Biogeochemistry of the Oxygen Minimum Zones (OMZs)

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Talk Outline

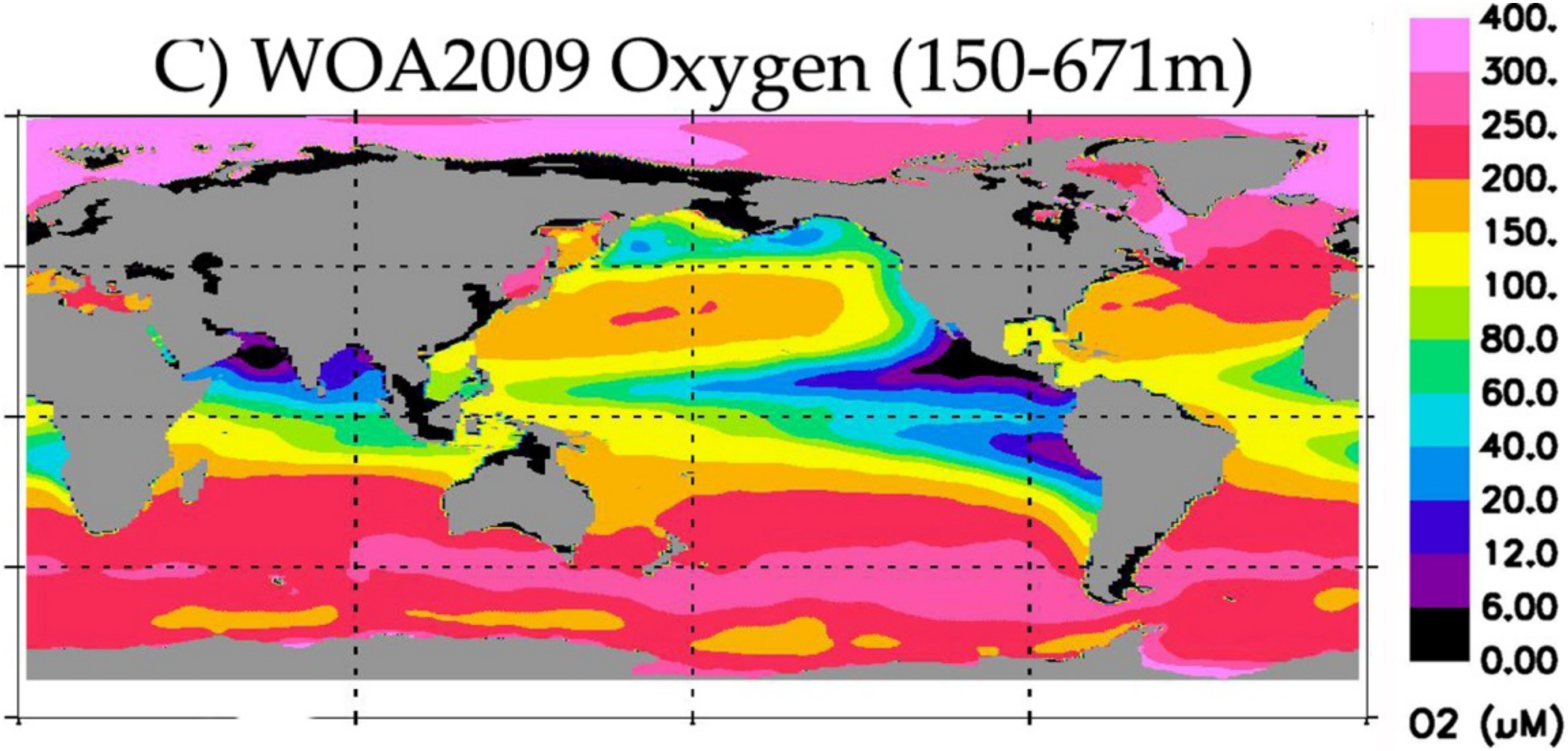
I. Ocean BGC in the Interim Coupled Simulations

II. Physical Biases that Impact the OMZs in CESM

II. Biological Pump Efficiency in the OMZs

IV. Conclusions

OMZs occur at mid-depths in regions with **elevated biological export** and **weak ventilation**.



OMZs are important for ocean biogeochemistry:

1) fixed nitrogen is lost to denitrification;

2) some is converted to N_2O, a key greenhouse gas.

The OMZs are expected to expand with climate change.

Ocean BGC in the Interim Coupled Simulations

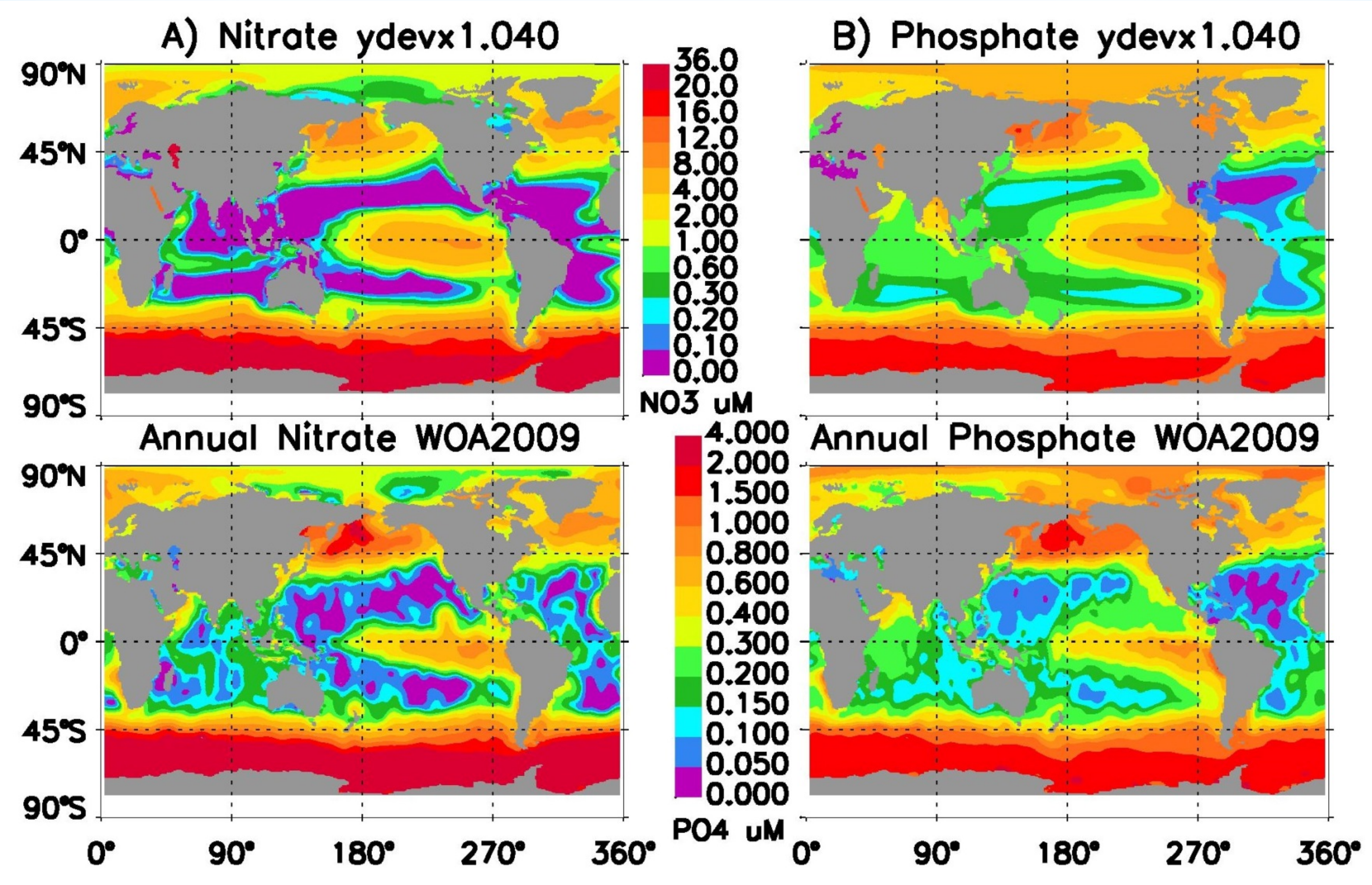
These simulations will use a modified version of ocean bgc from CESM 1.2.

