

Biogeochemical Cycling in the
Coarse Resolution (~3 degree)
CESM Ocean Model

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Oxygen Minimum Zones (OMZ) / N Cycle Imbalance

Excessively large OMZs leads to excessive denitrification.

Nitrogen cycle: loss >> sources (N depo, N fixation)

Low Latitudes:

High biomass (chlorophyll) bias at low latitudes

High nutrient bias at low latitudes

High Latitudes:

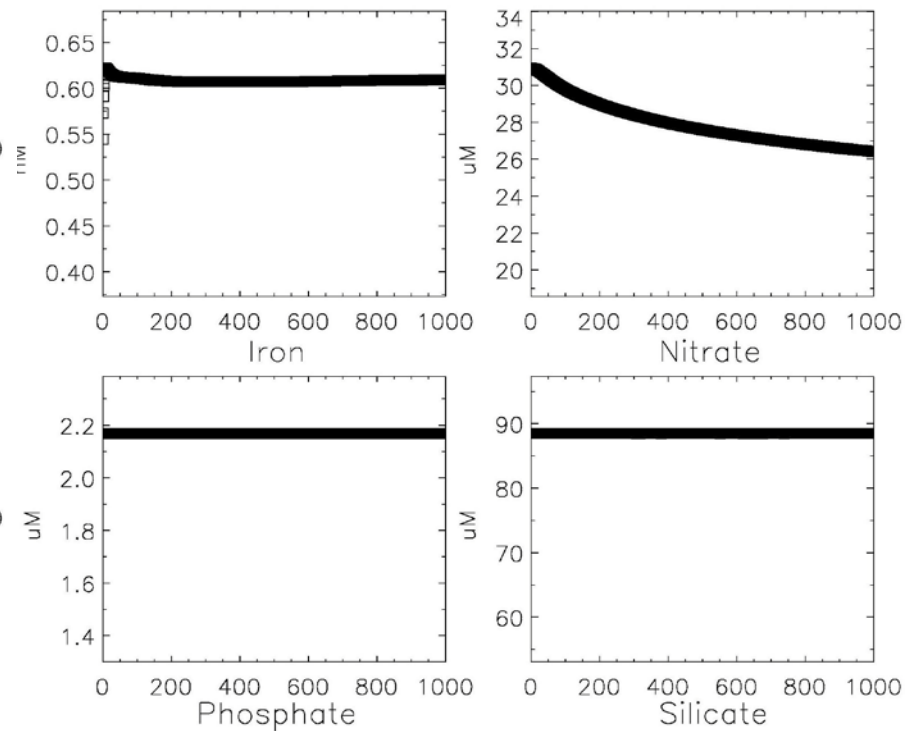
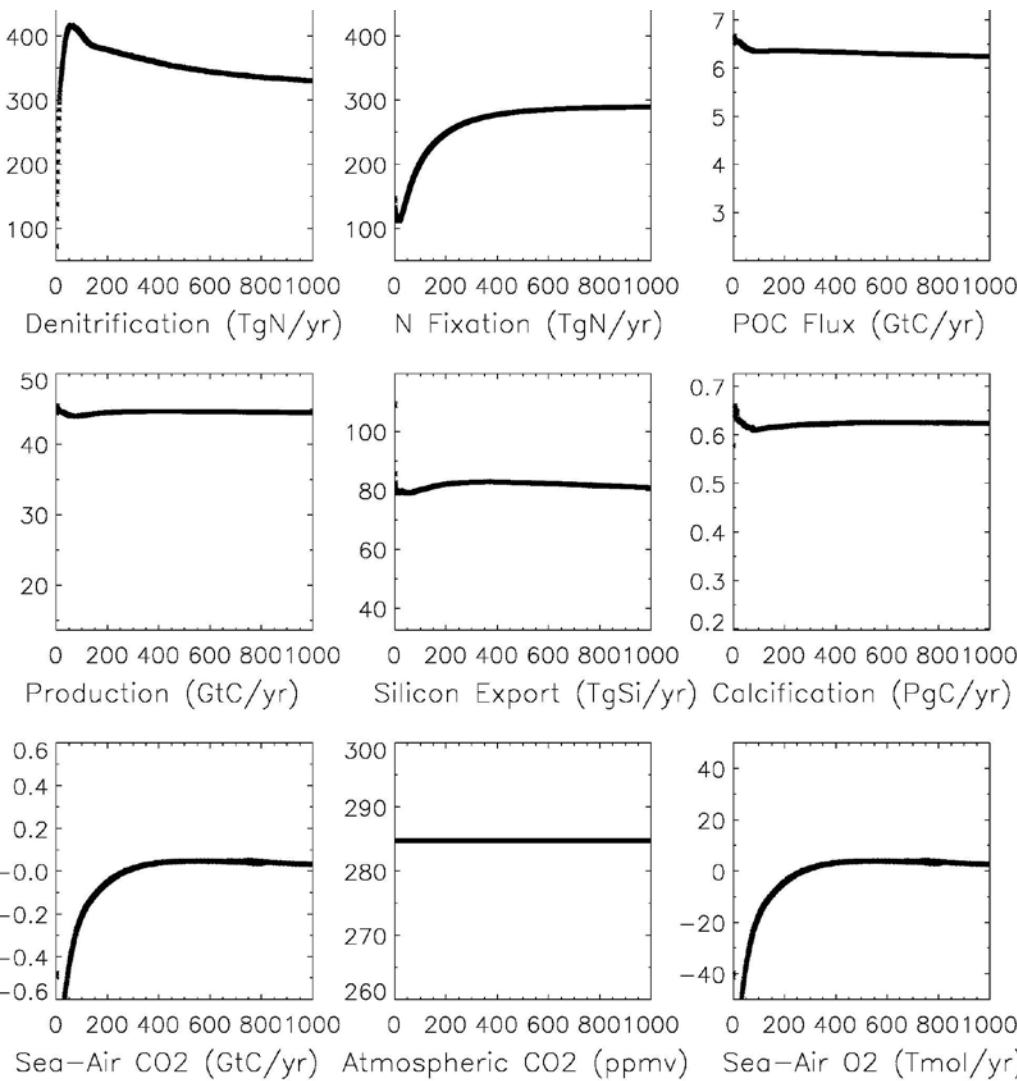
Low nutrient bias at high latitudes

Blooms are either missing, or too large

These problems are present in the X3 (~3 degree) and X1 (~1 degree).

