Ventilation of mid-depth waters and the Oxygen Minimum Zones in the CESM

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Outline

1) Oxygen and anthropogenic CO_2 biases in the CESM

2) Physical Modifications to Improve Ventilation and OMZs

    A) Increased Background Isopycnal Mixing

    B) Greatly Increased Equatorial Isopycnal Mixing

3) Sensitivity Tests and Parameter Optimization at X3

4) Results of Physics Modifications in X1 Simulations

Oxygen Minimum Zones

Oxygen Minimum Zones (OMZ) occur mid-depths in the water column (~150-800m) where oxygen concentrations are depleted to very low levels by remineralization of sinking organic matter. The occur where ventilation is weak and biological export is relatively high.

They are important for biogeochemistry because this is where dentrification occurs (also in the sediments, the biological conversion of nitrate to N_2). Nitrogen is a key limiting nutrient for the biology.

About half of the ocean N_2O production happens in OMZs.

OMZs are expected to expand with climate warming, due to decreased ventilation.

Methods

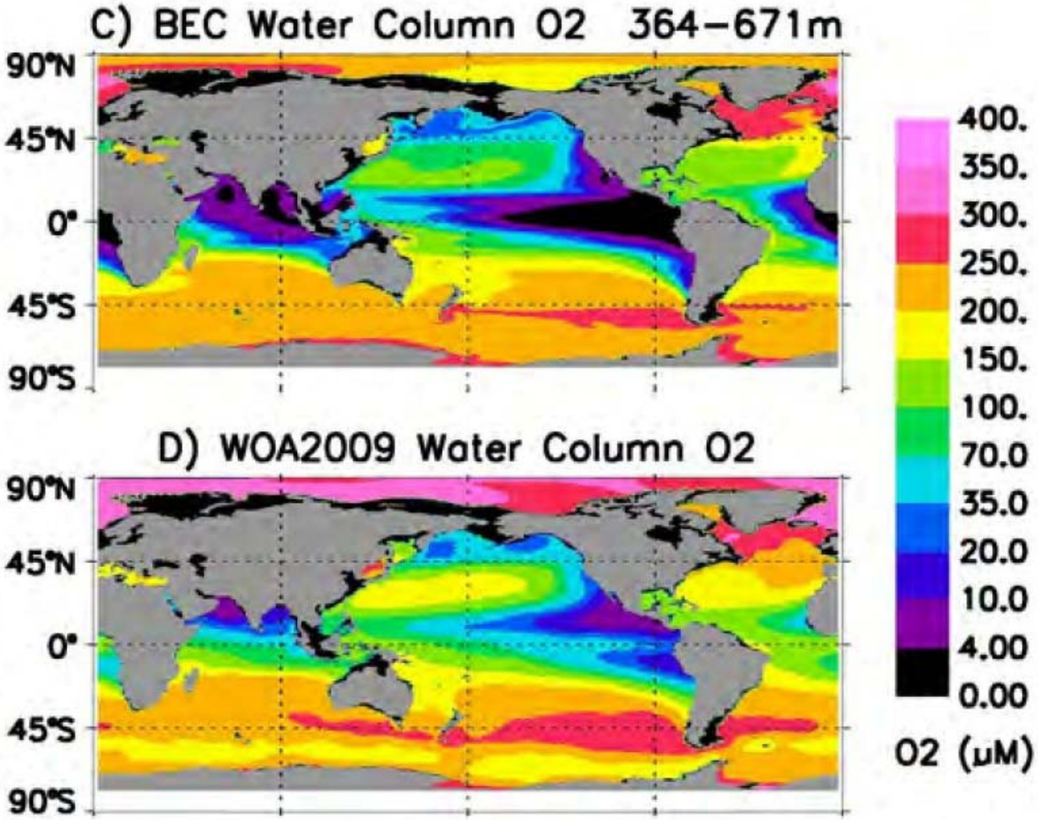
1) Focus on depth range from 150-671m where the O_2 biases are largest and most water column denitrification occurs.

2) CIAF gx3v7 and GIAF gx1v6 CESM 1.2 simulations, run for 310 years, averaged over last 20 years (1990-2009).

3) Temperature, salinity, and nutrients are compared with the WOA2009 (with Bianchi et al. (2012) oxygen corrections).

4) CFC12 data from GLODAP (all 1990s data), converted to pcfc12 according to (Warner and Weiss, 1985).

5) Oxygen Minimum Zones (OMZ) defined as $[O_2] < 20$ µM.



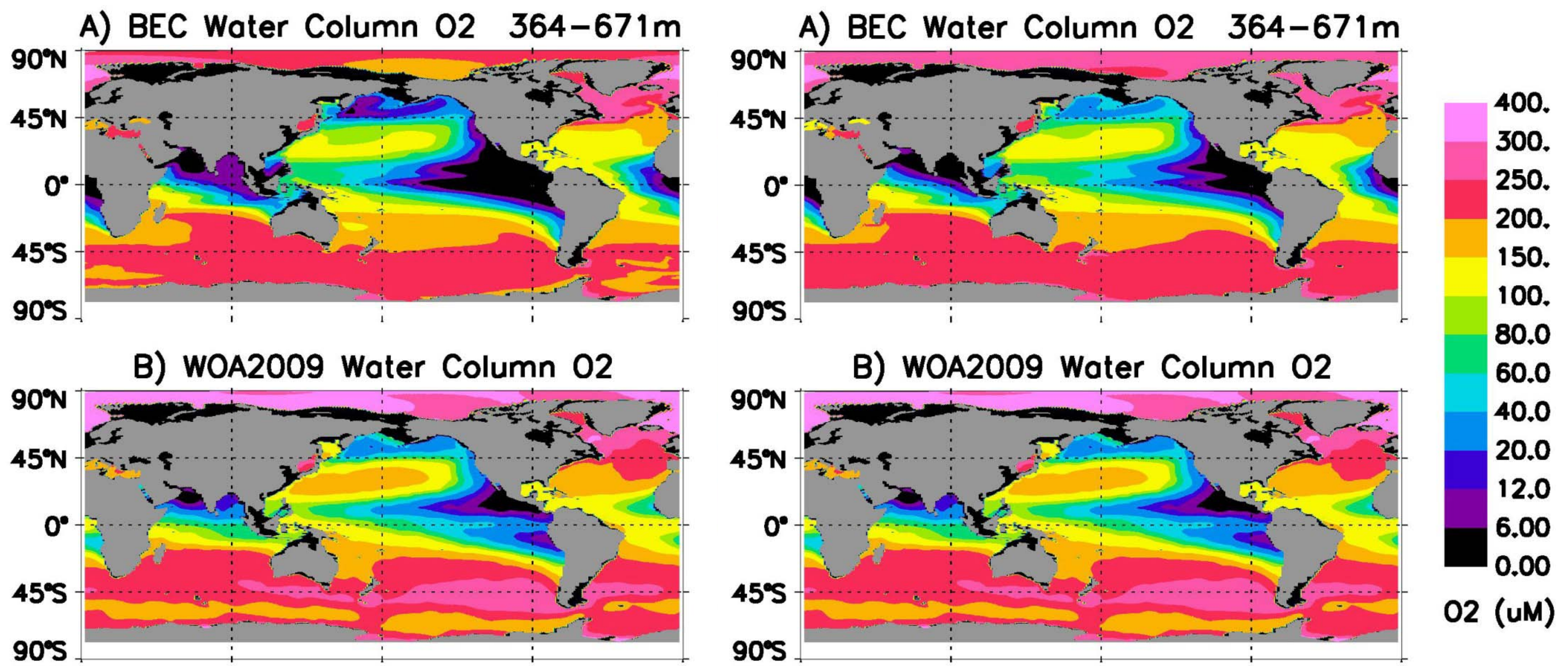
Low oxygen biases lead to greatly excessive water column **denitrification** (4-5 times the observational estimated rates).

Denitrification removes **nitrogen** from the oceans, it occurs where $[O_2] < \sim 6$ μM.

CESM 1.0 gx1v6

Large negative oxygen biases at low latitudes, in subarctic North Pacific, and mid-latitude Southern Ocean.

Also large **negative biases in anthropogenic CO_2 uptake** in the Southern Ocean in CMIP5 simulations.



CESM 1.0 gx1v6
OMZ volume 281% of observed

CESM 1.2.1 gx1v6
OMZ volume 180% observed

Negative oxygen biases were reduced due to changes in the biogeochemistry code, but still present.

Can modifications to the physics further reduce these biases?

Background/Minimum Isopycnal Diffusivity

Matt Long showed yesterday how increasing the minimum or background isopycnal diffusion rate improved cfcs in the Southern Ocean.

I make the same change here, increasing the minimum mixing rate at depth from ~10% of the maximum surface values to ~20% (imposed minimum value of 600 m^2/s).

Equatorial Intermediate and Deep Jets

There are strong zonal jets near the equator in all ocean basins extending from below the equatorial undercurrent to several thousand meters depth, as seen in ARGO data.

Observational (Brandt et al., 2008; 2012) and modeling studies (Dietze and Loeptien, 2013; Getzlaff and Dietze, 2013) have suggested that these zonal jets are important for oxygen distributions and ventilation of the eastern boundary shadow zones.

Equatorial Intermediate and Deep Jets

Zonal jets clearly seen in ARGO float velocities at depth.

(Cravatte et al., 2012)

