

Improving Biogeochemical Cycling in the CESM Ocean Model

Associate Professor Keith Moore

Department of Earth System Science
University of California, Irvine



Progress Report on Efforts to Reduce CESM Ocean BGC Biases

Biggest problem: Oxygen Minimum Zones (OMZ) / N Cycle

Excessively large OMZs leads to excessive denitrification.

Nitrogen cycle imbalance: loss >> sources

Low Latitudes:

High biomass (chlorophyll) bias

High nutrient bias at low latitudes

High Latitudes:

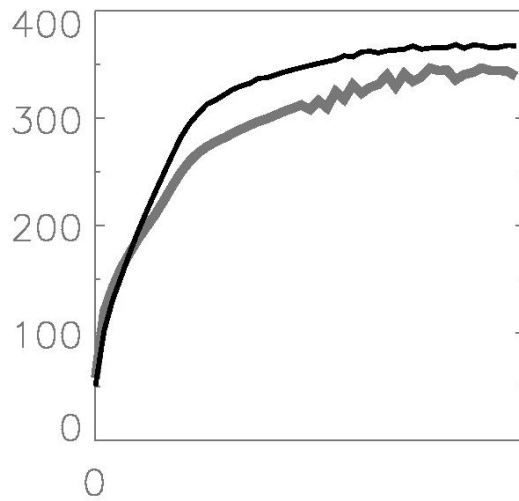
Low nutrient bias at high latitudes

Blooms are either missing, or too large

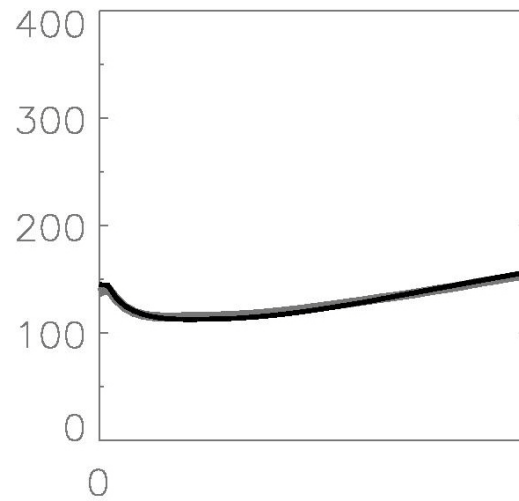
These problems are present in the X3 (~3 degree) and X1 (~1 degree).

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

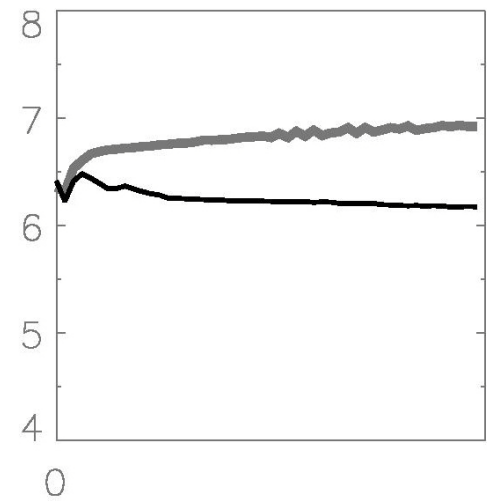




Denitrification (TgN/yr)



N Fixation (TgN/yr)



POC Export (PgC/yr)

Standard CESM simulations over 50 year period, without the artificial scaling factor to reduce denitrification.

Black line – X3 model (~ 3 degree)

Gray line – X1 model (~ 1 degree)

Nitrogen imbalance is equally bad in the X3 model.

Modifications to Standard CESM Ocean Model

Physics Changes:

Gent-McWilliams Mixing Parameterization (Eden et al., 2009)

BFRE – default option, mixing decreases rapidly with depth, a function of local stability frequency.

EDGR – mixing varies spatially, dependent on eddy length and time scales, more mixing in WBC, SO.

