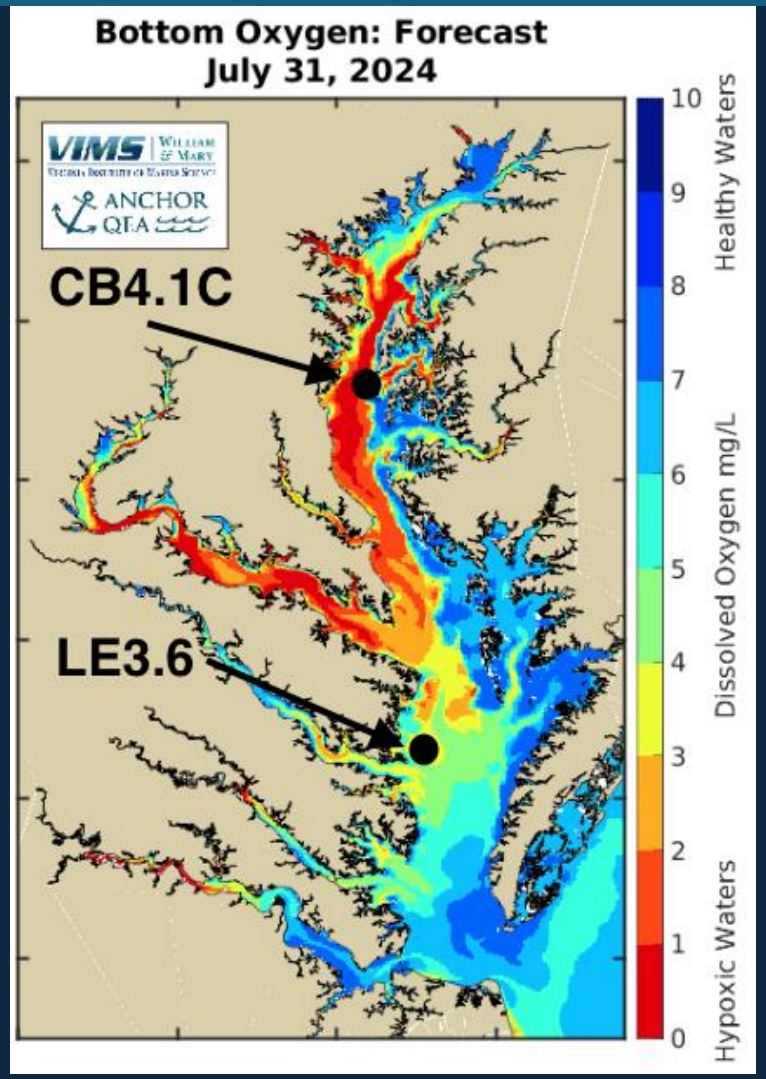
Improving Hypoxia Forecast within the Chesapeake Bay by refining a Primary Production Model

Sergey Dutt
Luther College
Dante M.L. Horemans, Pierre St-Laurent, & Marjorie A.M. Friedrichs

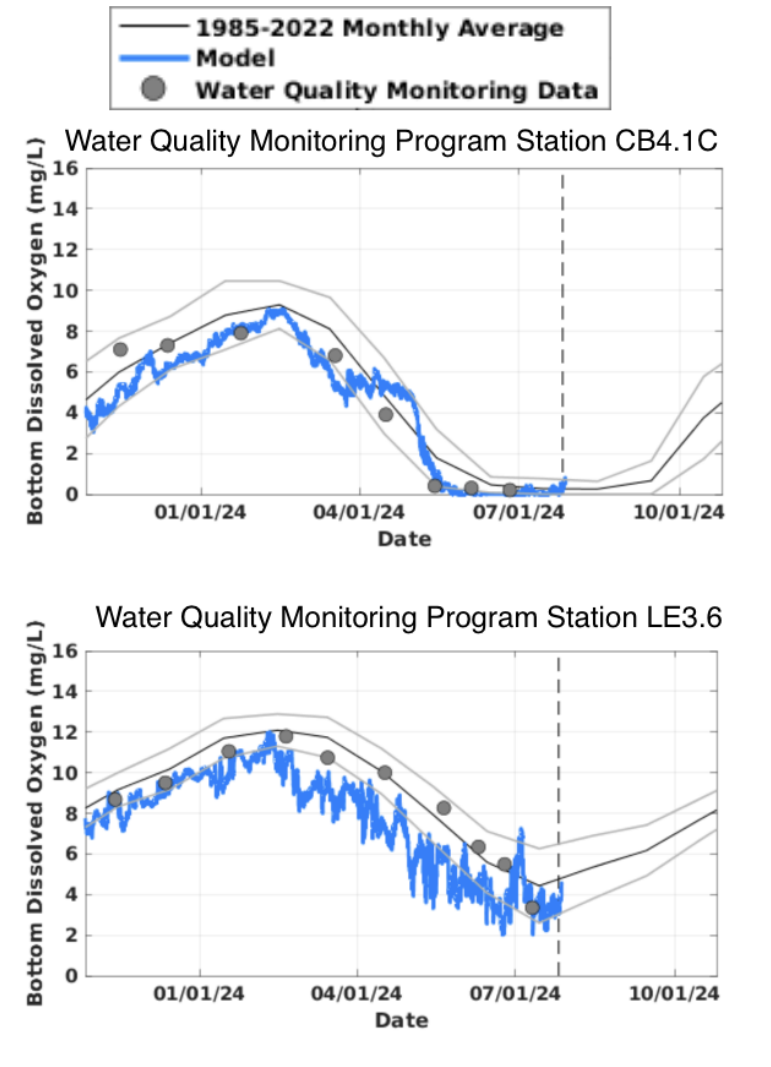
Hypoxia is an issue in the Chesapeake Bay

