Ocean Biogeochemistry in the CESM 1.2

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Improving Ocean Biogeochemistry in the CESM 1.2

CESM 1.2 contains a number of improvements and additions to the marine biogeochemistry module, the Biogeochemical Elemental Cycling (BEC) model.

The modifications lead to improved simulation of observed distributions of nutrients, chlorophyll, and oxygen.

All results here are from GIAF gx1v6 simulations (active ocean-ice-ecosys in the ~1 degree ocean model) averaged over the last 30 years of 300-year simulations.

CESM 1.0 results from release code, but without the artificial downscaling of water column denitrification.

Improving Ocean Biogeochemistry in the CESM 1.2

1) Increase phytoplankton maximum iron quotas
   (range 3-6 µmolFe/molC -> range 3-24 µmolFe/molC)
2) Improve cycling of dissolved organic matter
   (add refractory DON and DOP, allow uptake of DOP)
3) Optimize prescribed remineralization with depth curve
   (length scale increases with depth, and under low O_2)
4) Add riverine input of nutrients (C, N, P, Si, Fe, Alk)
5) Add parameterizations of sediment biogeochemistry
   A) Burial loss of organic matter (Dunne et al. 2007)
   B) Sedimentary denitrification (Bohlen et al., 2012)
   C) Burial loss of $CaCO_3$ (prescribed lysocline depth)
   D) Burial of biogenic Si (Rageneau et al., 2000)

Dissolved Organic Matter (DOM)

In CESM 1.0 dissolved organic carbon, nitrogen, and phosphorus (DOC, DON, DOP) include only the semi-labile DOM fractions and all cycle identically (same routing, same lifetimes).

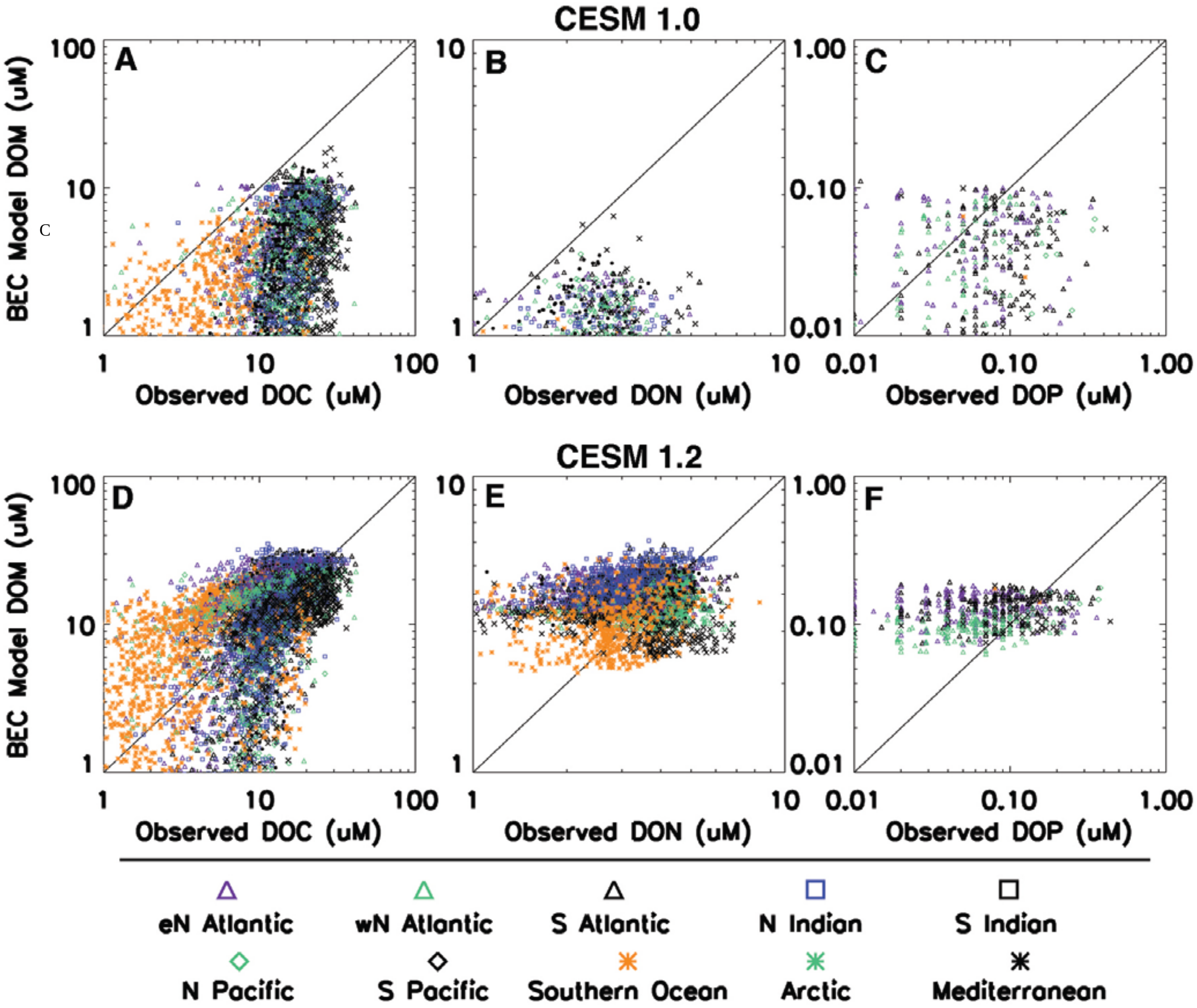
CESM 1.2 includes both semi-labile and refractory DON and DOP pools (ongoing work will add refractory DOC).

The prescribed lifetimes for the various DOM pools vary.

Phytoplankton can directly take up both phosphate and DOP, with a strong preference for phosphate when available.

DOM cycling is still an area of active development, but progress was sufficient to include in CESM 1.2.

