Simulating ecosystem dynamics and marine biogeochemical cycles with multiple plankton functional types

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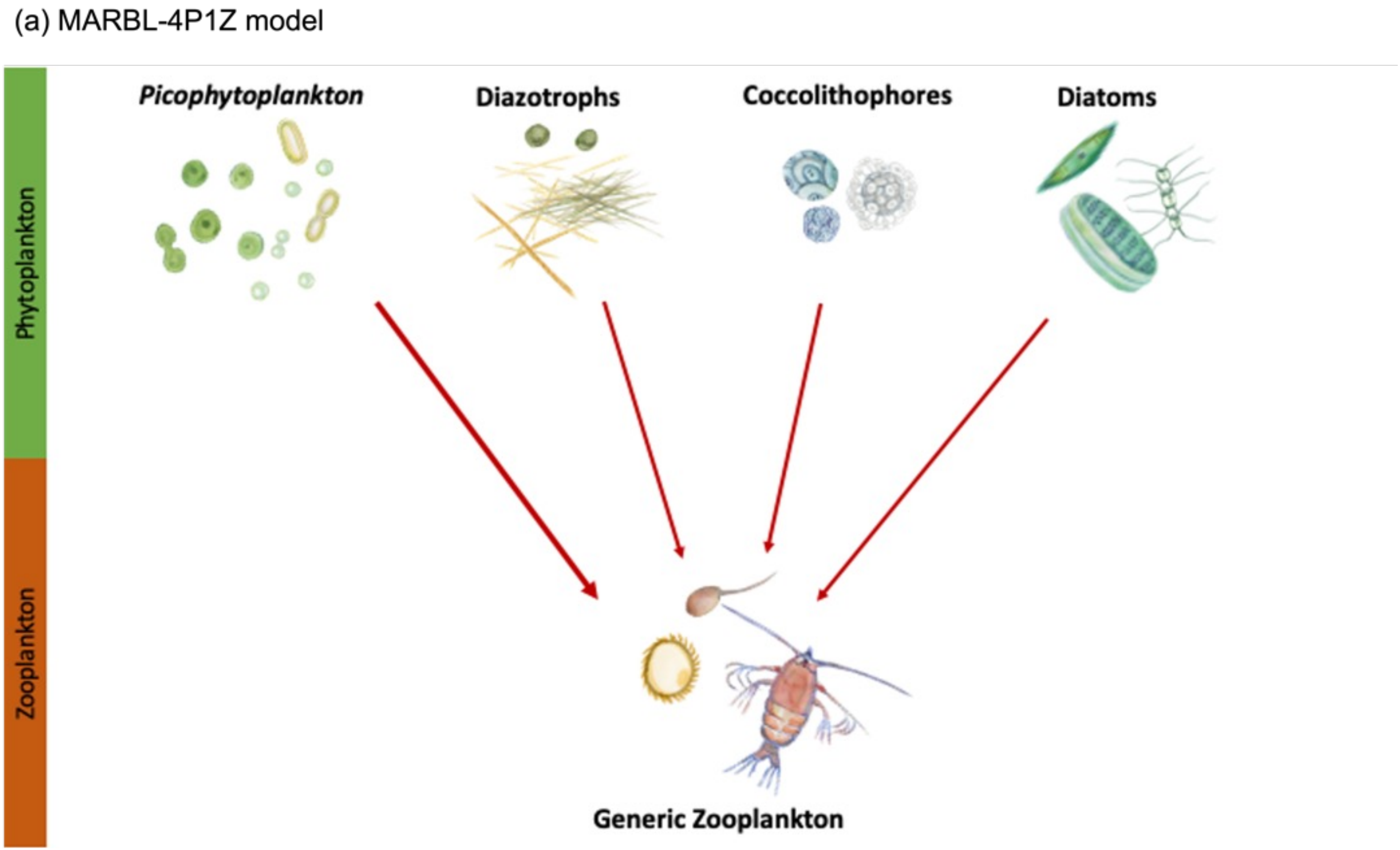
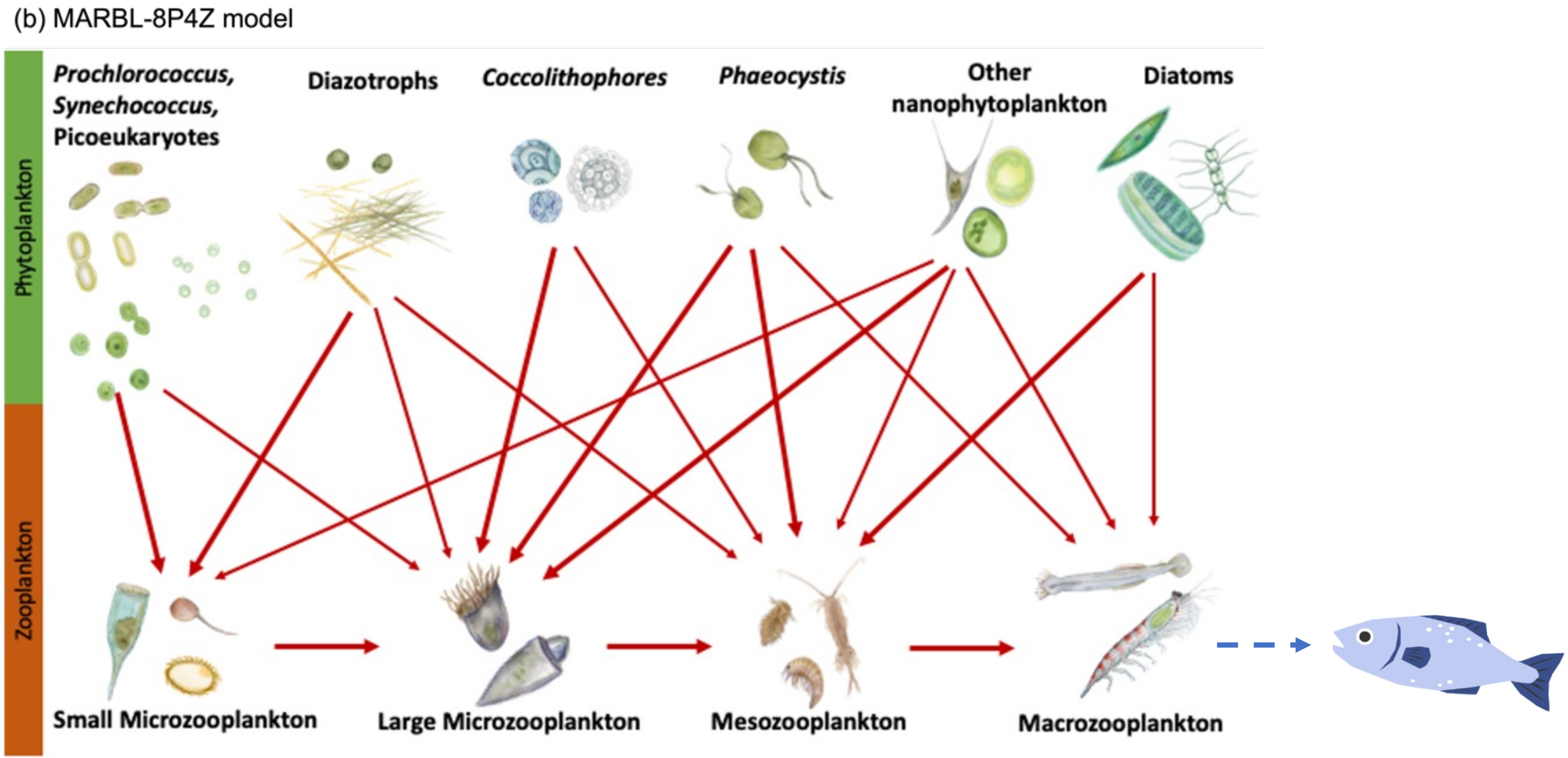
The old ecosystem model (CESM2-4P1Z)



The new ecosystem model (CESM2-8P4Z)