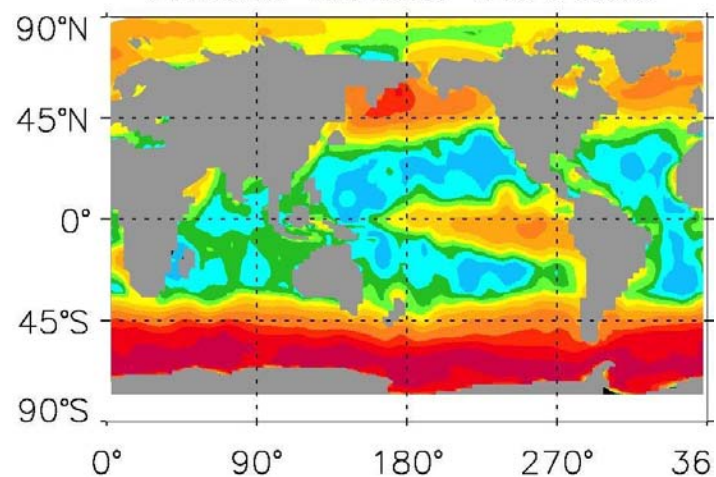
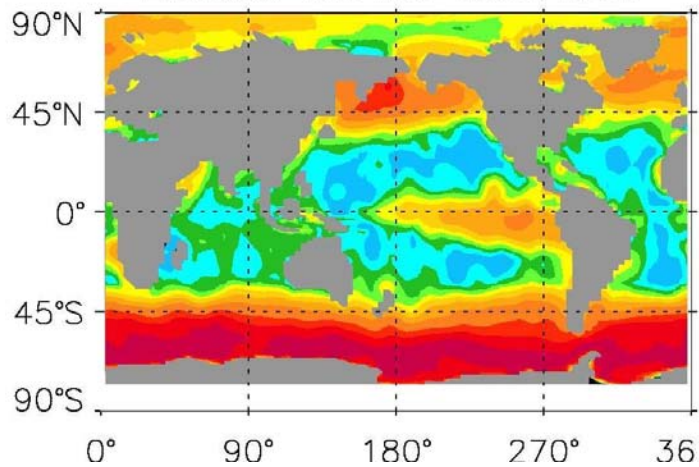
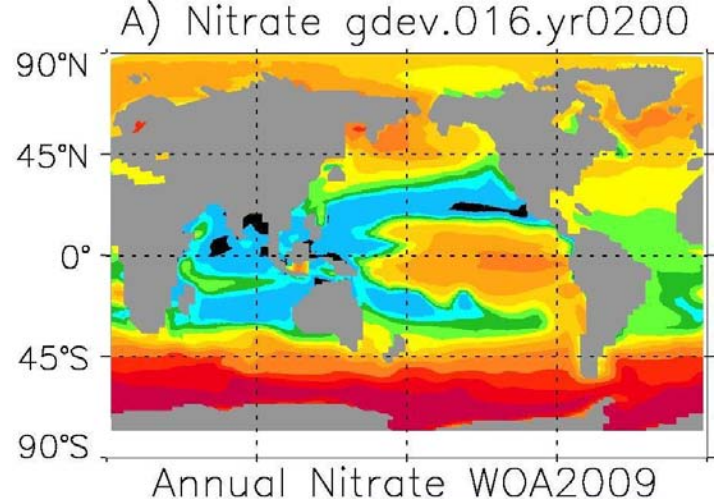
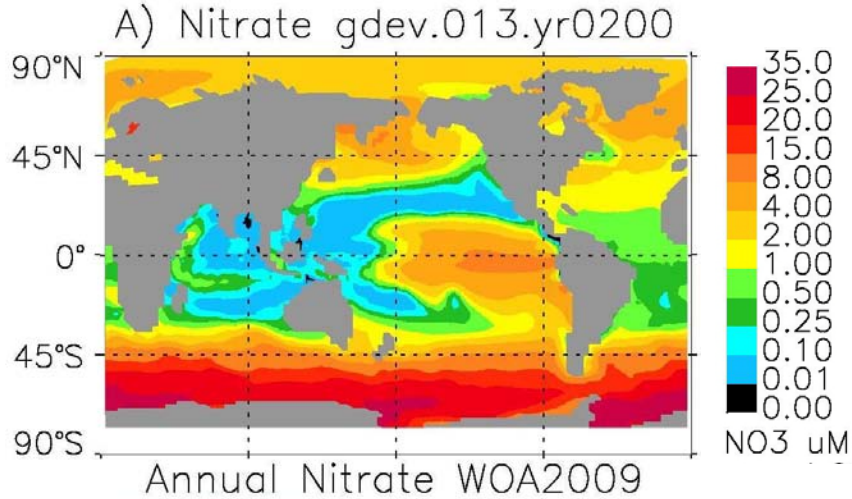
Latitudinal varying background diapycnal mixing (Jochum, 2009)

	Equator	Mid-latitudes	High Latitudes
Std. CESM	0.01	0.3	0.17
Mod. CESM	0.001	0.25	0.2

Additional increase in diapycnal mixing in the NW Pacific.

(Temporary fix, likely not necessary with CPT inertial mixing.)

Biggest effect is the BFRE > EDGR switch, it improves ocean biogeochemistry, but needs to be evaluated more for influence on circulation and heat transport and in coupled climate simulations.



BFRE GM Option

High Latitude Nitrate Too Low
Air-sea O₂ and CO₂ exchange
will also be low.

EDGR GM Option

High Latitude Nitrate Better
Increased Vertical Exchange