Alternating zonal jets, strongest 5S-5N

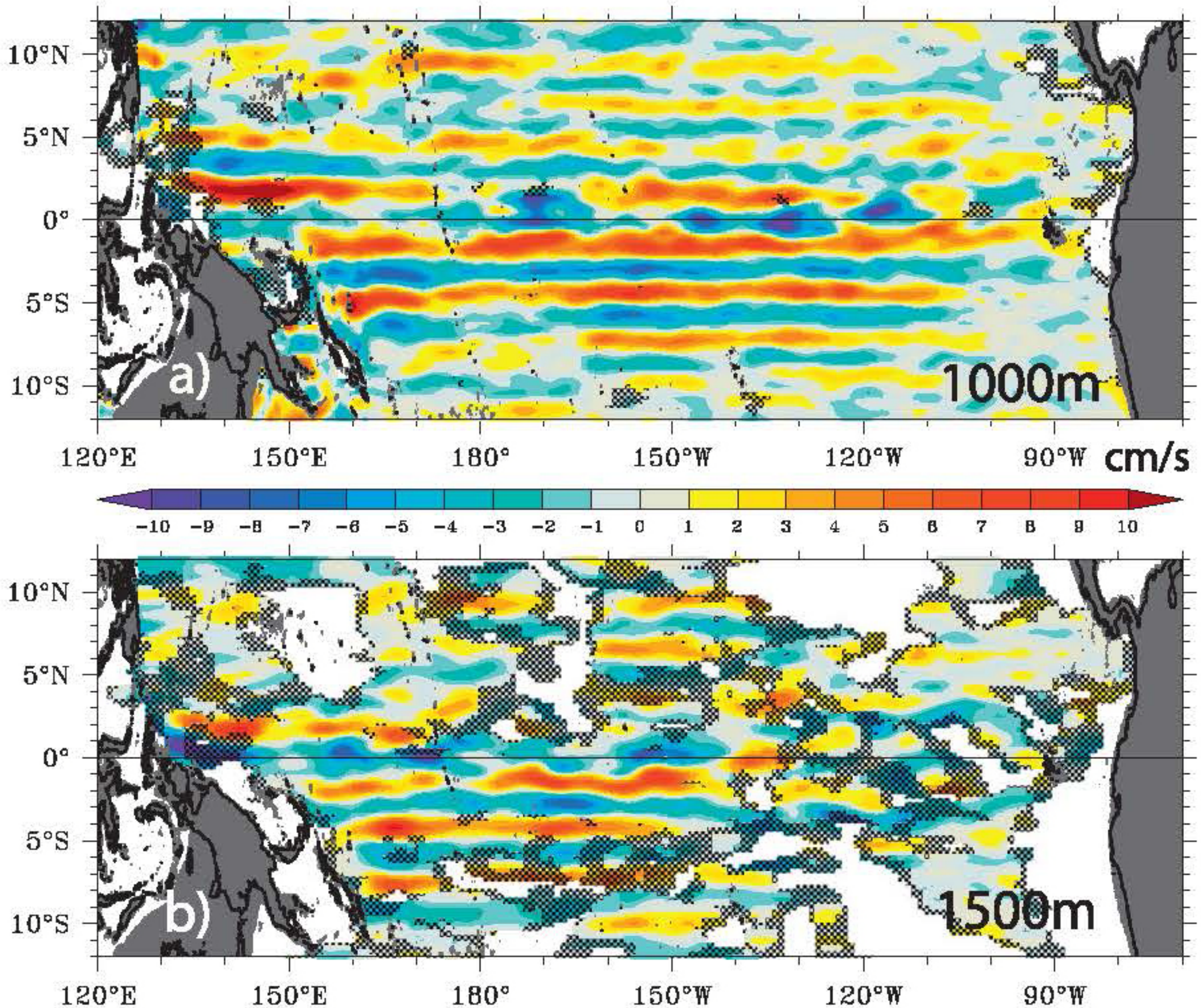
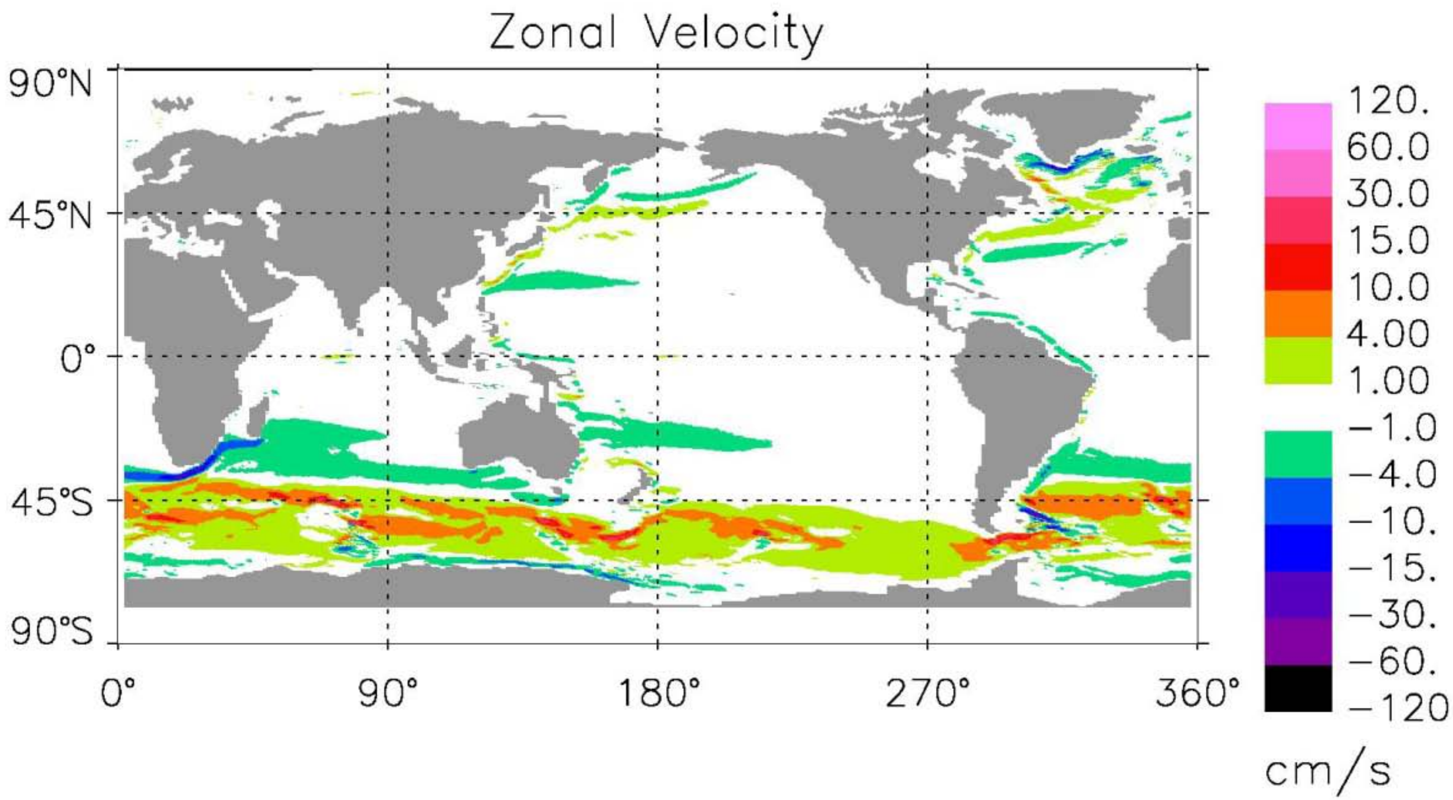


FIG. 2. Mean zonal currents (cm s^{-1}) at (a) 1000 and (b) 1500 m, from optimal interpolation. Topography shallower than 1000-m depth is shaded in dark gray. Boxes with less than five values are blanked. Regions where zonal velocity estimates could be biased seasonally are hatched in black (see text in section 2).

Equatorial Intermediate and Deep Jets

Getzlaff and Dietze (2013) examined a number of ocean models and argued that even high resolution models do not capture these zonal jets (missing physics?).



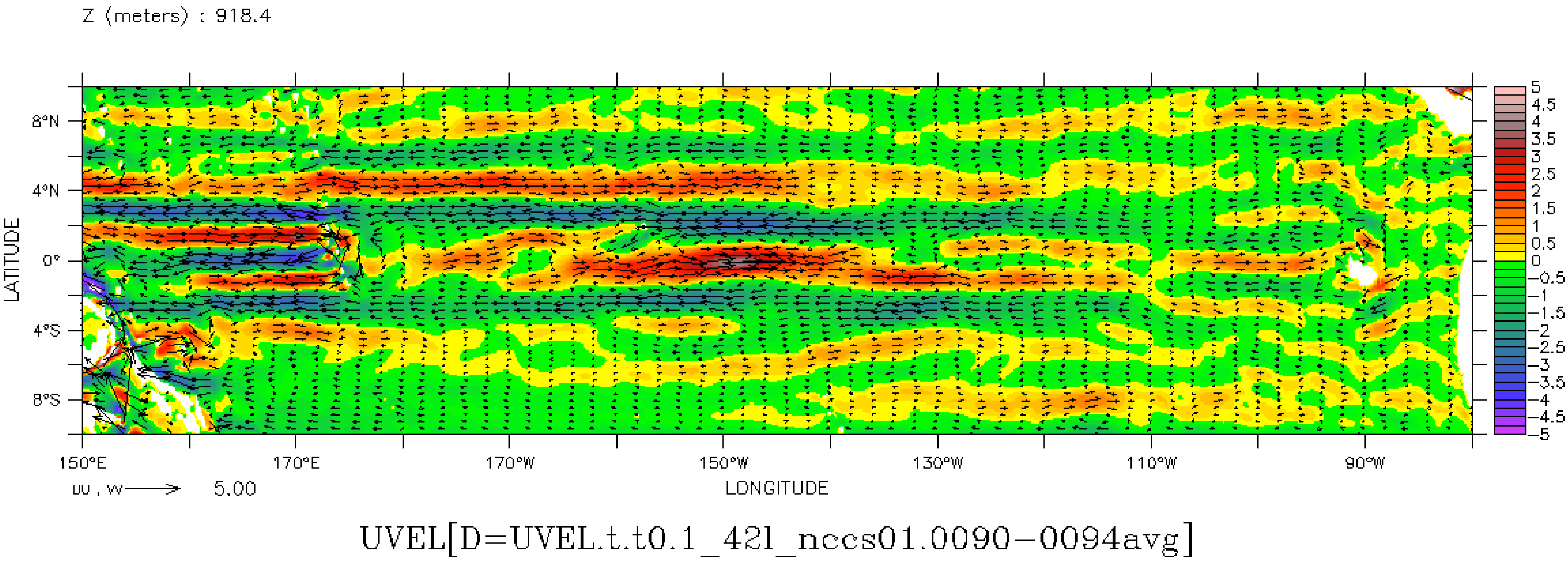
Mean zonal velocity (gx1v6) at 1000m depth.

No equatorial zonal jets in any basin.

Equatorial Intermediate and Deep Jets

But the zonal jets due show up in 0.1 degree POP2 simulations (here at 918m depth in the Pacific).

(image courtesy Mat Maltrud, 10 day mean zonal velocity).



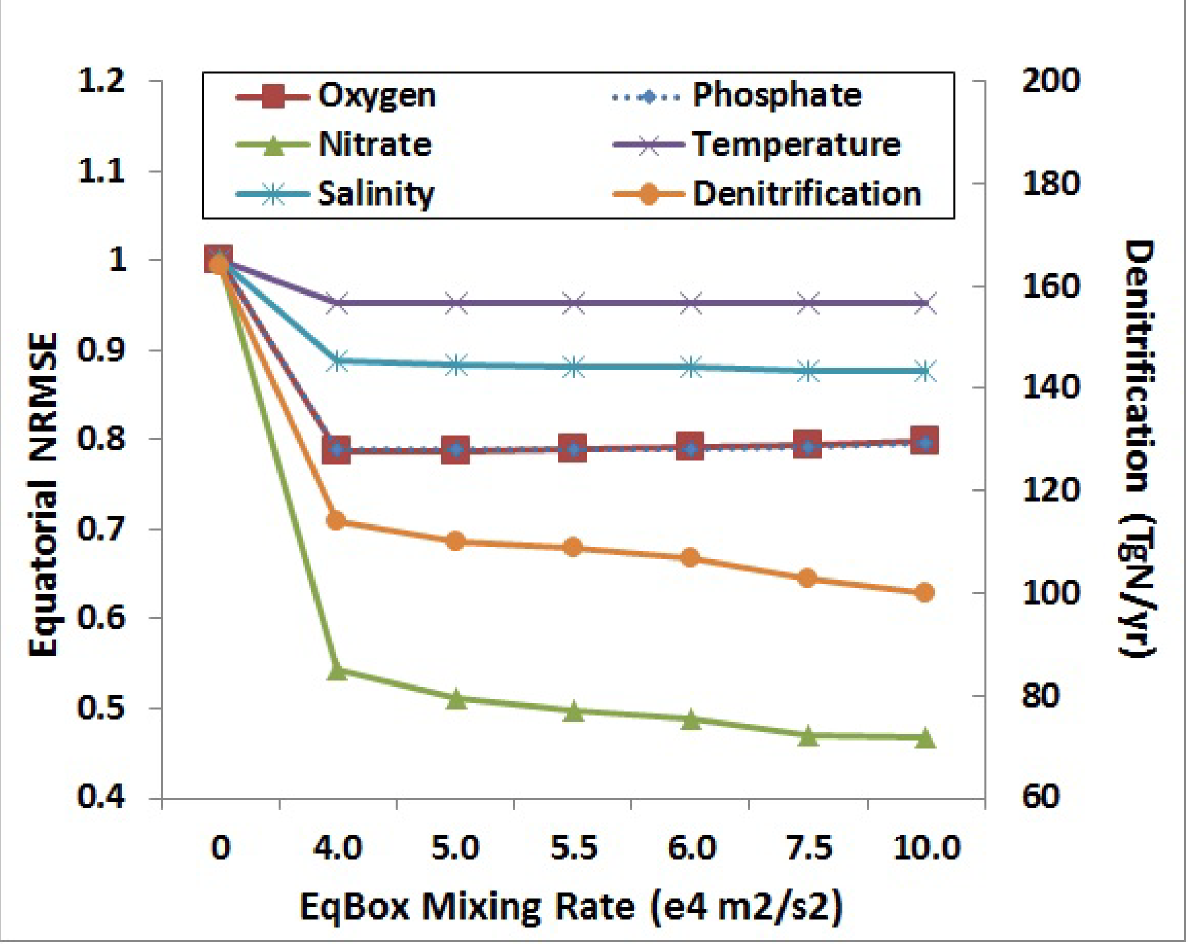
Equatorial Intermediate and Deep Jets

To mimic the deep zonal jet transport, Getzlaff and Dietze (2013) increased zonal isopycnal diffusion by a factor of ~100 in the equatorial region (**5S-5N, 260-2500m depth**, hereafter referred to as the **Equatorial Box, EqBox**).