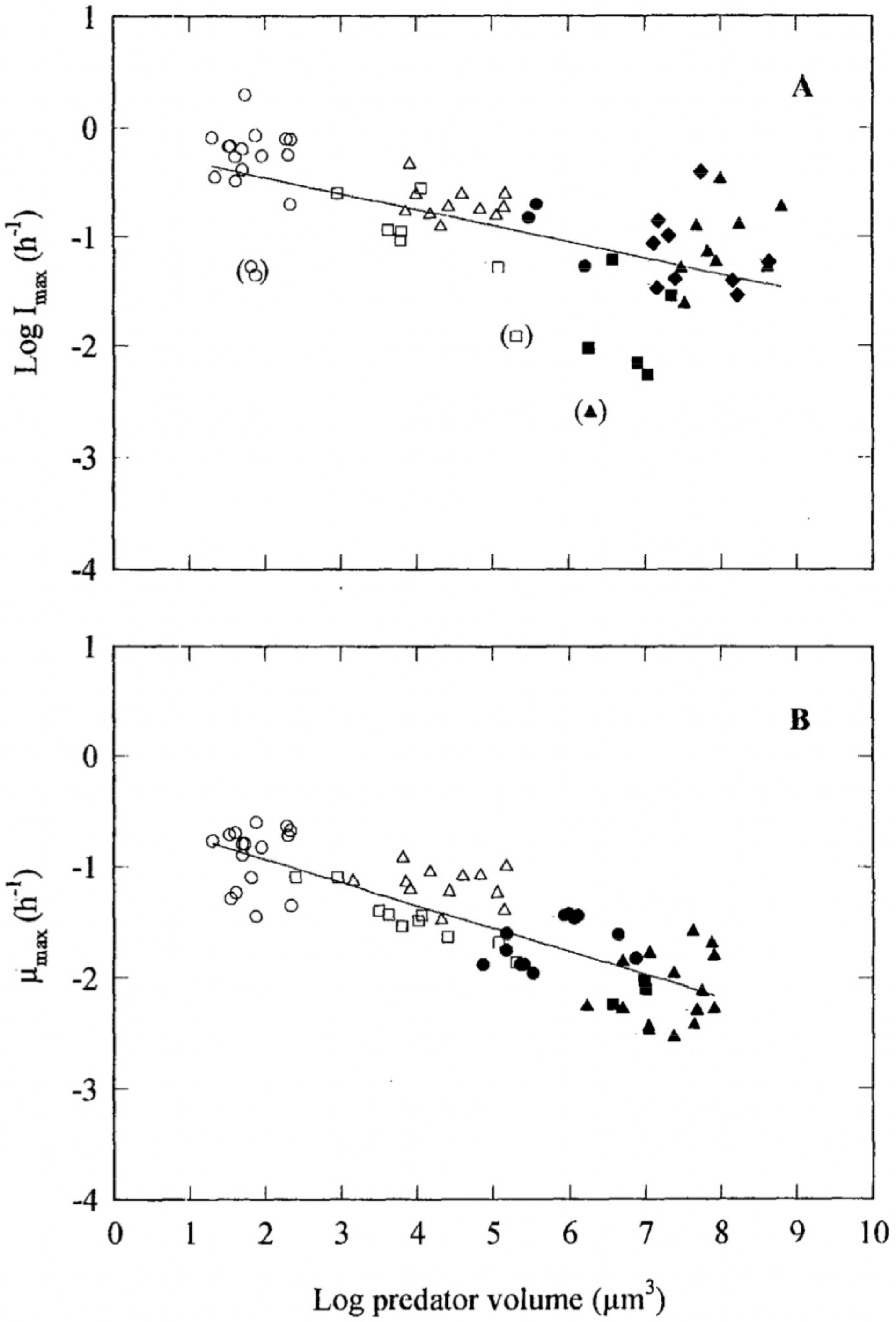


The grazing terms

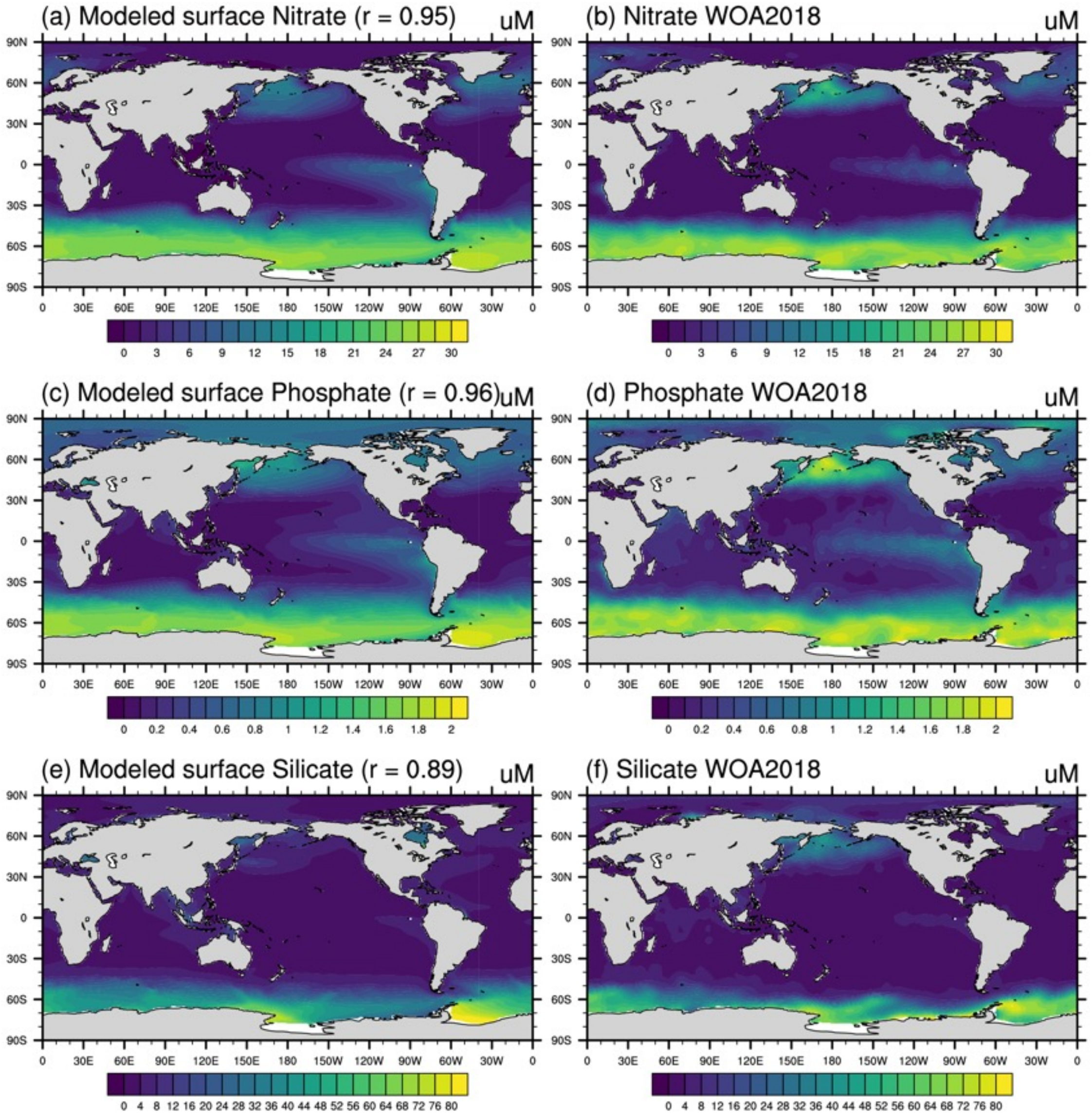
$$G = \frac{g^{max} \cdot T_f \cdot \sum_{i=1}^{n} \boldsymbol{d_i}\, p_i}{K + \sum_{i=1}^{n} \boldsymbol{d_i}\, p_i}$$

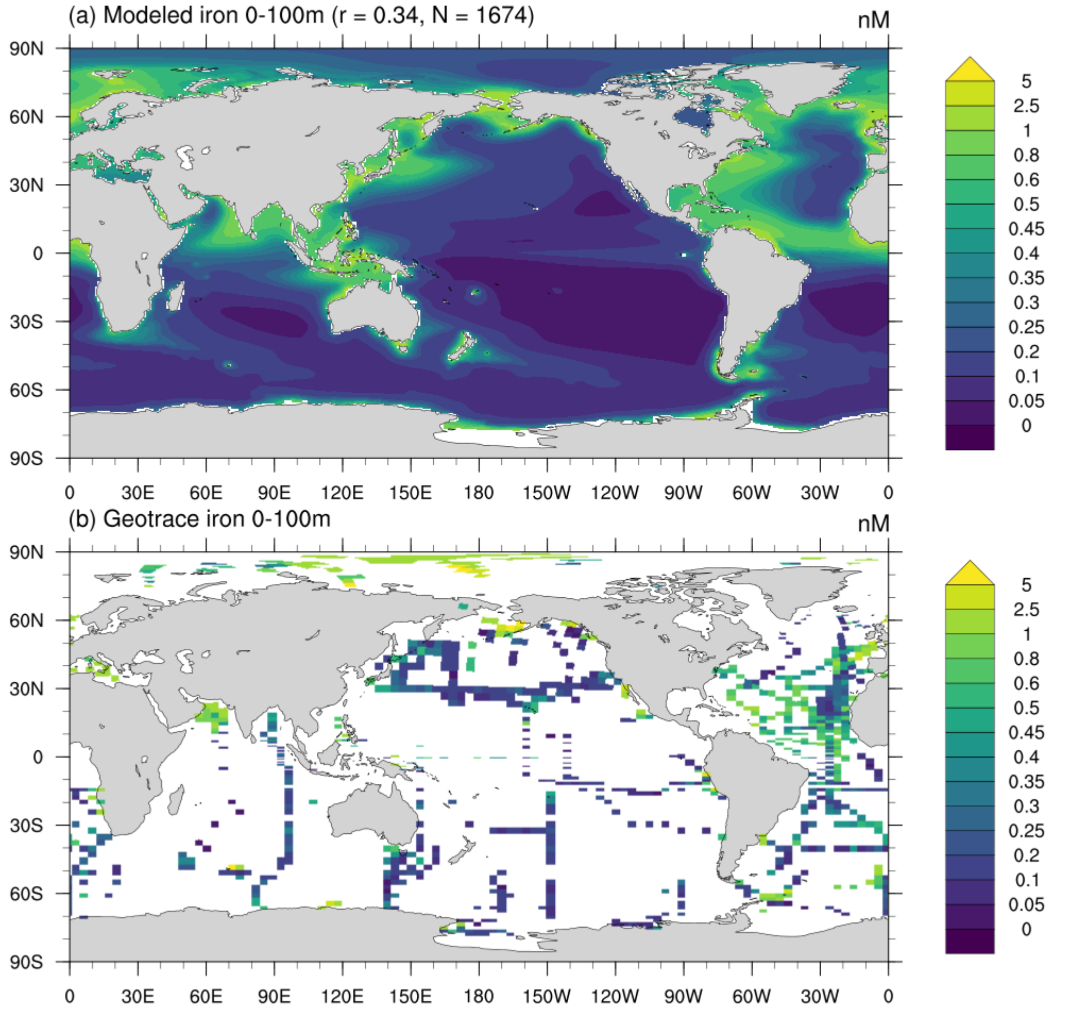
$$\boldsymbol{d_i} = \frac{p_i}{\sqrt{p_1^2 + p_2^2 + \cdots + p_n^2}}$$