Simulated Vs. Observed Dissolved Organic Matter over depth range of 100-315m



CESM 1.0 (c,n,p)

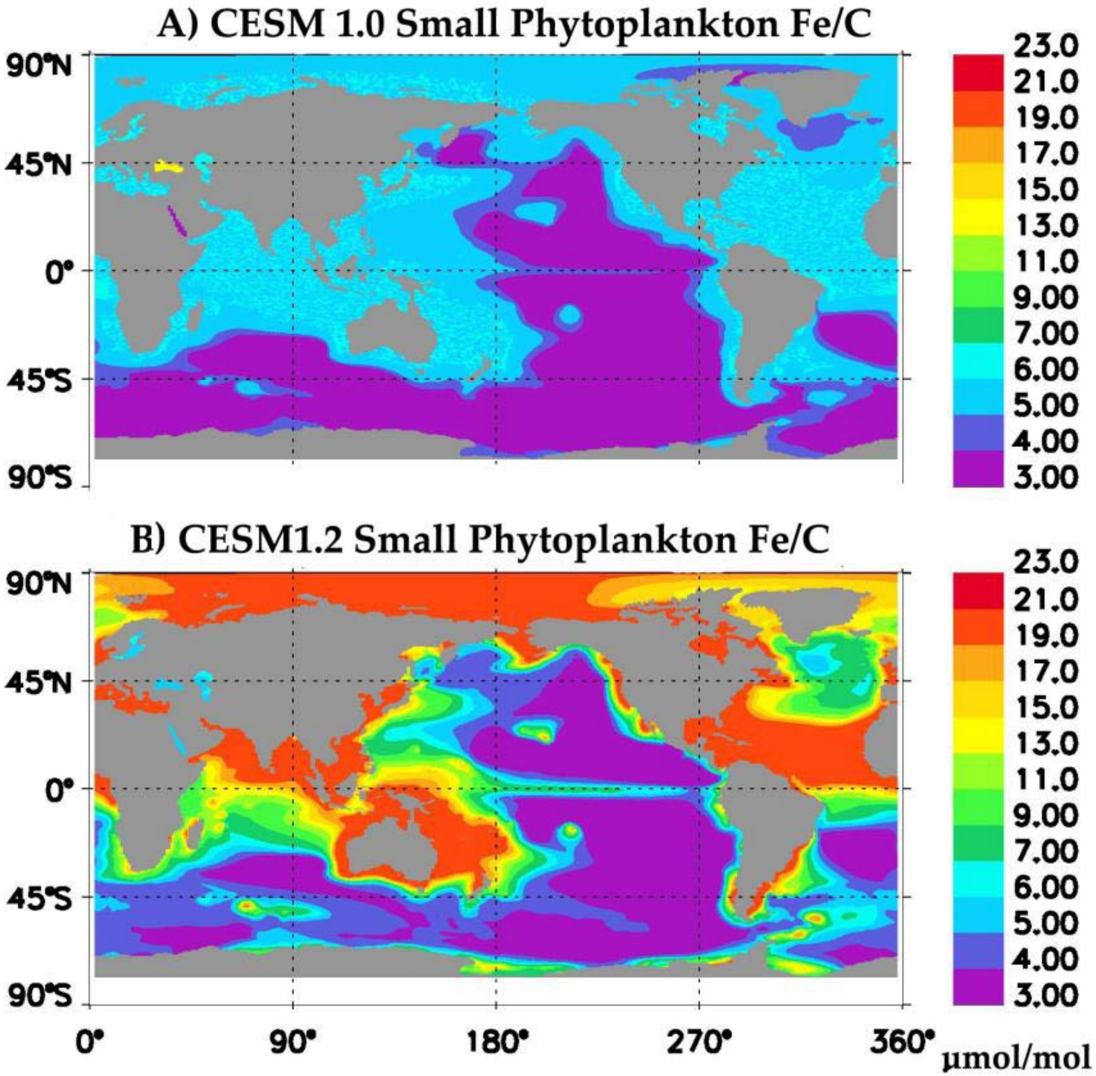
r = 0.50, 0.38, 0.26

bias = -9.5, -1.4, -0.025

CESM 1.2 (c,n,p)