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 Phytoplankton Stoichiometry (switch to traditional Redfield)

C/N/P 117/16/1 new ratios 106/16/1 (Anderson 1995)

Improved Grazing Parameterizations

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

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

Modified Remineralization Curves

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

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 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)

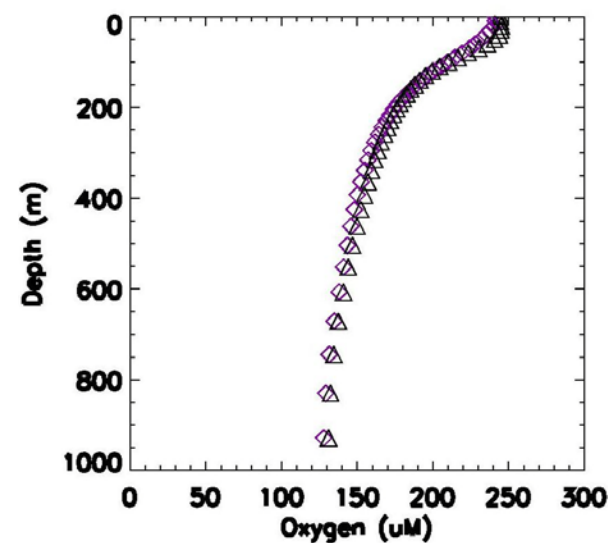
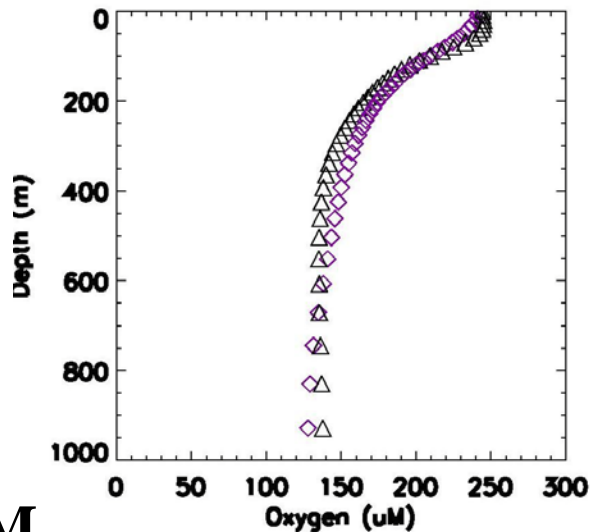
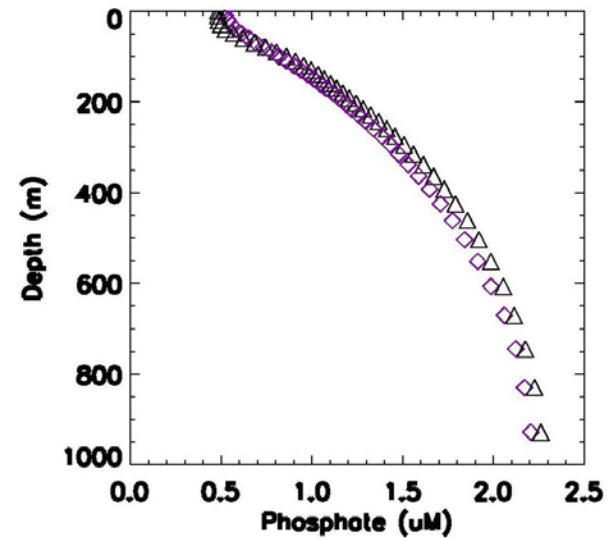
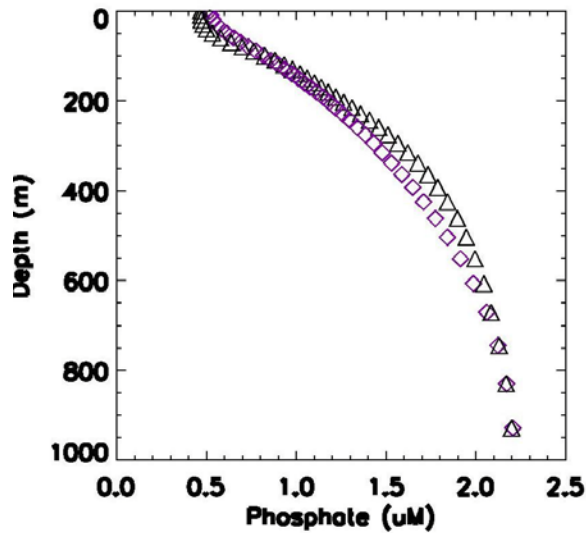
Slower sinking particles remineralize completely < 300-500m depth.
Smaller particles are repackaged into larger particles through zooplankton grazing and physical aggregation, which then sink faster.