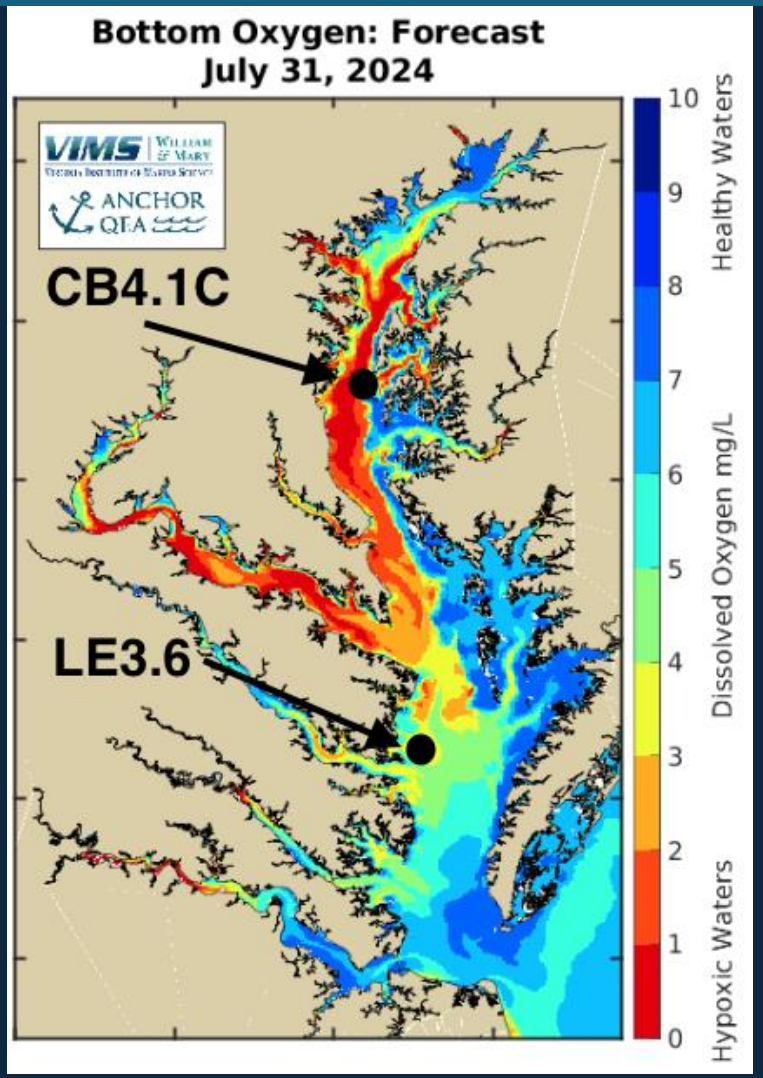
Hypoxia: when the concentration of dissolved oxygen (< 2 or 3 mg O_2 L^{-1}) is low enough to harm aquatic life

https://www.vims.edu/cbefs



Hypoxia model skill varies in time and space



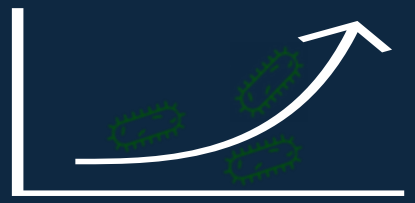


Complex mechanisms affecting hypoxia

- Air-Sea Exchange 
- Ecosystem Respiration 
- Primary Production 

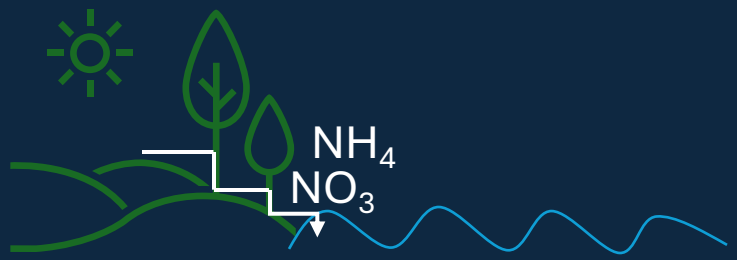
Primary production

- Primary production: the rate that inorganic carbon is converted into organic biomass (photosynthesis)