- The feeding strategy follows a modified Holling Type II relationship;
- We initially set decreased maximum specific grazing rates (g^{max}) with predator size (Hansen et al., 1997);
- Density-dependent grazing to stabilize model dynamics by creating a refuge for the less abundant prey species.

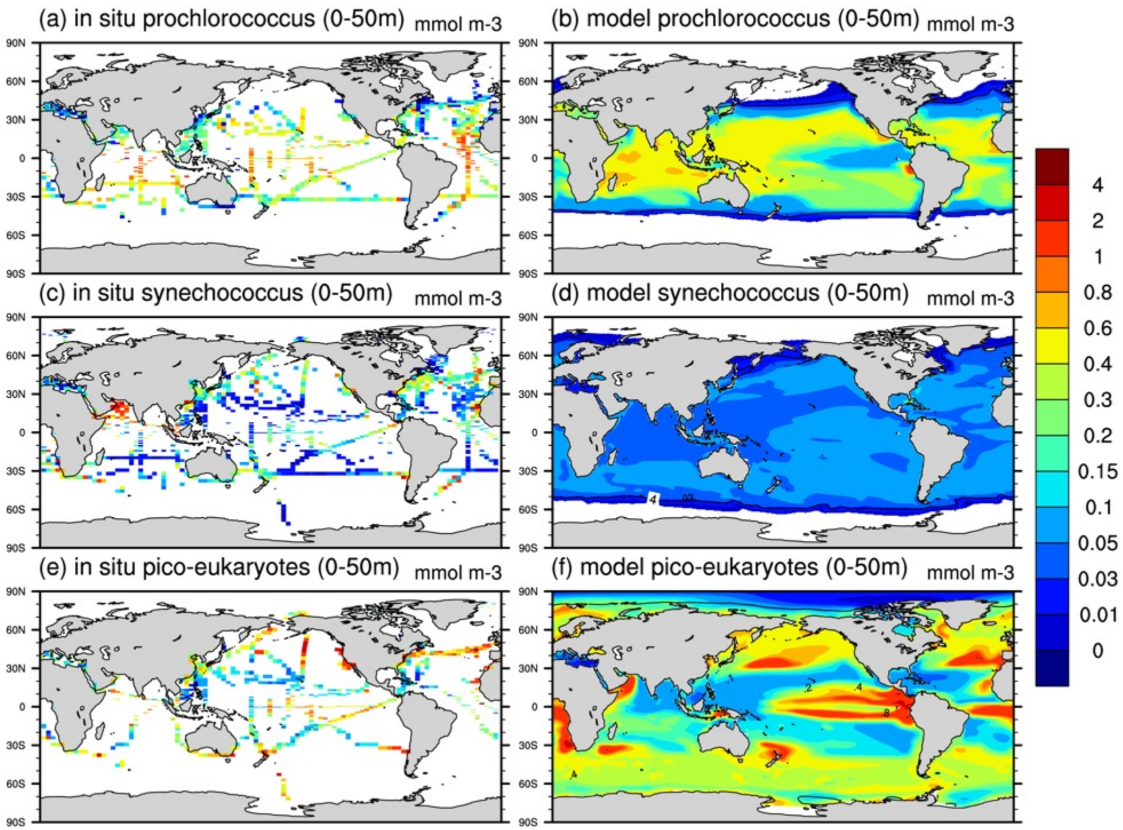


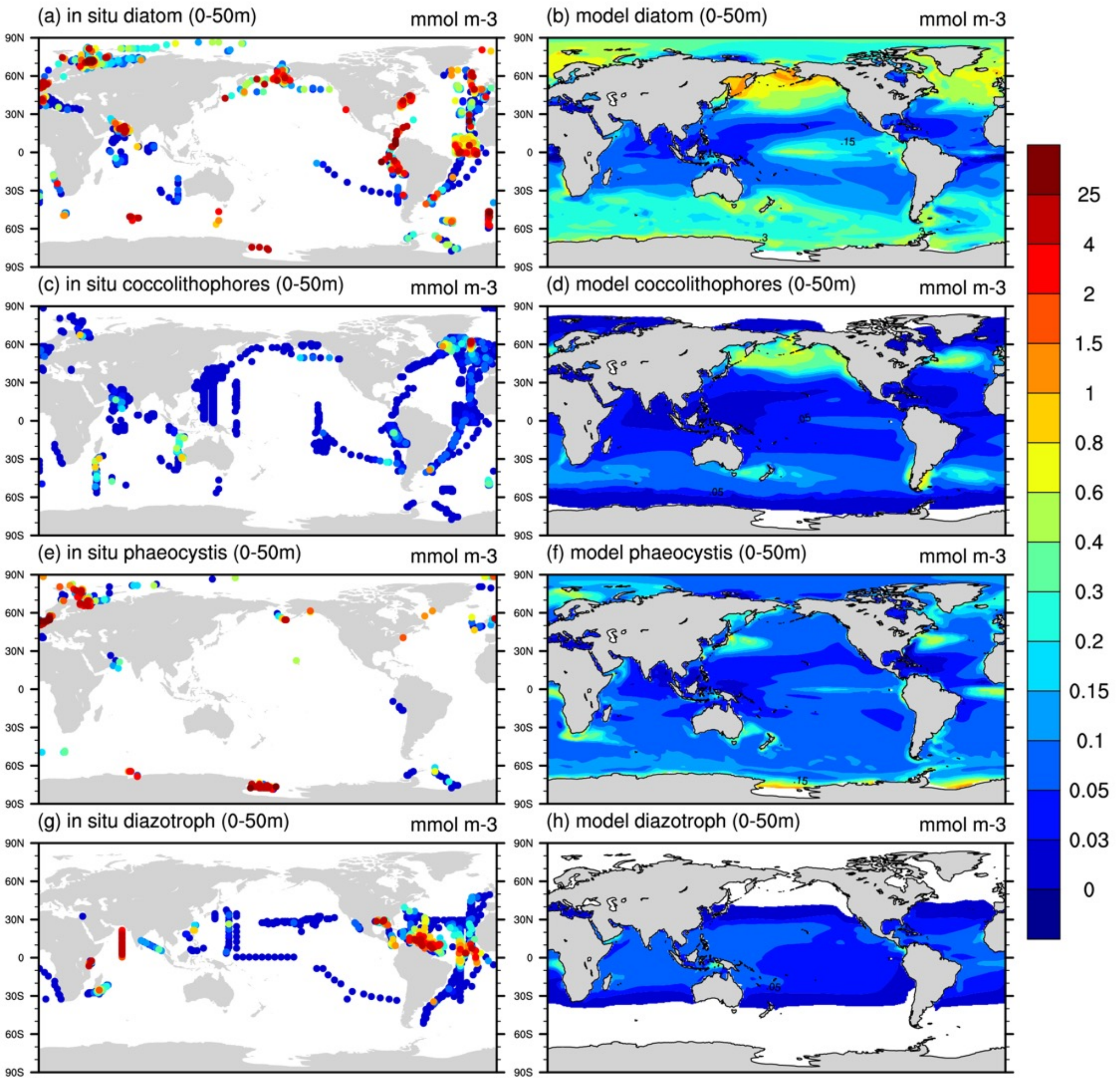
Model performance: nutrients field





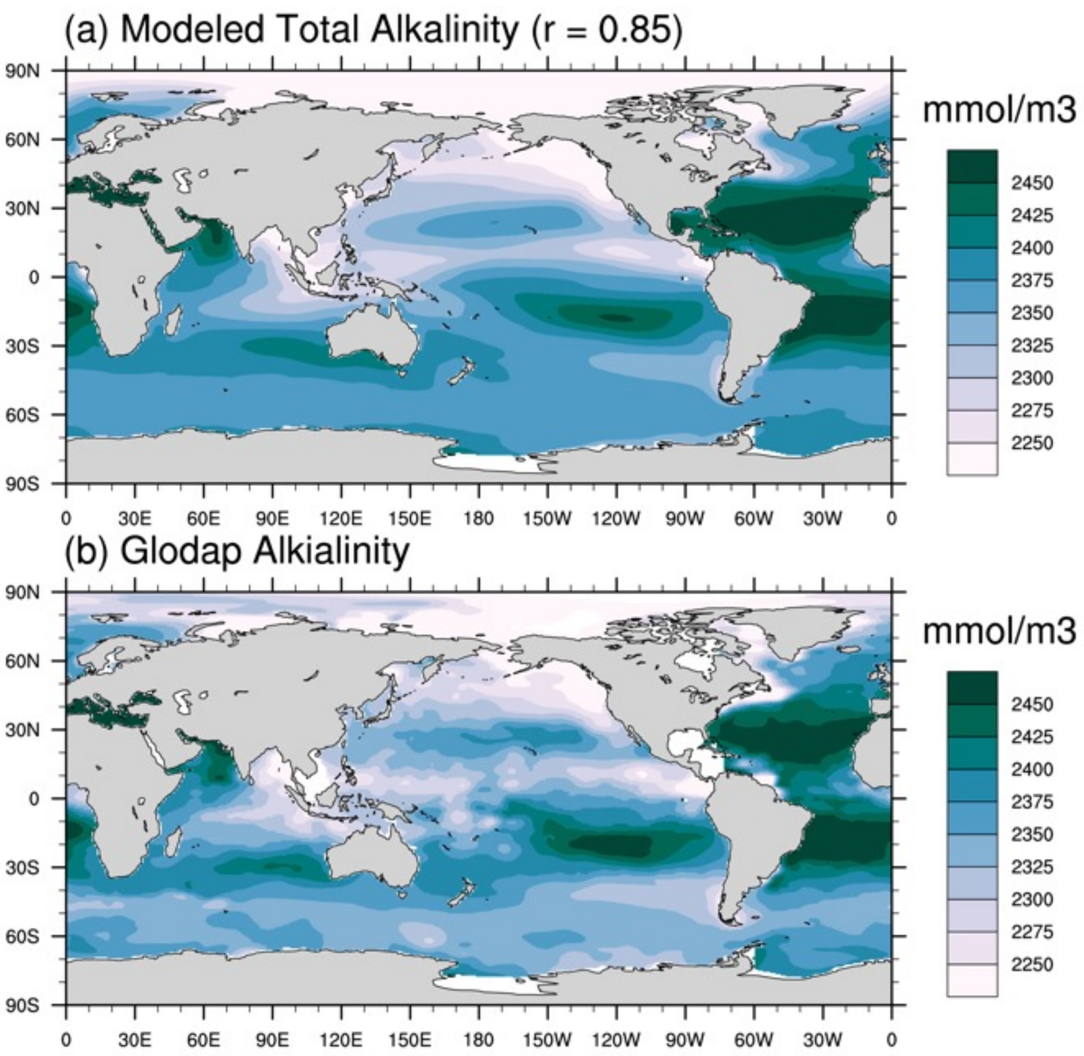
Phytoplankton biomass

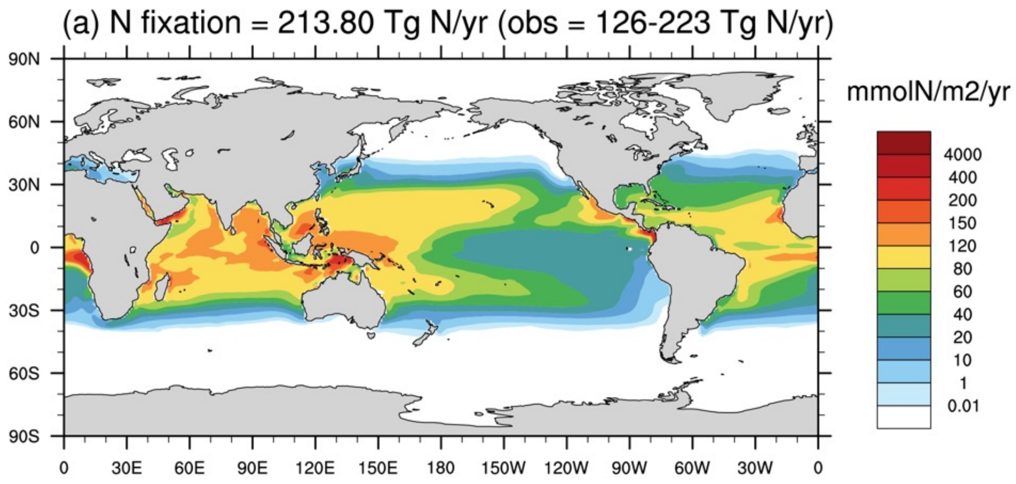




- ❖ MAREDAT dataset faces considerable uncertainties related to cell counts, unidentified species, and conversions of cell abundance to biomass, thus carbon conversion estimates are susceptible to large errors if cell size is not accurately assessed.