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, also has an increasing length scale with depth.

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



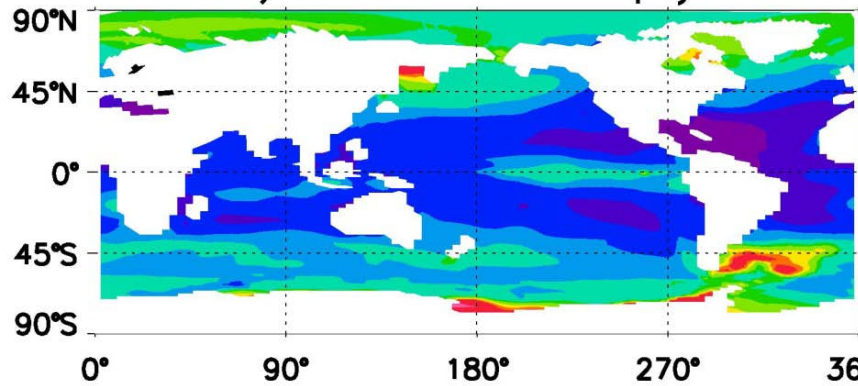
STD CESM

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

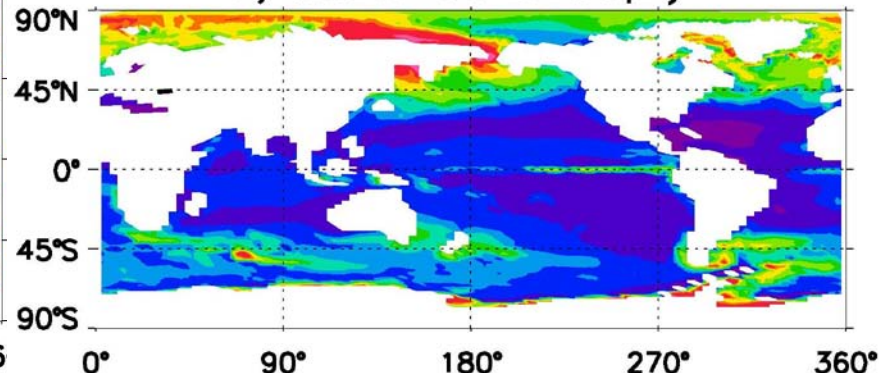
MOD CESM

**Start with shorter lengthscale,
increase X4 from 100-550m,
further increase to X5, 1500m.**

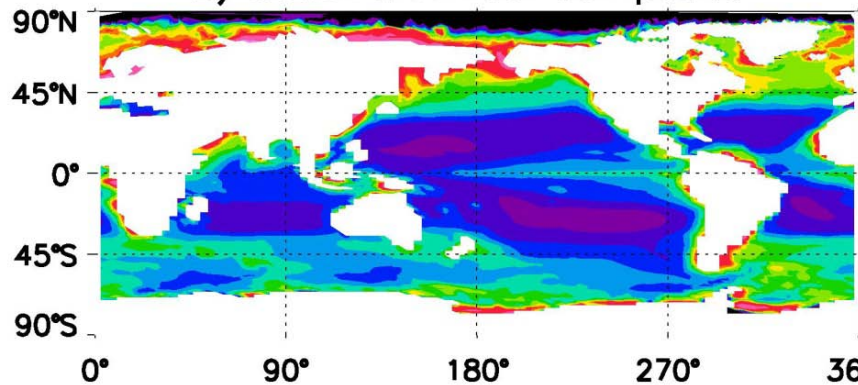
