Adding phytoplankton UV inhibition to CESM

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Motivations

- Objective: Develop tool capable of simulating UV radiation inhibition of phytoplankton for many cases that may deplete stratospheric ozone:
  - asteroid impact (soot, dust, water vapor, NOx, halogens)
  - nuclear war (soot, NOx),
  - volcanic eruptions (sulfates, water vapor),
  - SAI-based climate mitigation (sulfates),
  - large-scale wildfires (soot, NOx).
- Determine role of UV pulse after asteroid impact towards extinction of marine photosynthesizers.

Methods: Atmosphere model

We developed “**CESM2-UVphyto**” with the following components and modifications:

- Atmosphere: WACCM4 (Marsh et al., 2013) coupled to the Tropospheric Ultraviolet and Visible (TUV) model version 4.2 (Madronich et al., 1997).
  - used to simulate chemical, physical, and radiative consequences of aerosol injections into the stratosphere.
  - computes surface UV-A, UV-B, and UV-C radiation.
  - CARMA is used for aerosols.

Methods: Atmosphere model

We developed “**CESM2-UVphyto**” with the following components and modifications:

- TUV model calculates spectral integrals in-line across 100 wavelength intervals between 120 nm and 750 nm and includes:
  - spectral radiation, irradiance, actinic flux
  - absorption by ozone, aerosols
  - scattering by air, clouds, and aerosols (Rayleigh and Mie)
  - biologically effective irradiance (dose rates)
- Computes inhibition using biological weighting functions that represent cell damage as a function of wavelength.

$$E^*_{inh} = \sum_{\lambda=280nm}^{400} E(\lambda) \cdot \epsilon(\lambda) \cdot \Delta\lambda,$$

Methods: Ocean model

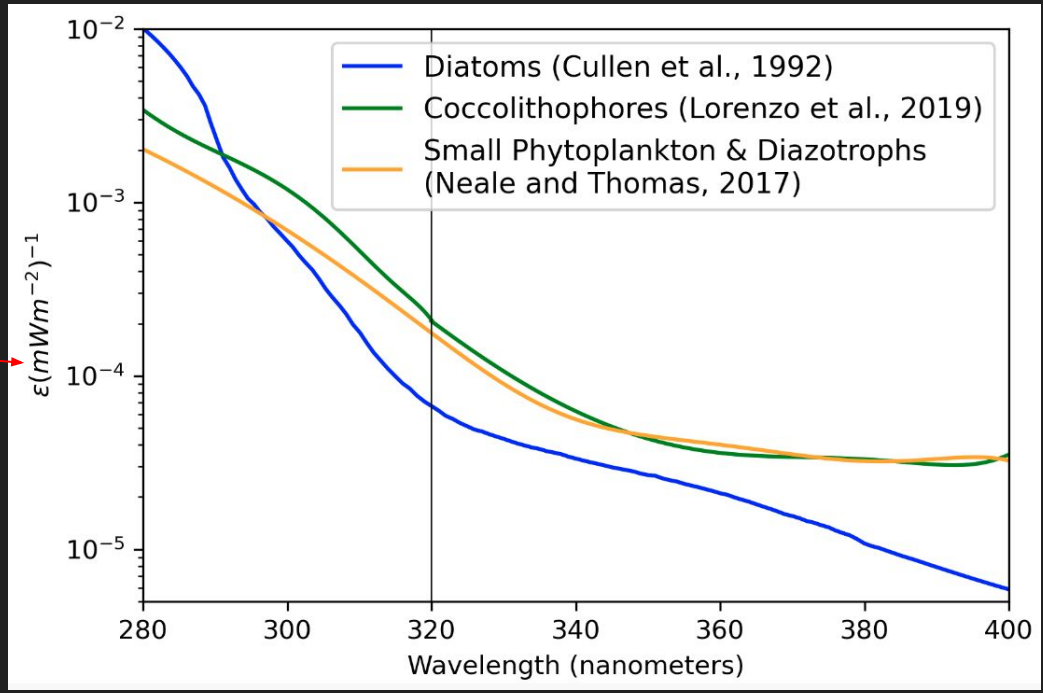
We developed “**CESM2-UVphyto**” with the following components and modifications:

- Ocean: POP2 (Danabasoglu et al., 2012) coupled to the MARine Biogeochemistry Library (MARBL, Long et al., 2021).
  - includes 4 phytoplankton functional types (small phytoplankton, diatoms, coccolithophores, diazotrophs) and 2 zooplankton functional types (microzooplankton and mesozooplankton).
  - can simulate biogeochemical response to climatic extremes.