Other constraints

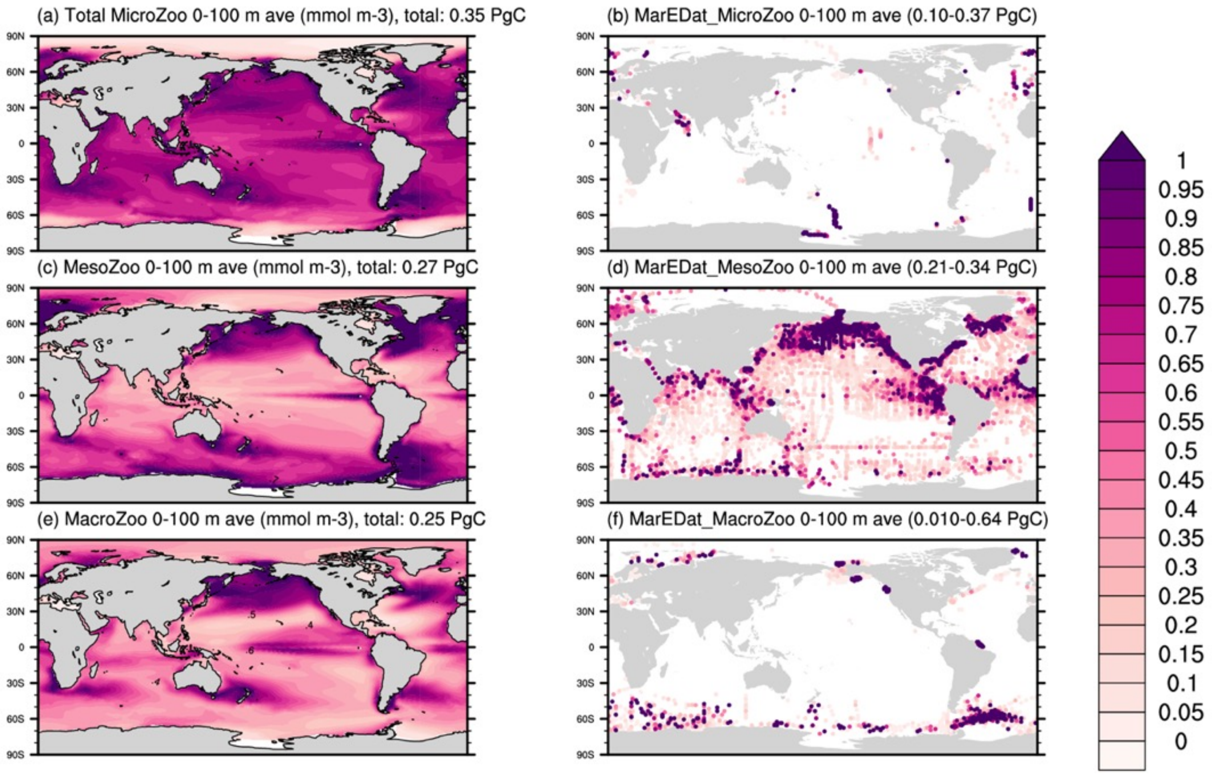


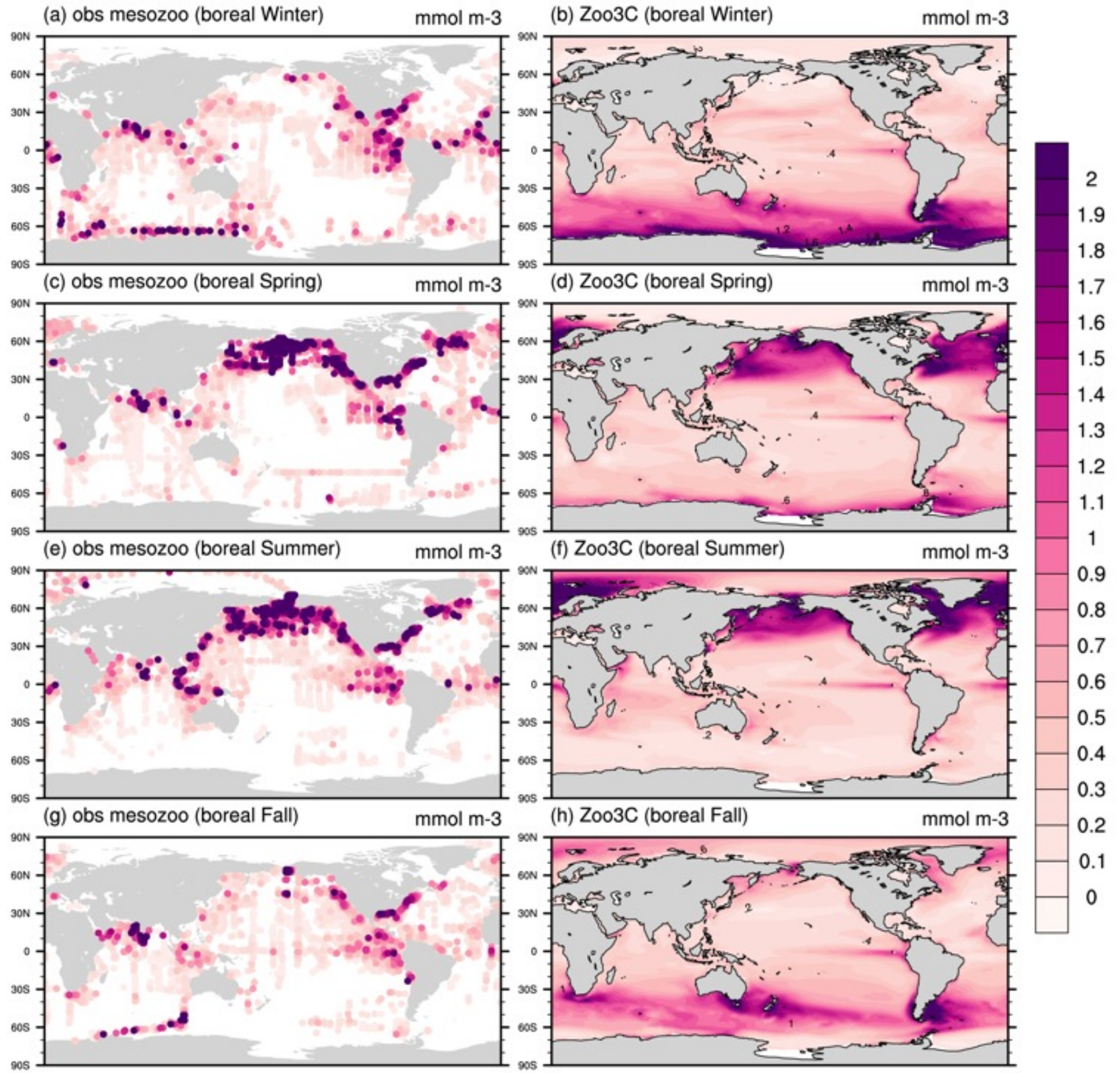


Other constraints for modeled phytoplankton performance:

- Modeled Si performance for diatoms;