r = 0.58, 0.17, 0.18

bias = 1.5, 0.5, 0.037

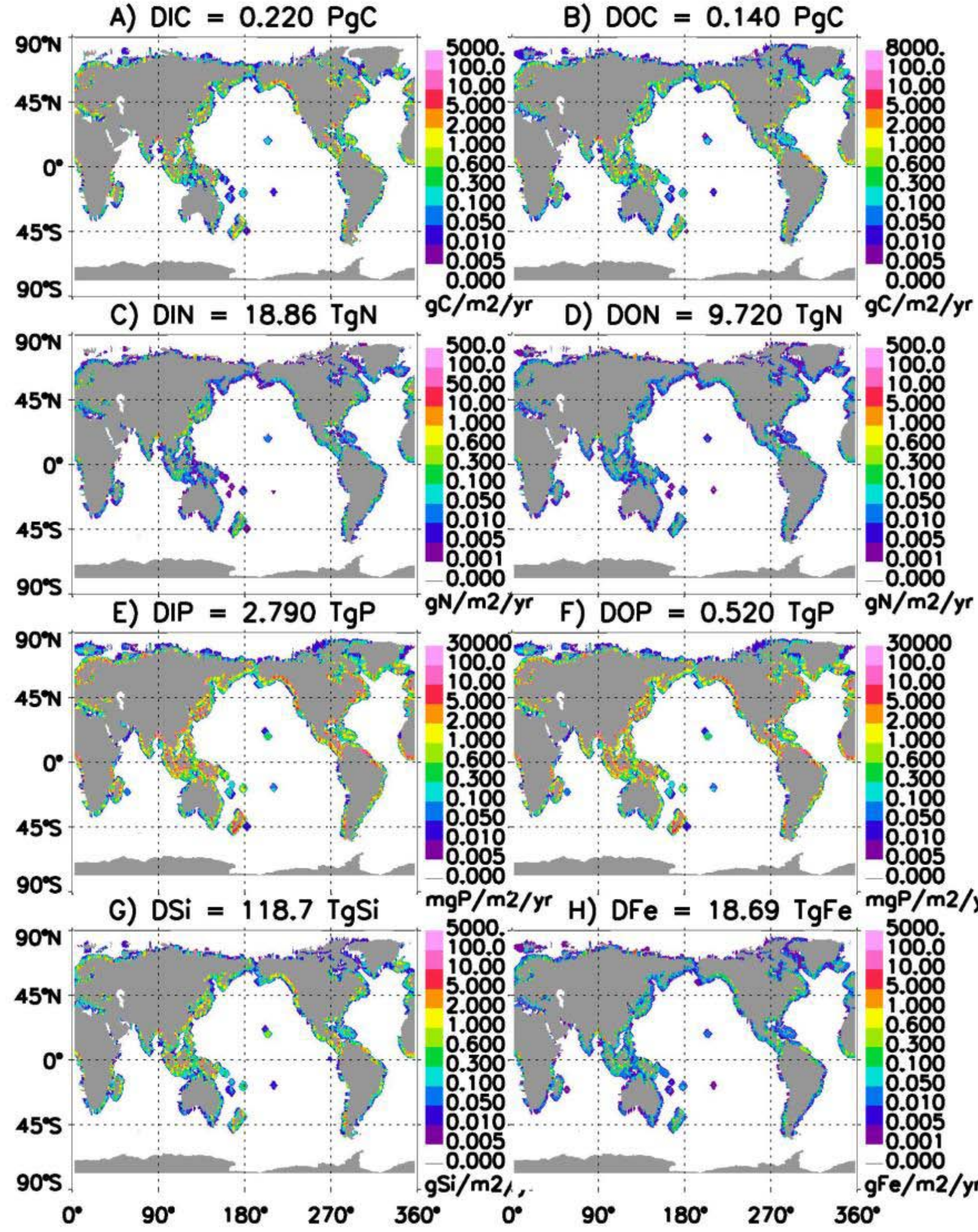


CESM1.0 range of phytoplankton Fe/C ratios 3-6 µmol/mol.

Varies as a function of ambient iron.

CESM 1.2 range of phytoplankton Fe/C ratios 3-22 µmol/mol.

Recent field studies indicate that Fe/C ratios in phytoplankton are often higher than used in CESM 1.0 (i.e. McKay et al., 2005; Twining et al., 2004; 2011; King et al., 2012; Hopkinson et al., 2013).



River Nutrient Inputs

Dissolved nutrient inputs from Nutrient Export from WaterSheds (NEWS) set of linked global-scale models (Mayorga et al., 2010; Seitzinger et al., 2010)

Spatial pattern follows river water inputs to the oceans in CESM.

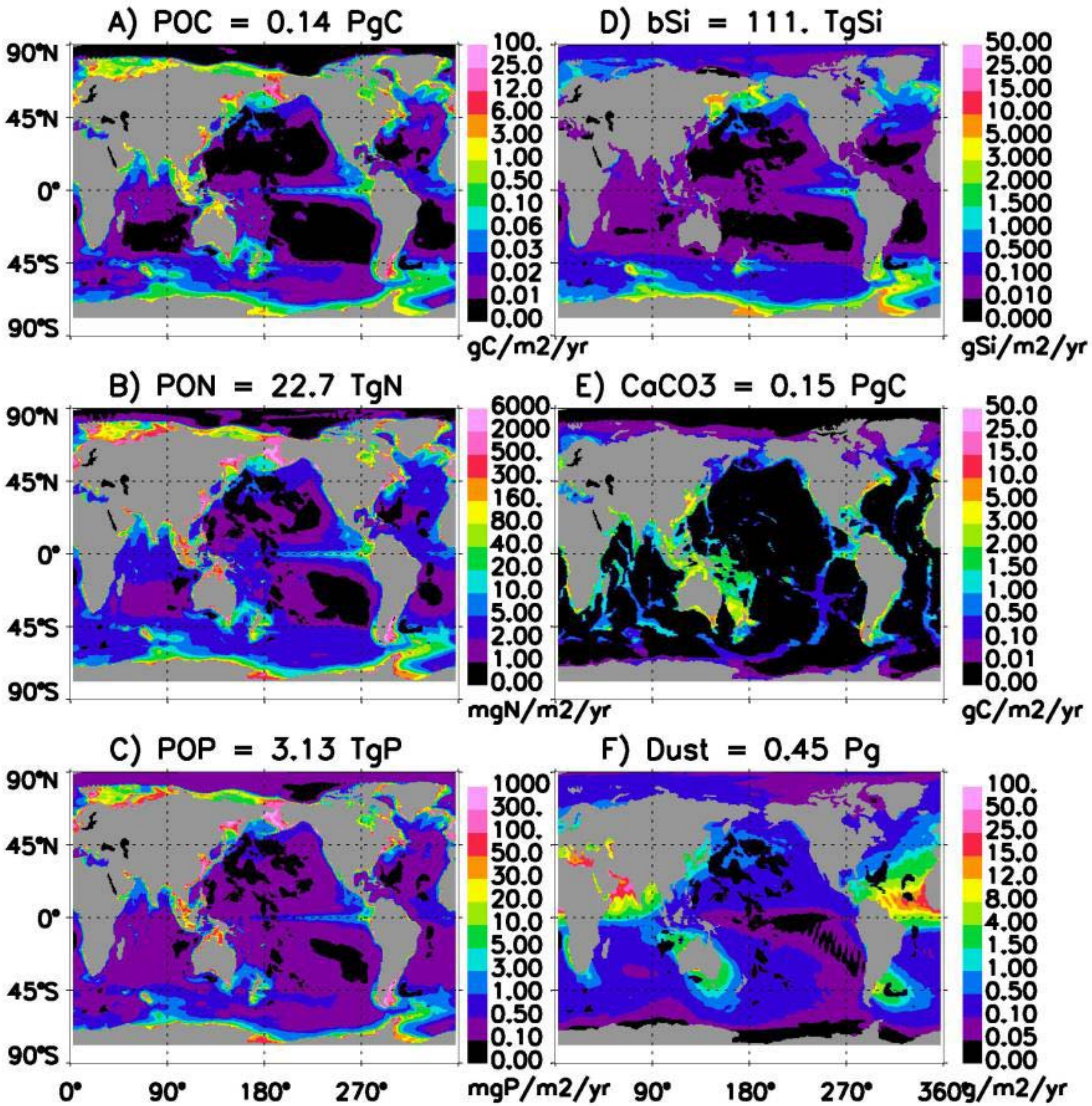
NEWS nutrient flux estimated for the year 2000 cycled repeatedly.

Does not include particulate inputs.

Dissolved iron inputs estimated assuming constant river water concentration (10 nM).

Ongoing work to link with CLM nitrogen runoff (see Nevison talk).