Phytoplankton Growth Rate

Sunlight



Nutrients

Respiration

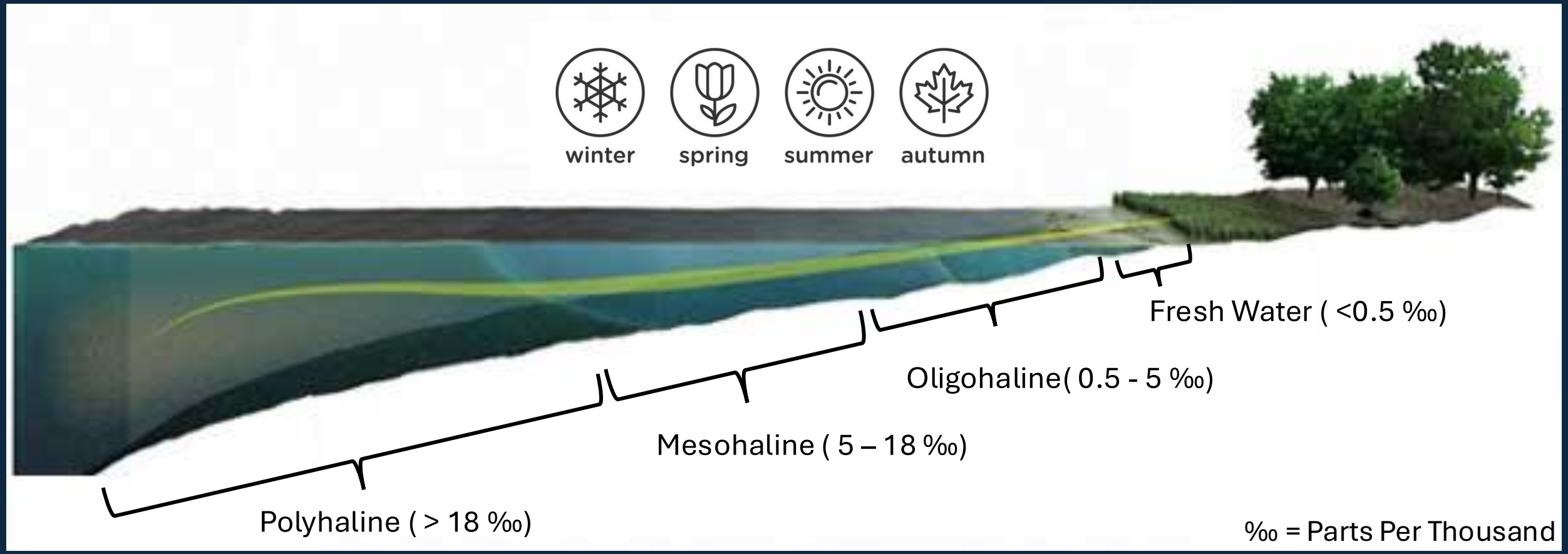
Objective

Understand seasonal and spatial variability in the model skill, focusing on primary production

Hypothesis:

- Various seasons and regions in the Chesapeake Bay come with unique phytoplankton characteristics that require their own set of model assumptions

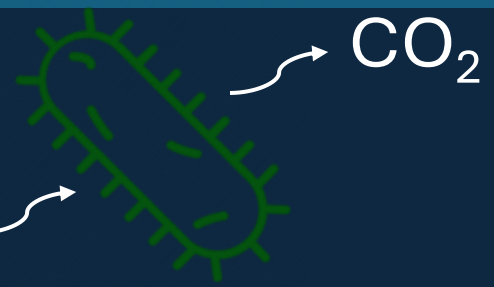
Methods: seasons and regions



Methods: observations

- We used a primary production dataset that covers the Chesapeake Bay between 1984-2009 (>13,000 data points)
- ^{14}C incubation (primary production) under saturated light conditions and observations of the environmental conditions (salinity, nutrients, temp. Chl-a)

Methods: primary production model



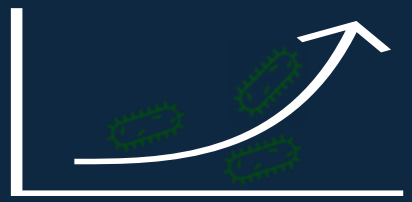
Primary production

Constant respiration

Linearity in phytoplankton abundance (Chl-a * C:Chl-a)

$$\partial_t P = \mu_{\max}(1 - \gamma_P)\left(L_{\mathrm{NO_3}} + L_{\mathrm{NH_4}}\right)P$$

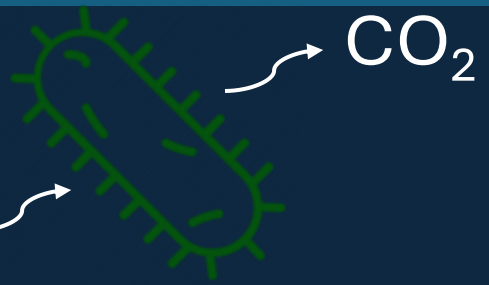
Max. algal growth rate (temperature dependent)



Nitrogen limitation

Methods: model experiments

Primary production



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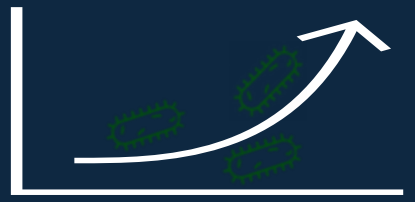
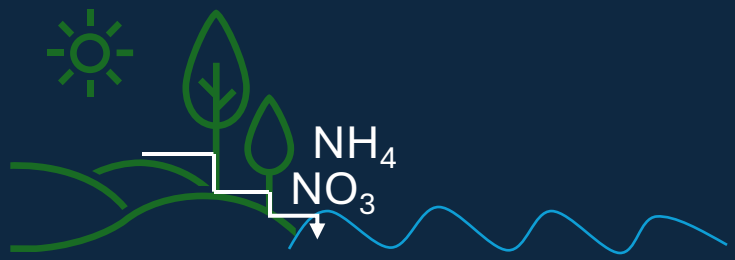