Methods: Biological weighting functions

We developed "**CESM2-UVphyto**" with the following components and modifications:

$$E^*_{inh} = \sum_{\lambda=280nm}^{400} E(\lambda) \cdot \epsilon(\lambda) \cdot \Delta\lambda,$$



Methods: Ocean model

We developed "**CESM2-UVphyto**" with the following components and modifications:

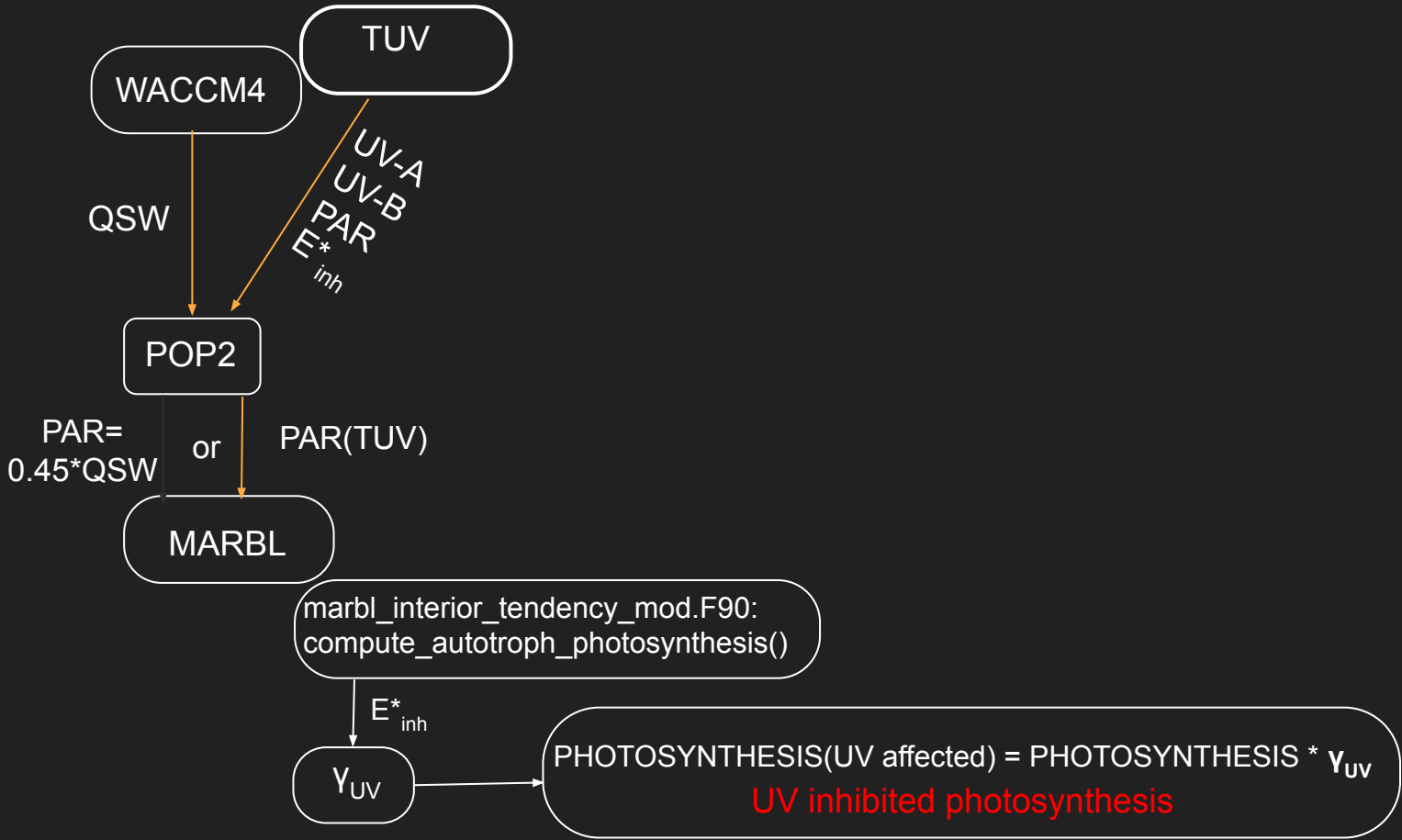
E*inh is passed from atmosphere to ocean, attenuated with depth, and inhibits photosynthesis by the following equation:

where the maximum growth rate is inversely related to E*inh

$$\gamma_{UV} = \frac{1}{1 + E*_{inh}}$$

$$\mu_i = \mu_{max}(T) \cdot \gamma_N \cdot \gamma_l \cdot \gamma_{UV}$$

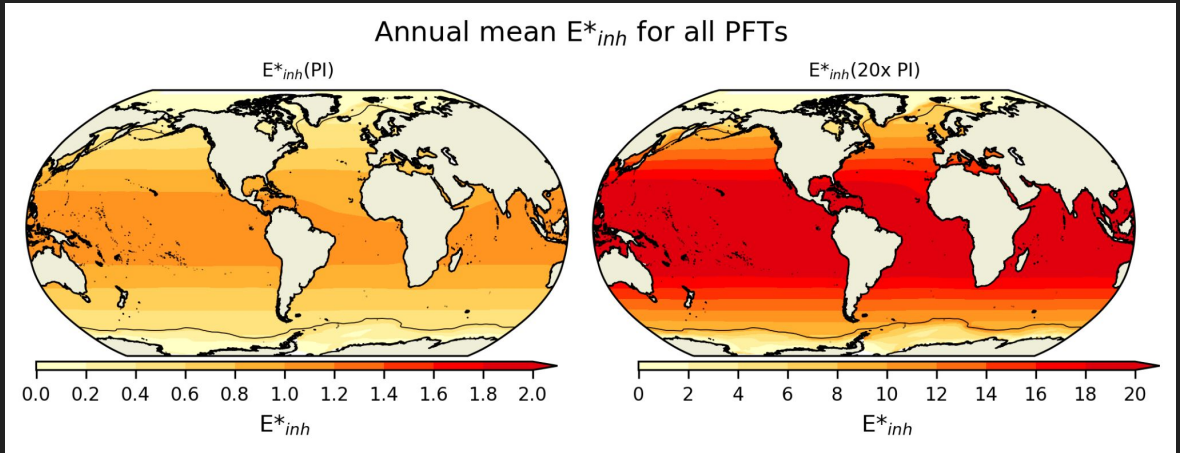
Model setup


TUV
WACCM4
UV-A
UV-B
PAR
E*inh
QSW
POP2
PAR=
0.45*QSW
or
PAR(TUV)
MARBL
marbl_interior_tendency_mod.F90:
compute_autotroph_photosynthesis()
E*inh
γUV
PHOTOSYNTHESIS(UV affected) = PHOTOSYNTHESIS * γUV
UV inhibited photosynthesis