This change greatly improved simulated T, S, oxygen and nutrients in the equatorial Pacific, reducing strong negative oxygen biases and positive phosphate biases in the eastern tropical Pacific (had no effect on air-sea heat fluxes or meridional overturing).

I’ve increased isopycnal diffusion within the EqBox.

Given the narrow latitudinal band the effective increased mixing/transport is mainly zonal.

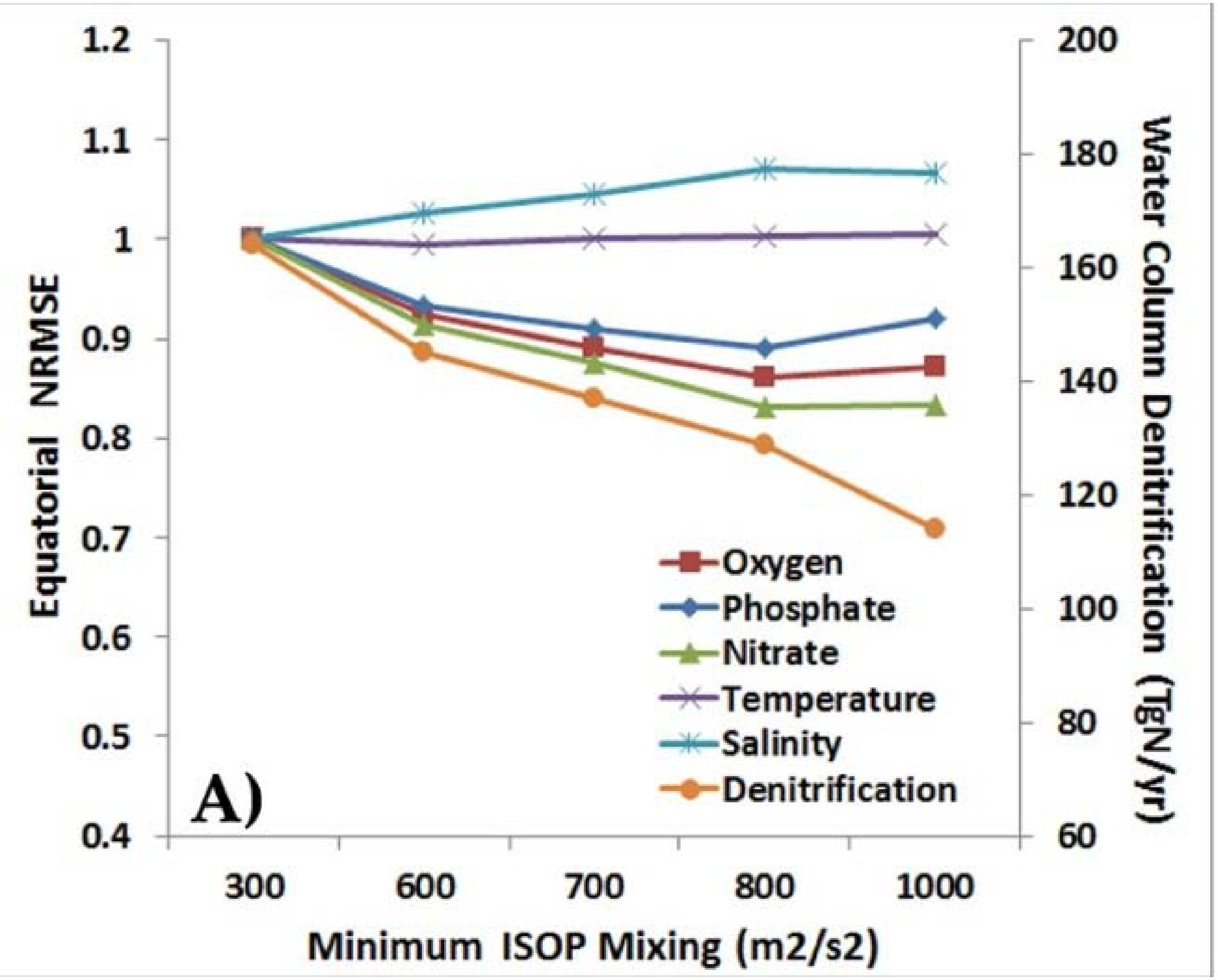


X3 Simulations

NRMSE in EqBox (5S-5N, 260-2500m)

Greatly **increased isopycnal mixing in the EqBox** improves tracer distributions 5S-5N.

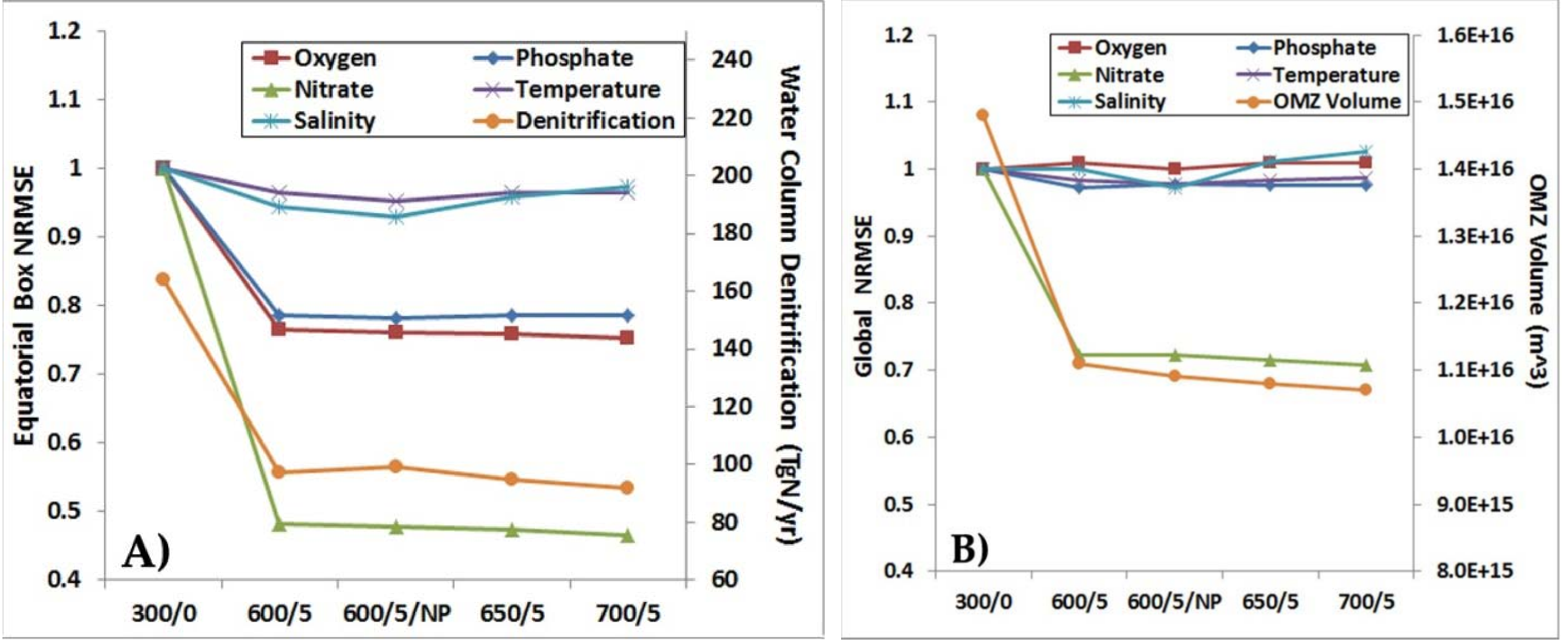
The improvements in simulated oxygen reduces OMZ volumes. This lowers water column denitrification and further improves simulated nitrate distributions.



X3 Simulations

NRMSE in EqBox (5S-5N, 260-2500m)

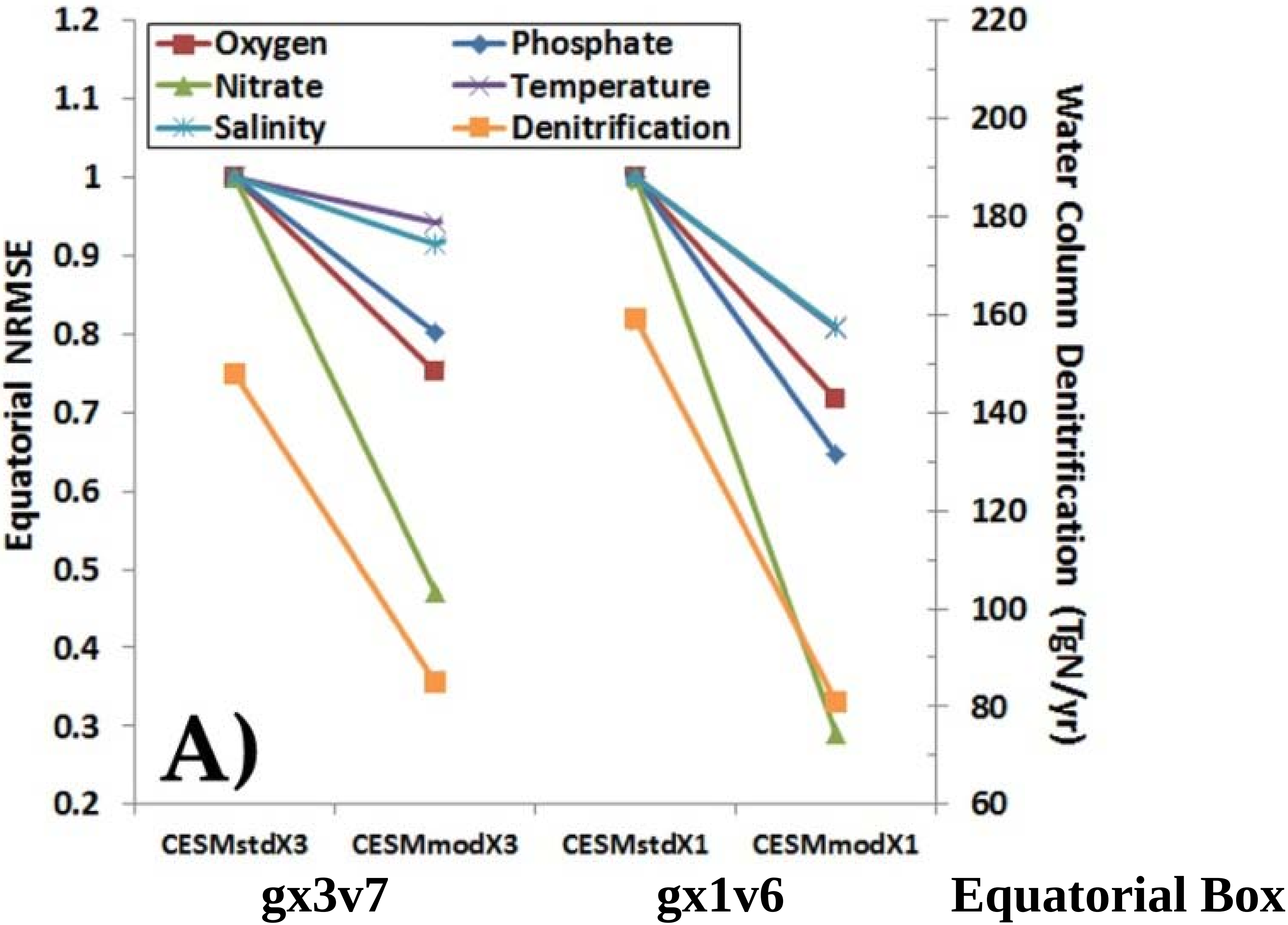
Increased background isopycnal mixing also improves tracer distributions 5S-5N.