Nitrogen limitation

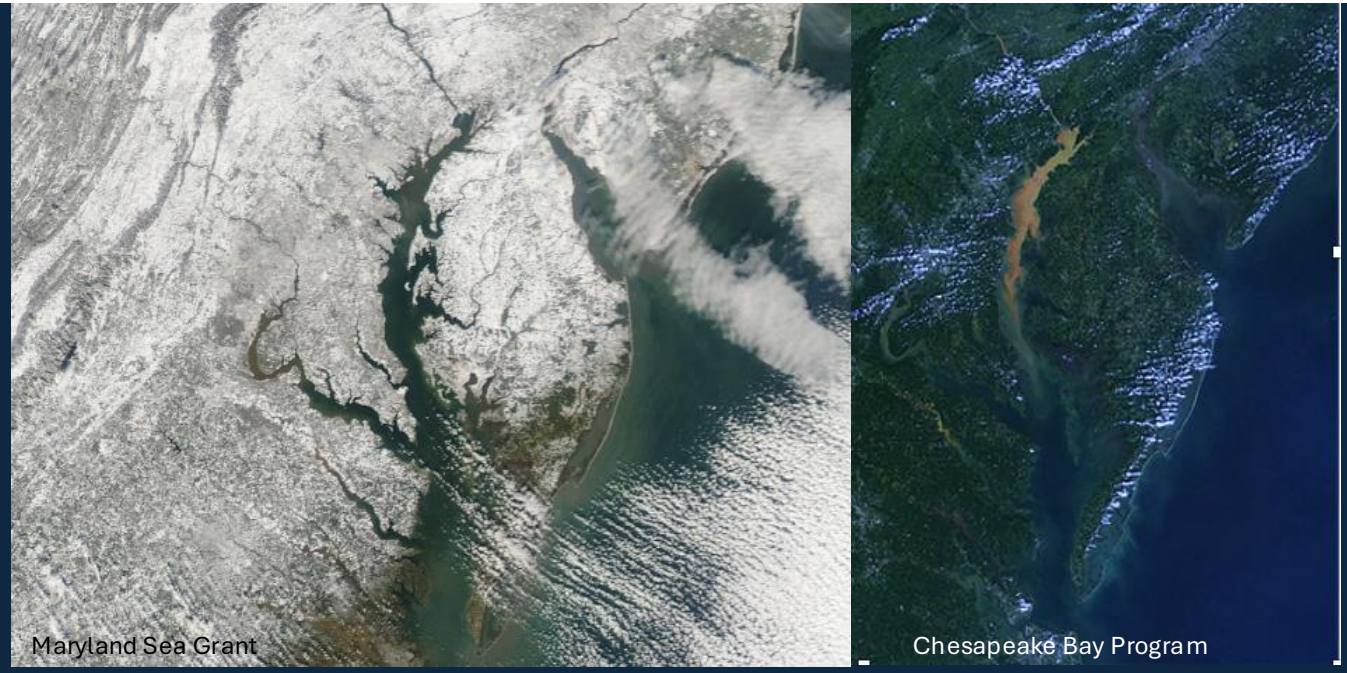


Methods: tuning C:Chl-a ratio

C:Chl-a is tuned in all model experiments

Phytoplankton Abundance

$$\partial_t P = \mu_{\max}(1-\gamma_P)\left(L_{NO_3}+L_{NH_4}\right)P$$



Methods: adjusting max. algal growth rate

$$\partial_t P = \mu_{\max}(1-\gamma_P)\left(L_{\mathrm{NO_3}} + L_{\mathrm{NH_4}}\right) P$$

Max. algal growth rate

- Model 1 $\mu_{\max}(T) = \max\left[4\ \mathrm{day}^{-1}, 0.55 e^{\psi_{\mathrm{pmax}} \cdot T}\ \mathrm{day}^{-1}\right]$

- Model 2 $\mu_{\max}(T) = \mu_{00}\mu_{01}^{T}$

Methods: calibrating nutrient limitation

$$\partial_t P = \mu_{\max}(1-\gamma_P)\left(L_{\mathrm{NO_3}} + L_{\mathrm{NH_4}}\right) P$$

Nutrient limitation

$$L_{\mathrm{NO_3}} = \frac{NO_3}{NO_3 + K_{\mathrm{NO_3}}} \frac{1}{1 + NH_4/K_{\mathrm{NH_4}}}$$