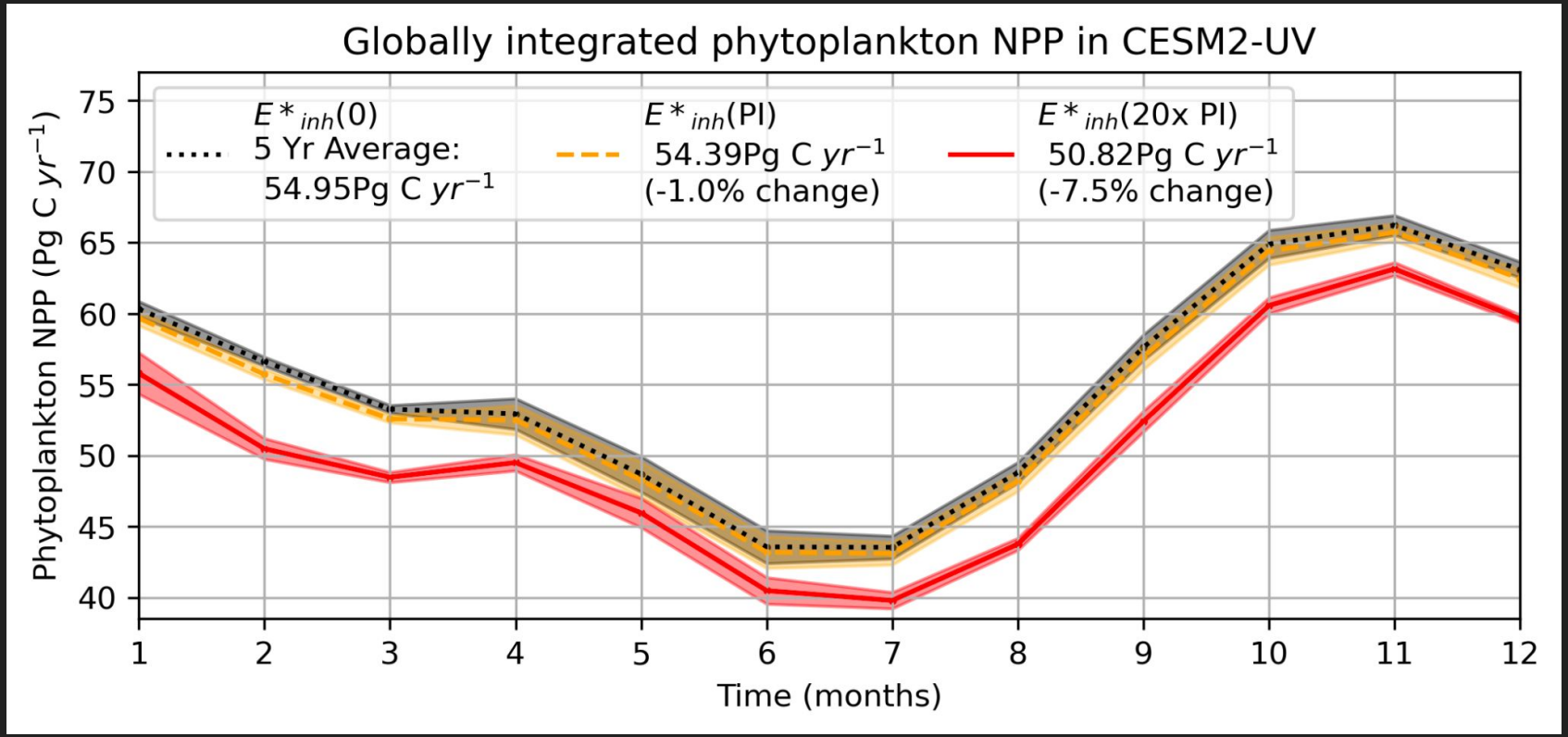
Methods: Simulations

To test UV inhibition of photosynthesis, we run the following simulations:

(1) Simulation with no UV inhibition “E*inh(0)”
(2) Simulation with pre-industrial levels of UV inhibition “E*inh(PI)
(3) Simulation with 20x pre-industrial levels of UV inhibition “E*inh(20x PI)
(4) Chicxulub-like (10 km) asteroid impact simulation in pre-industrial with and without UV radiation.