Ocean-Sediment Biogeochemical Fluxes in CESM 1.2



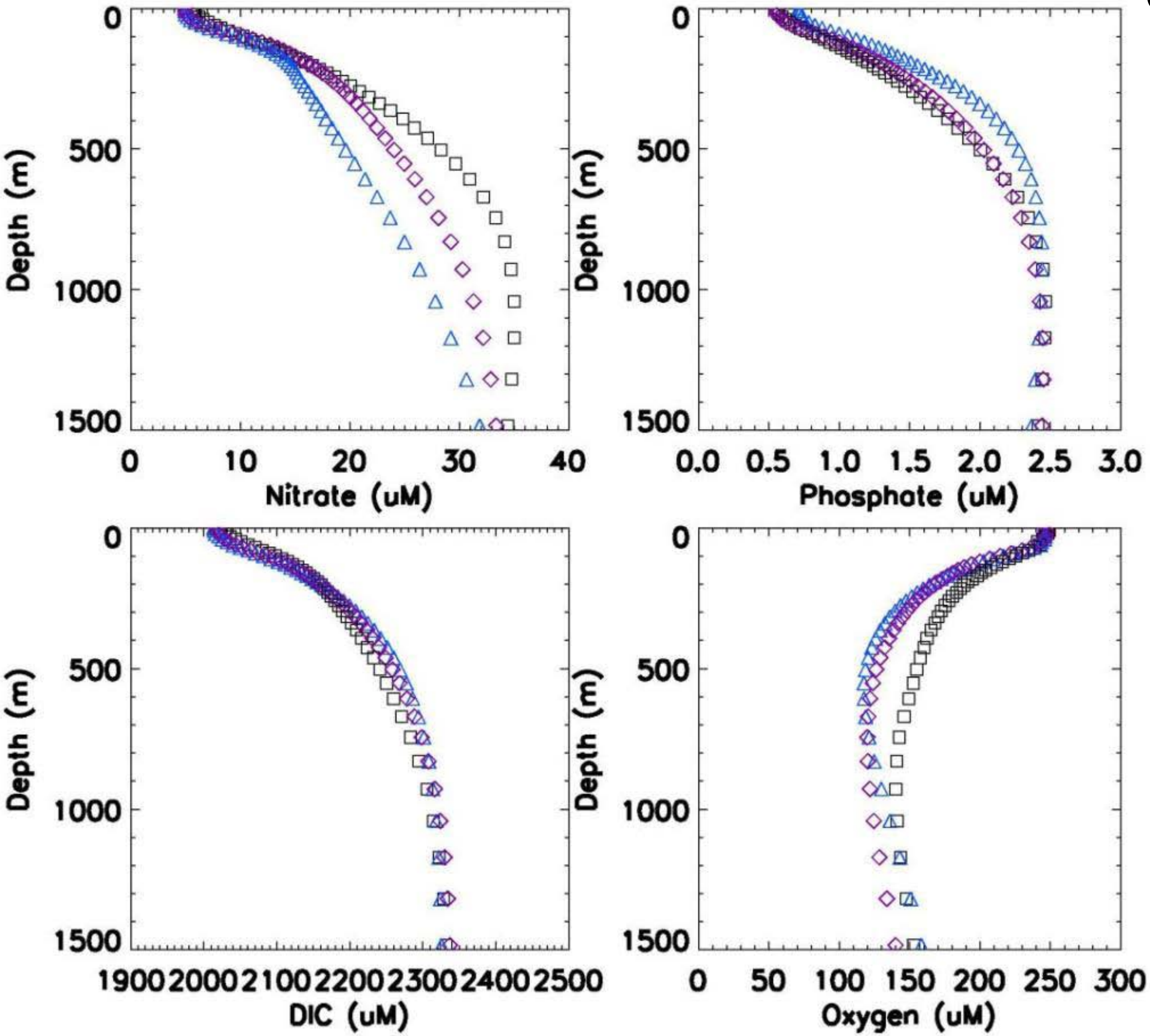
Organic matter burial (Dunne et al., 2007) with fixed C/N/P of 117/16/1. Scaling factor applied so P org burial ~balances the inputs of DIP + DOP.

Biogenic Silica burial (Rageneau et al., 2000). Burial efficiency is low except at high flux rates. Also scaled so burial loss is approx. equal to river input.

$CaCO_3$ burial occurs above prescribed, global lysocline depth. Balances riverine alkalinity input. Future work will link to carbon chemistry.

Sedimentary denitrification (see following slides).