Modifications include:

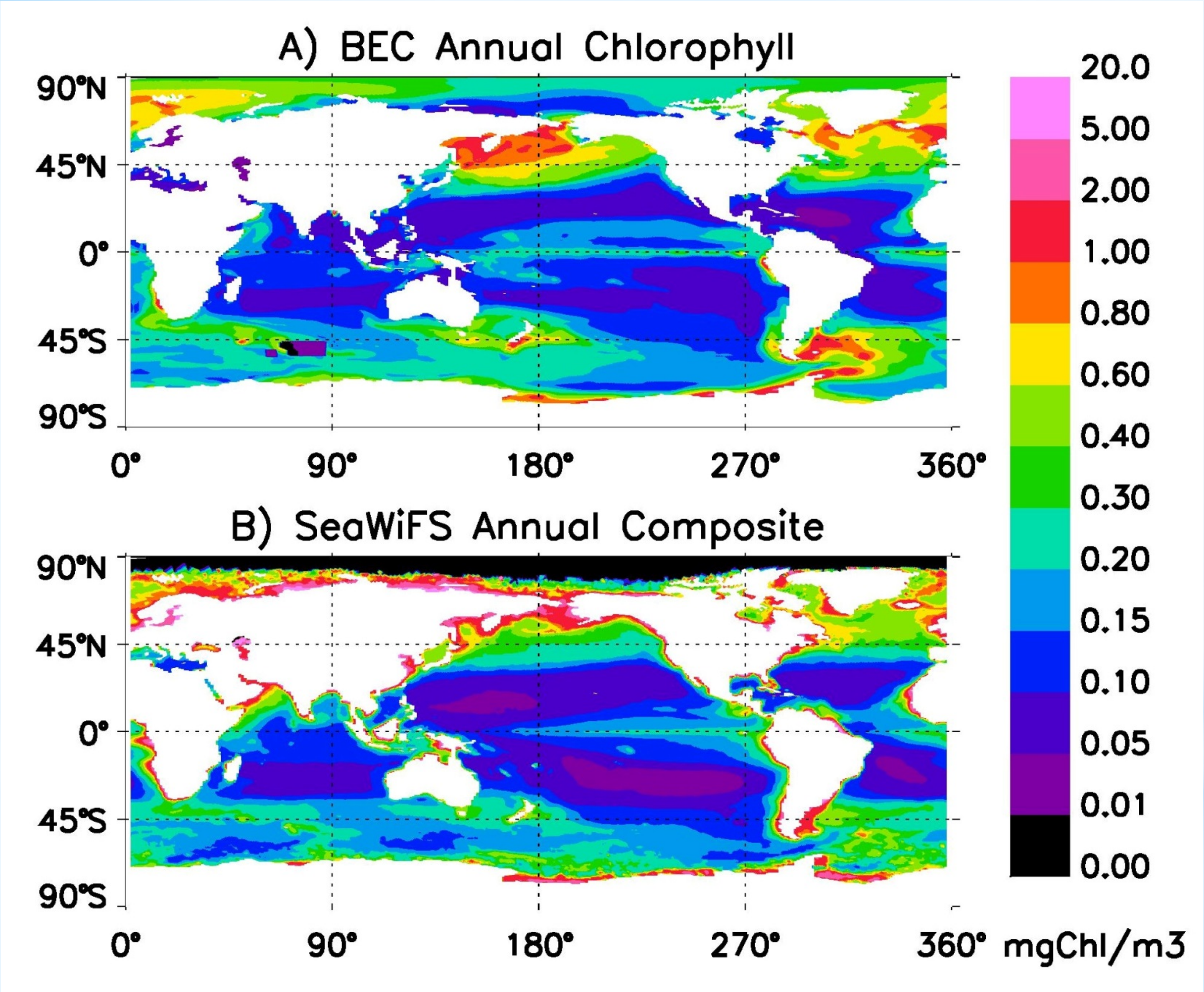
1) addition of a refractory dissolved organic carbon (DOC) tracer;
2) optimization of all DOM parameters (Letscher et al. 2015);
3) addition of hydrothermal vent iron source
4) improved treatment of light in sea ice;
5) parameter optimization for remineralization of sinking organic matter.
6) minimum value of GM mixing coefficients increased from 300 to 600 m^2/s.