Including **both physics modifications** results in better simulation of physical and biogeochemical tracers than either change alone.

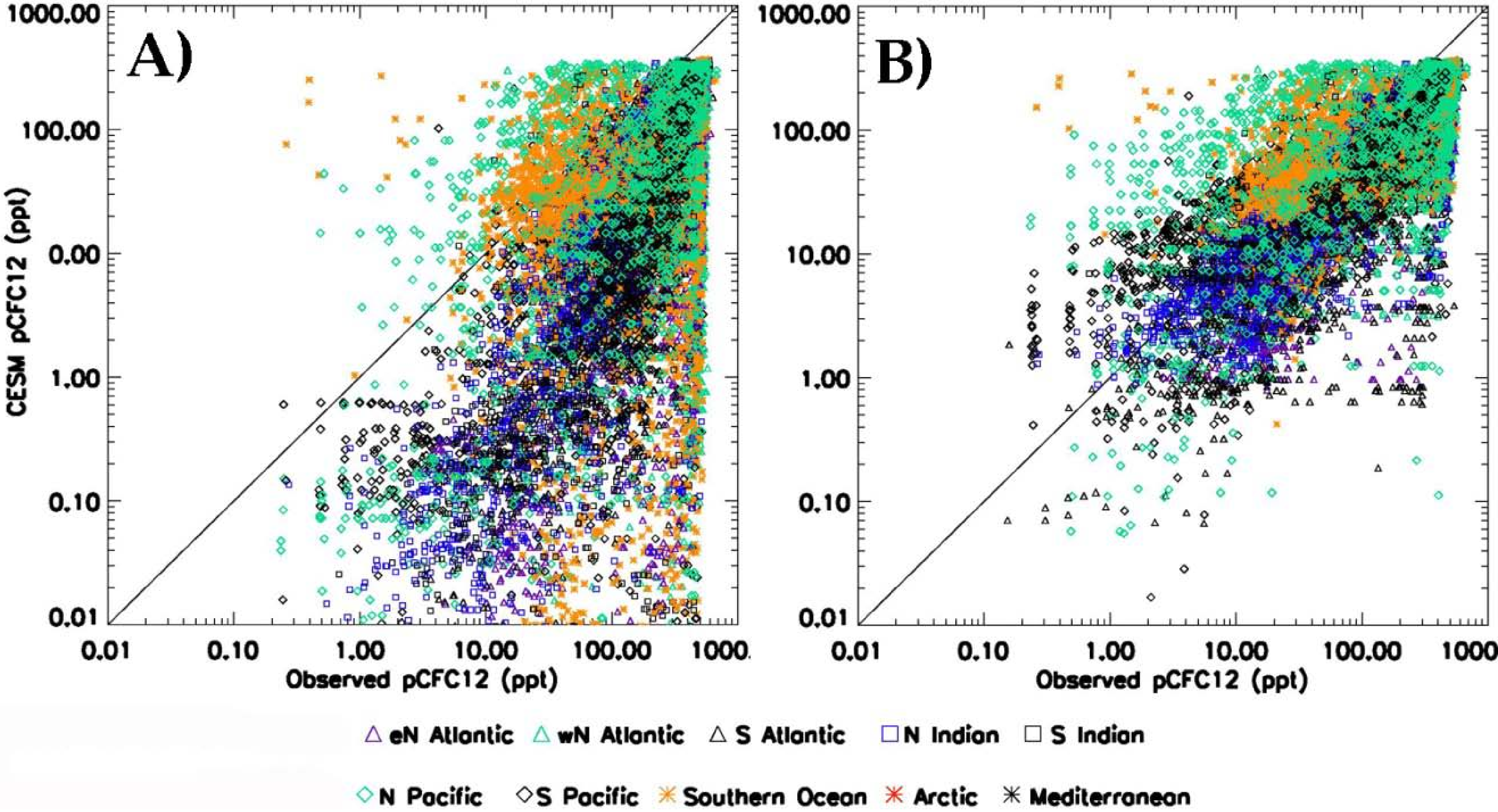
Best results with **600 m^2/s background mixing** and with **EqBox mixing of 50,000 m^2/s**.

These values used in gx1v6 simulation.


Oxygen
Phosphate
Nitrate
Temperature
Salinity
Denitrification
Equatorial NRMSE
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
220
200
180
160
140
120
100
80
60
Water Column Denitrification (TgN/yr)
A)
CESMstdX3
CESMmodX3
CESMstdX1
CESMmodX1
gx3v7
gx1v6
Equatorial Box

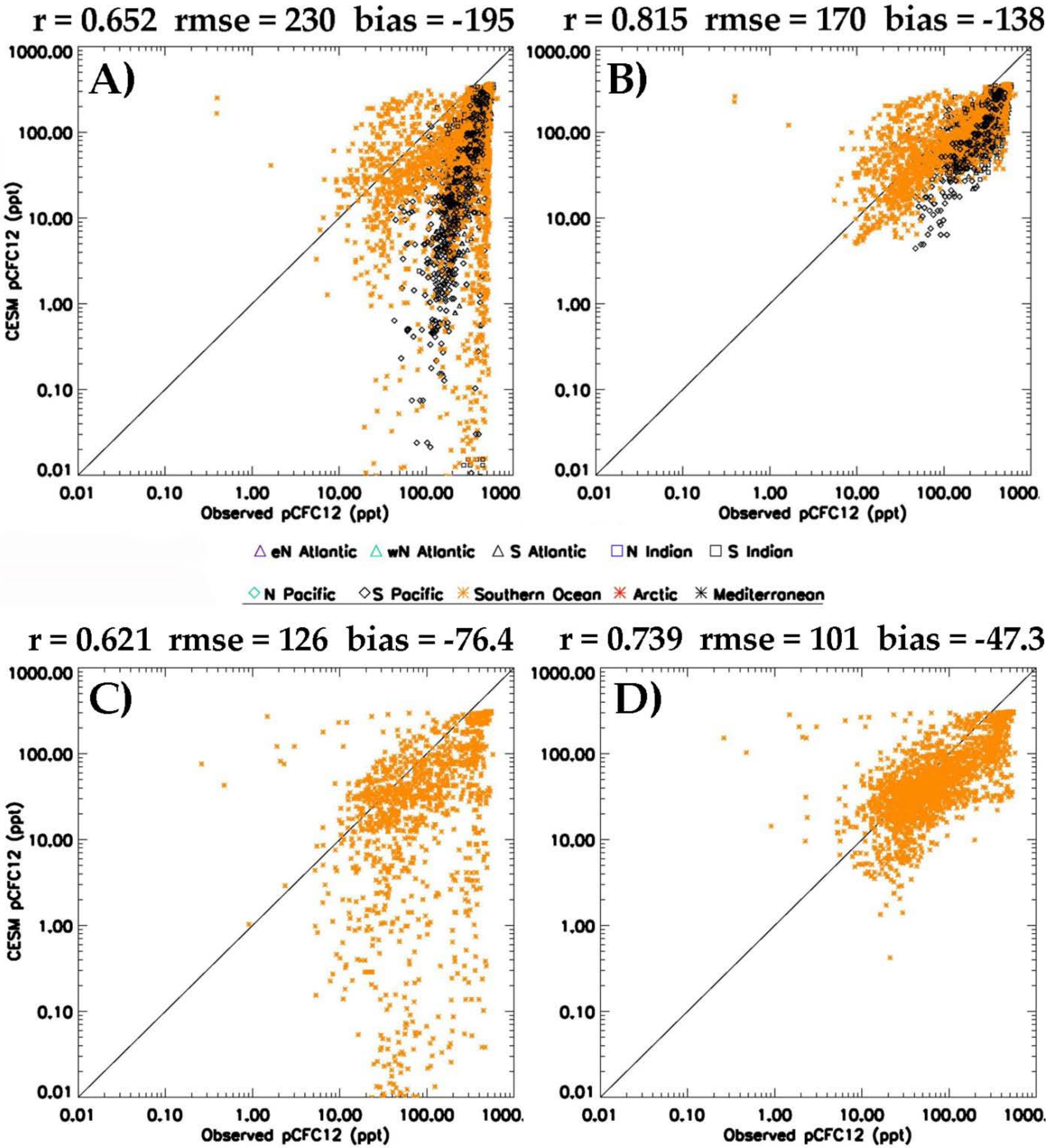
Standard CESM X1 **Modified CESM X1**

r = 0.703 rmse = 200 bias = -150 r = 0.842 rmse = 150 bias = -104



Match to global pcfc12 observations (150-671m depth).