Global Nutrient Profiles



CESM1.0 = blue ▲

CESM1.2 = purple ♦

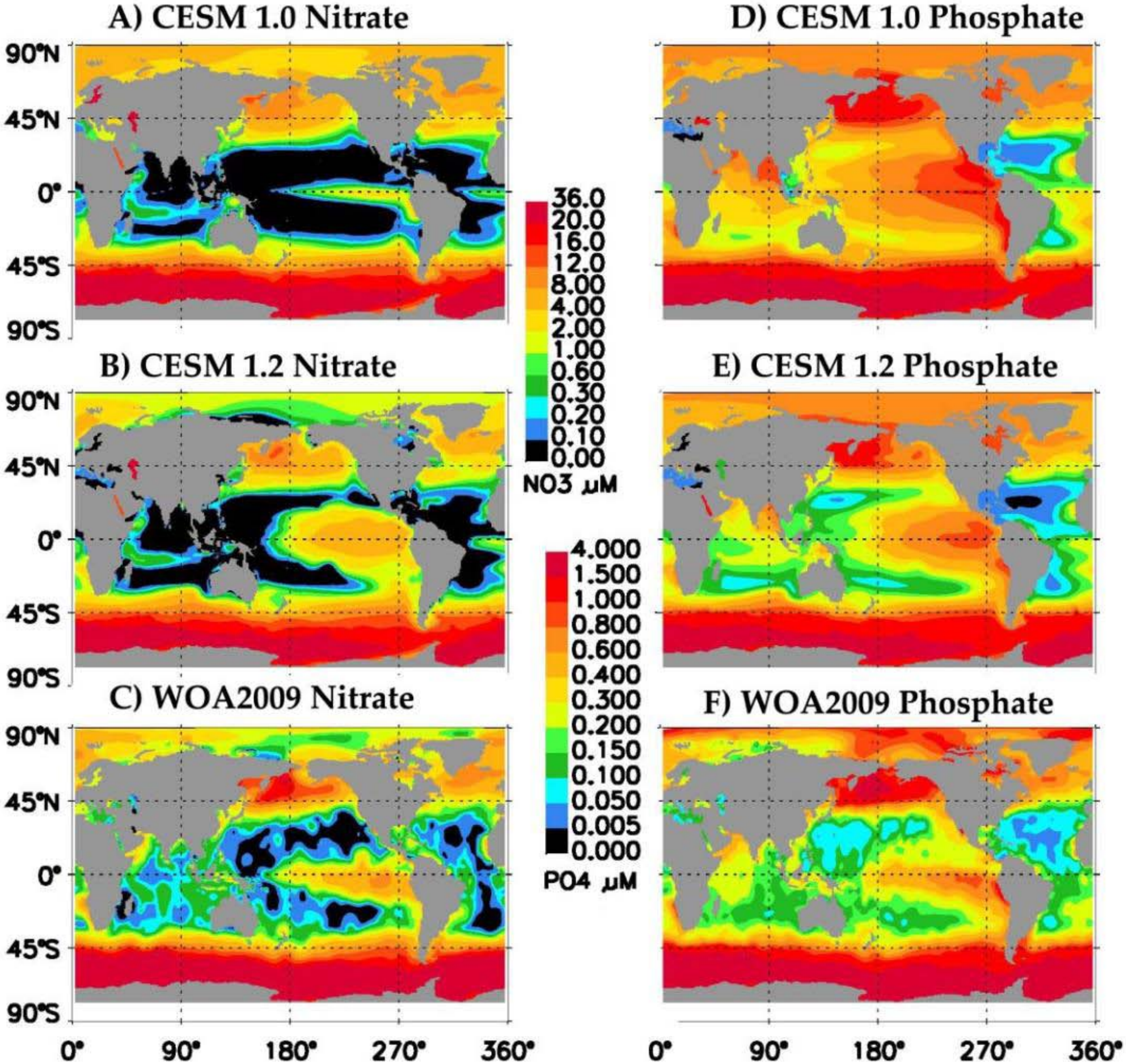
WOA2009 = black ■

Remin lengthscale of sinking organic matter increases w/ depth CESM 1.2.

Was an exponential decay with fixed lengthscale in CESM 1.0.

Remineralization lengthscale further increases under low oxygen concentrations.