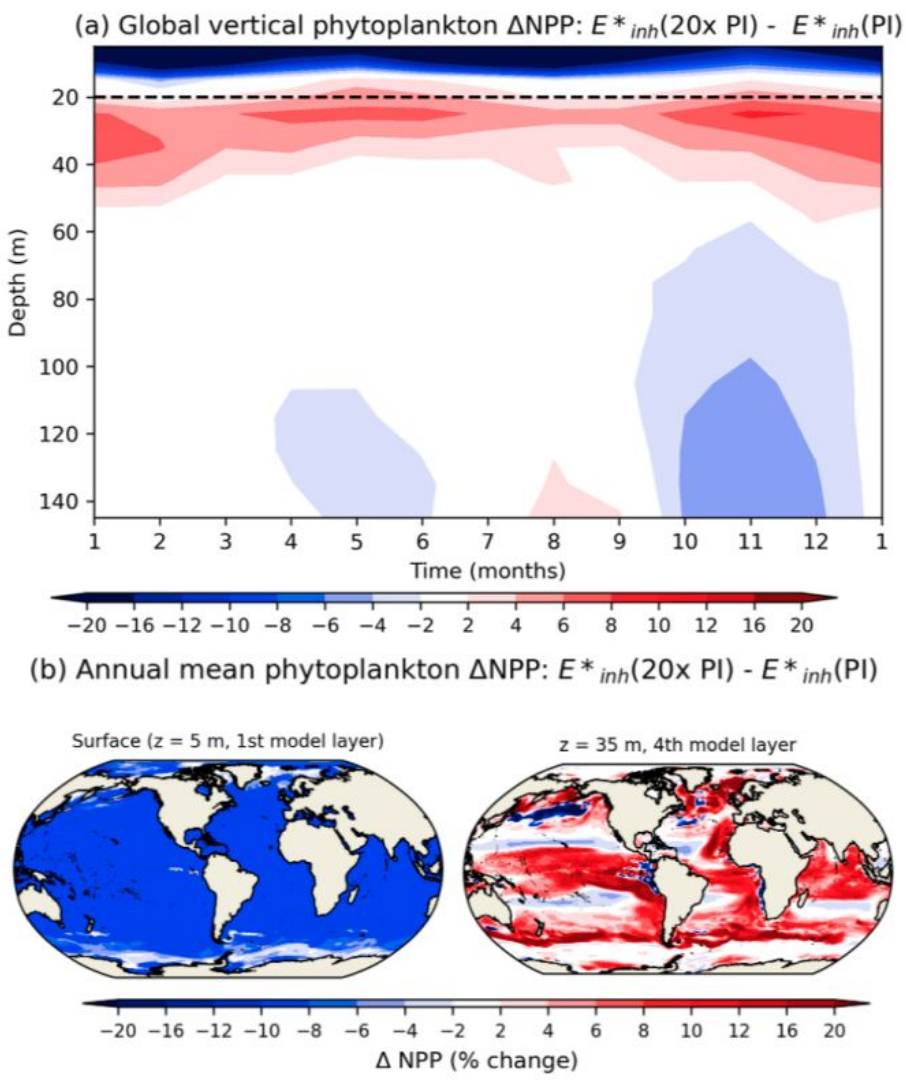


Results: E*inh(0), E*inh(PI), E*inh(20x PI)