Results here are from the X3 model with restoring of surface salinity.

Artificial scaling term introduced to reduce denitrification.



Standard CESM without down-scaling of denitrification.

Oceans rapidly losing nitrate (~15% over 1000 years).

Nitrogen fluxes still drifting, N imbalance still of 40 TgN/yr.

BGC Changes

Reduced export ratios (% of primary production to sinking POC)

Small phytoplankton ratio lowered, better agreement with observations.

Increased phytoplankton Fe/C ratios ($\mu\text{mol Fe/mol C}$)

Diatoms: range 3-6 new range 3-15

Small Phyto: range 3-6 new range 6-28

Diazotrophs: range 14-42 new range 14-56

New ratios in better agreement with field observations (McKay et al., 2005)

Modified Remineralization Curves

Increase the length scale for remineralization of sinking particles with depth.

Improved Grazing Parameterizations

Improves the low latitude biomass biases, match to satellite chlorophyll.

Better phytoplankton bloom patterns at high latitudes, not super blooms.

Some physics modifications as well, increased mixing in NW Pacific.

Remineralization of Sinking Particles in CESM/BEC

Two Classes of sinking Particulate Organic Carbon (POC):

- 1) “Soft” organic matter, sinking flux decays exponentially with a fixed, specified length scale (~200-300m).**
- 2) Ballasted organic matter (ballast = dust, bSi, CaCO₃) much longer remineralization length scales.**

At base of euphotic zone, < 10 % of sinking POC is ballasted.

In the deep ocean, below 2000m, > 75 % of POC is ballasted.

So combining both classes, the mean remineralization length scale increases with depth.

A stronger increase with depth in all the length scales gives a better match to observed nutrients and oxygen.

Remineralization Length Scale Increases with Depth in the Oceans

Sediment trap data indicates mean sinking speeds increase with depth
increases by X 2-10 between 100 and 2000m,
increase of X 1.15 – 1.6 between 2000 and 3000m (Berelson, 2002)
increase of X 6 between surface and 2500m (Iverson et al., 2010)
increases from X 2-17 (Fischer and Karakas, 2009)

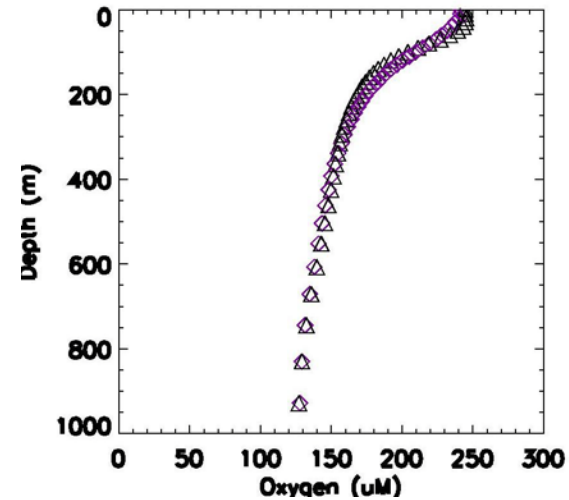
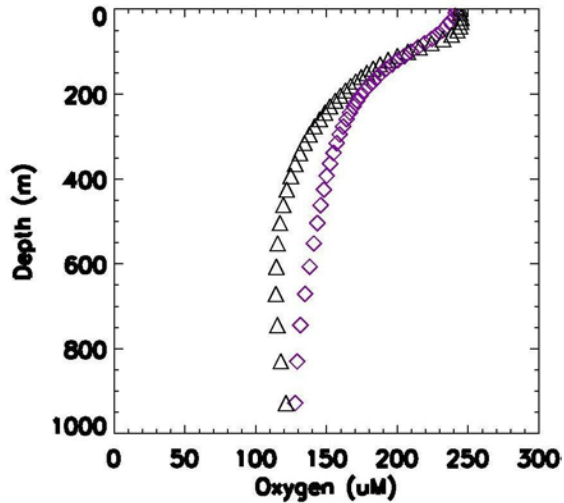
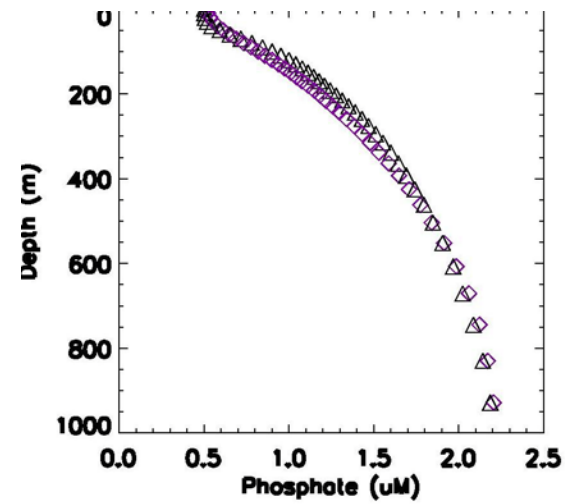
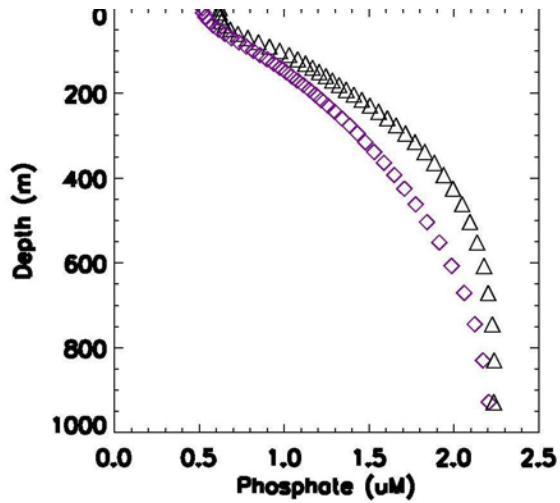
Slower sinking particles largely remineralize < 300-500m depth.
Some smaller particles are repackaged into larger particles through zooplankton grazing and physical aggregation, which then sink faster.