- Modeled Alk performance for coccolithophores;
- Modeled N-fixation performance for diazotrophs.

Zooplankton biomass





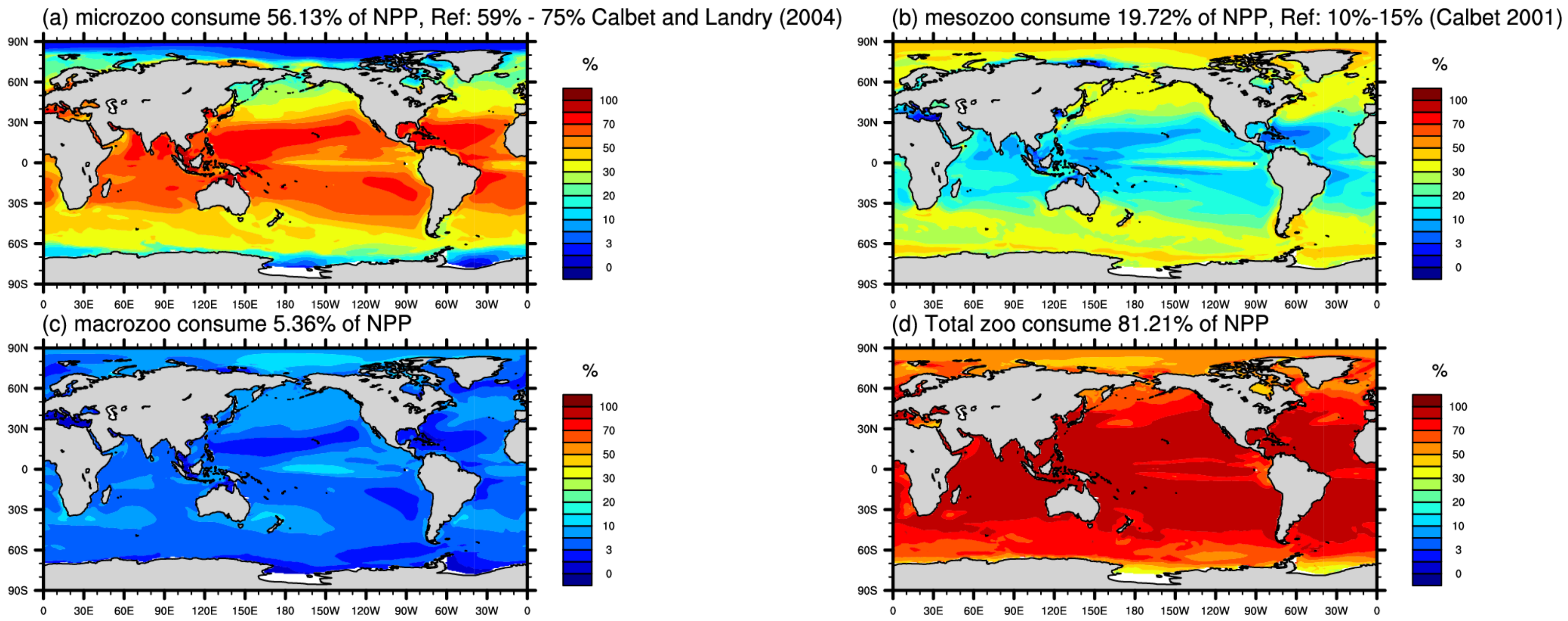
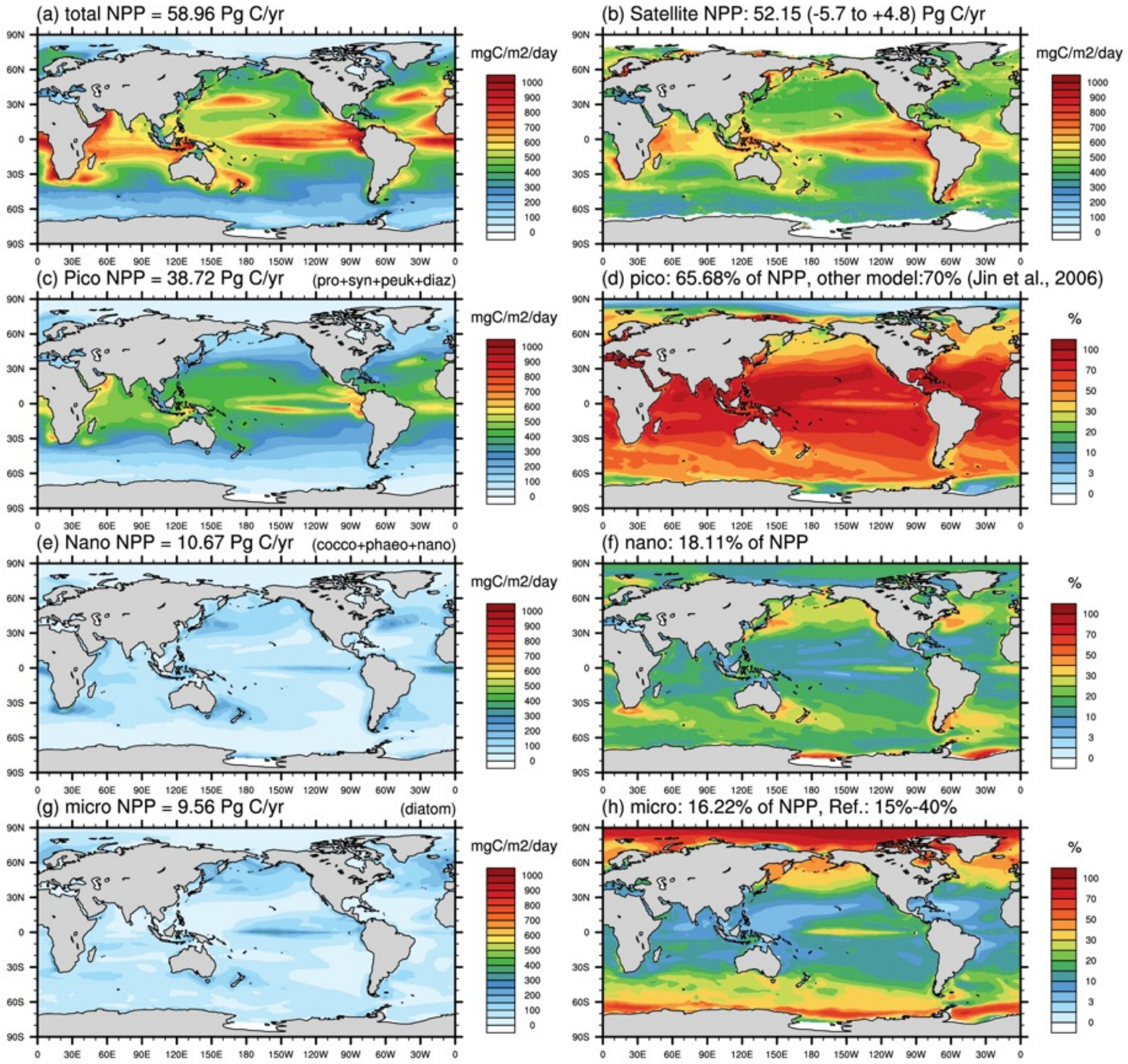