A) BEC Annual Chlorophyll



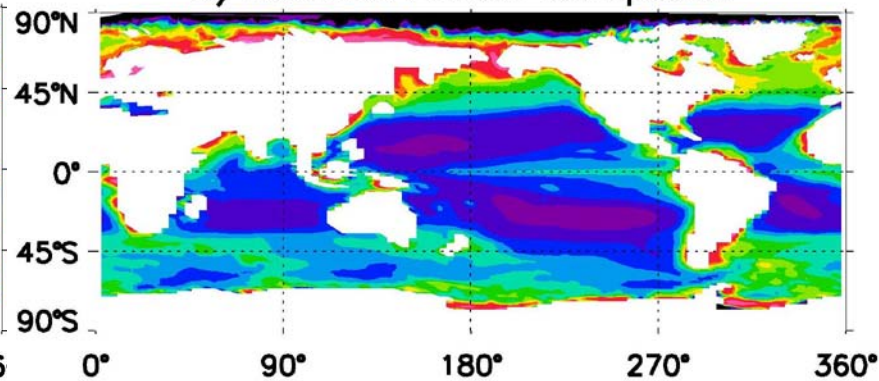
A) BEC Annual Chlorophyll



B) SeaWiFS Annual Composite



B) SeaWiFS Annual Composite



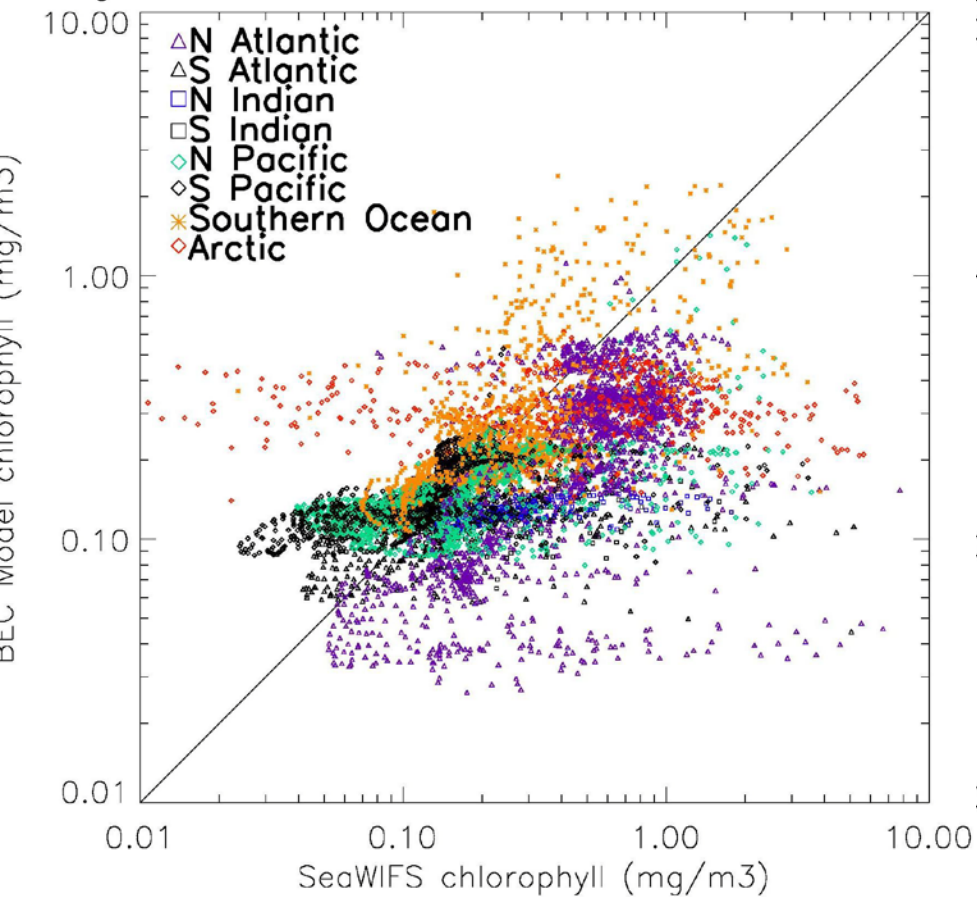
STDCESM

Low latitude chlorophyll > observed
High latitude blooms missing

MODCESM

Low latitude bias reduced
Bloom dynamics improved

Log r = 0.526 RMS = 0.355 Bias = -0.147 StdRot = 0.614



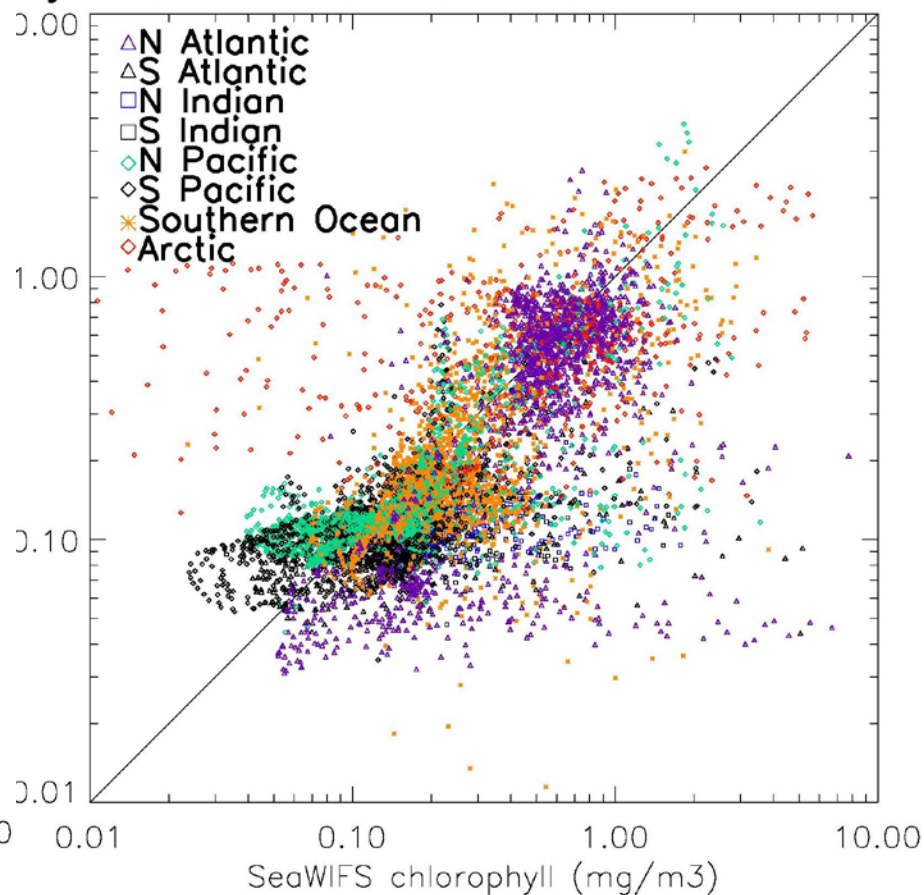
STDCESM