Zooplankton biomass and grazing on sinking particles very strong < ~500m depth
Below ~500m zooplankton biomass declines sharply (i.e. Steinberg et al., 2008),
> 500-1000m bacteria dominate remineralization (Iverson et al., 2010).

Some modeling studies find better match to observations with increasing length scales at depth (Howard et al., 2006; Kriest and Oschlies, 2008).

The Martin curve, often used to predict these remineralization vs. depth relations, has an increasing length scale with depth.

Mean vertical profiles of PO_4 and O_2 (black Δ model, purple \diamond observed)

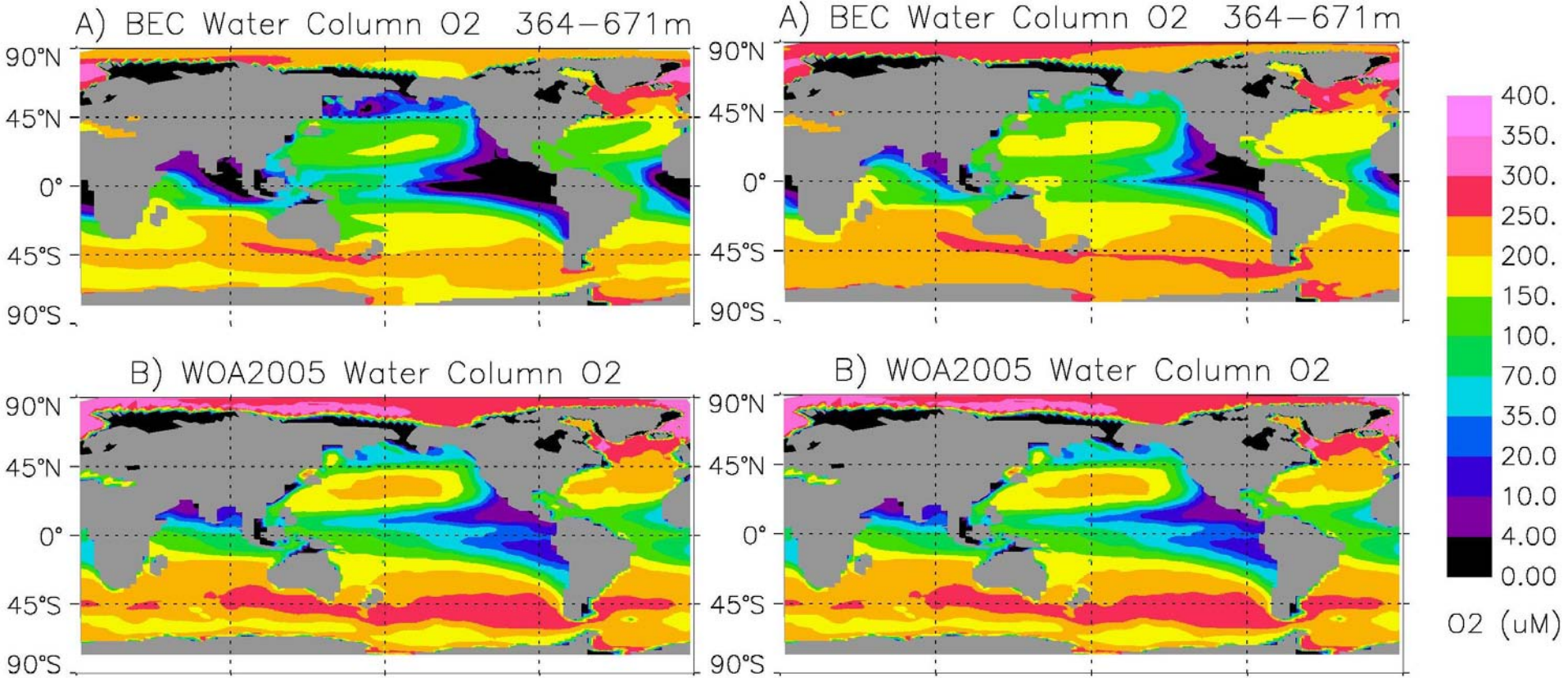


STD CESM

**Note phosphate + bias 200-600m
and oxygen – bias 200-600m**

MOD CESM

**Start with shorter lengthscale,
145m, then increase to X5
from ~120-550m.**



OMZ = O₂ < 20μM

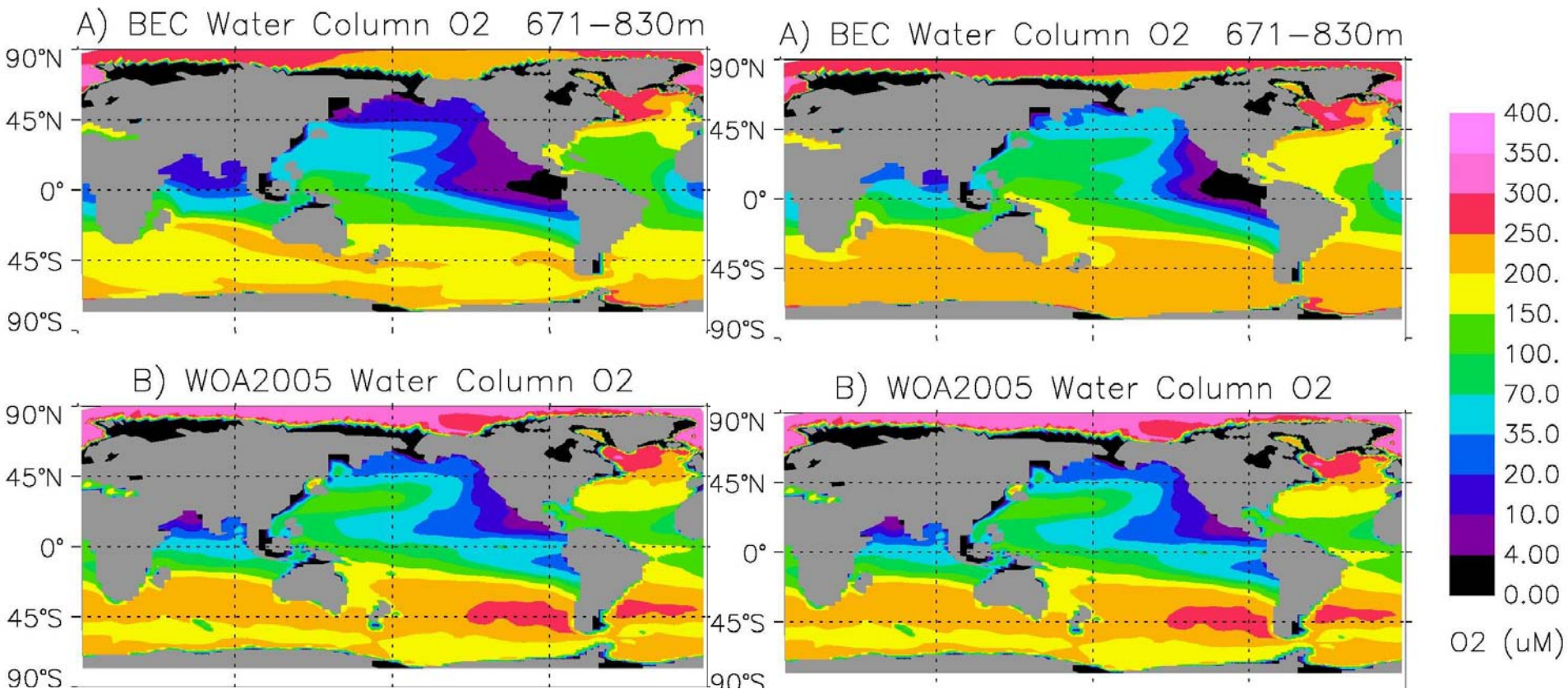
Depth 364-641m

STDCESM

MODCESM

OMZ volume 32% > Observed

OMZ volume 17% < Observed



Depth 641-830m

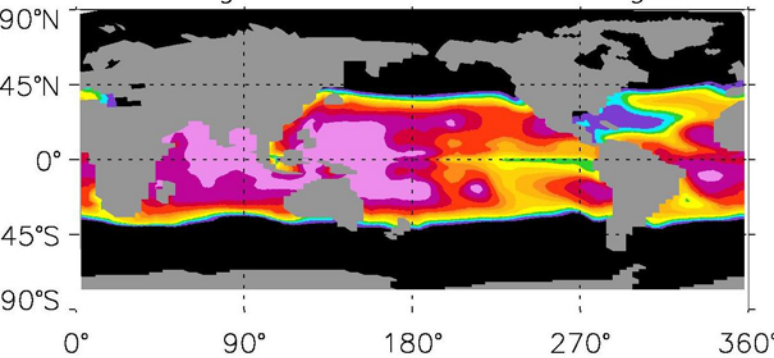
STDCESM

MODCESM

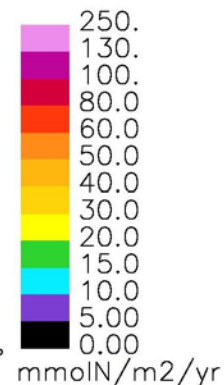
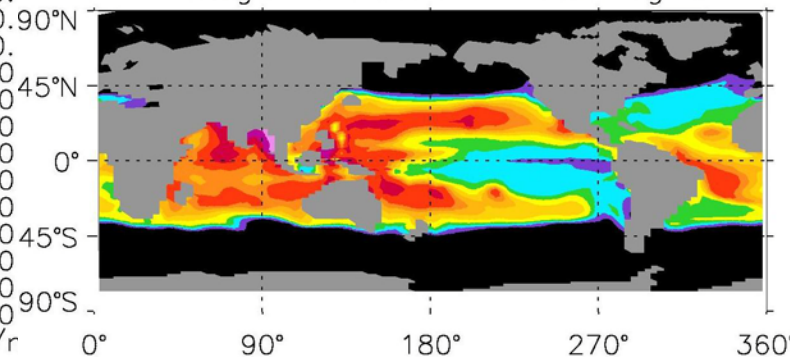
OMZ volume 100% > Observed