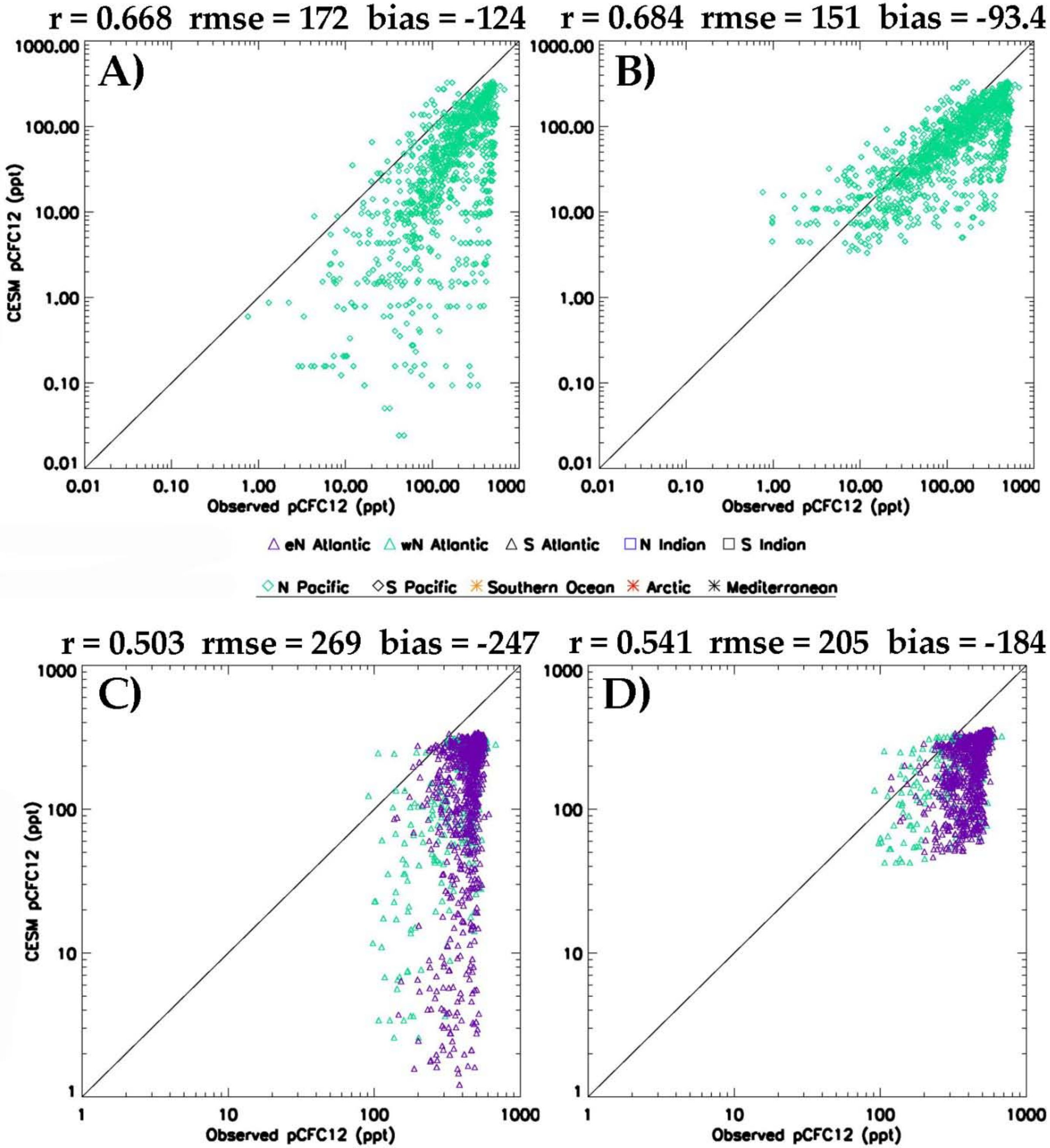
Standard CESM **Modified CESM** **Match to pcfc12 data (150-671m)**



Southern Ocean (30-60S)

Southern Ocean (> 60S)

Standard CESM **Modified CESM** **Match to pcfc12 data (150-671m)**

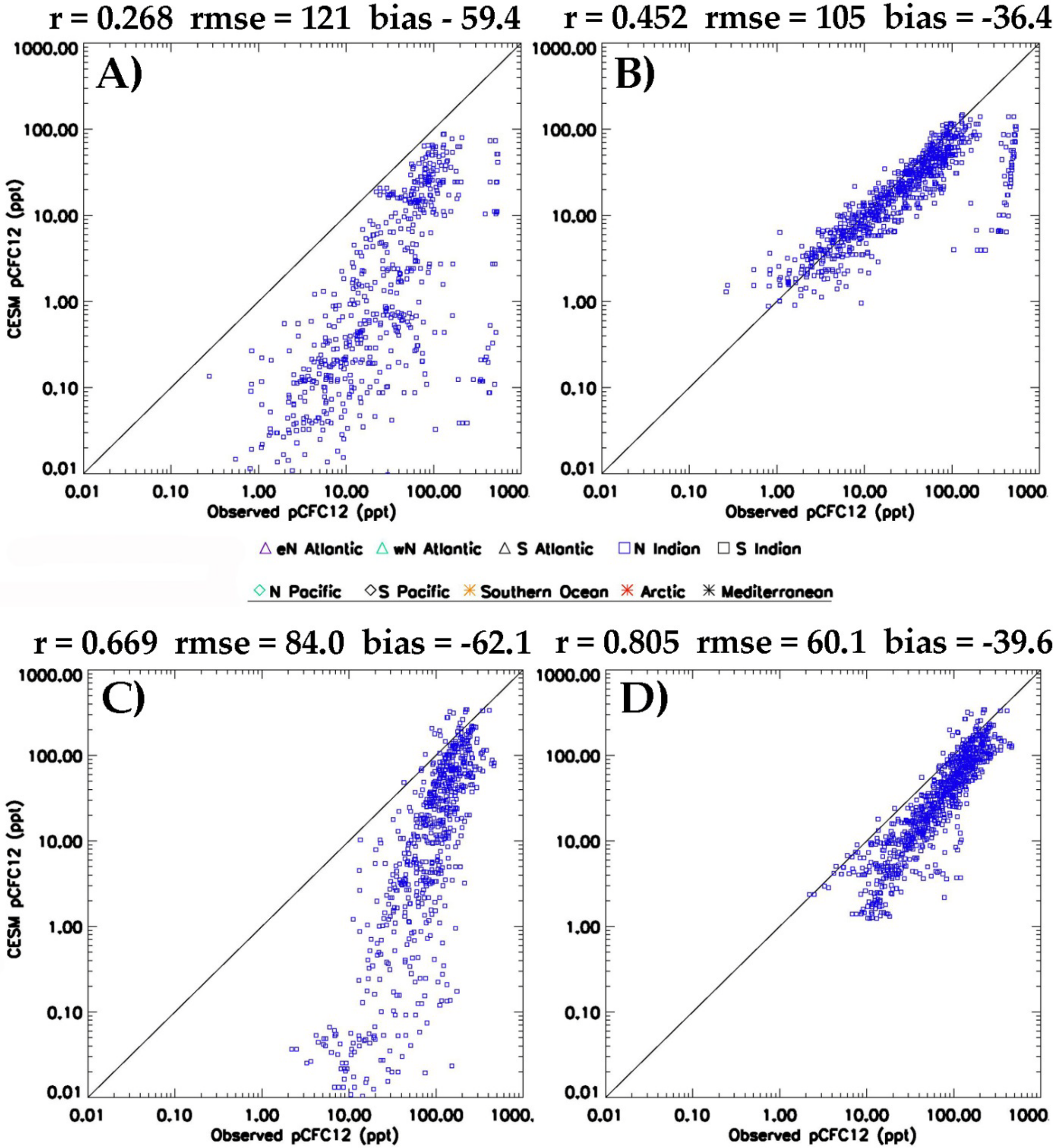


North Pacific (45-62N)

North Atlantic (> 40N)

Standard CESM **Modified CESM**

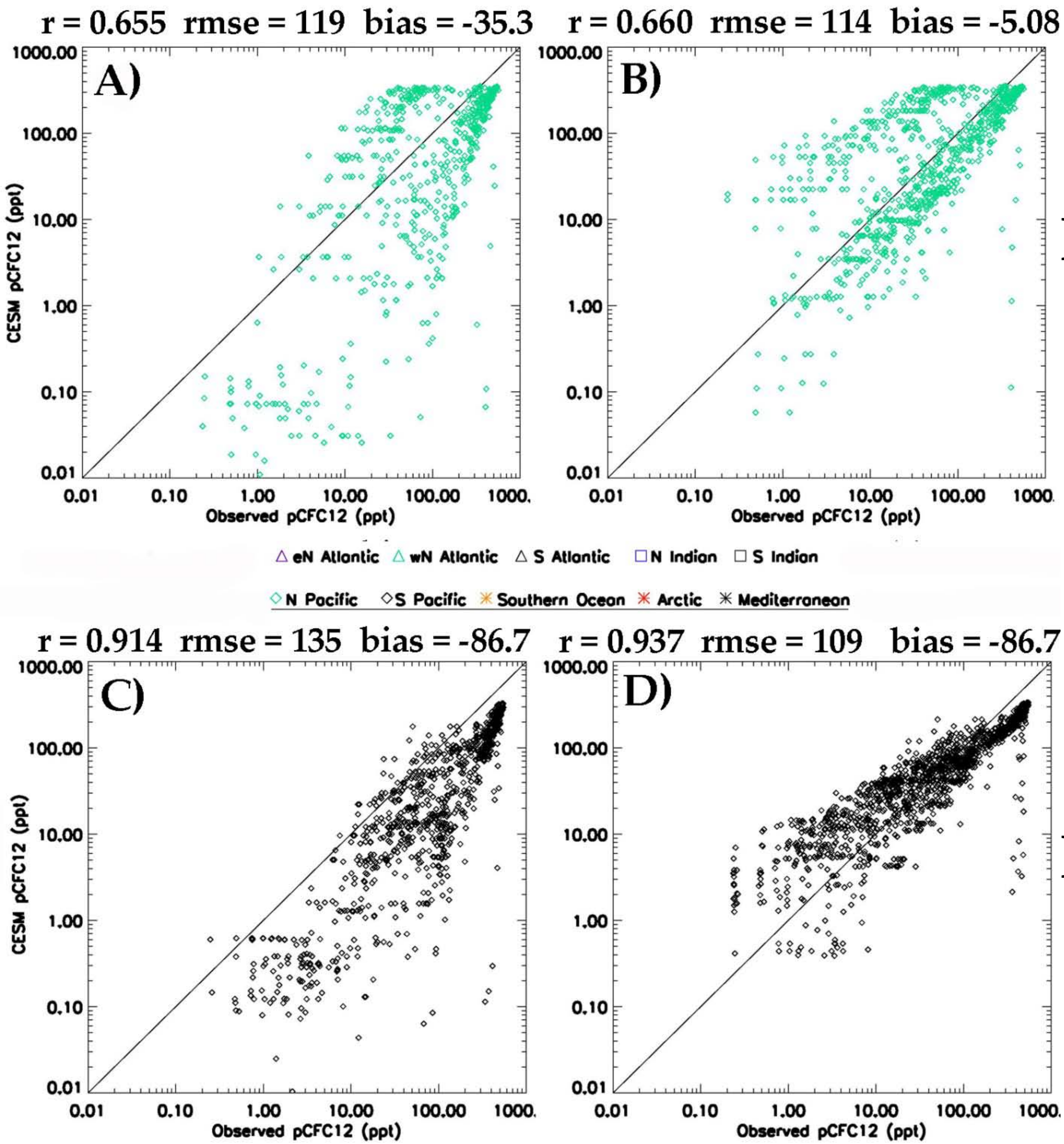
Match to pcfc12 data (150-671m)