- Model 1: reference values

$$L_{\mathrm{NH_4}} = \frac{NH_4}{NH_4 + K_{\mathrm{NH_4}}}$$

- Model 3: tuned values

Methods: summary of model experiments

Phytoplankton Abundance

- Calibrated during all experiments

Max. Algal Growth Rates

- Model 1: reference growth rate model
- Model 2: Eppley based growth rate model

Nutrient Limitations

- Model 1: reference values
- Model 3: calibrated values

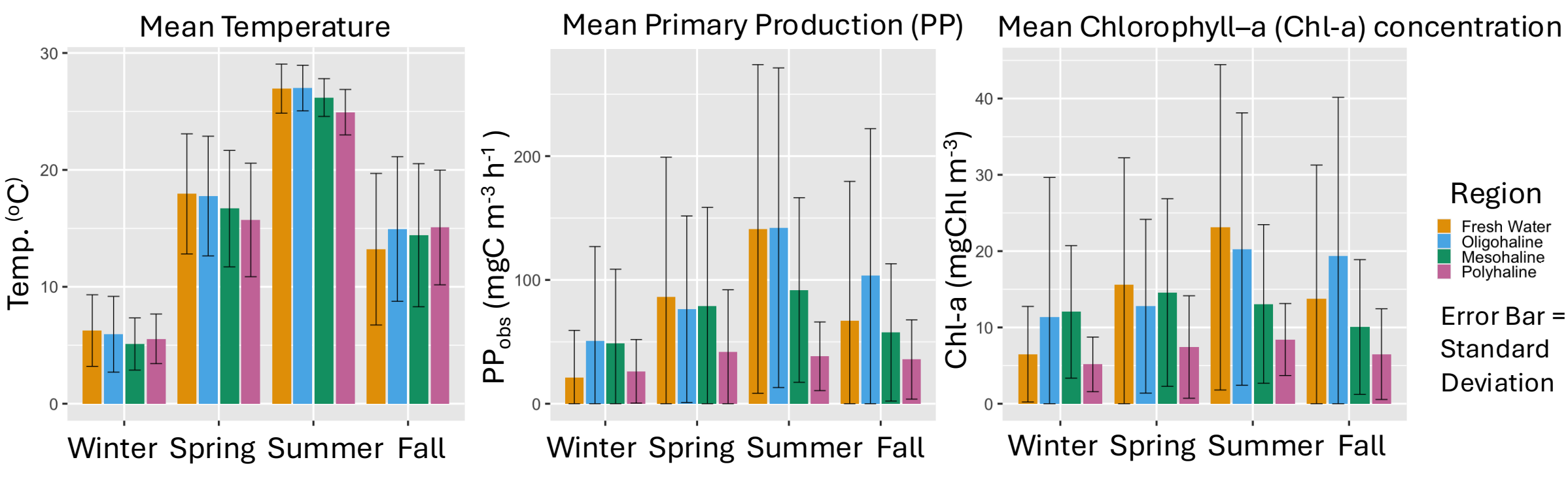
Methods: model skill metrics

- We calculated model skill for each experiment to evaluate if different parameter values improve the model

Model Skill

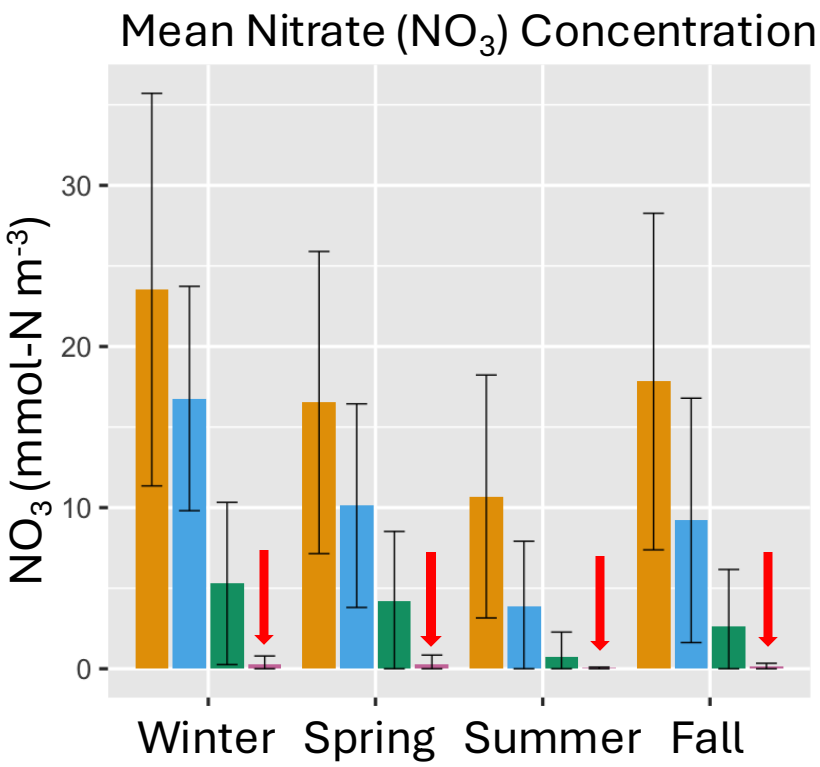
- Correlation
- Bias (average error)
- Root Relative Squared Difference (RRSD)