OMZ volume 2% < Observed

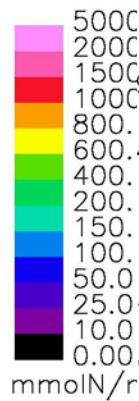
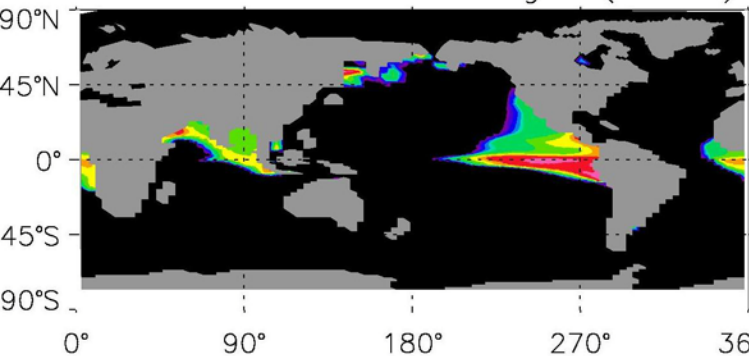
Nitrogen Fixation = 268.7 Tg N



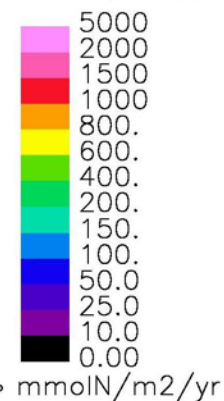
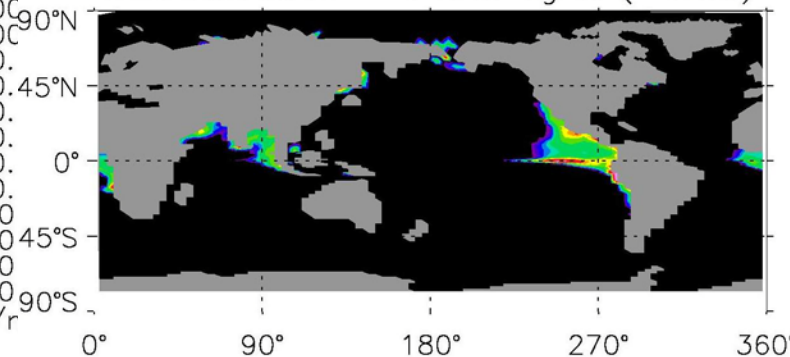
Nitrogen Fixation = 133.0 Tg N



Denitrification = 367.8 Tg N (-99.1)



Denitrification = 145.8 Tg N (-12.8)