Ocean BGC in the Interim Coupled Simulations

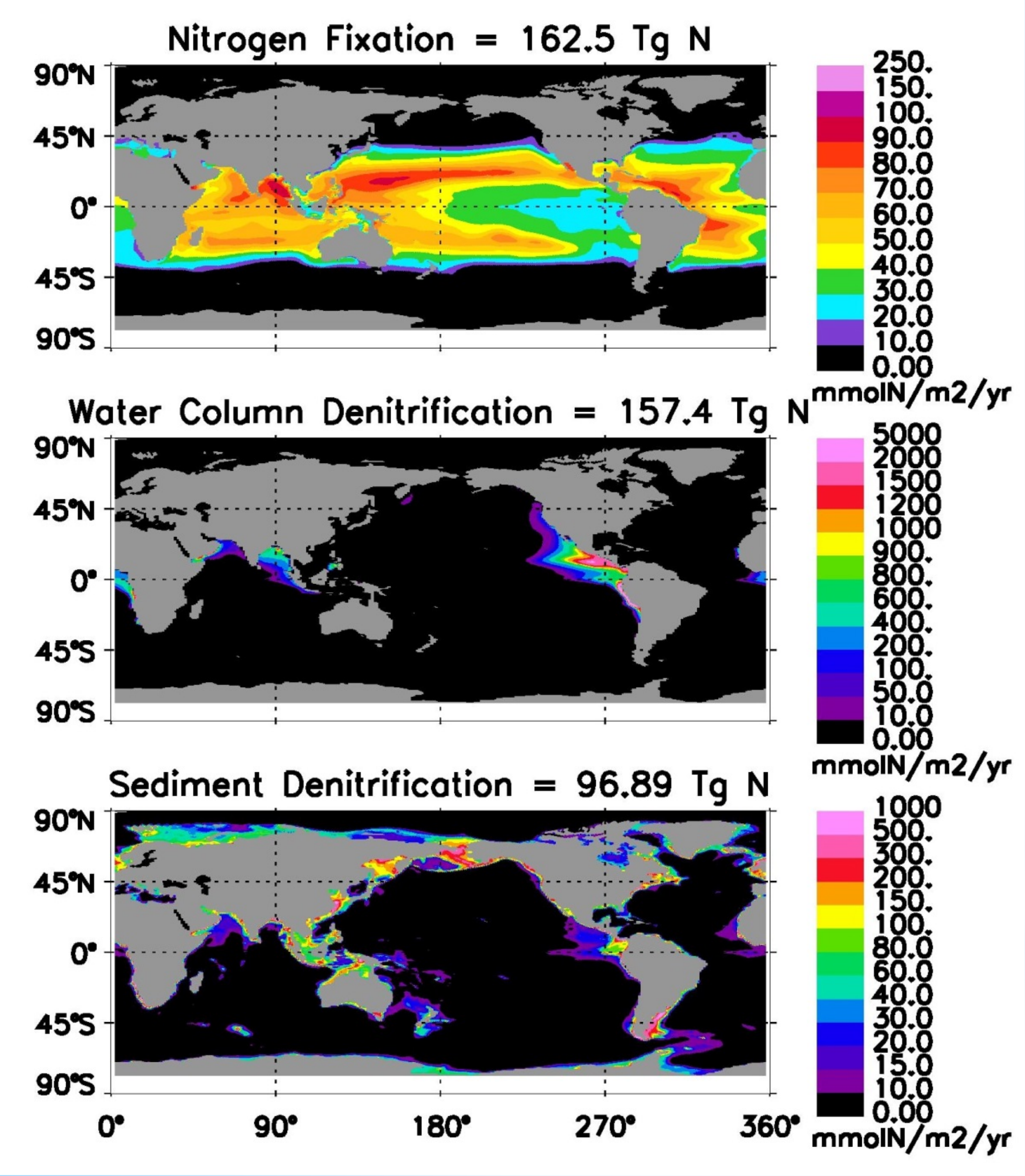
Following plots from GIAF gx1v6 simulation run through five cycles, or 310 years, with output averaged over last 20 years.