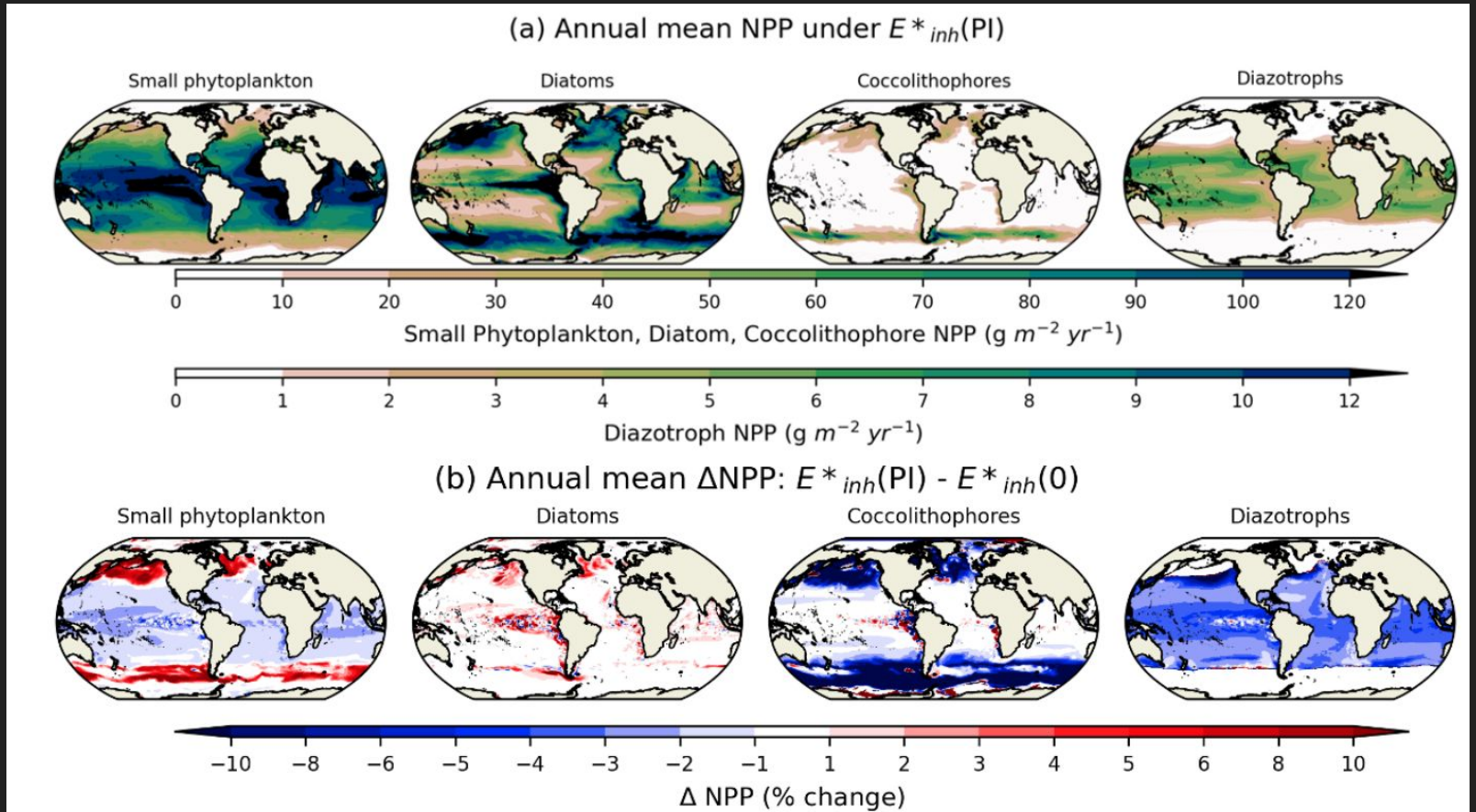


Results: Shift in vertical distribution of productivity

- UV radiation only penetrates the top ~15 m of the open ocean, while PAR can reach beyond 100 m.
- >20% reduction in productivity at the surface ocean with productivity benefits only a few layers below.
    - reduced phytoplankton shading causes benefits with depth.

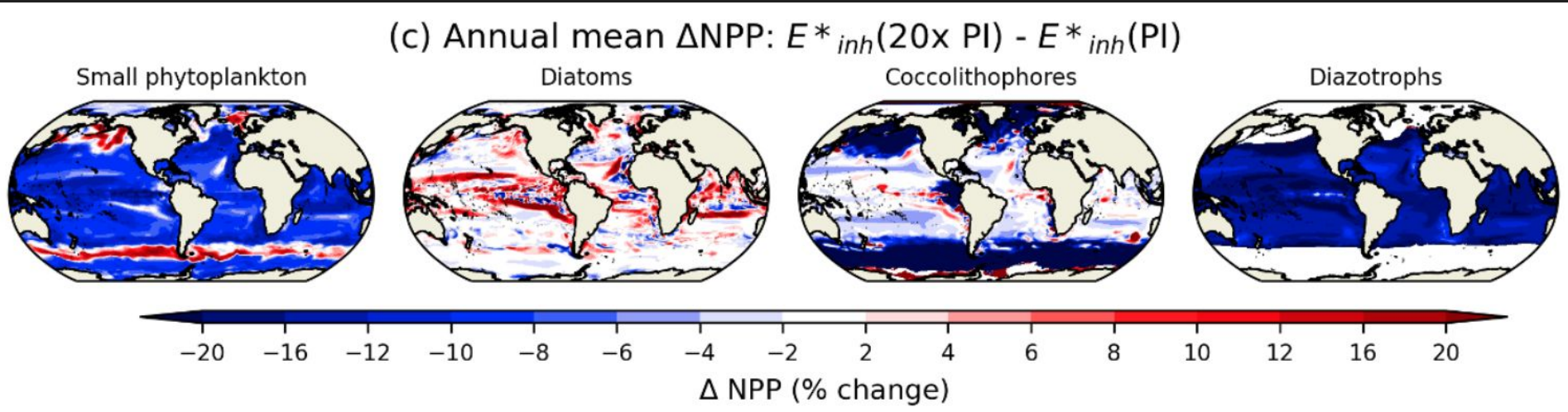


Results: Shift in spatial distribution of productivity



Results: Shift in spatial distribution of productivity

- Not shaped by distribution of E*inh
- Instead, determined by features unique to each phytoplankton type and competition.



Summary

- CESM2-UVphyto requires modifications to atmosphere, coupler, ocean, and ocean biogeochemistry models.
- Simulates minimal response to PI UV radiation, moderate response to enhanced UV radiation.
- Manuscript describing model modifications has been submitted to Geoscientific Model Development.

Sunburned plankton: Ultraviolet radiation inhibition of phytoplankton photosynthesis in the Community Earth System Model version 2

Joshua Coupe[1,2], Nicole S. Lovenduski[1,2], Luise S. Gleason[3], Michael N. Levy[4], Kristen Krumhardt[4], Keith Lindsay[4], Charles Bardeen[5], Clay Tabor[6], Cheryl Harrison[7], Kenneth G. MacLeod[8], Siddhartha Mitra[9,10], and Julio Sepúlveda[2,11]