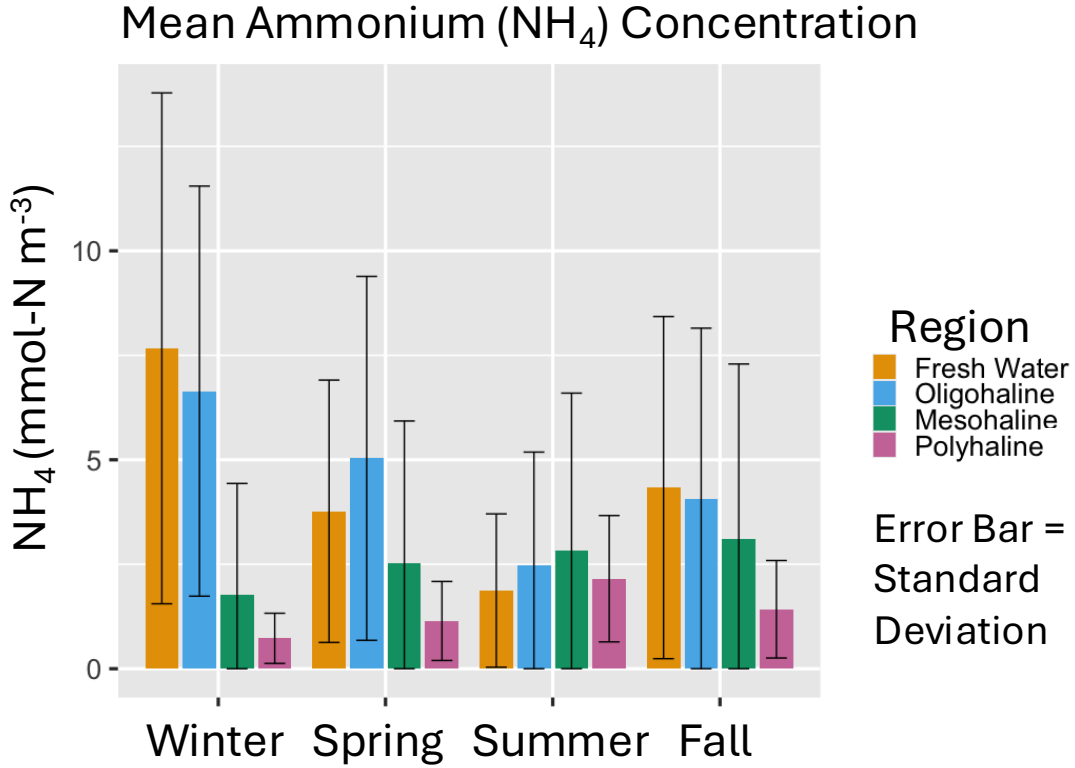
Results: environmental observations



- Observations exhibit a seasonal pattern
- Primary production and Chl-a follow similar patterns