Surface Nitrate and Phosphate Concentrations



CESM1.0

r = 0.79, 0.79

CESM1.2

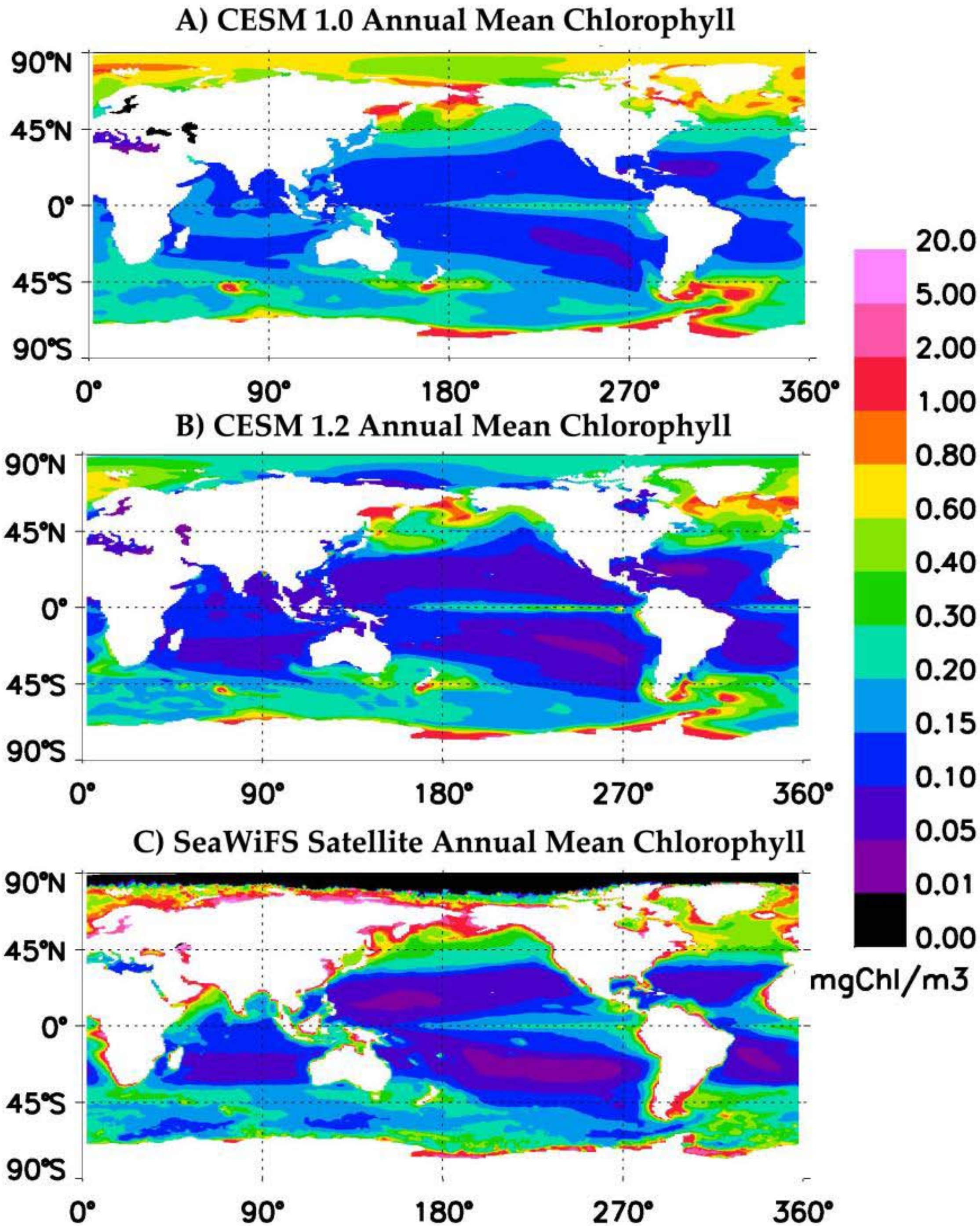
r = 0.73, 0.88

WOA2009 Observations

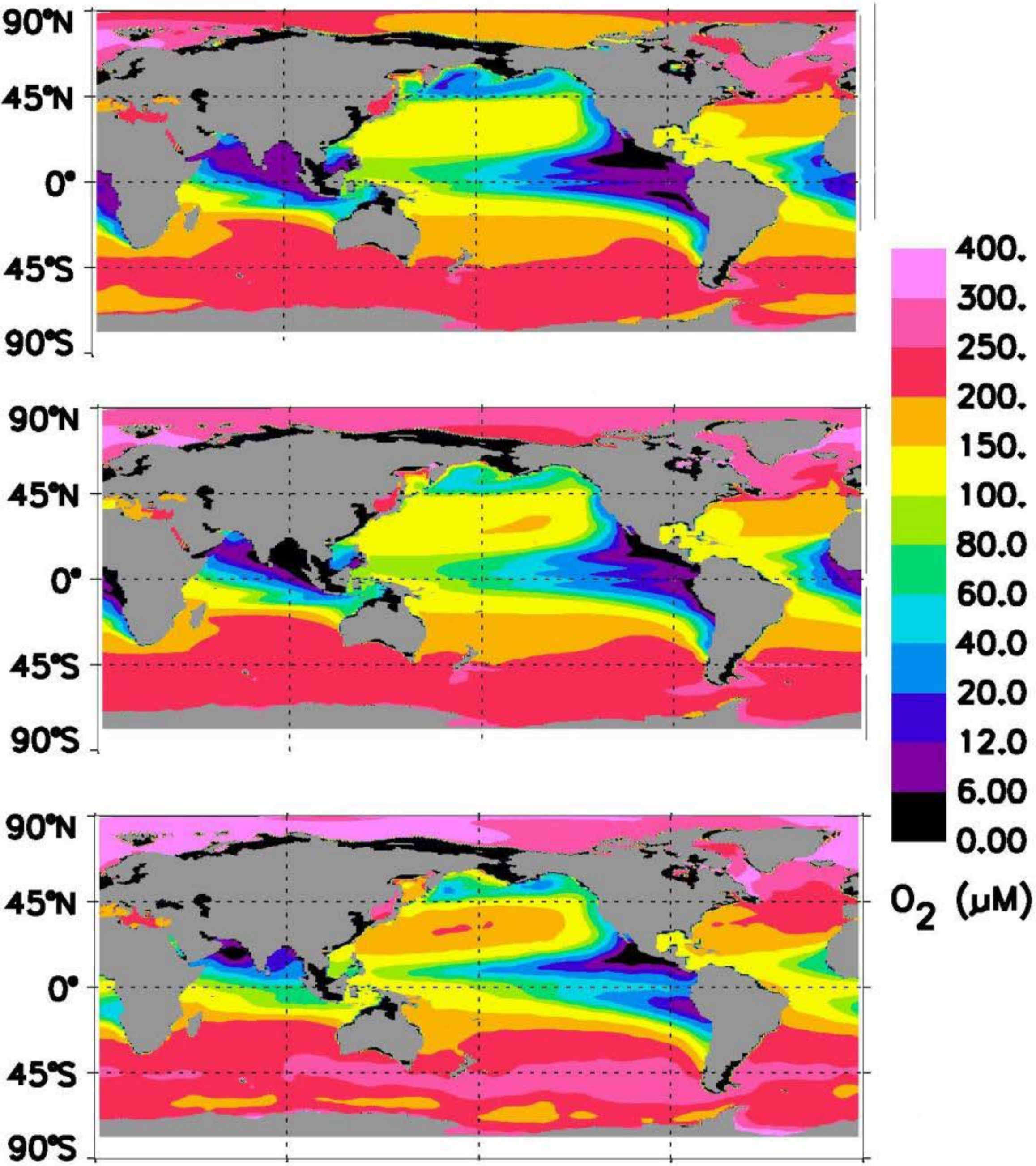
CESM1.0

CESM1.2

SeaWiFS
Satellite
Observations



Mean Oxygen Concentrations 150-671m Depth

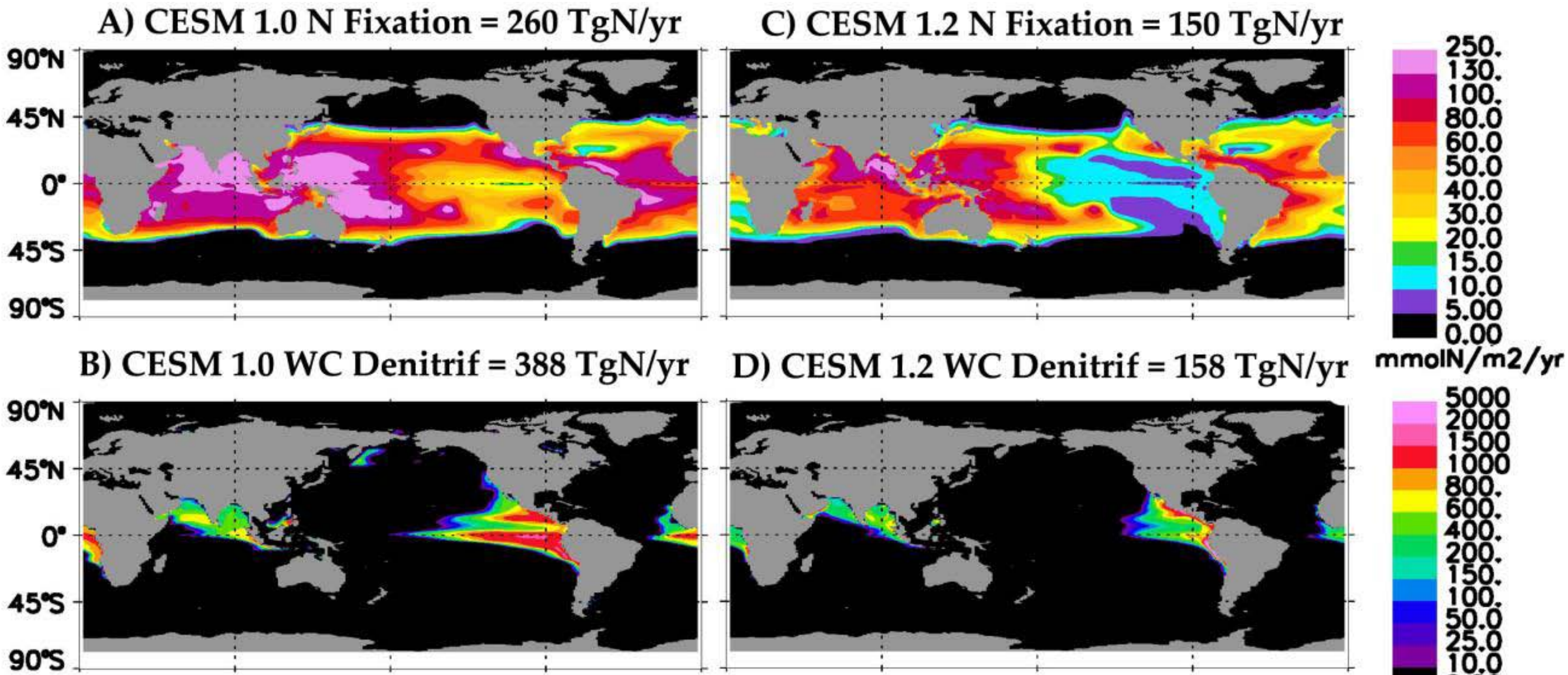


CESM1.0
OMZ volume 261% observed
bias = -25 μM
rmse = 40 μM