r = 0.53

bias = -0.15

ratio var = 0.61

Log r = 0.621 RMS = 0.349 Bias = -0.099 StdRot = 0.949

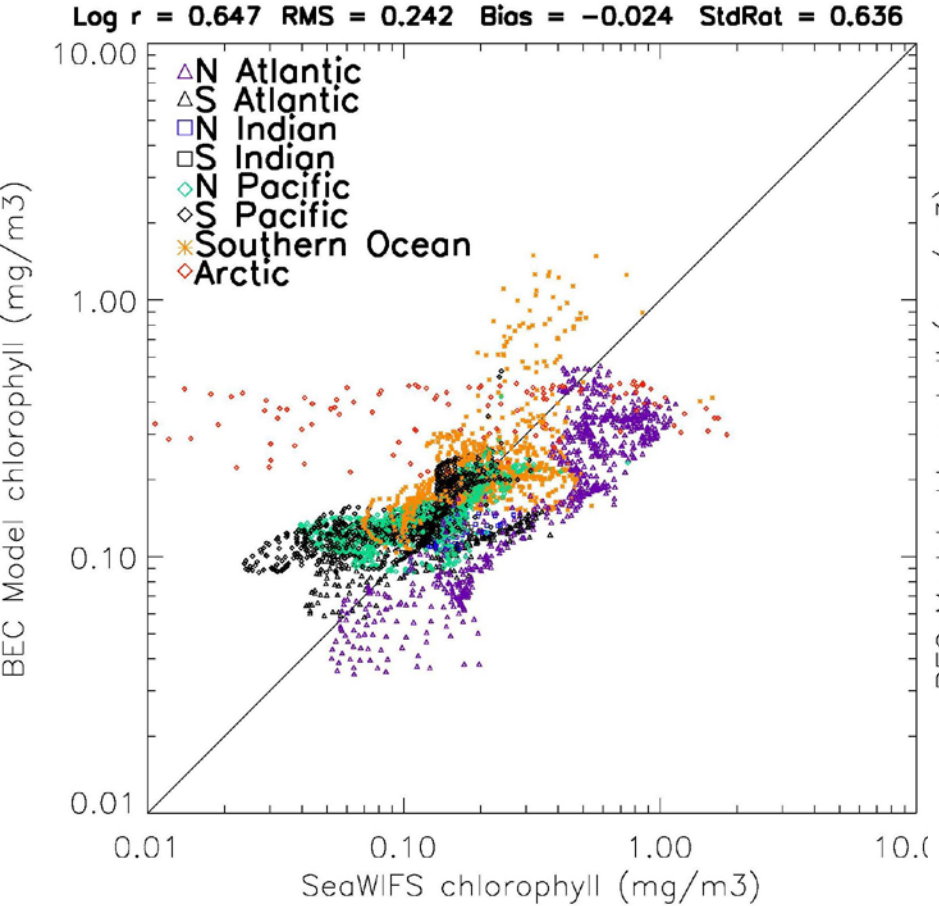


MODCESM

r = 0.62

bias = -0.099

ratio var = 0.95

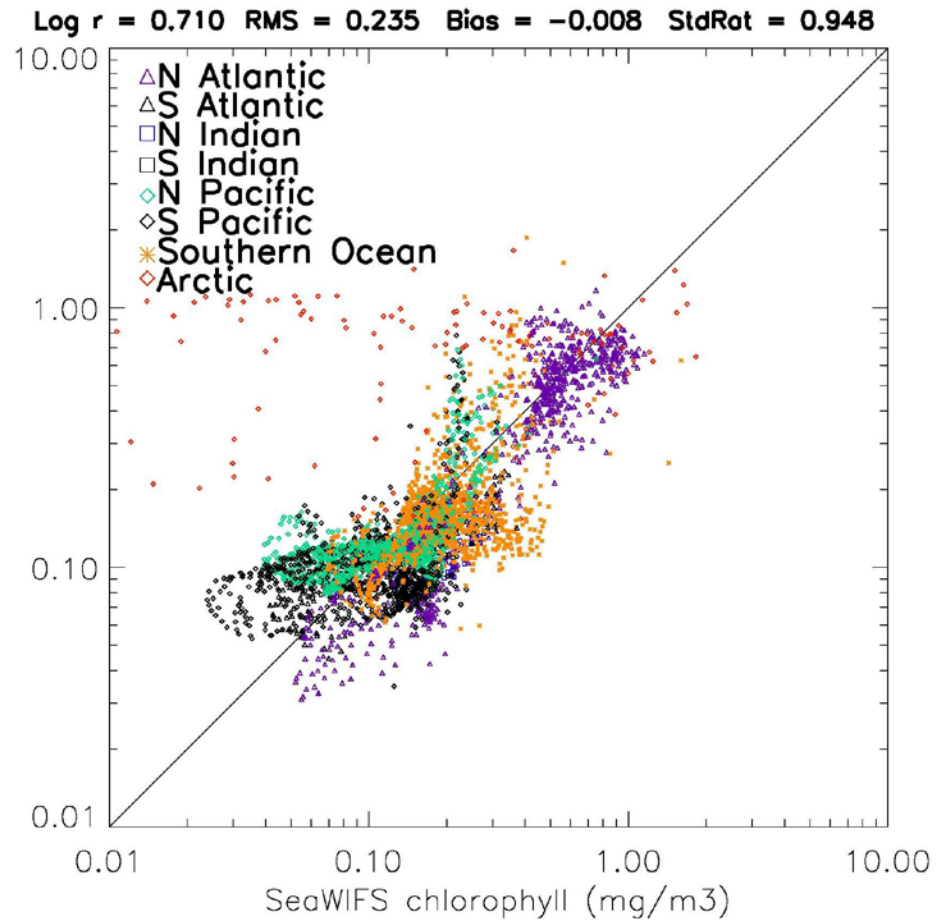


STDCESM

r = 0.65

bias = -0.024

ratio var = 0.64

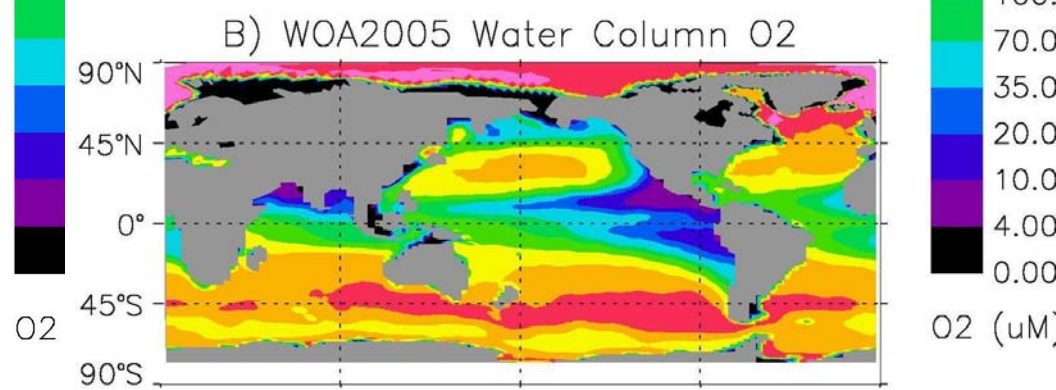
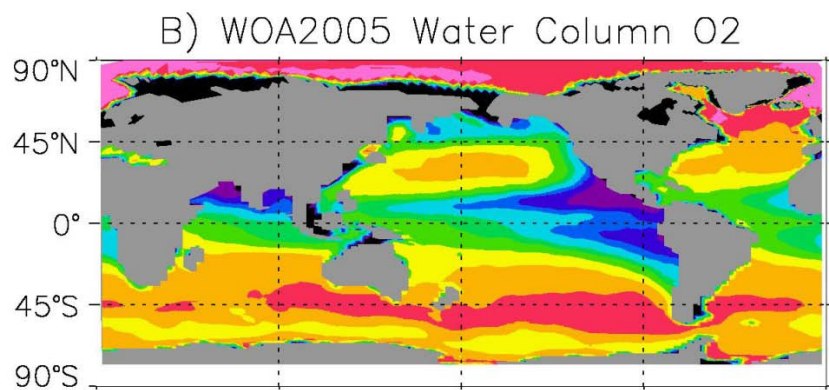
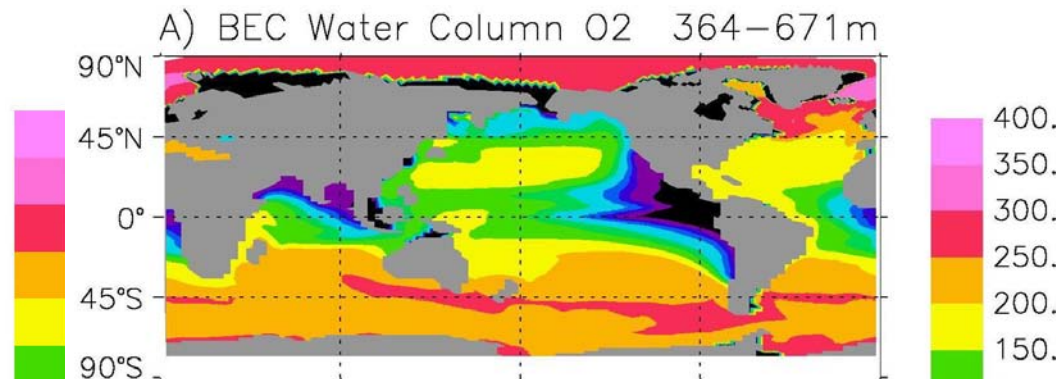
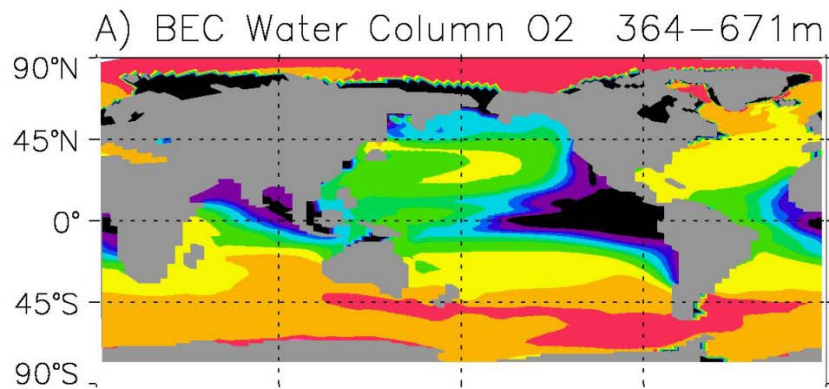