Ocean BGC in the Interim Coupled Simulations

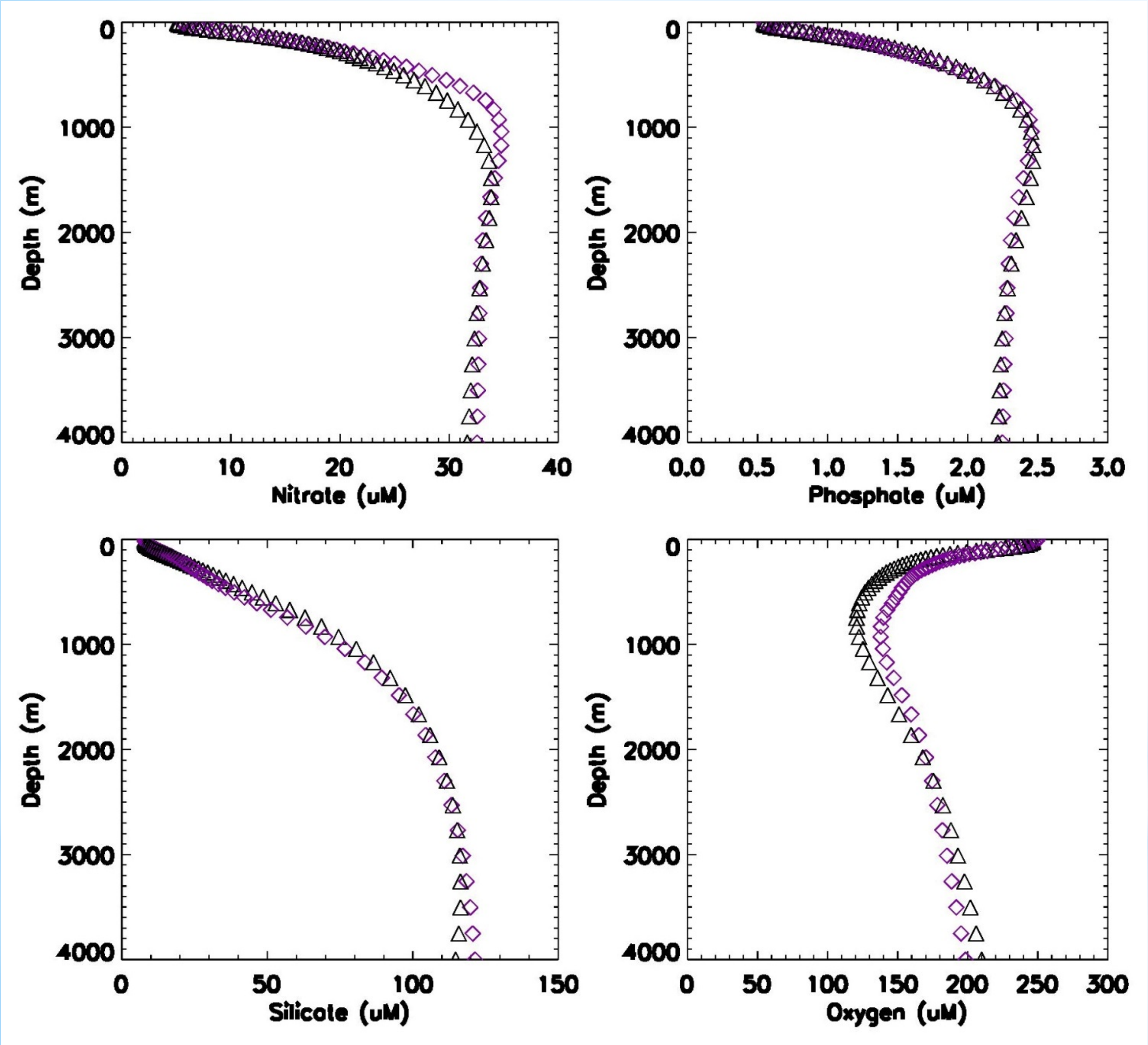


Ocean BGC in the Interim Coupled Simulations



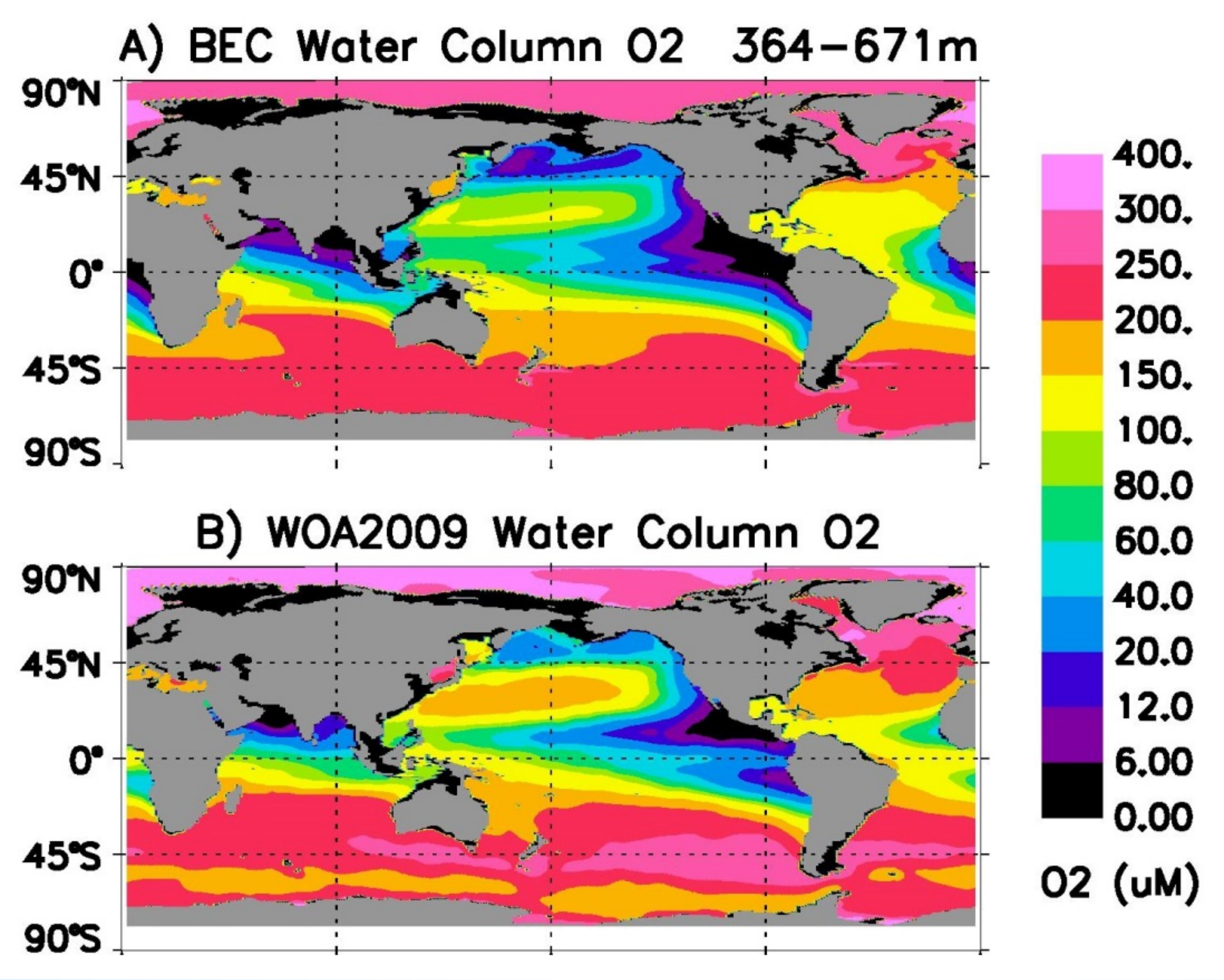
WC denitrification down > 50%, from earlier CCSM/CESM versions, but is still higher than observational estimates (< 100 TgN/yr).