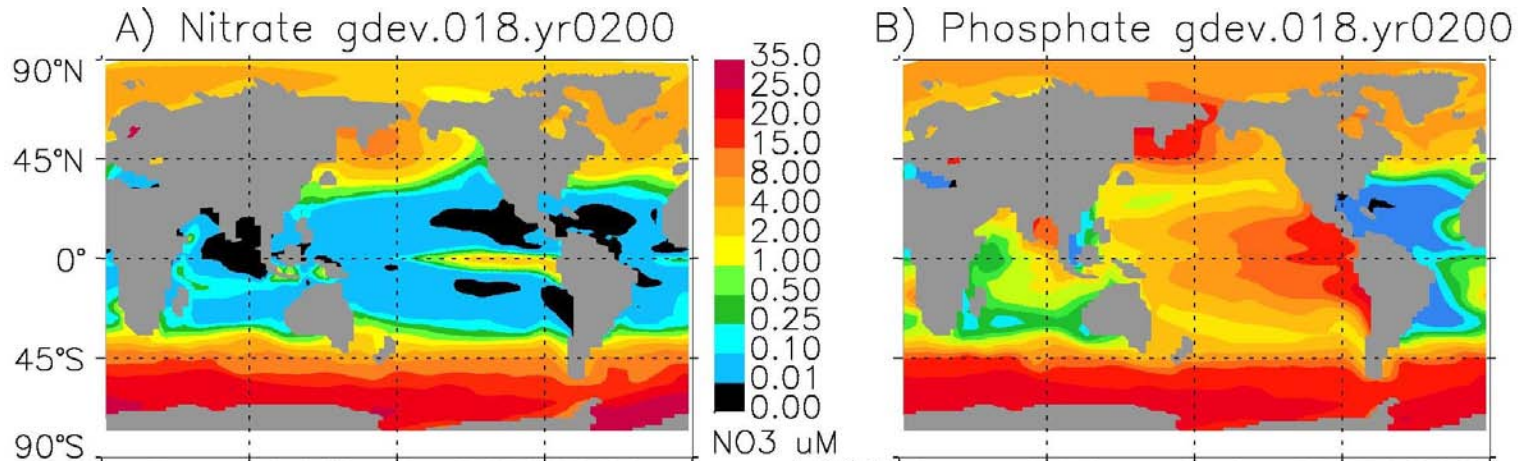
STDCESM

Denitrification >> N Fixation

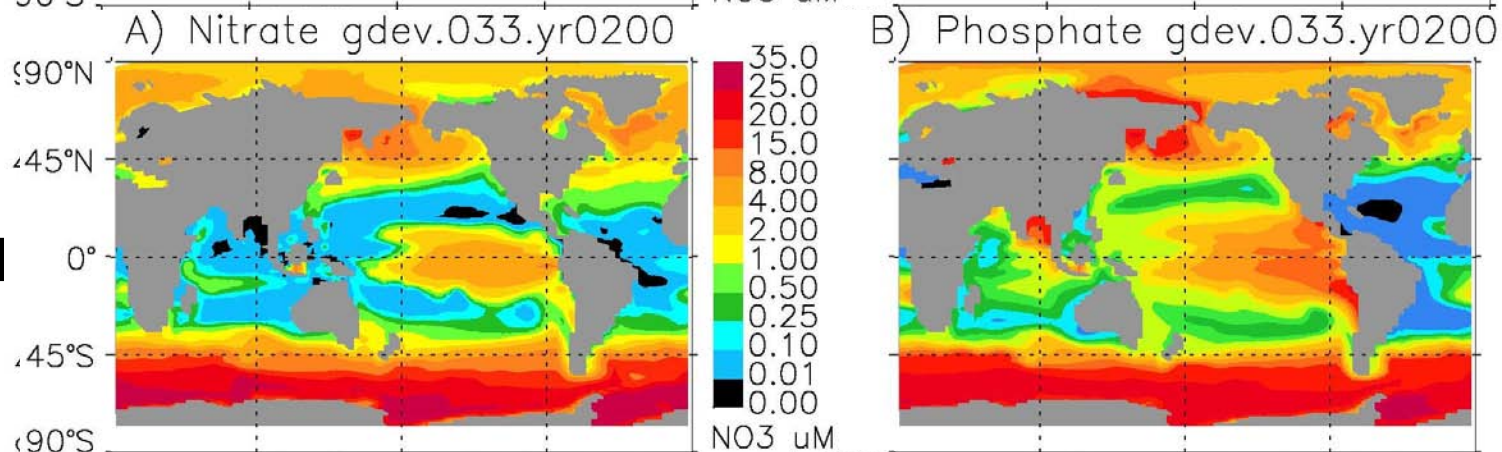
MODCESM

Nitrogen Cycle ~balanced

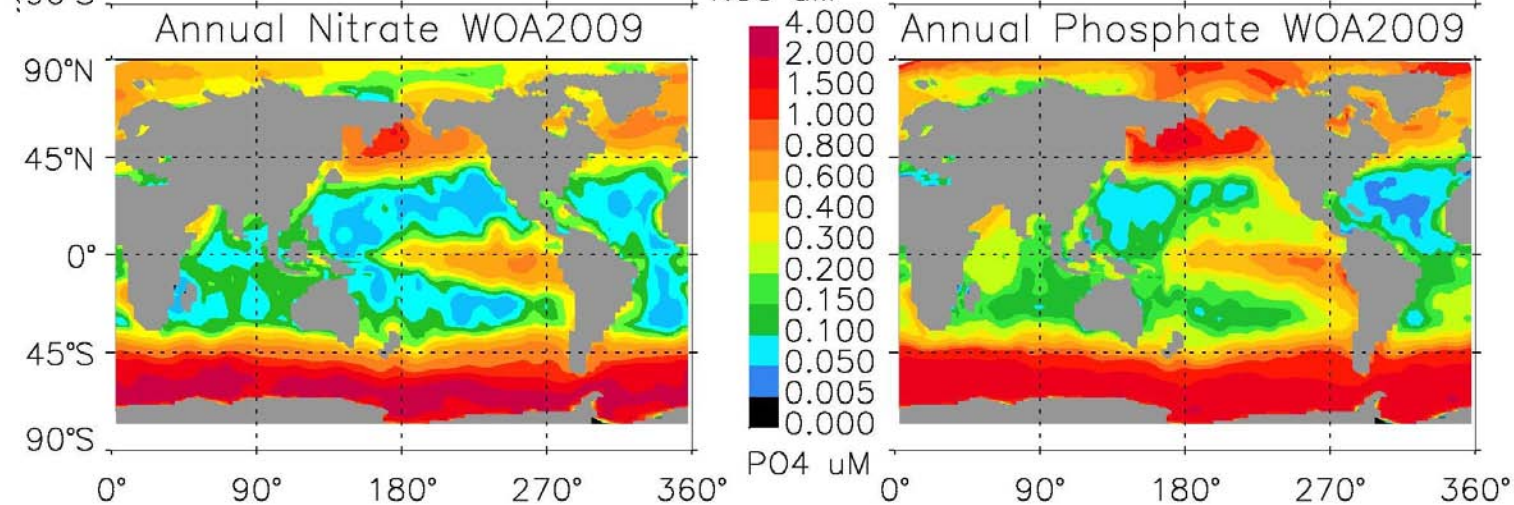
STD CESM

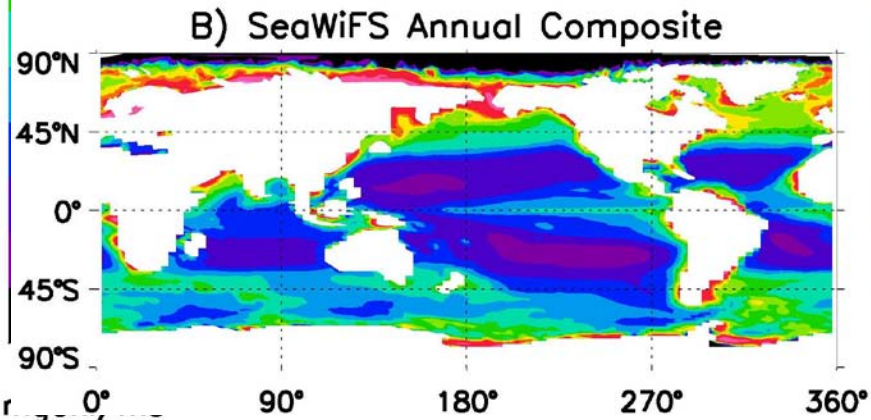
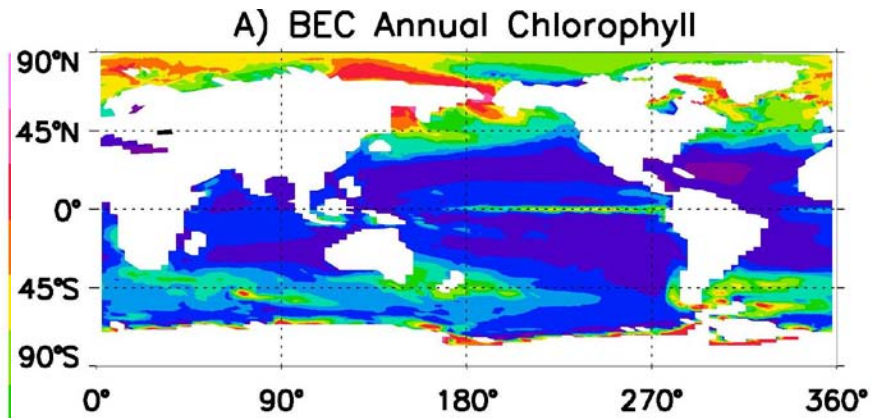
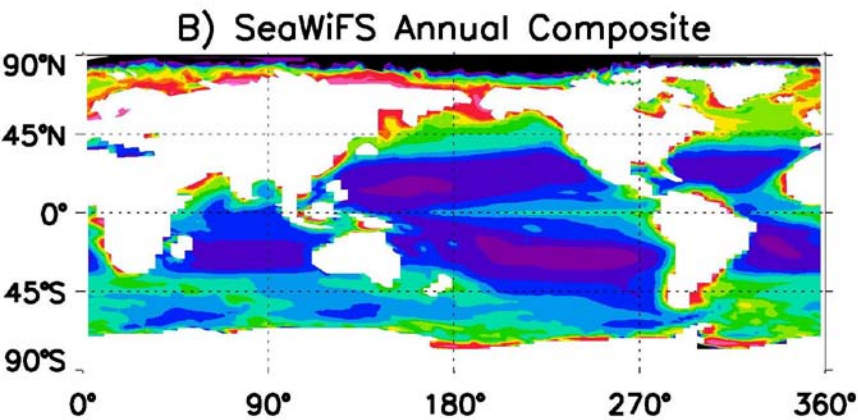
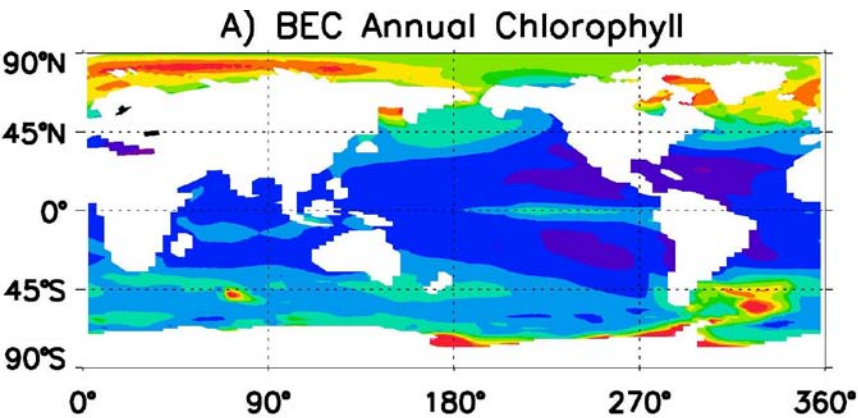


MOD CESM



Observed





STDCESM

Low latitude chlorophyll > observed
High latitude blooms missing

MODCESM

Low latitude bias reduced
Bloom dynamics improved

A) Diatom Growth Limitation gdev.018.yr0200



Nitrogen 76.19%, Iron 21.87%, Silica 0.546%, Phosphorus 1.383%