MODCESM

r = 0.71

bias = -0.008

ratio var = 0.95



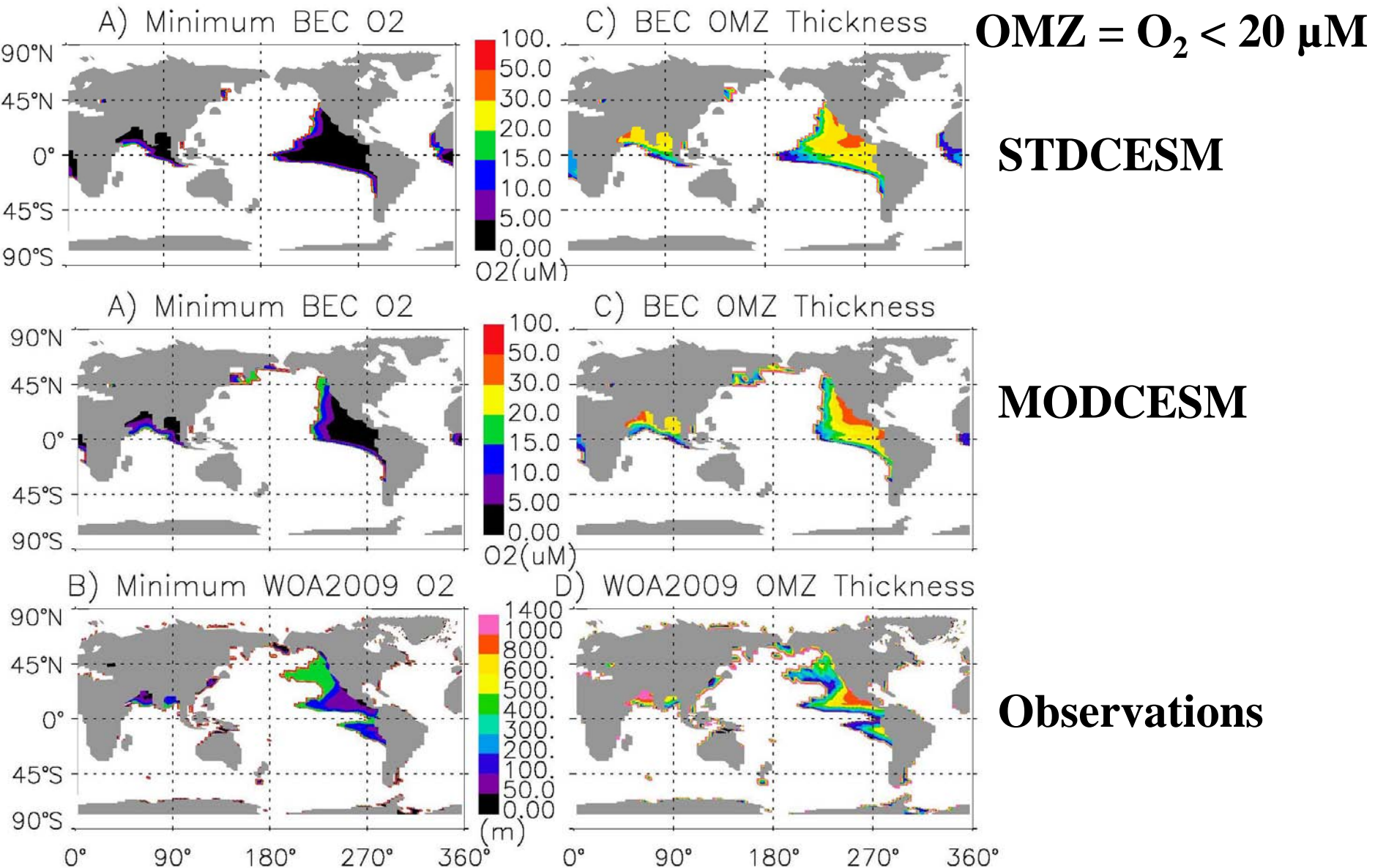
Depth 364-641m

STDCESM

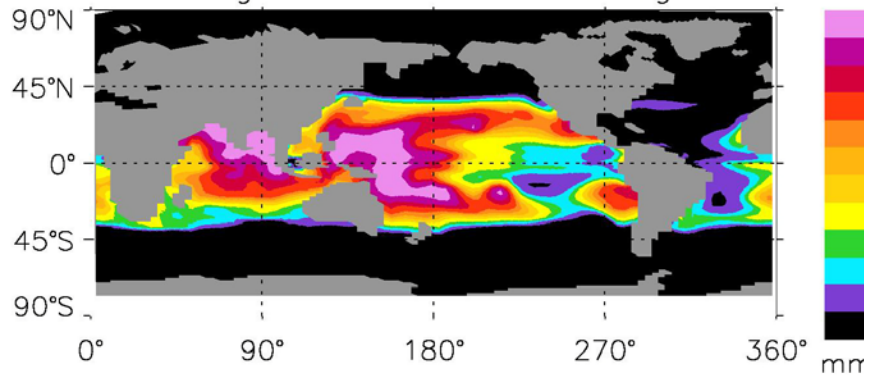
OMZ volume 21% > Observed

MODCESM

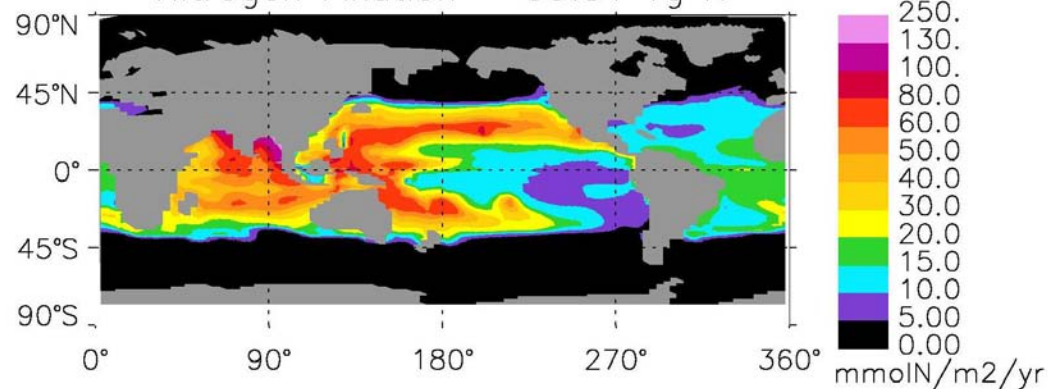
OMZ volume 9% < Observed



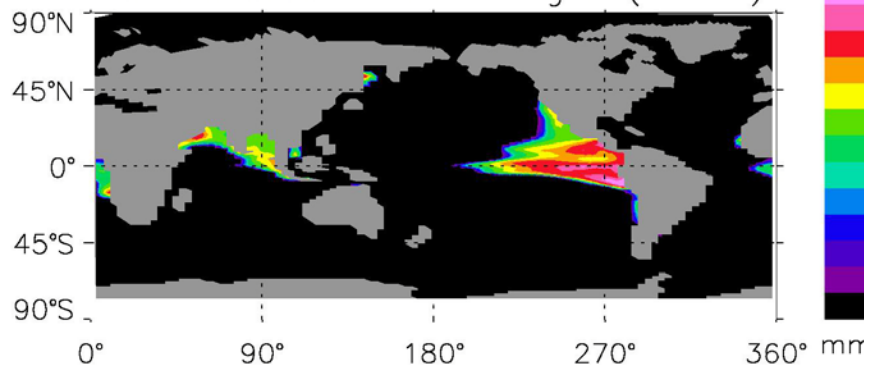
Nitrogen Fixation = 155.9 Tg N



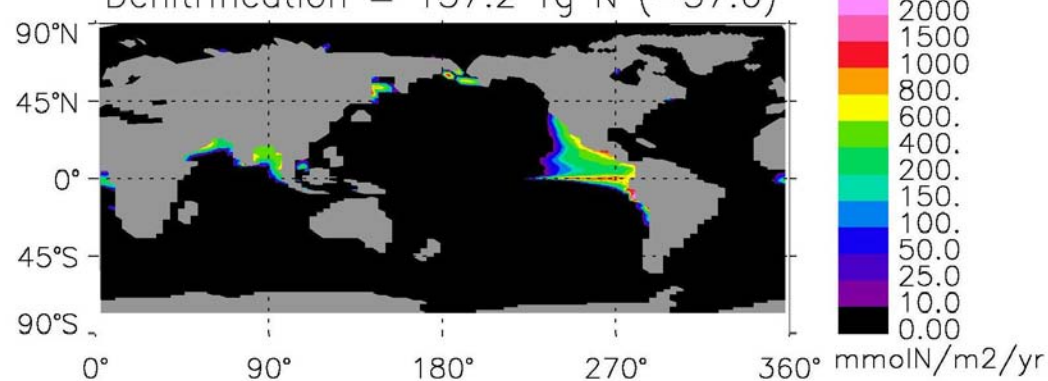
Nitrogen Fixation = 99.51 Tg N



Denitrification = 367.7 Tg N (-211.)



Denitrification = 137.2 Tg N (-37.6)

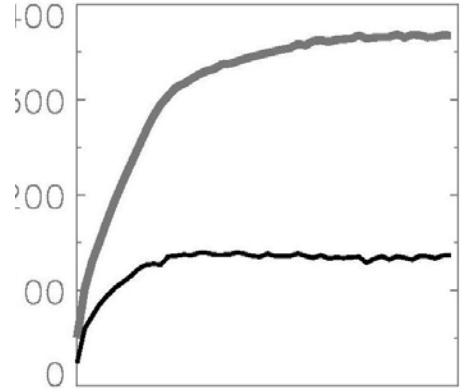


STDCESM

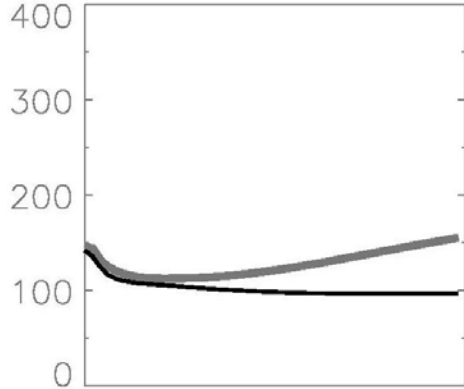
Denitrification >> N Fixation

MODCESM

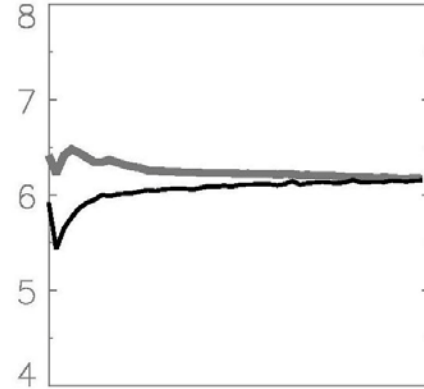