Ocean BGC in the Interim Coupled Simulations

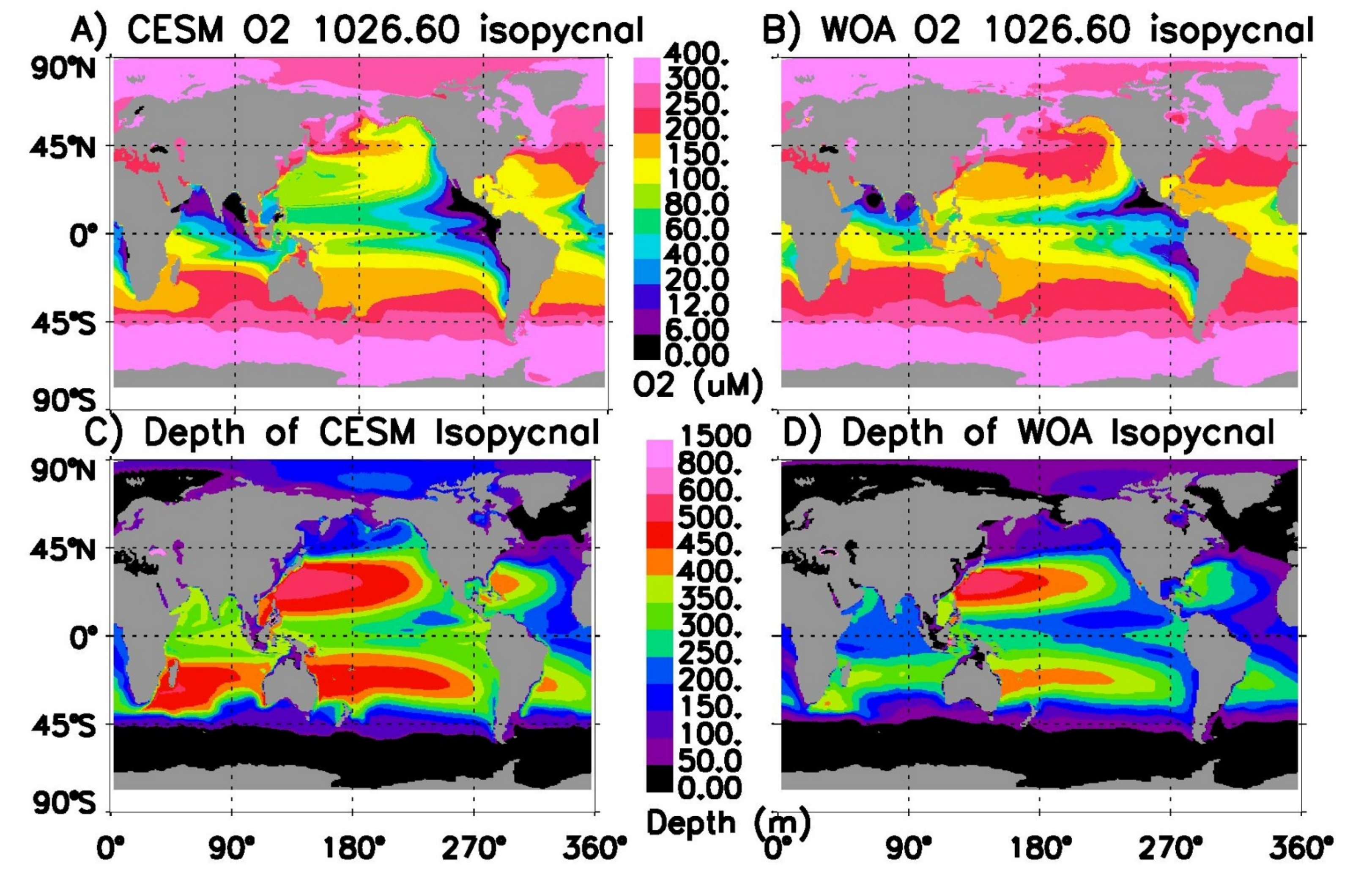


CESM - black trianges, WOA observations purple diamonds

Ocean BGC in the Interim Coupled Simulations



Ocean BGC in the Interim Coupled Simulations



Physical Biases Impacting the Oxygen Minimum Zones

1) Vertical mixing and ventilation is too weak in the NW Pacific and in the Southern Ocean.
2) Missing deep zonal equatorial jets are an important O_2 source for the OMZs.

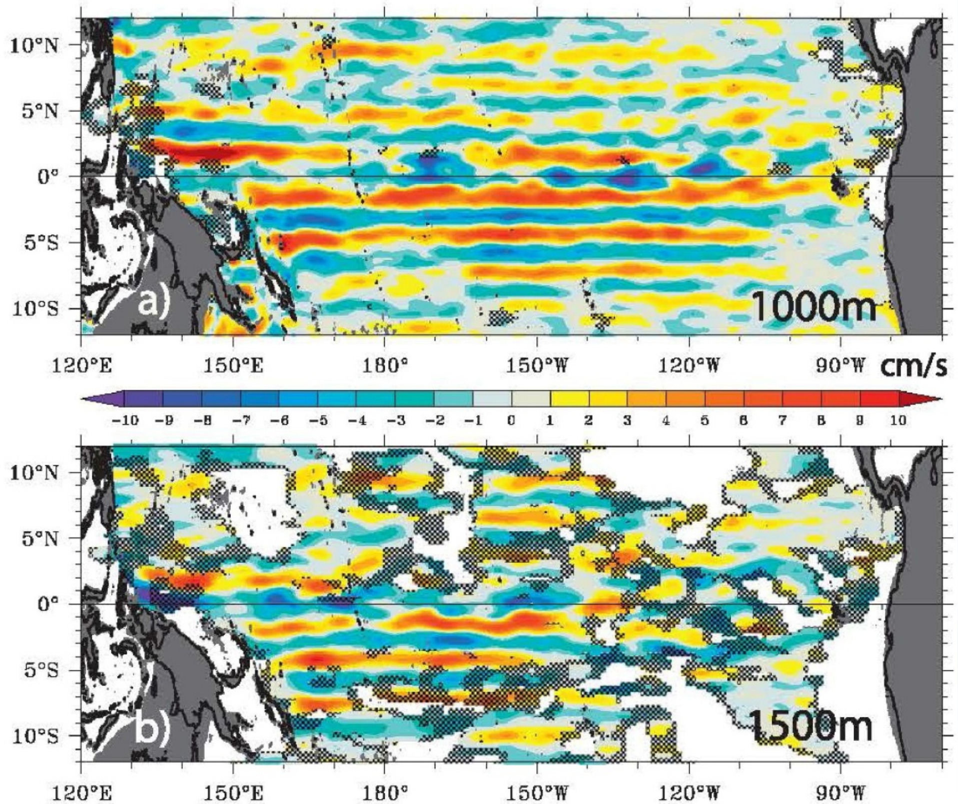


FIG. 2. Mean zonal currents (cm s^{-1}) at (a) 1000 and (b) 1500 m, from optimal interpolation. Topography shallower than 1000-m depth is shaded in dark gray. Boxes with less than five values are blanked. Regions where zonal velocity estimates could be biased seasonally are hatched in black (see text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

Zonal jets in ARGO float data (Cravatte et al., 2012).