Light/Grazing 0.000%

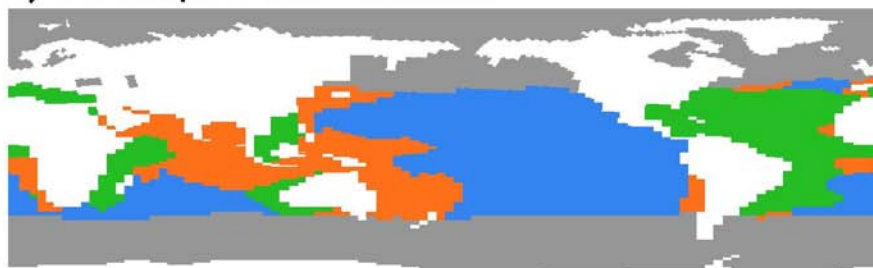
■ Nitrogen ■ Iron ■ Phosphorus ■ Silicon
■ Temperature ■ Light/Grazing

B) Small Phytoplankton Growth Limitation



Nitrogen 70.39%, Iron 22.50%, Phosphorus 0.754%
Light/Grazing 6.347%

C) Diazotroph Growth Limitation



Nitrogen 0.000%, Iron 33.66%, Phosphorus 16.73%
Light/Grazing 16.58%, Temperature 33.01%

STD CESM

A) Diatom Growth Limitation gdev.033.yr0200



Nitrogen 50.85%, Iron 36.78%, Silica 0.833%, Phosphorus 11.51%
Light/Grazing 0.015%

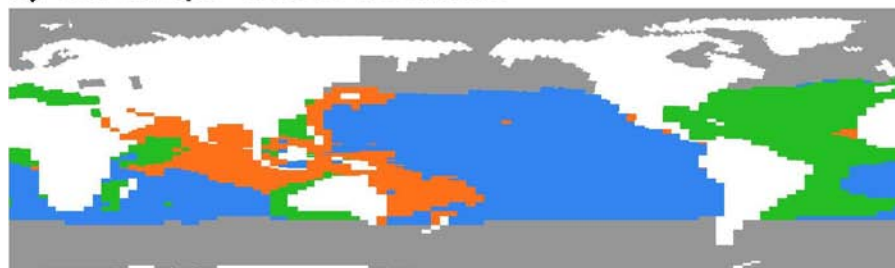
■ Nitrogen ■ Iron ■ Phosphorus ■ Silicon
■ Temperature ■ Light/Grazing

