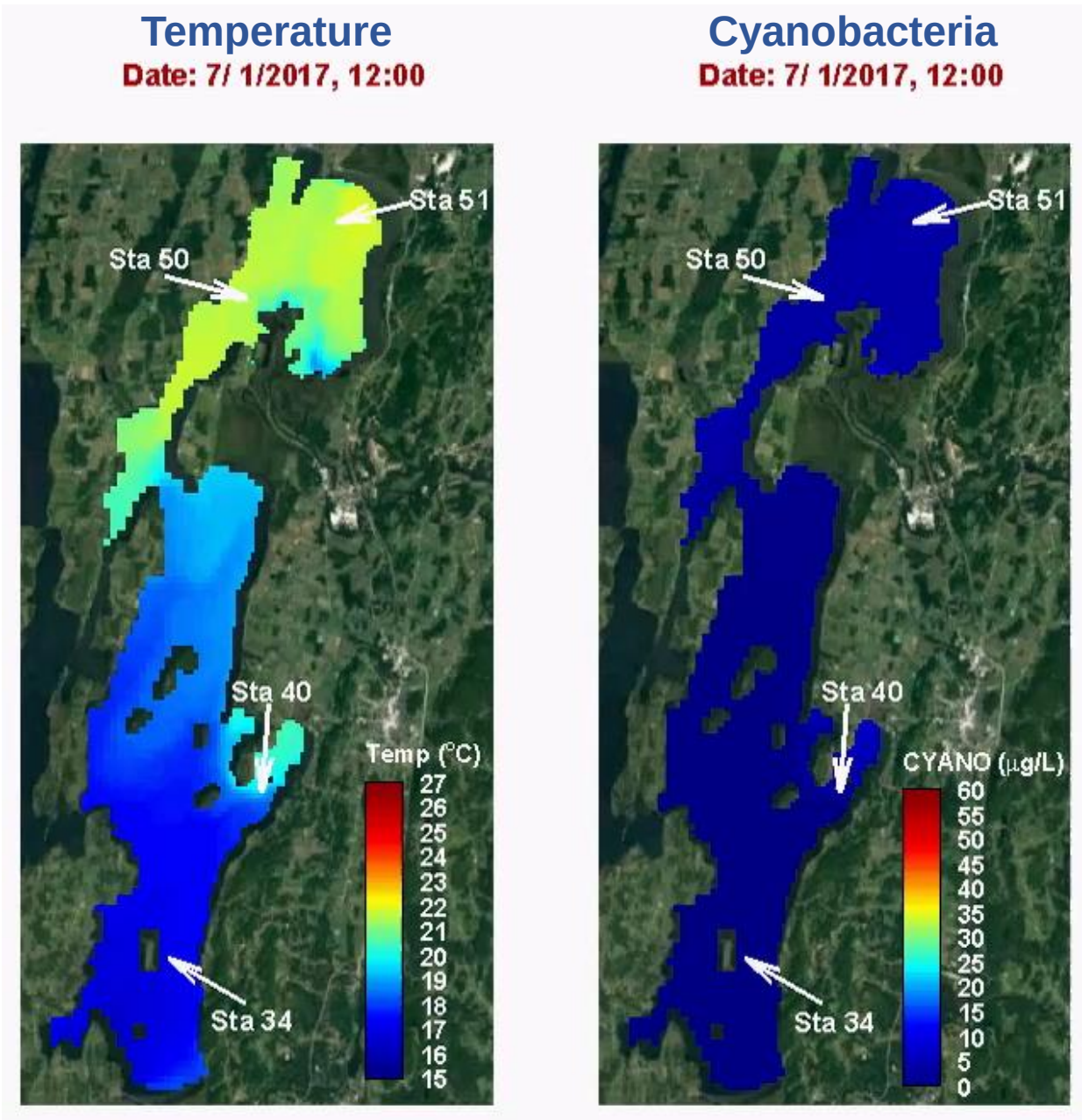


CHLA COMPARISON: SAB VARIOUS STATIONS

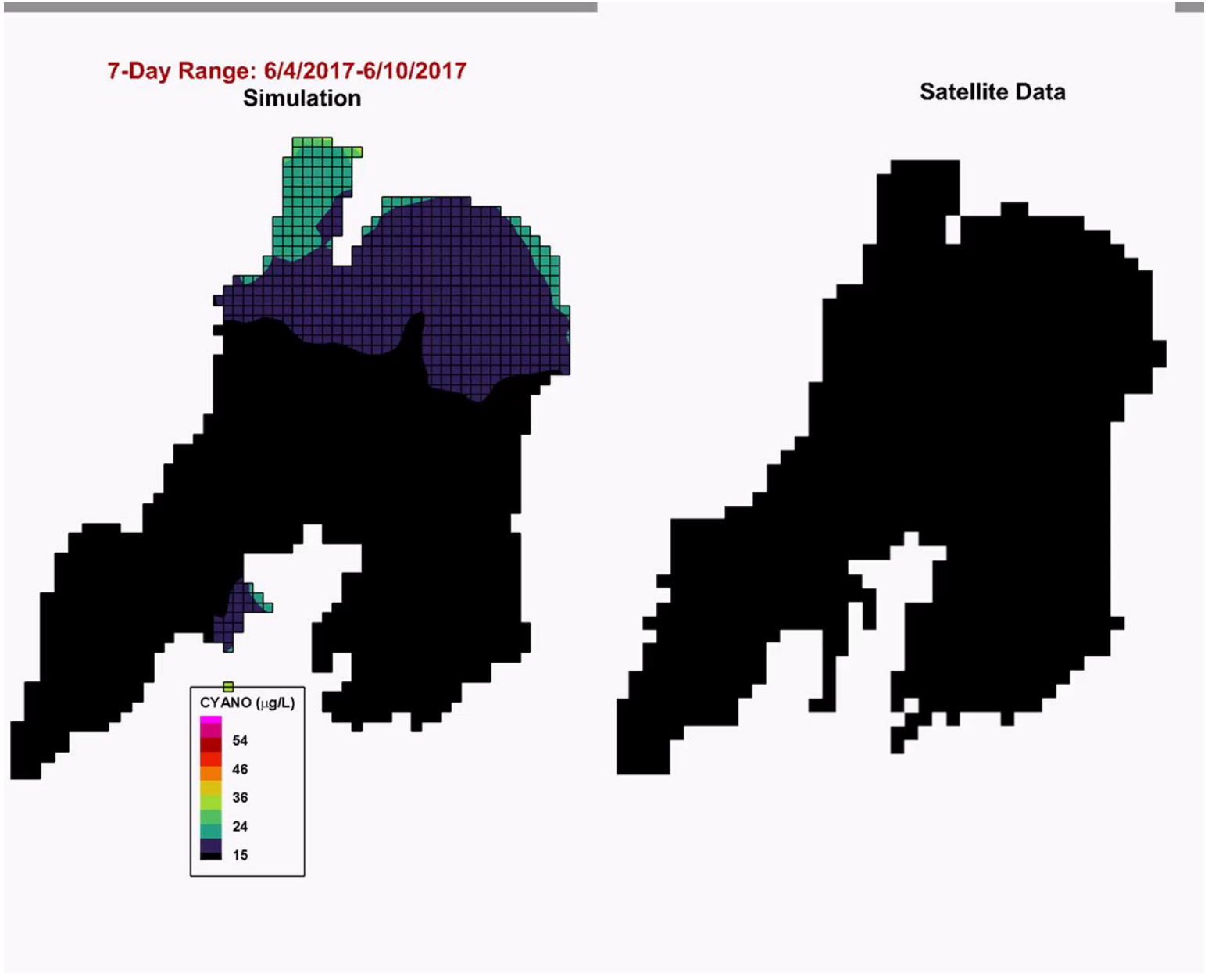




Animation: Weekly Temp vs. Cyanobacteria (2017)



Animation: 7-Day Max Cyano in MB (2018)

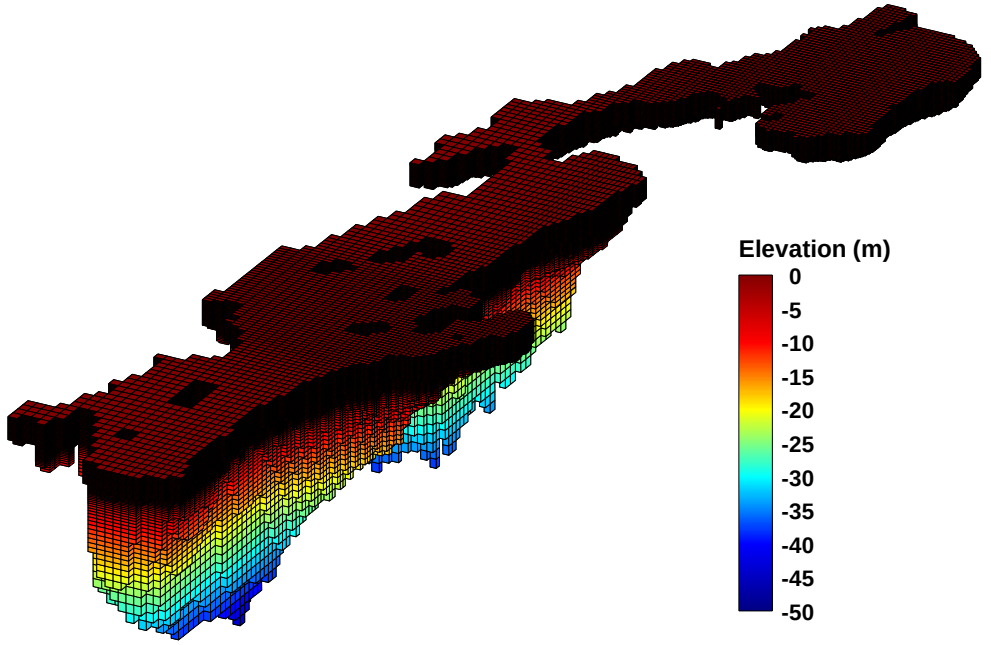


Conclusions

- 3D hydrodynamic and water quality model of Inland Sea successfully calibrated
- Physical and water quality parameters reproduced in MB and SAB with good accuracy
- Timing and spatial distribution of cyanobacteria blooms reproduced accurately in MB and SAB
- Water quality model will be coupled to hydrological, land use, and climate models to simulate a range of possible future conditions

Future Opportunities for Improvement

- Develop whole-lake model to better capture dynamics in Inland Sea and St. Albans Bay
- Develop focused field data measuring plans
  - Sediment characterization
  - Increased monitoring period
  - Additional IS monitoring
  - Ice depth measurements
  - Additional year-round meteorological data
- Enhance calibration of lake ice dynamics
  - More in-lake and meteorological data Nov-May needed
- Upgrade modeling of external loading
  - Incorporate additional C-Q relationships for inflows
  - Enhance modeling of minor inflows into St. Albans Bay



Thank You

Water Quality Solutions

Website:

Wqsinc.com

Email:

Kareem Hannoun

khannoun@wqsinc.com

Imad Hannoun

ihannoun@wqsinc.com