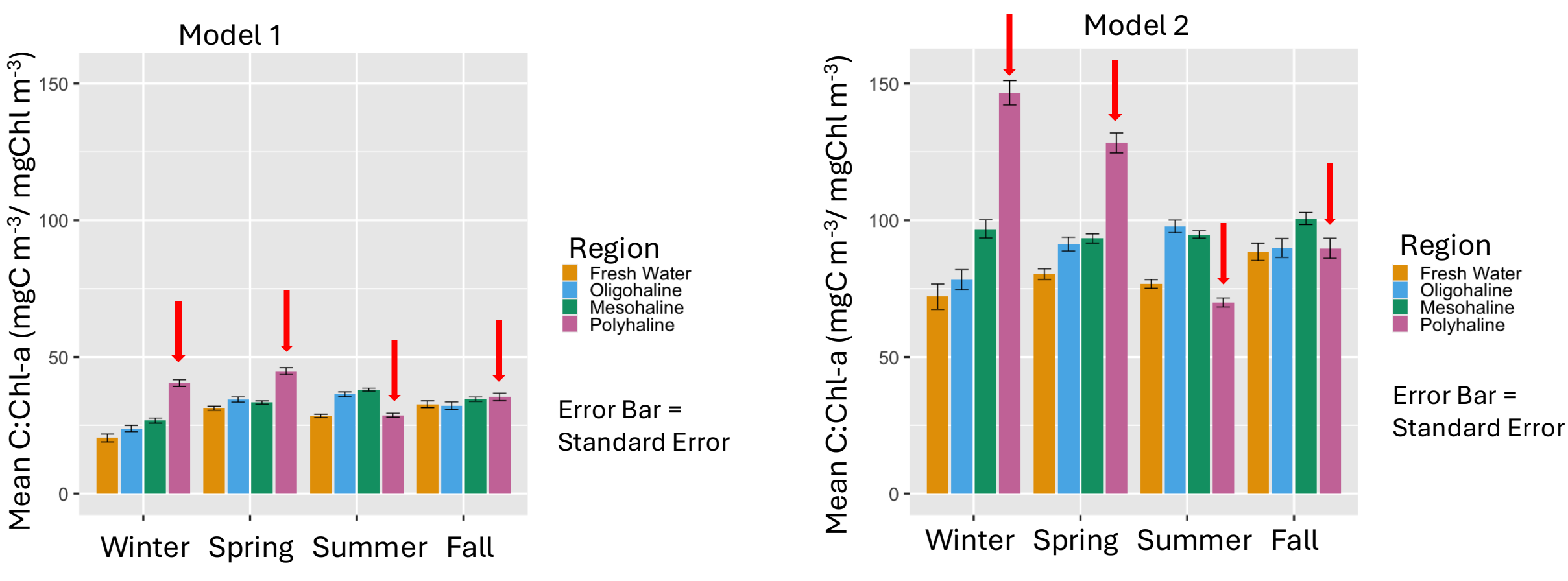
Results: environmental observations





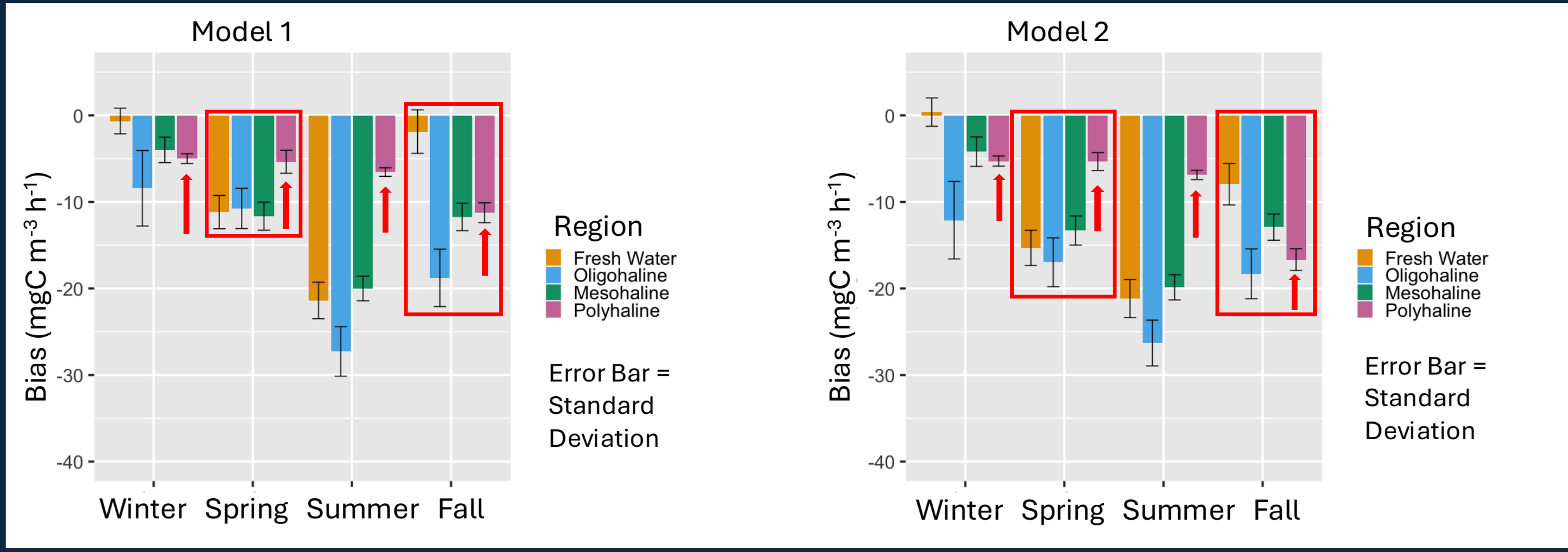
- Observations exhibit a regional pattern
- We expect NO_3 limitation only in the polyhaline (< 0.5 mmol-N m^{-3})

Results: calibrated C:Chla ratios



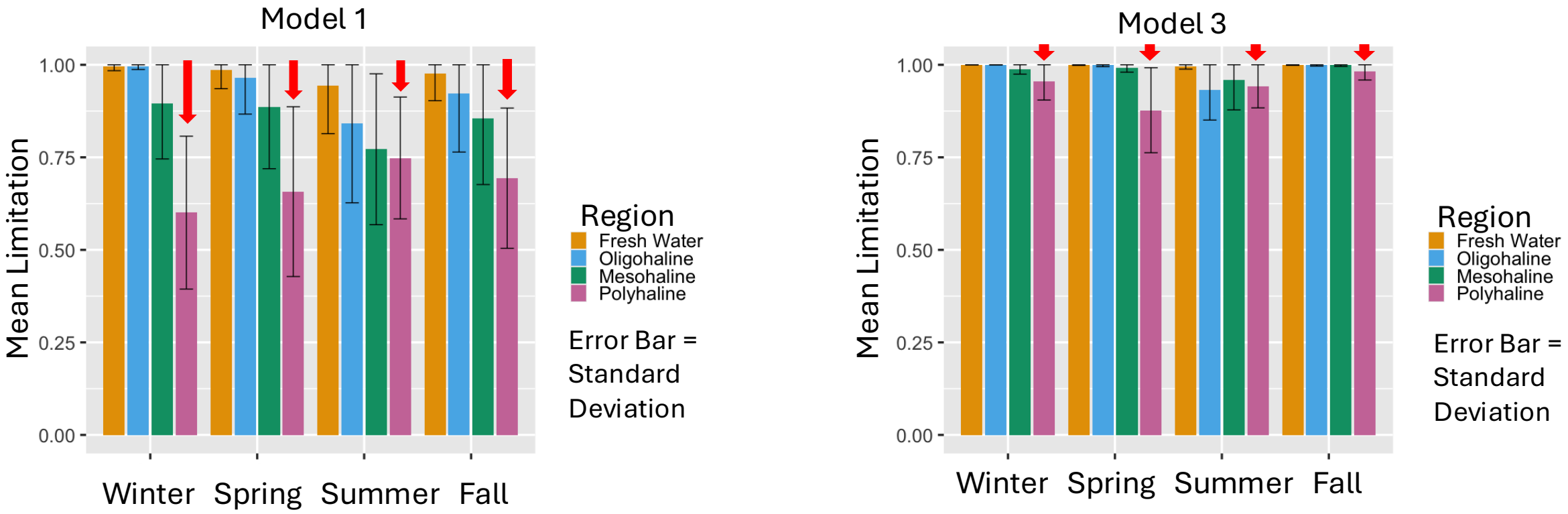
- Polyhaline region has a seasonal pattern