Physical Biases Impacting the Oxygen Minimum Zones

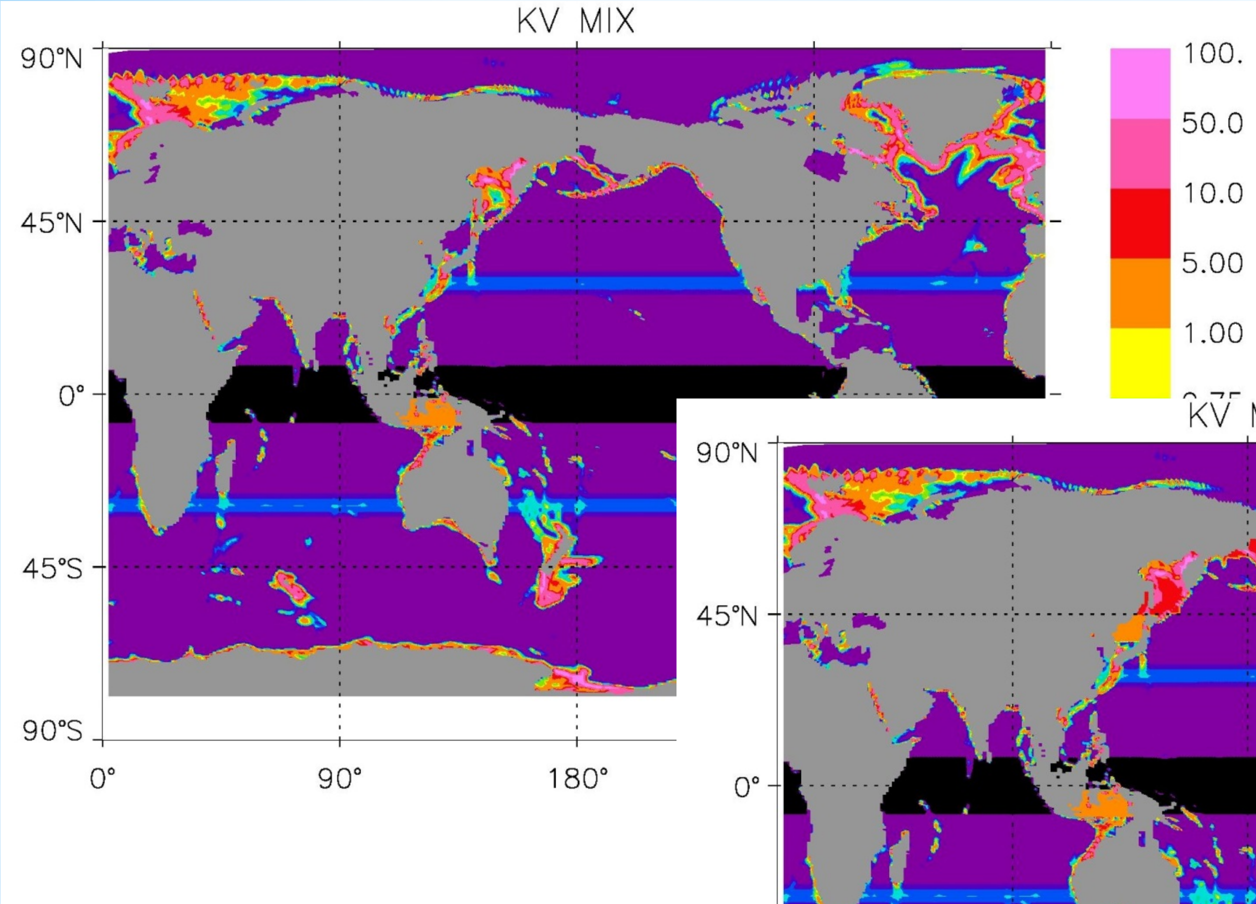
The deep equatorial jets are not present in gx1v6, but do show up at 0.1 degree resolution.

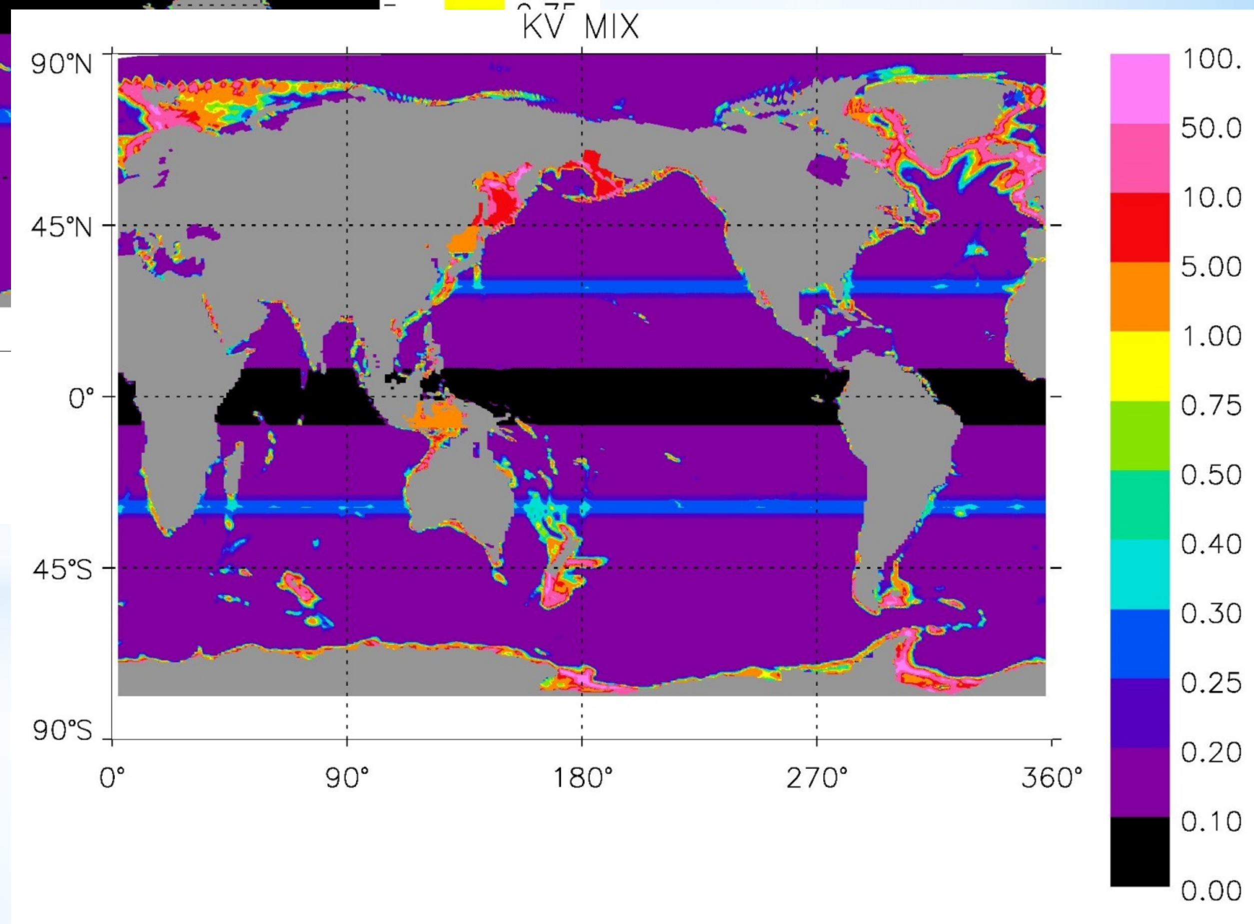
Getzlaff and Dietze (2013) increased isopycnal diffusion along the equator (5S-5N) to mimic the advective transport by the deep equatorial jets.