B) Small Phytoplankton Growth Limitation



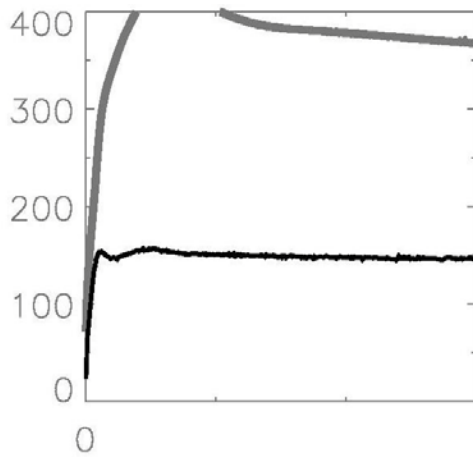
Nitrogen 46.81%, Iron 41.93%, Phosphorus 9.452%
Light/Grazing 1.792%

C) Diazotroph Growth Limitation

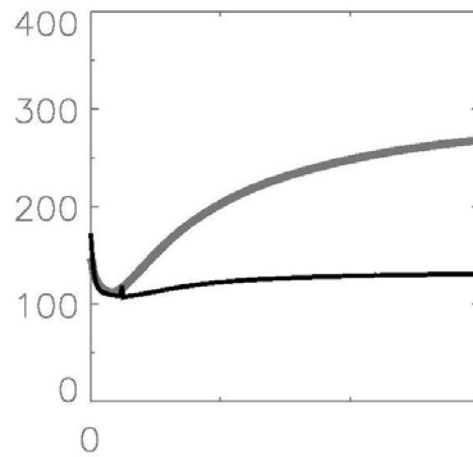


Nitrogen 0.000%, Iron 38.61%, Phosphorus 16.84%
Light/Grazing 11.68%, Temperature 32.85%

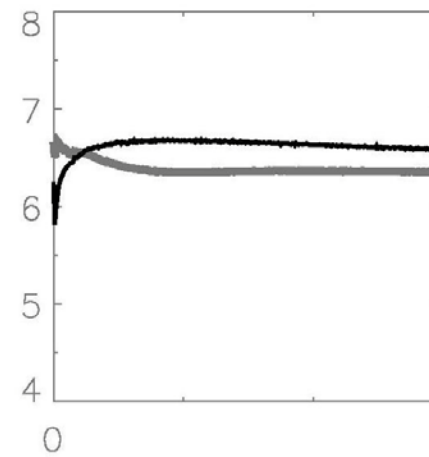
MOD CESM



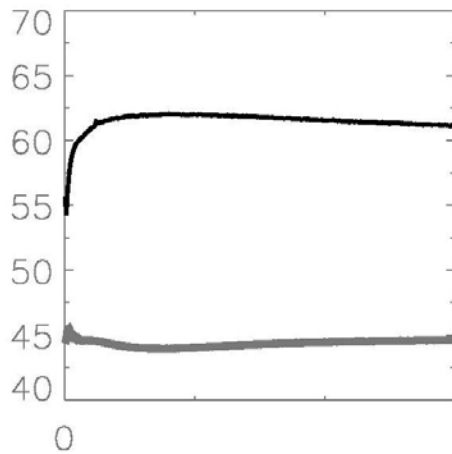
Denitrification (TgN/yr)



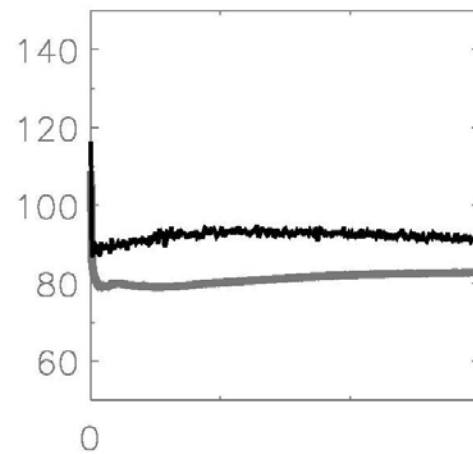
N Fixation (TgN/yr)



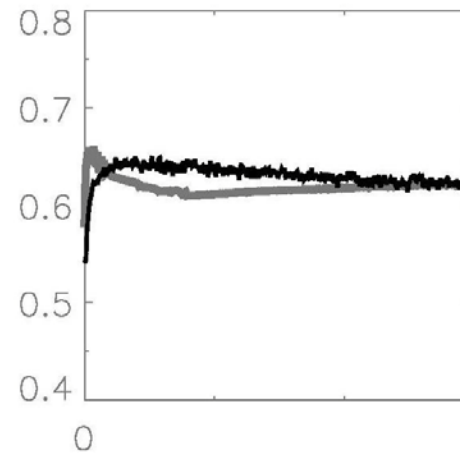
POC Export (PgC/yr)



Production (GtC/yr)



Silicification (TgSi/yr)



CaCO3 Export (PgC/yr)

STD CESM – gray line

MOD CESM – black line

300 year simulations

Conclusions and Future Work

- 1) CESM biases much reduced, N cycle able to balance and OMZ distributions much more reasonable.
- 2) NIW CPT mixing modifications will improve OMZs.
- 3) Need to port these modifications back to X1 model.
- 4) Need to spin up X3 ocean model for coupled climate-carbon simulations.