Nitrogen Cycle ~balanced



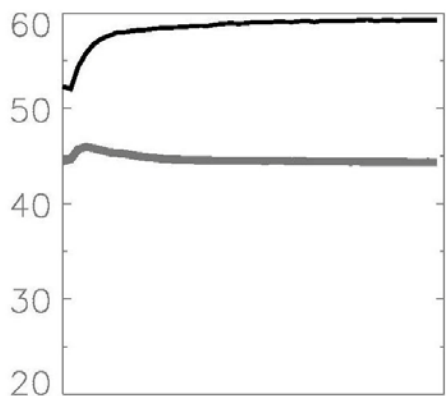
Denitrification (TgN/yr)



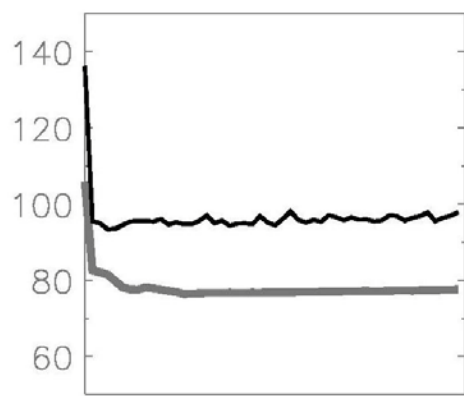
N Fixation (TgN/yr)



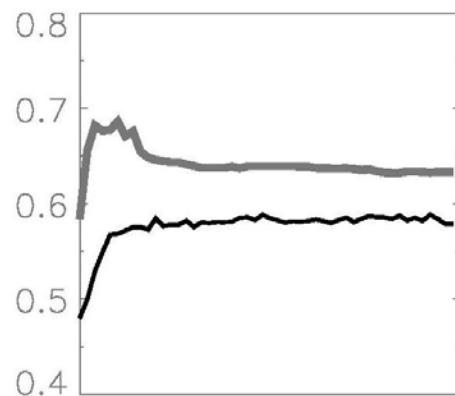
POC Export (PgC/yr)



Production (GtC/yr)



Silicification (TgSi/yr)



CaCO3 Export (PgC/yr)

STDCESM – gray line

MODCESM – black line

50 year simulations

Conclusions and Future Work

- 1) CESM biases much reduced, N cycle able to balance and OMZ distributions much more reasonable.
- 2) Next spin up X3 NCEP-forced, ocean-ice only simulation.
- 3) Need to port these modifications back to X1 model.
- 4) Need to spin up X3 ocean model for coupled climate-carbon simulations.