Next, compare simulation shown previously with a simulation with some physical modifications:

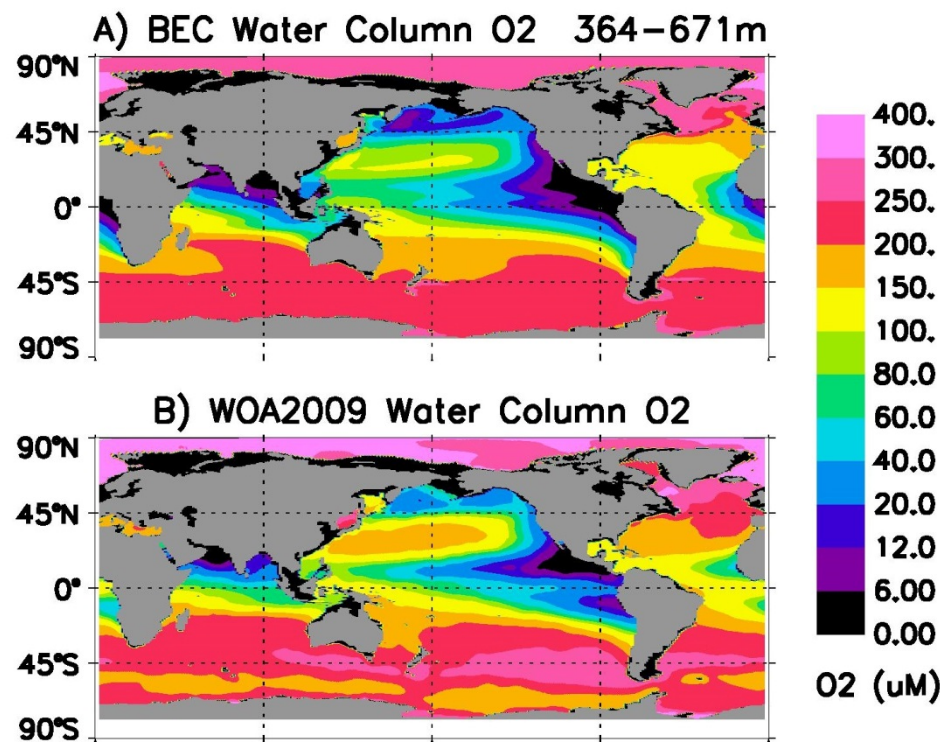
1) enhanced diapycnal mixing in NW Pacific and at the Bering Sea shelf break;
2) greatly enhanced isopycnal mixing along the equator at depth (5S-5N, 180-1860m).

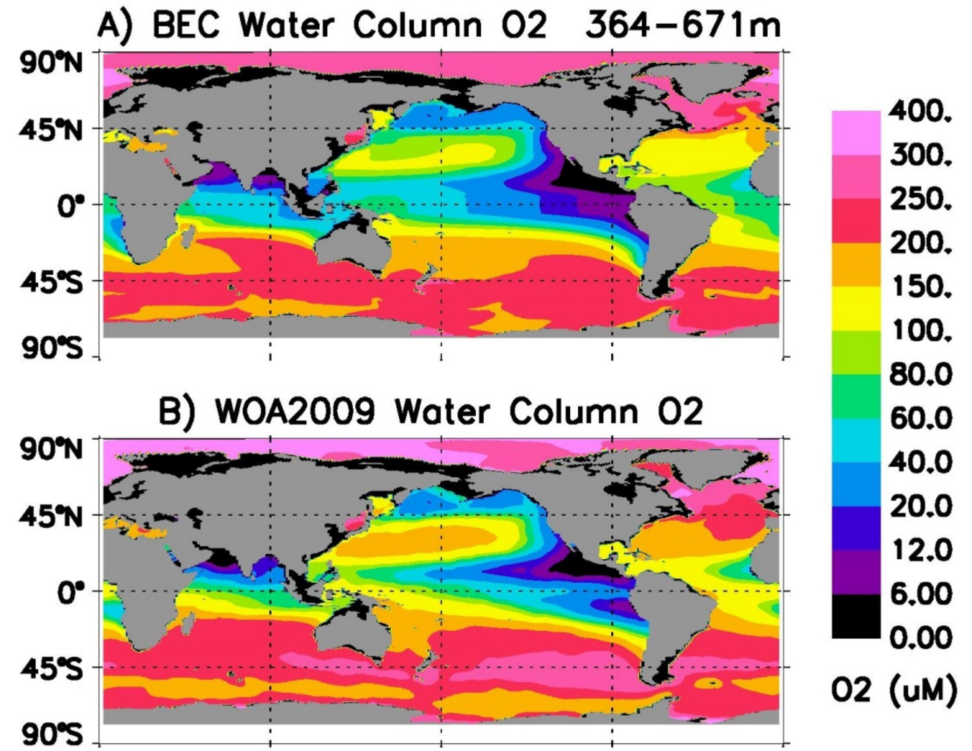
Physical Biases Impacting the Oxygen Minimum Zones