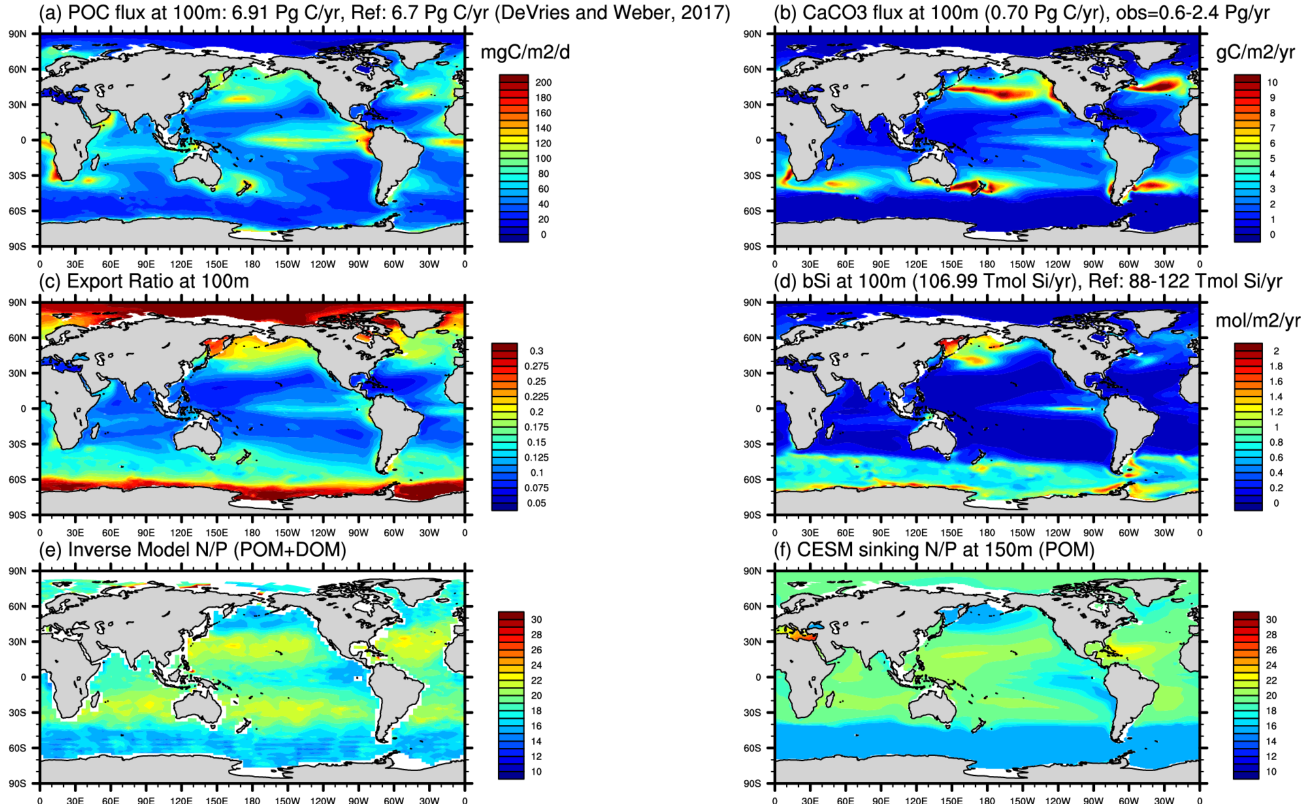
Table 1. Regional comparisons of system characteristics from the full data set of dilution experiments. Data are distinguished among oceanic, coastal (overlying the continental shelf), and estuarine habitats in the upper table and among tropical/subtropical, temperate/subpolar, and polar habitats in the lower table. Mean values (± standard errors) are given for initial Chl *a*, phytoplankton growth rate (μg), grazing mortality (m), % Chl *a* grazed day^{-1}, and % primary production (PP) grazed day^{-1}. Growth and mortality rate averages are significantly different among zones and climates ($p < 0.05$, Tukey–Kramer test), except for oceanic and coastal (μm and m), and for tropical and temperature (μ).

	Chl *a* (μg L^{-1})	μ (day^{-1})	m (day^{-1})	% Chl *a* grazed	% PP grazed
Oceanic	0.58±0.03	0.59±0.02	0.39±0.01	41.5±1.4	69.6±1.5
Coastal	3.06±0.53	0.67±0.05	0.40±0.04	47.3±4.4	59.9±3.3
Estuarine	13.0±1.8	0.97±0.07	0.53±0.04	78.7∓7.3	59.7±2.7
Tropical	1.01±0.21	0.72±0.02	0.50±0.02	55.1±2.3	74.5±2.0
Temperate	5.18±0.66	0.69±0.03	0.41±0.02	51.4±2.9	60.8±1.8
Polar	0.62±0.06	0.44±0.05	0.16±0.01	19.5±2.1	59.2±3.3

(Calbet and Landry, 2004)