Results: calibrated C:Chla ratios model skill



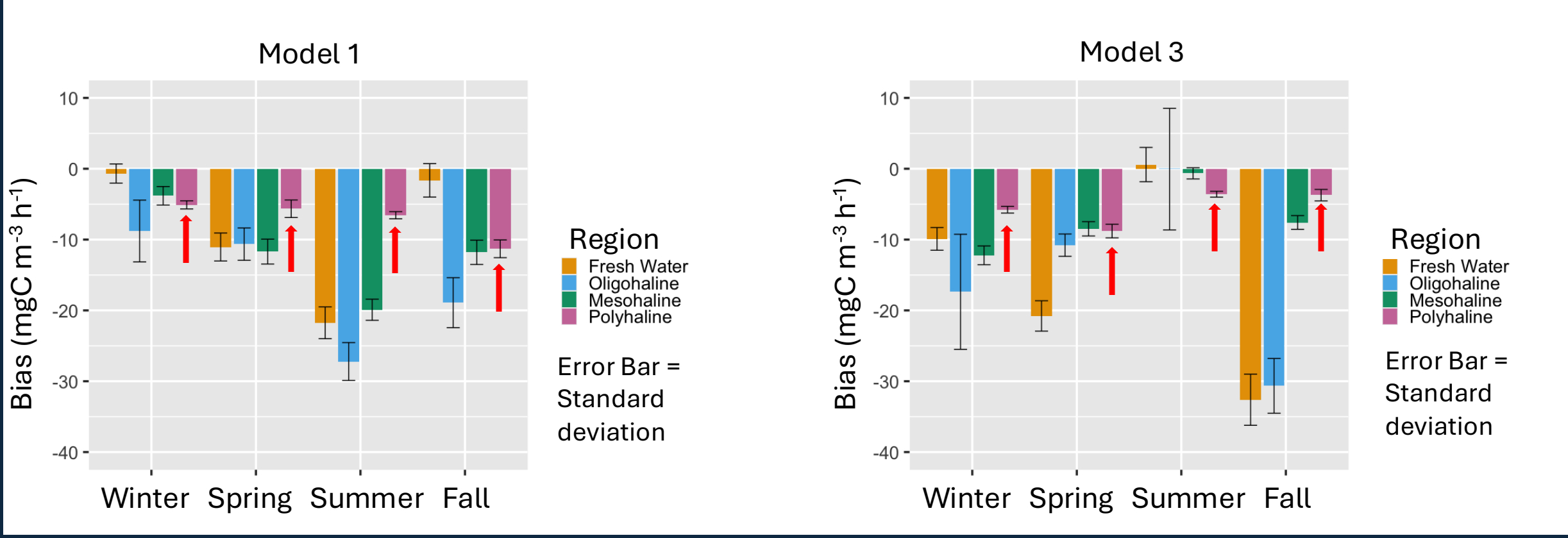
- Other tests showed little to no difference between the growth rates

Results: nutrient limitations



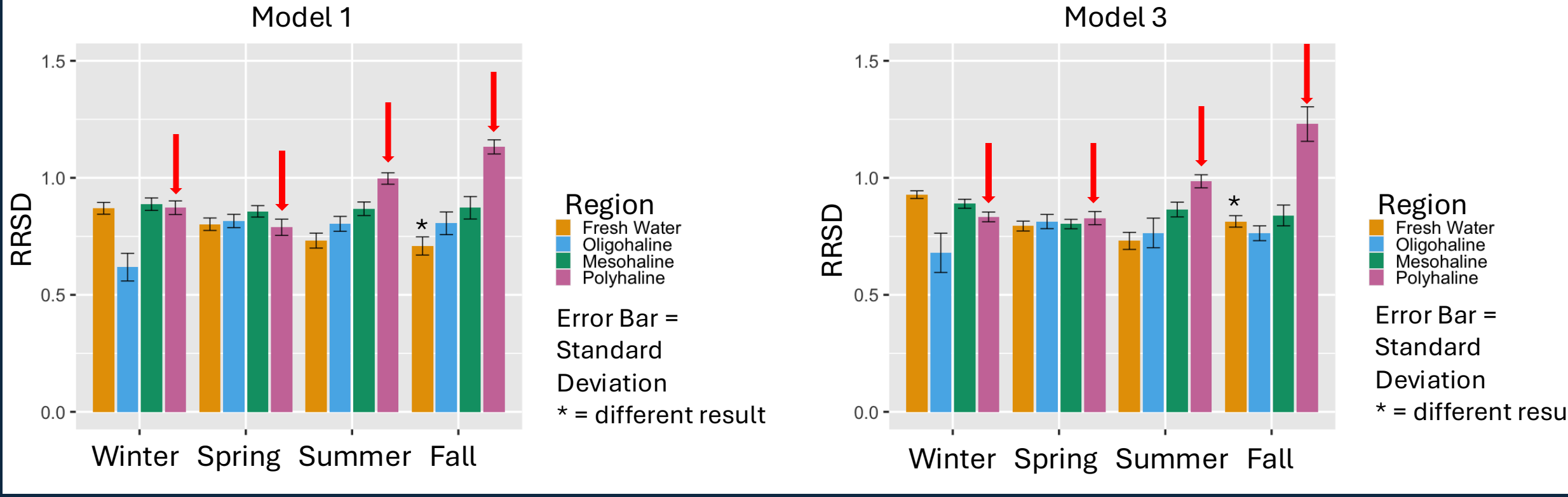
- Current model underestimates PP in the polyhaline region

Results: calibrated K_{NO3} & K_{NH4} model skill



- Model 1 and 2 show different bias in summer and fall

Results: calibrated K_{NO3} & K_{NH4} model skill



- Model 1 and 2 show similar Root Relative Squared Difference

Conclusion

- Calibrated Values did vary from across seasons and regions
- The current primary production model has low sensitivity to changes in model parameters
- We did not find strong indicators that we have to change the max. algal growth rate and nitrogen dependence in our current primary production model

Acknowledgments

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Further Research

- Add a phosphorous limitation
- Calibrate the model focusing on regions with different Total Suspended Solids (TSS)