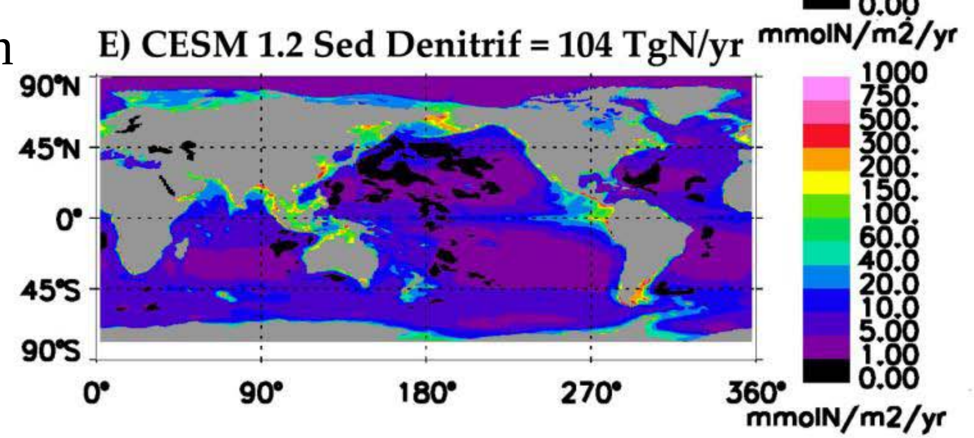
CESM1.2
OMZ volume 179% observed
bias = -18 μM
rmse = 32 μM

Observed WOA2009 (with Bianchi et al., 2012 correction)

(Oxygen Minimum Zone (OMZ) = < 20 μM)

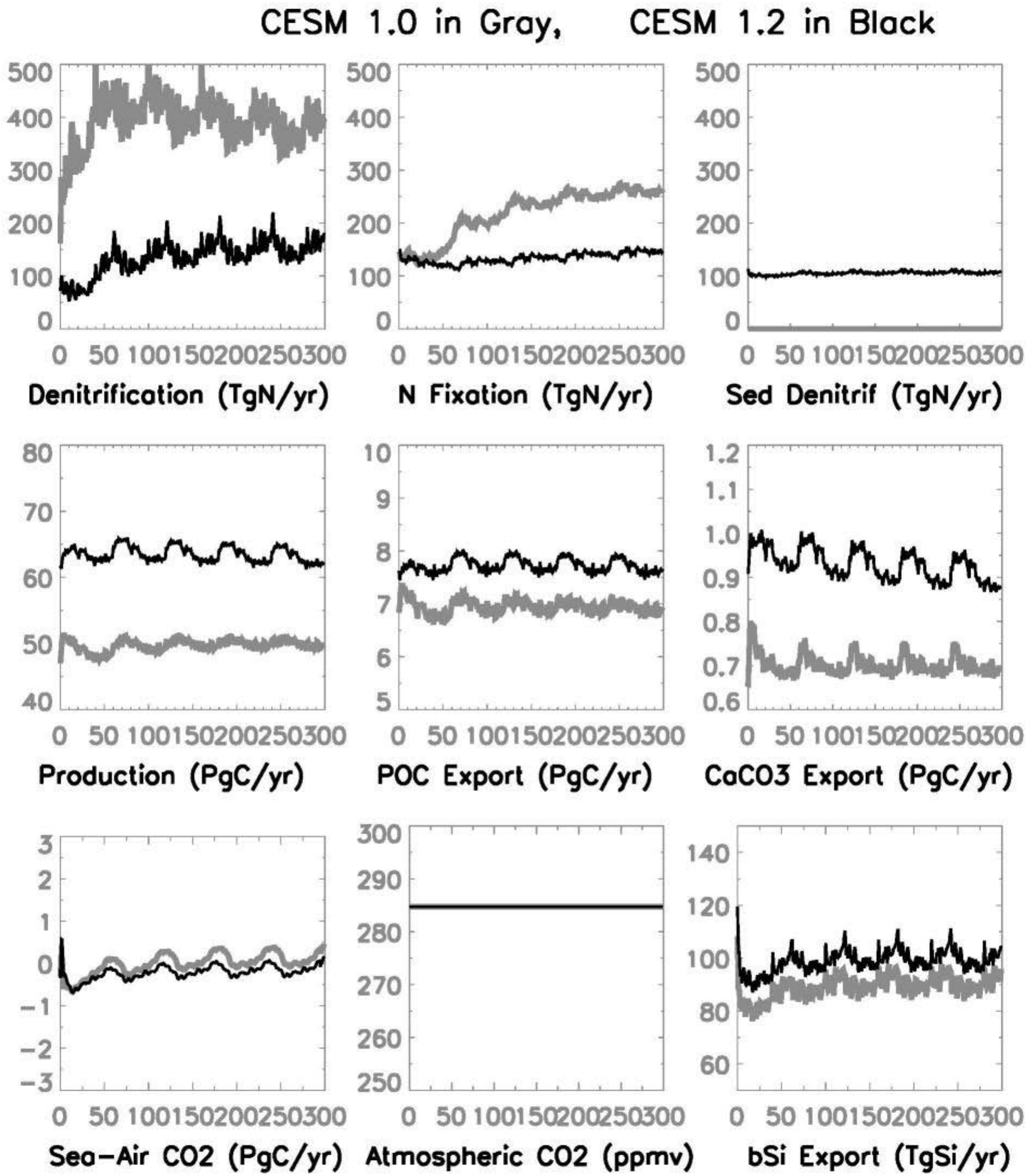


Sedimentary denitrification based on empirical relations from Bohlen et al., (2012). It is a function of the sinking organic matter flux and bottom water concentrations of oxygen and nitrate.