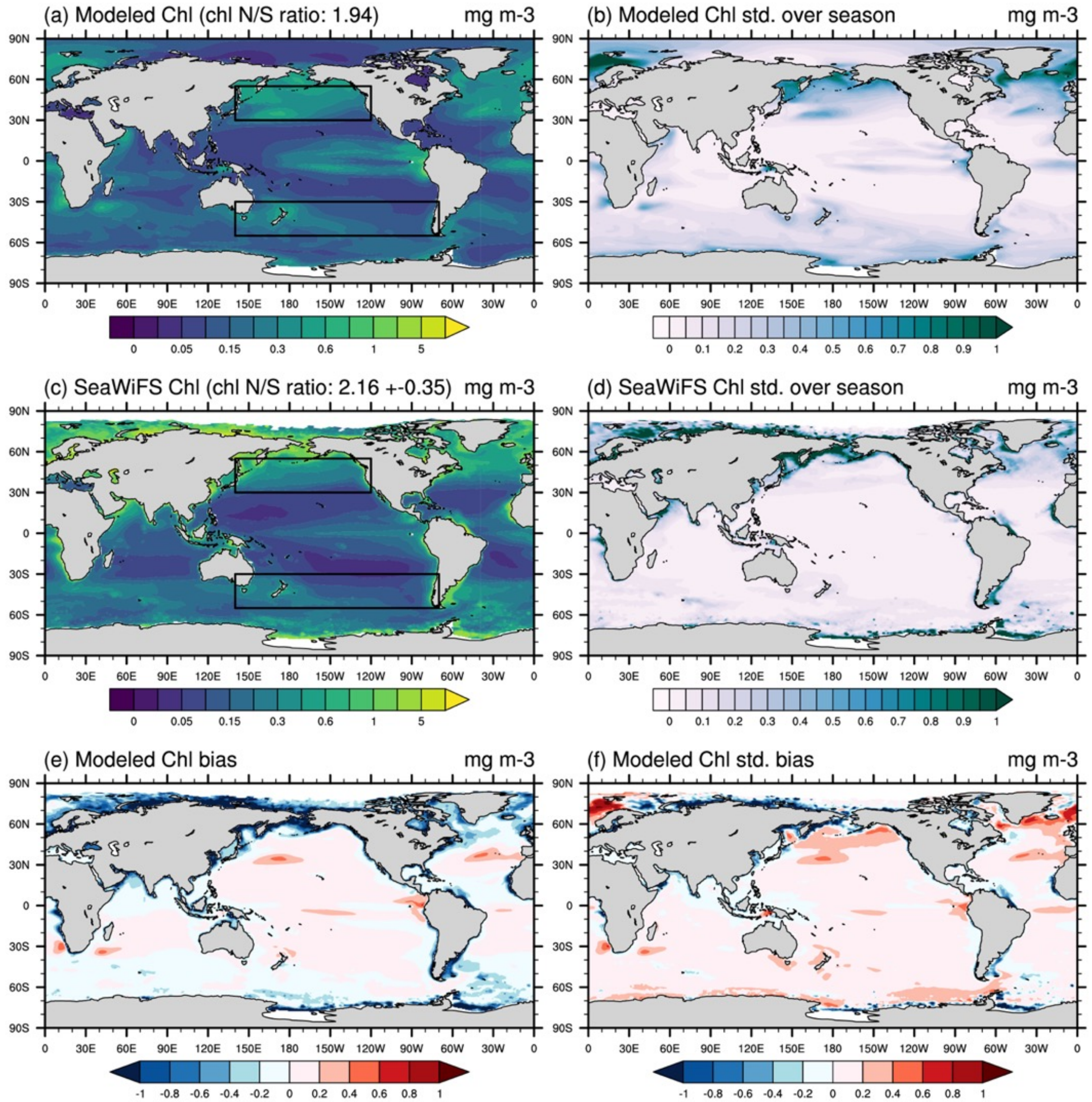
Biogeochemical fluxes



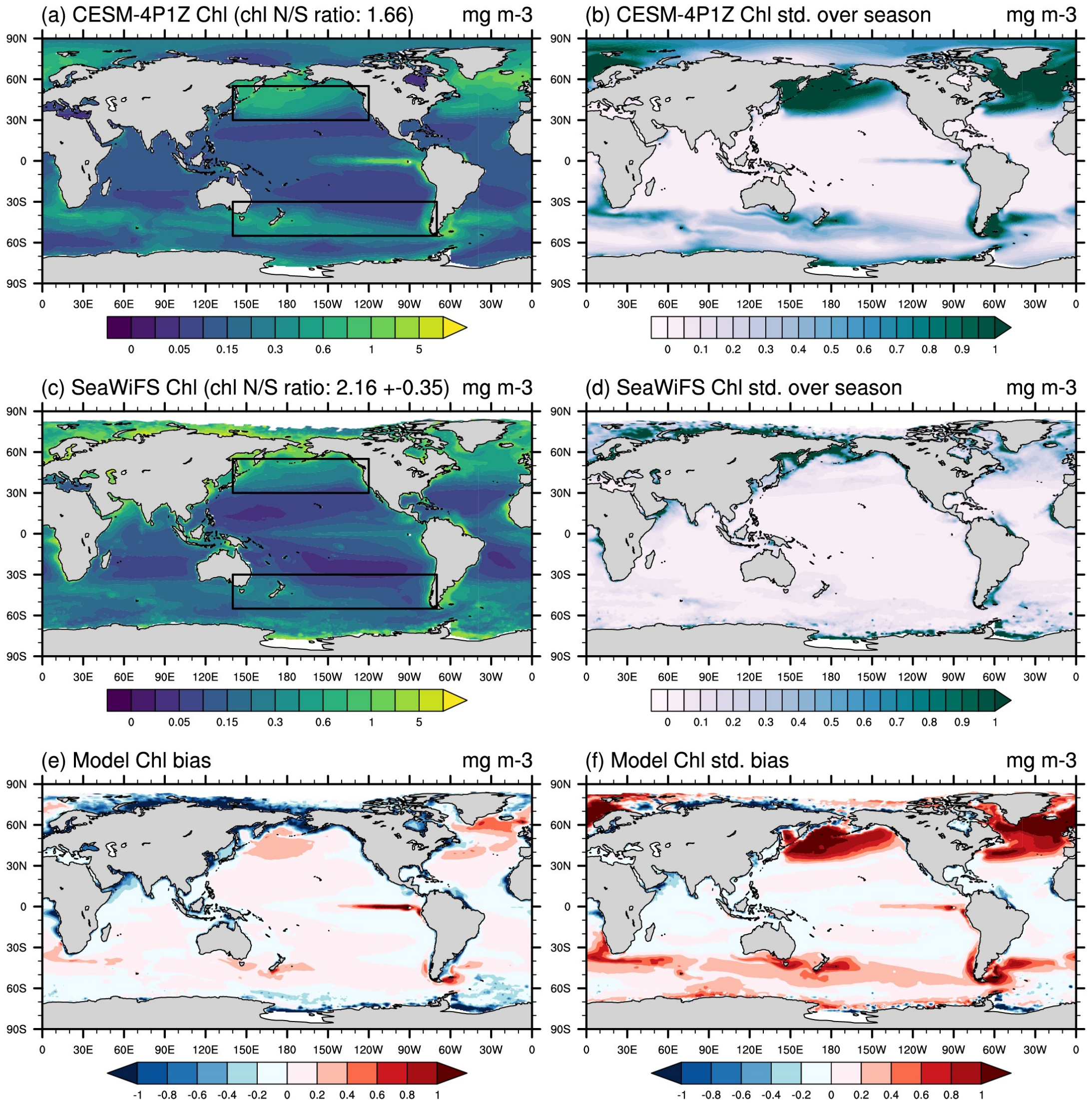


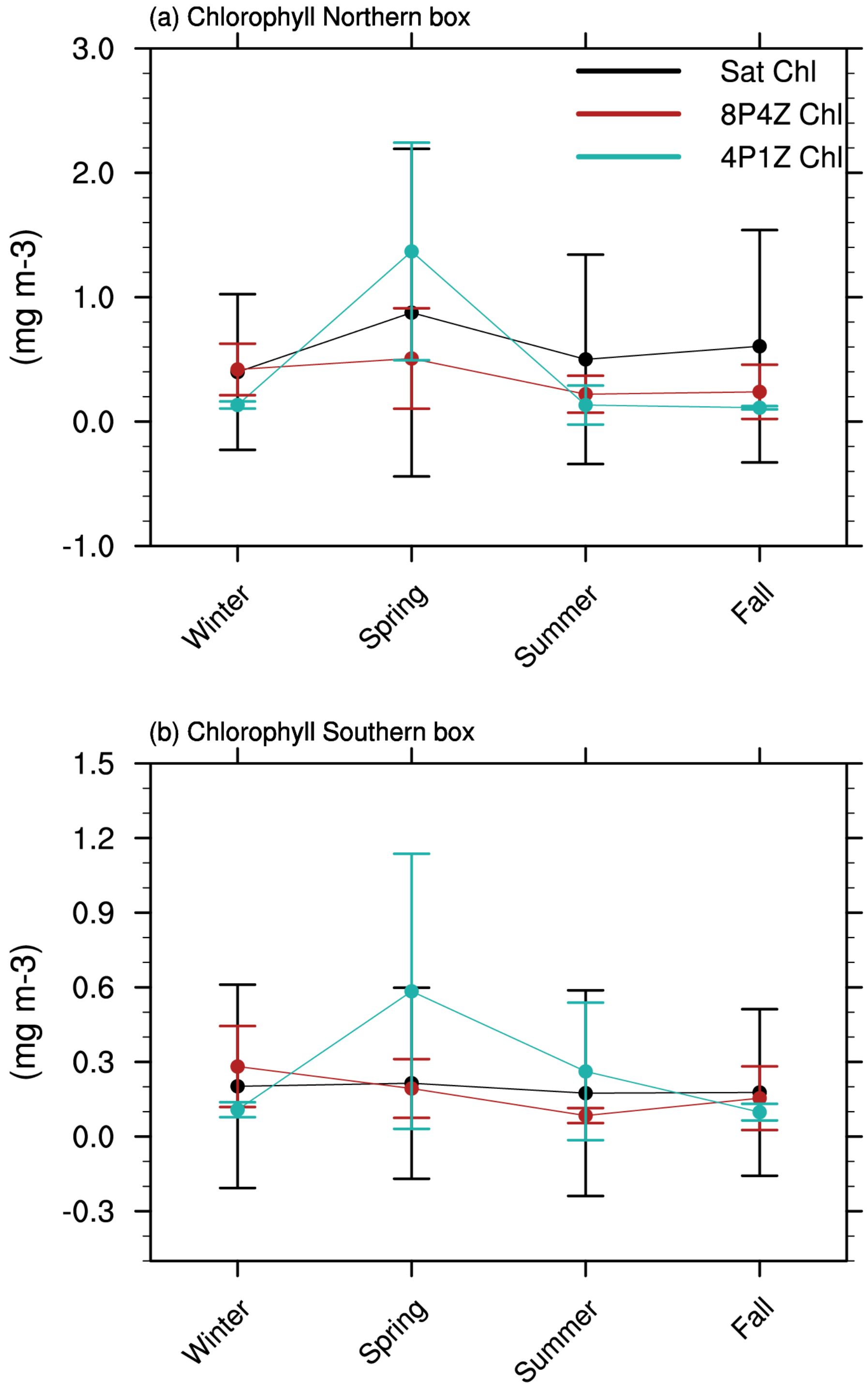
Improved seasonal variations

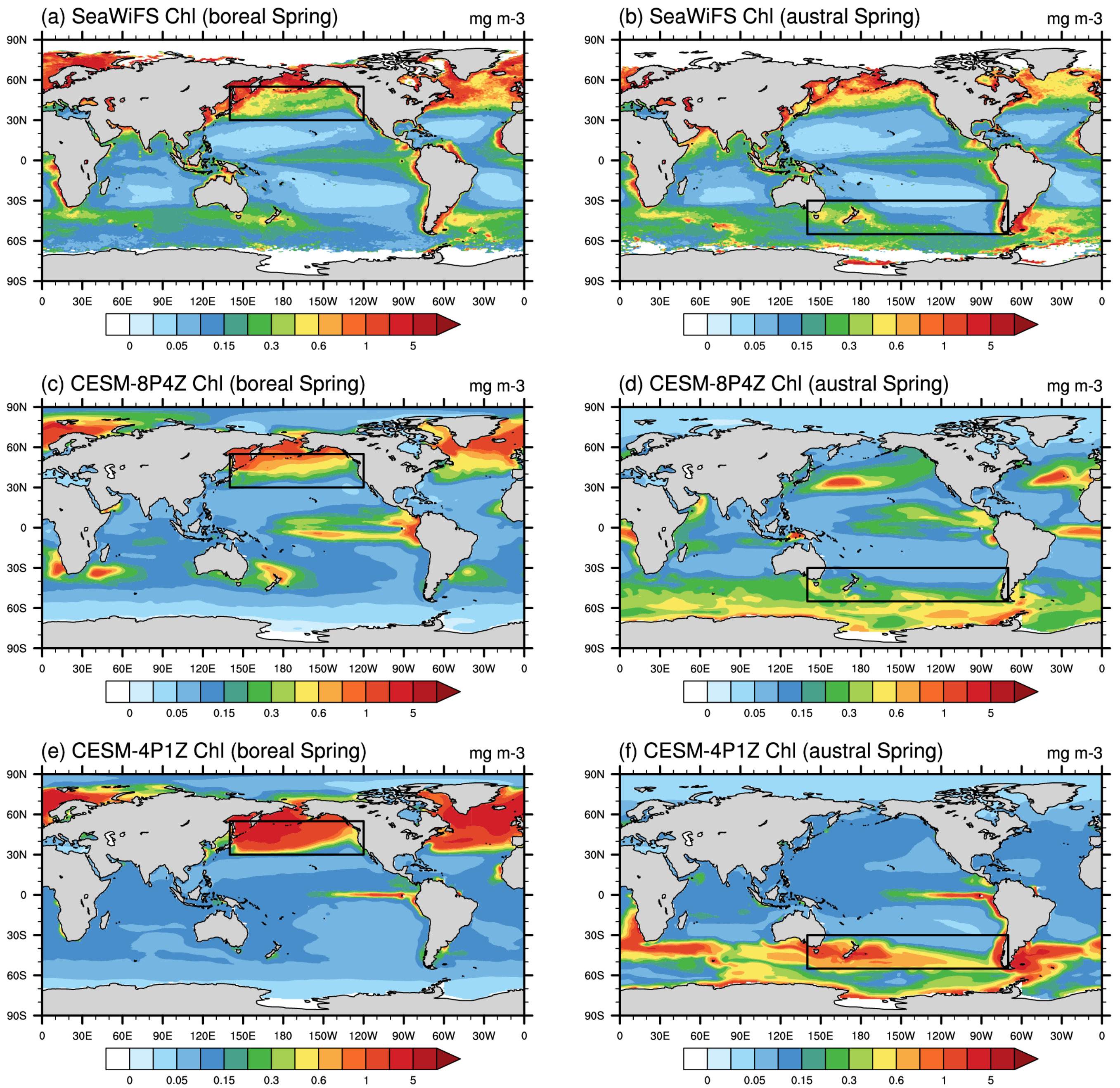
8P4Z



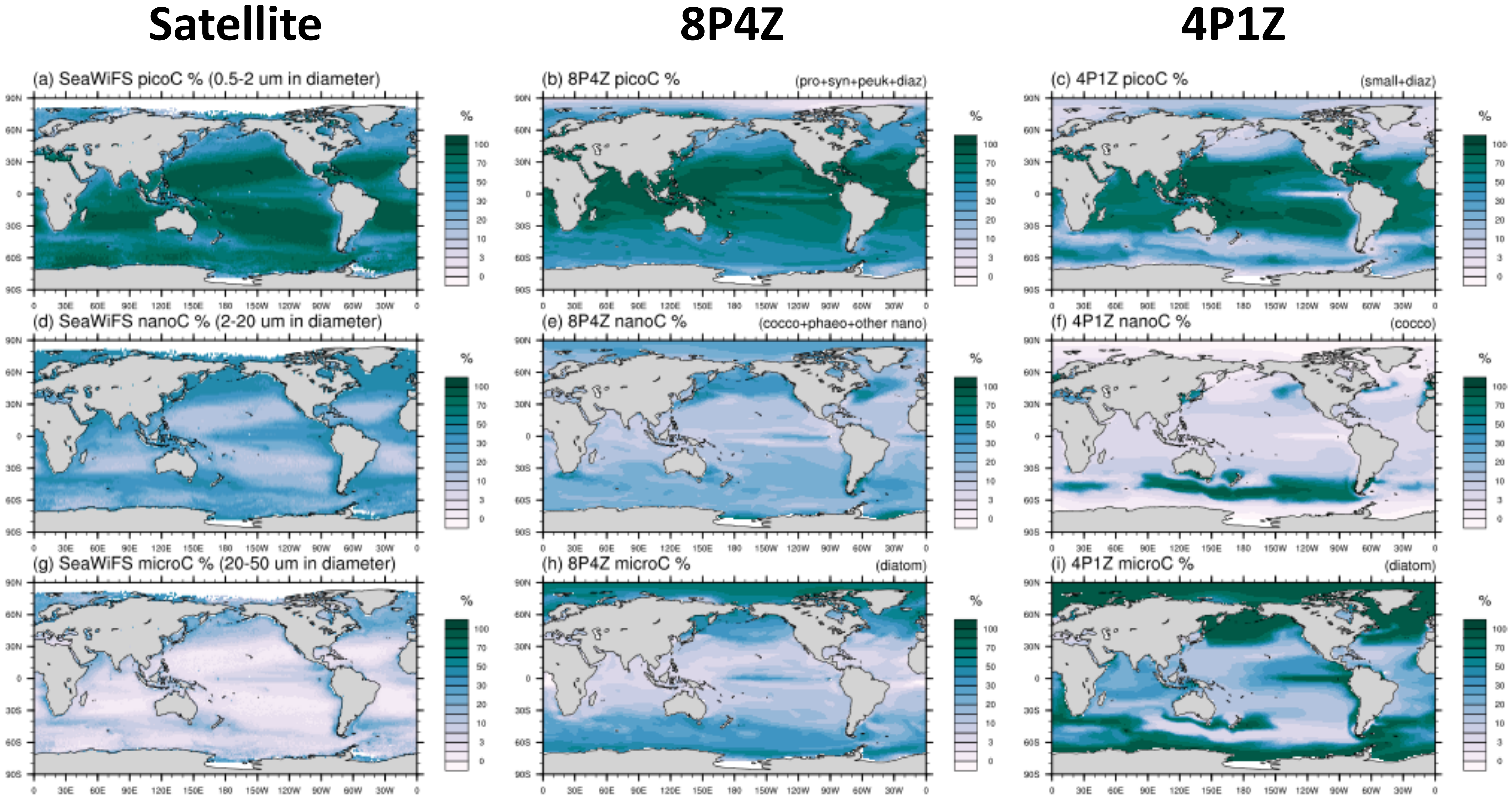
4P1Z




(a) Chlorophyll Northern box
Sat Chl
8P4Z Chl
4P1Z Chl
(mg m-3)
3.0
2.0
1.0
0.0
-1.0
Winter
Spring
Summer
Fall
(b) Chlorophyll Southern box
(mg m-3)
1.5
1.2
0.9
0.6
0.3
0.0
-0.3
Winter
Spring
Summer
Fall


(a) SeaWiFS Chl (boreal Spring)
mg m-3
(b) SeaWiFS Chl (austral Spring)
mg m-3
(c) CESM-8P4Z Chl (boreal Spring)
mg m-3
(d) CESM-8P4Z Chl (austral Spring)
mg m-3
(e) CESM-4P1Z Chl (boreal Spring)
mg m-3
(f) CESM-4P1Z Chl (austral Spring)
mg m-3
90N 60N 30N 0 30S 60S 90S
0 30E 60E 90E 120E 150E 180 150W 120W 90W 60W 30W 0
0 0.05 0.15 0.3 0.6 1 5

Improved phytoplankton community composition



Conclusions

- We developed a next-generation marine biogeochemical model with an expanded ecosystem in CESM2-MARBL, with the ability to model key species observed in the ocean;
- The 8P4Z model generally reproduces the observed phytoplankton community composition and stoichiometry, facilitating reasonable estimations of integrated biogeochemical elemental fluxes;
- The 8P4Z model improves the modeled chlorophyll spring bloom compared with the simplified ecosystem CESM, benefiting from a better representation of bottom-up (resource competition) and top down (target grazers) controls.