Bay of Bengal

Arabian Sea

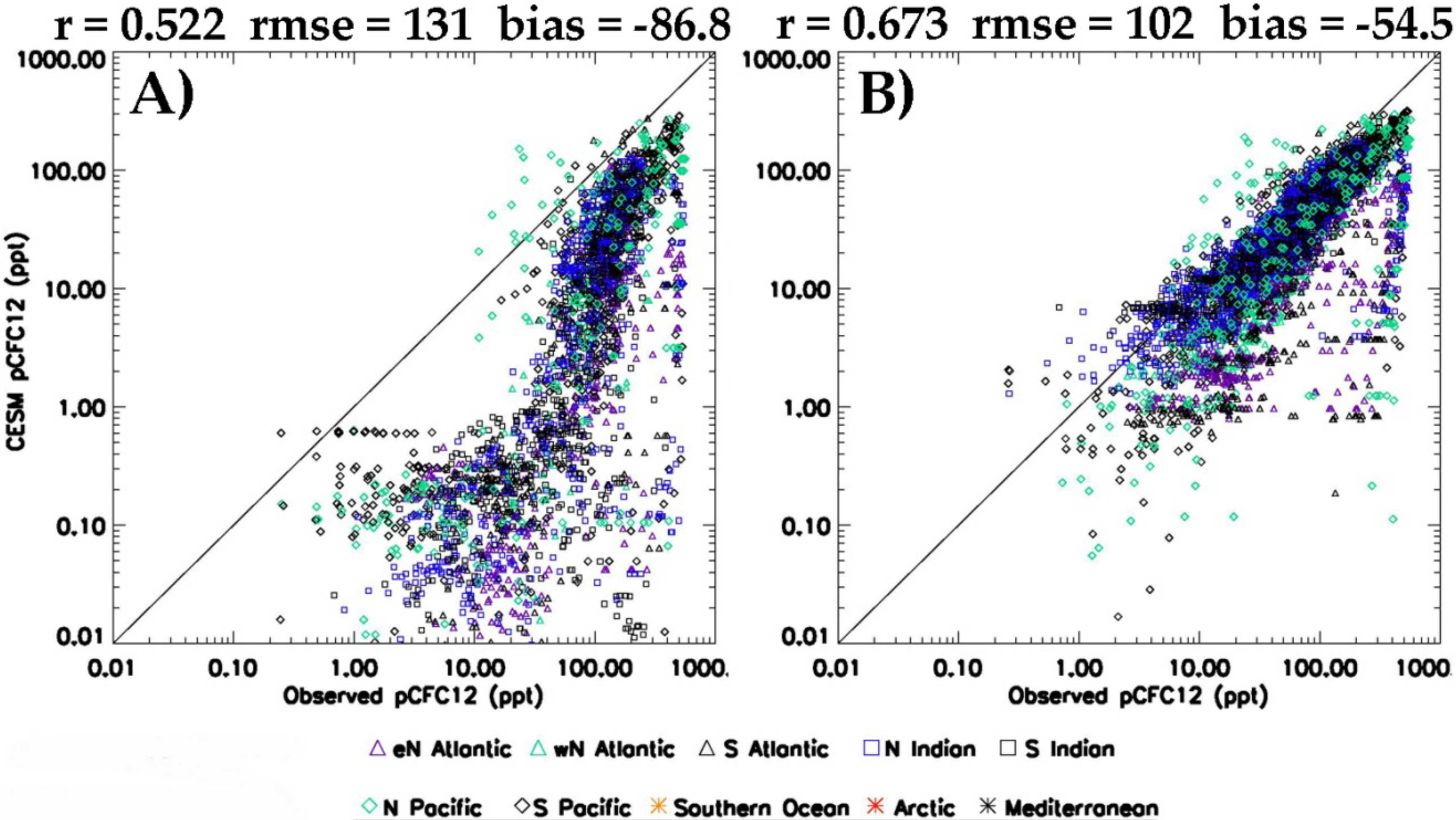
Standard CESM   Modified CESM   Match to pcfc12 data (150-671m)



ETNP

ETSP

Standard CESM **Modified CESM**

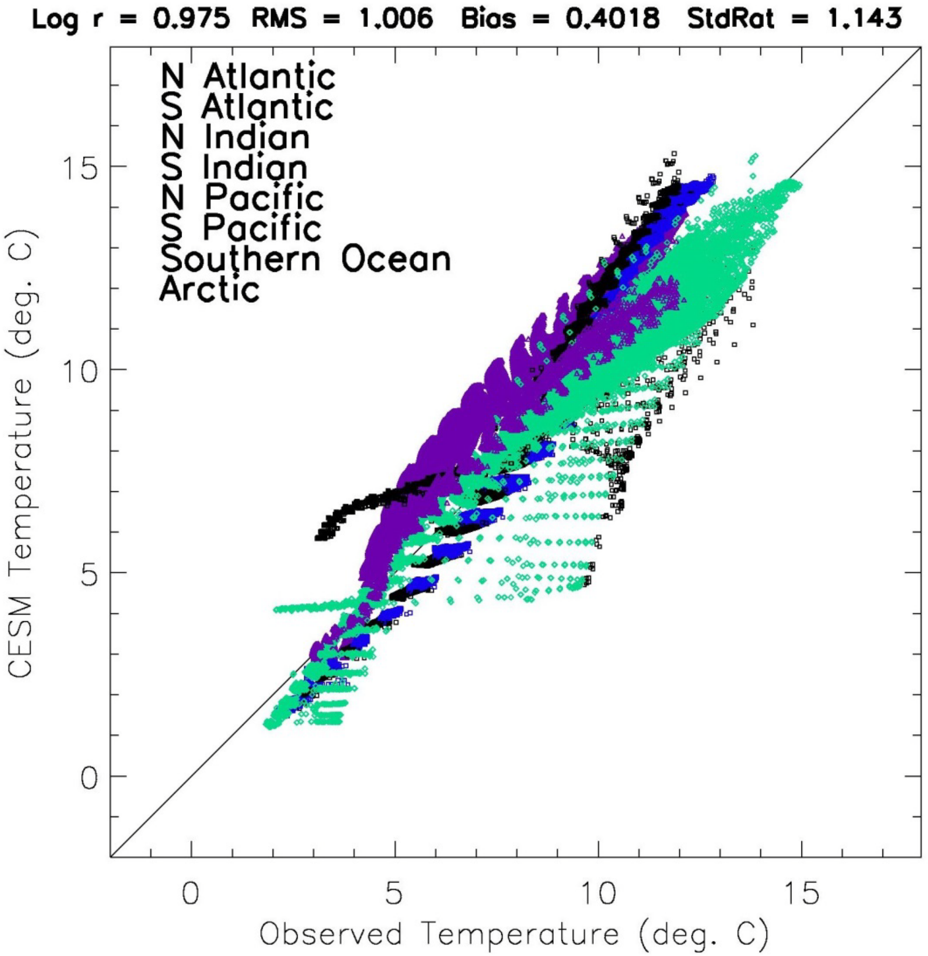


Equatorial match to observed pcfc12 data (10S-10N)

(150-671m)