The improved oxygen distributions in CESM 1.2 lead to lower water column denitrification rates.

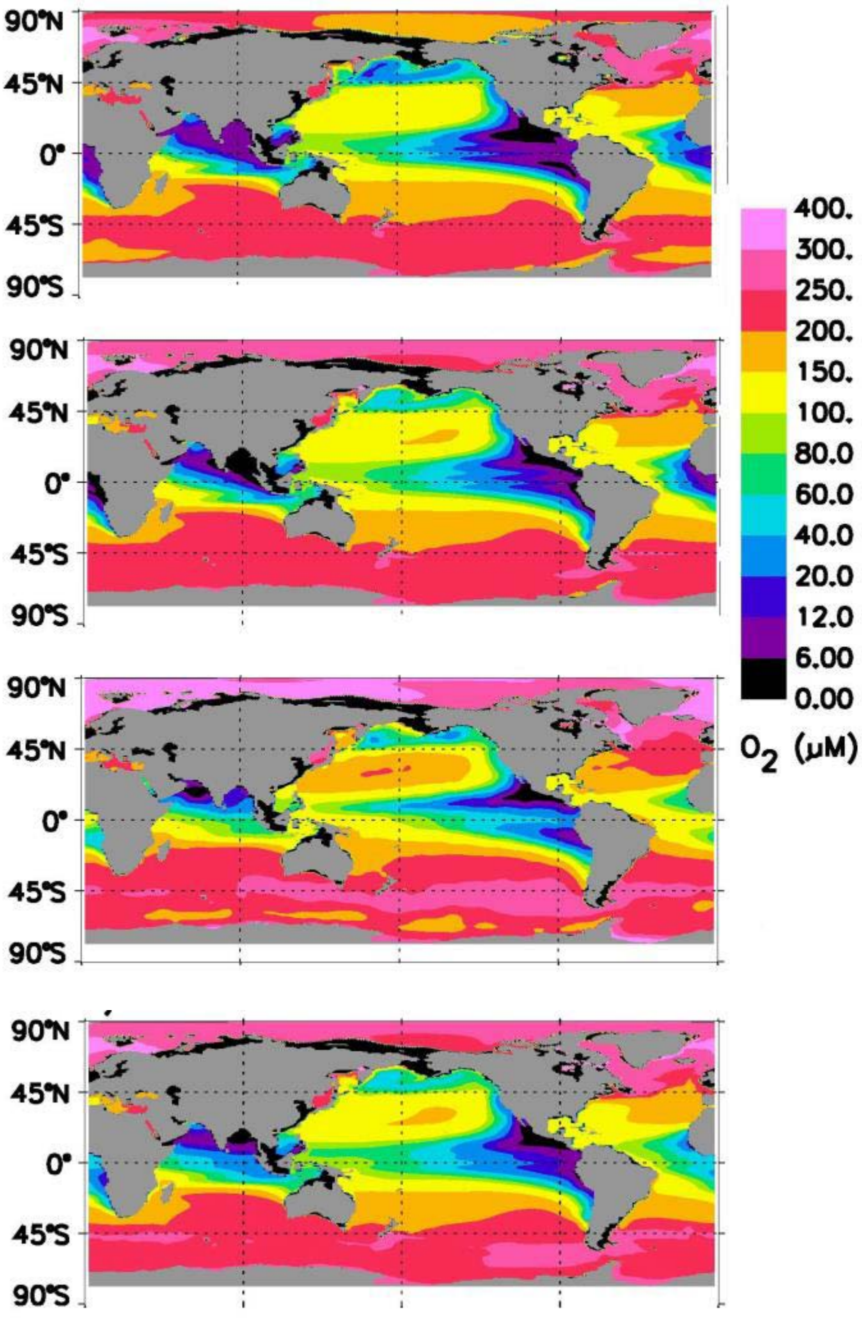
This allows for a balanced preindustrial marine nitrogen cycle, without the artificial scaling in CESM 1.0.


CESM 1.0 in Gray, CESM 1.2 in Black
Denitrification (TgN/yr)
N Fixation (TgN/yr)
Sed Denitrif (TgN/yr)
Production (PgC/yr)
POC Export (PgC/yr)
CaCO3 Export (PgC/yr)
Sea-Air CO2 (PgC/yr)
Atmospheric CO2 (ppmv)
bSi Export (TgSi/yr)

Improving Ocean Biogeochemistry in the CESM 1.2

1) CESM 1.2 contains a number of notable improvements and additions to the BEC marine biogeochemistry module.
2) The modifications lead to improved simulation of observed nutrients, chlorophyll, and oxygen distributions.
3) Ongoing work shows that the remaining oxygen biases can be further reduced with modest changes to model physics.
4) Best results for ocean biogeochemistry with the coarse resolution version, ~3 degree ocean model (gx3v7 grid), are obtained using prescribed sea ice cover, CIAF compset, with restoring of surface temperature and salinity.
5) The CESM 1.2 developments will be documented in paper by Moore et al., (email me if you want a copy, jkmoore@uci.edu).

Oxygen concentrations over 150-671m Depth



CESM1.0

OMZ volume 261% observed

bias = -25 µM

rmse = 40 µM

CESM1.2

OMZ volume 179% observed

bias = -18 µM

rmse = 32 µM

Observed WOA2009

(with Bianchi et al., 2012 correction)

(Oxygen Minimum Zone (OMZ) = < 20 µM)

CESM 1.2 with physics mods

OMZ volume 136% observed

bias = -18 µM

rmse = 32 µM