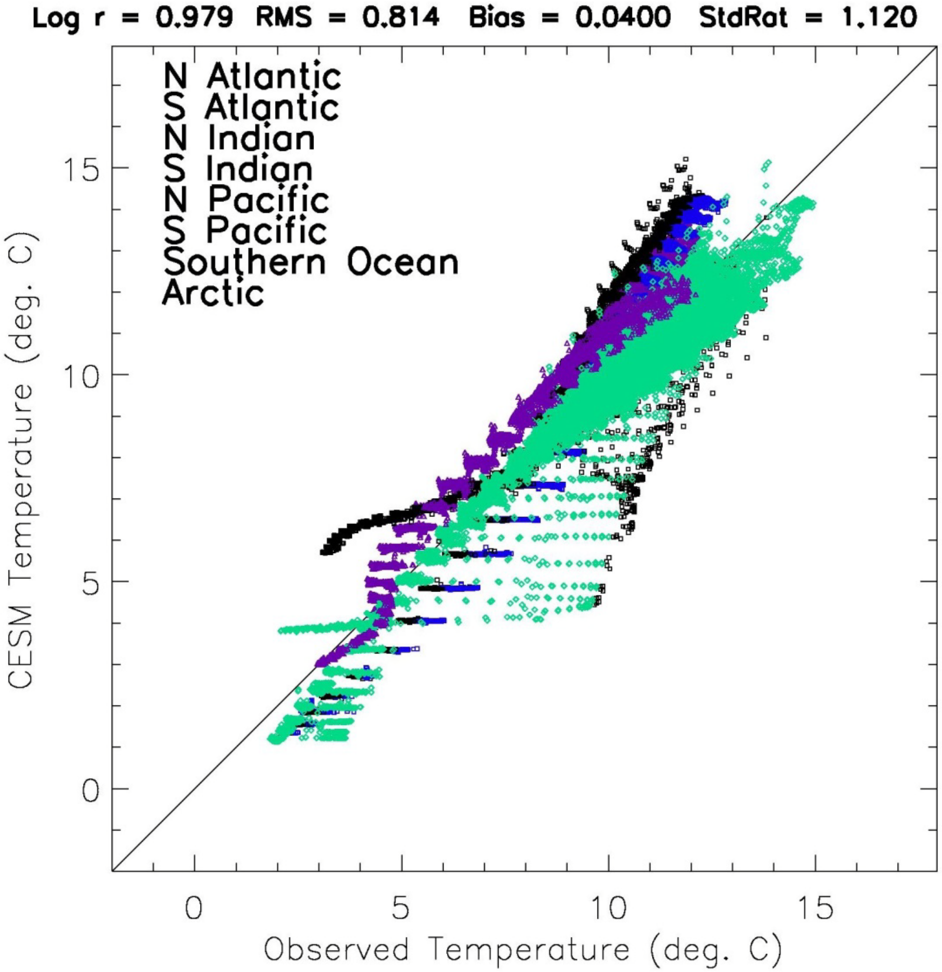
Temperature in the Equatorial Box

Standard CESM



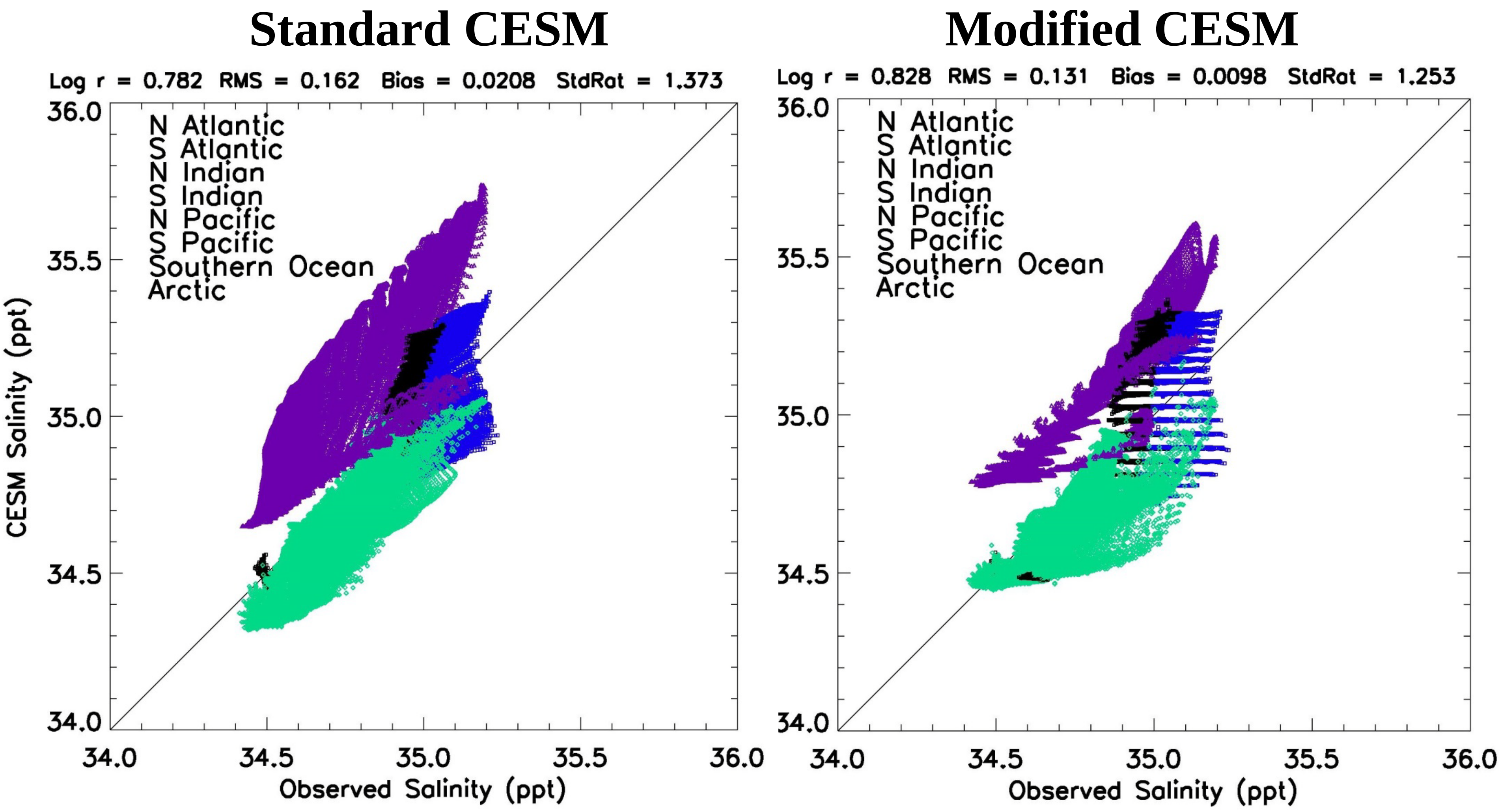
r = 0.98 rmse = 1.0

Modified CESM



r = 0.98 rmse = 0.81

Salinity in the Equatorial Box

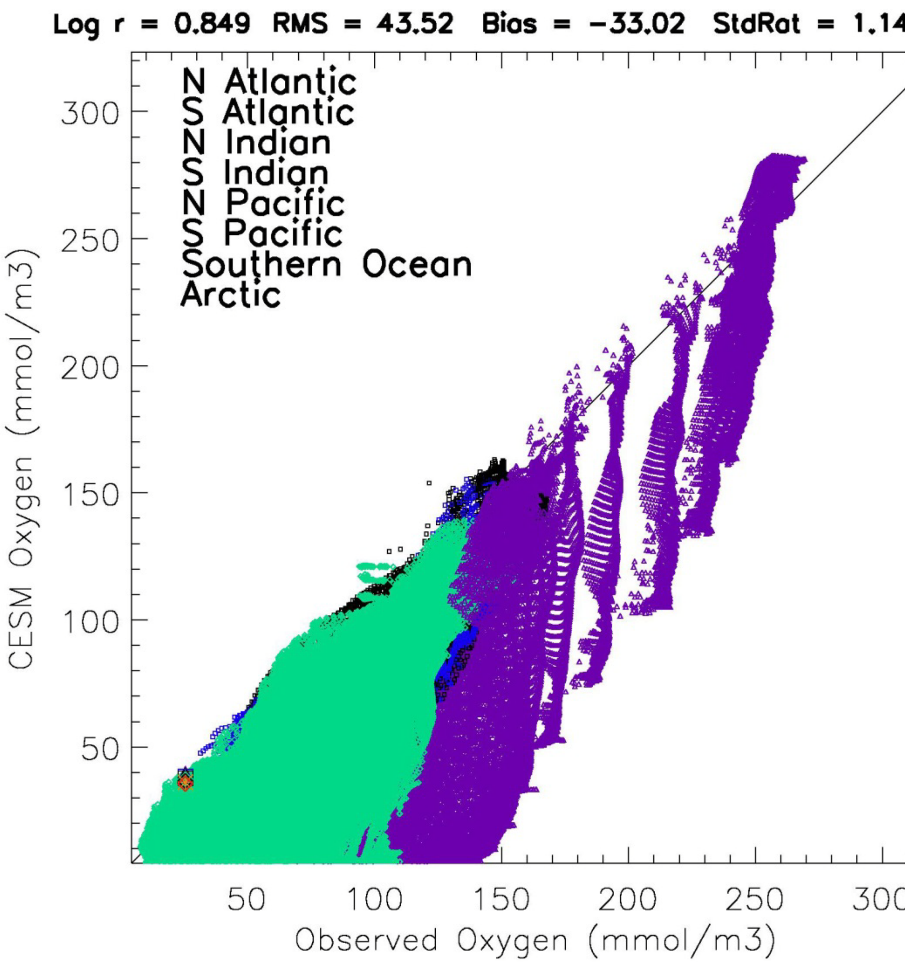


r = 0.78 rmse = 0.162

r = 0.83 rmse = 0.13

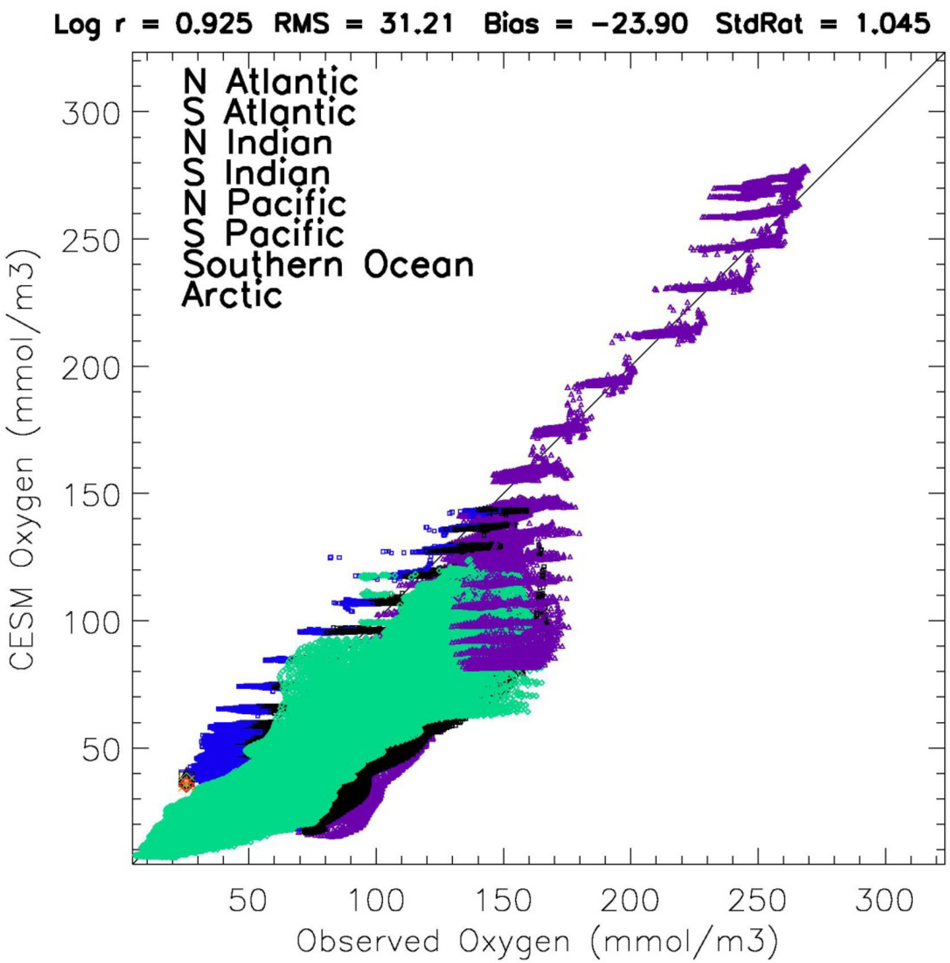
Oxygen in the Equatorial Box

Standard CESM



r = 0.85 rmse = 43 bias = -33

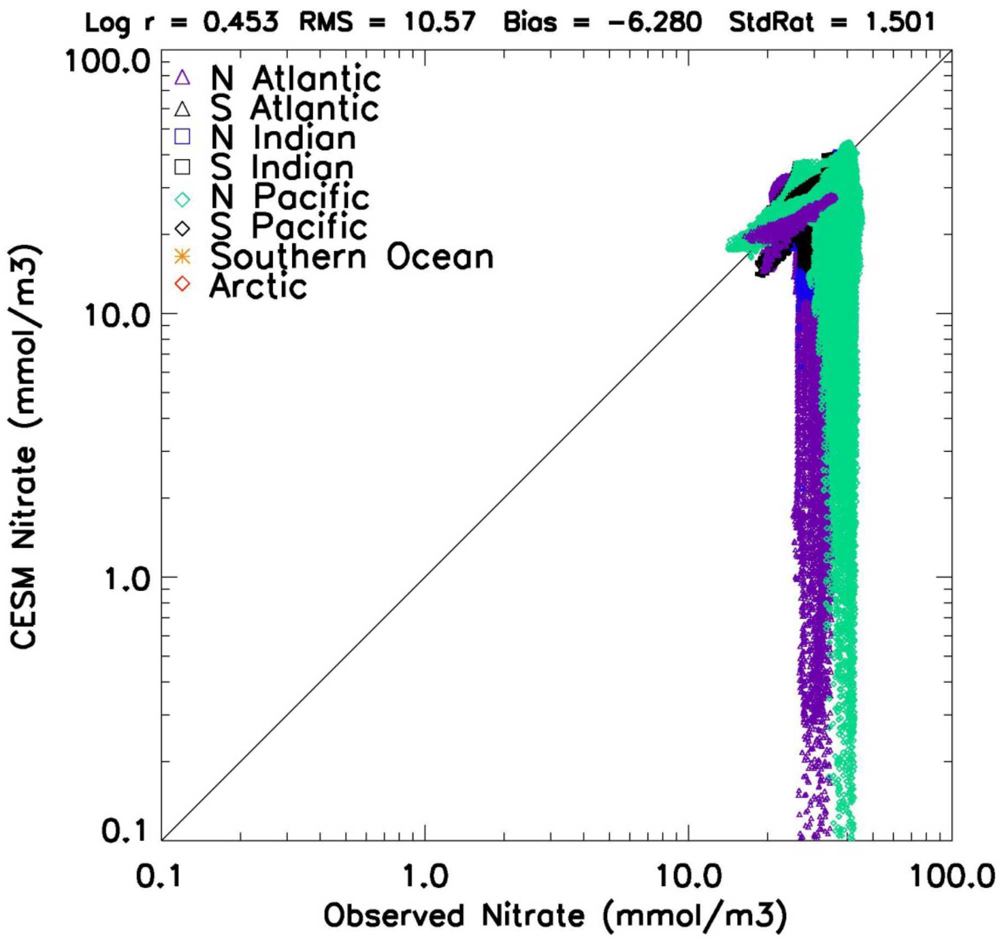
Modified CESM



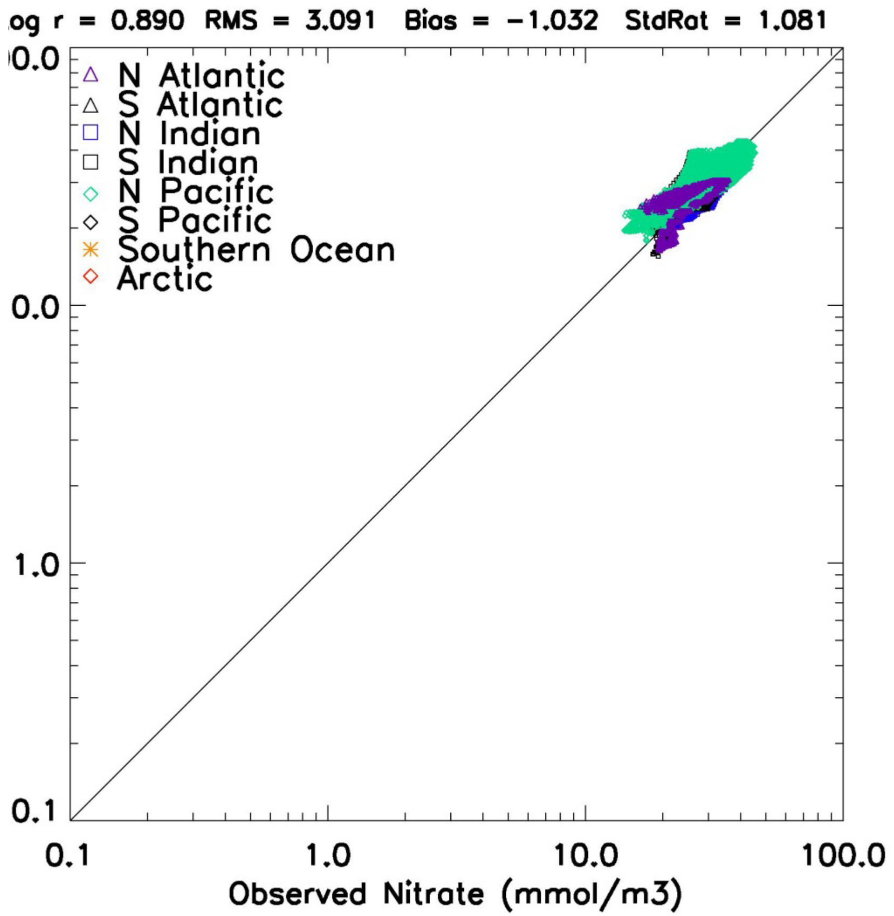
r = 0.93 rmse = 31 bias = -24

Nitrate in the Equatorial Box

Standard CESM

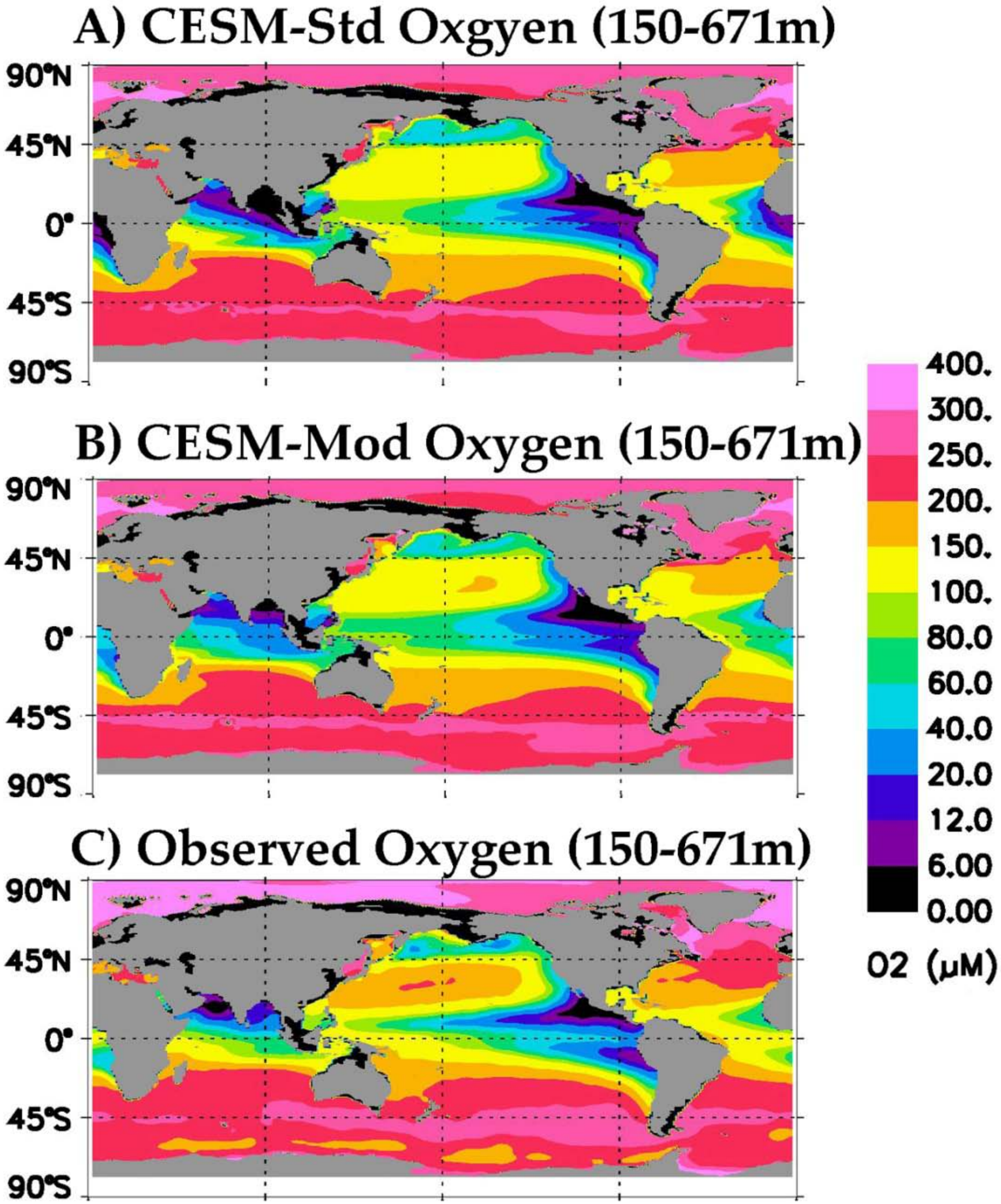


Modified CESM



r = 0.45 rmse = 11 bias = - 6.3

r = 0.89 rmse = 3.1 bias = - 1.0

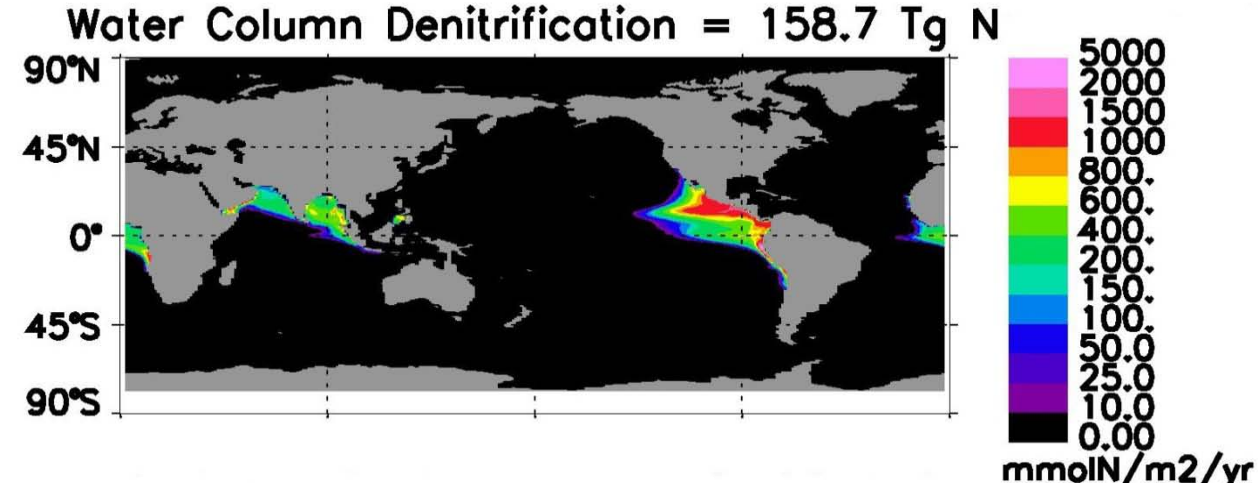


Standard CESM Oxygen
OMZ volume 173% obs

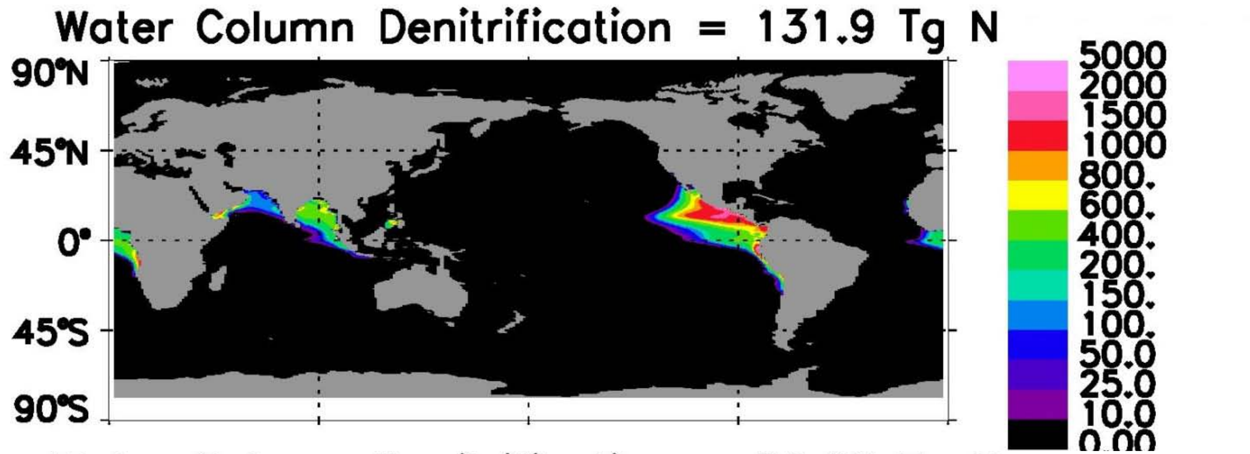
Modified CESM Oxygen
OMZ volume 124% obs

Observed WOA Oxygen

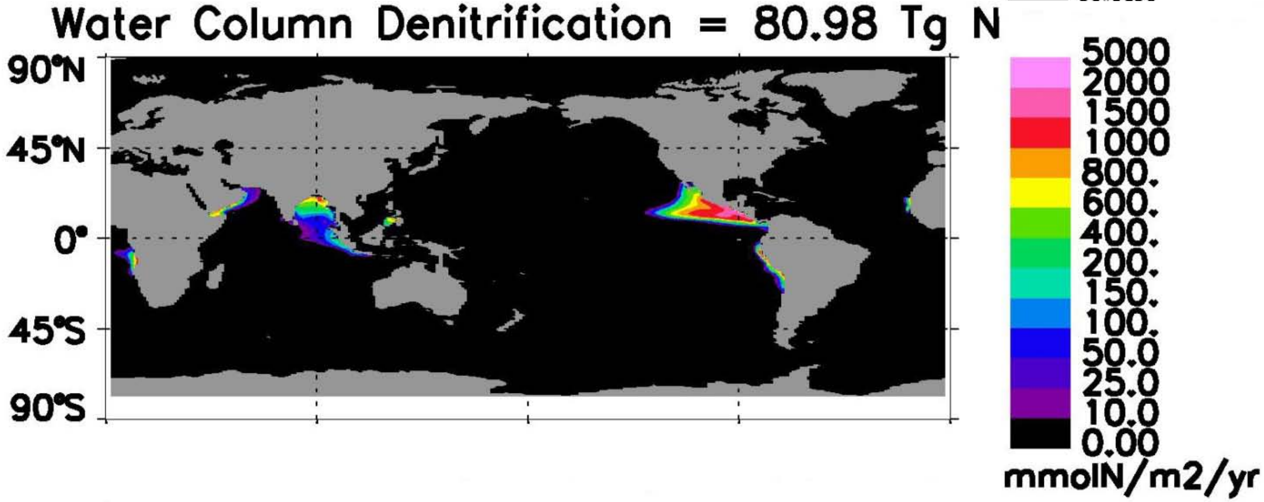
Improved SO oxygen suggests improved anthropogenic CO_2 uptake.



Standard physics



With increased minimum isopycnal diffusion



With both physics modifications

Conclusions

Increasing the minimum isopycnal diffusion from 10% to 20% of the surface maximum greatly improves simulated cfcs at depth.

Including both physics modifications greatly improves simulated OMZs, leading to realistic water column denitrification rates.

The crude parameterization of transport and mixing by the deep equatorial zonal jets greatly improves equatorial physical and biogeochemical tracers (also key to fixing the OMZ problem).

Increasing this equatorial isopycnal mixing only in the zonal direction could lead to further improvements (anisotropic GM).

Match to observed pcfcs and oxygen greatly improved, but both still have significant negative biases, likley tied to vertical mixing and mixed layer shallow biases at high latitudes.