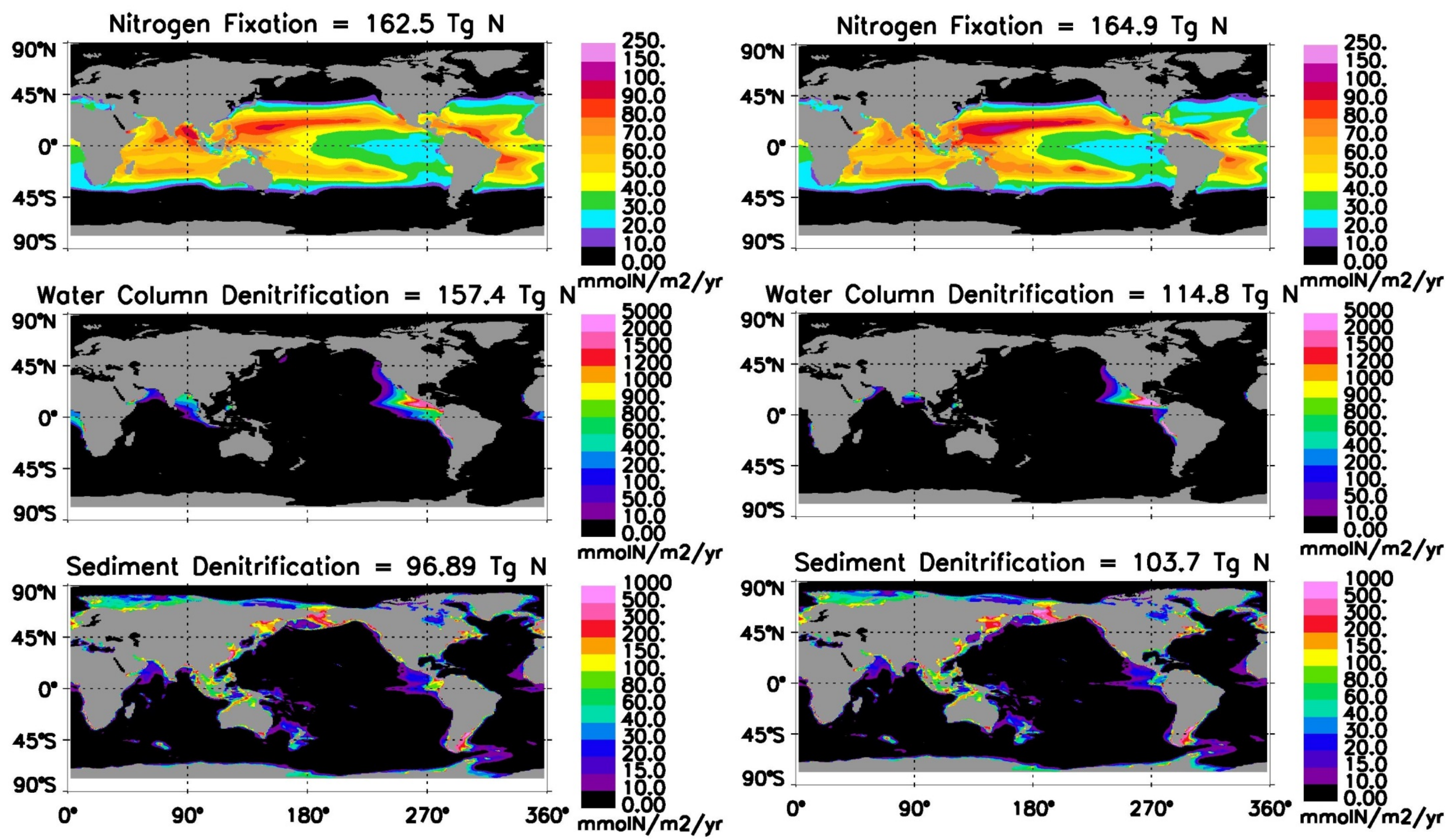


Physical Biases Impacting the Oxygen Minimum Zones





Physical Biases Impacting the Oxygen Minimum Zones



Potential climate feedbacks with OMZ expansion:

1) **Increased water column denitrification** in the OMZs reduces ocean fixed nitrogen inventory, increasing N limitation and weakening the biological pump (vertical export of C to ocean interior).

2) Increased water column denitrification leads to **increased oceanic N_2O production** and emission to the atmosphere.

3) Decreasing oxygen concentrations slow the breakdown and remineralization of sinking organic matter, leading to **more efficient downward transport of carbon**.

Downward flux of sinking organic matter in the OMZs

The breakdown and remineralization of sinking particles should be less efficient in the OMZs because:

1) remineralization using nitrate through denitrification is less efficient than using oxygen;
2) zooplankton, which graze on sinking particles, are largely excluded from the OMZs.

These factors should lead to longer remineralization length scales and more efficient downward transport of carbon (a more efficient biological pump).

Current ocean models increase the remineralization length scale by up to a factor of 5 under low O_2 conditions (< 5μM). In CESM 1.2 we used a factor of 3.3.

Downward flux of sinking organic matter in the OMZs

GIAF gx1v6 simulations varying the O_2 effect on remineralization length scale ranging from X1 to X5.

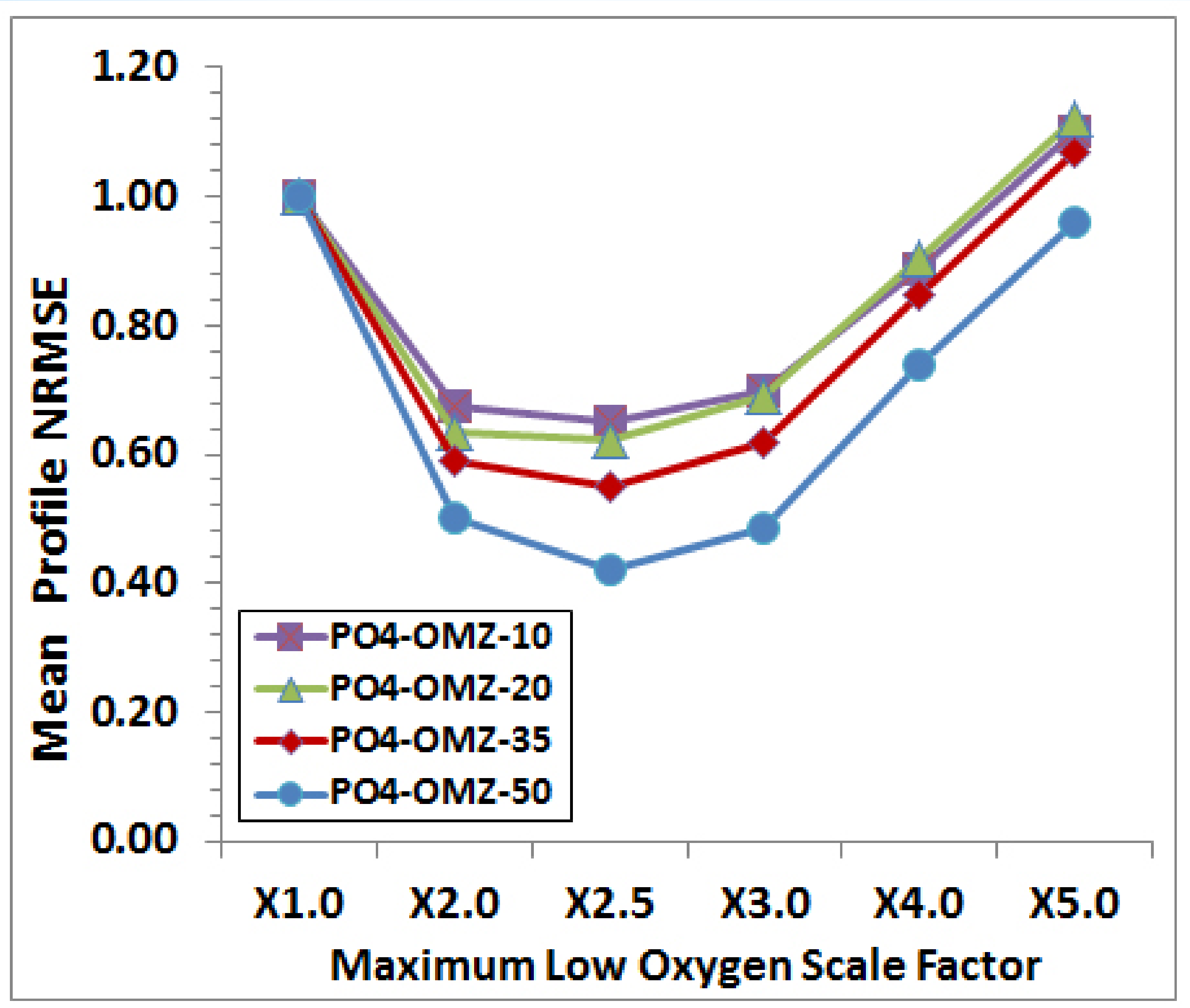
Remin length scale increases linearly below 35 μM to a maximum value at 5 μM.

Results evaluated through comparisons with observed phosphate profiles in OMZ and nonOMZ regions.

Here, OMZ regions are defined as areas with minimum O_2 concentrations in the water column < 20 μM.

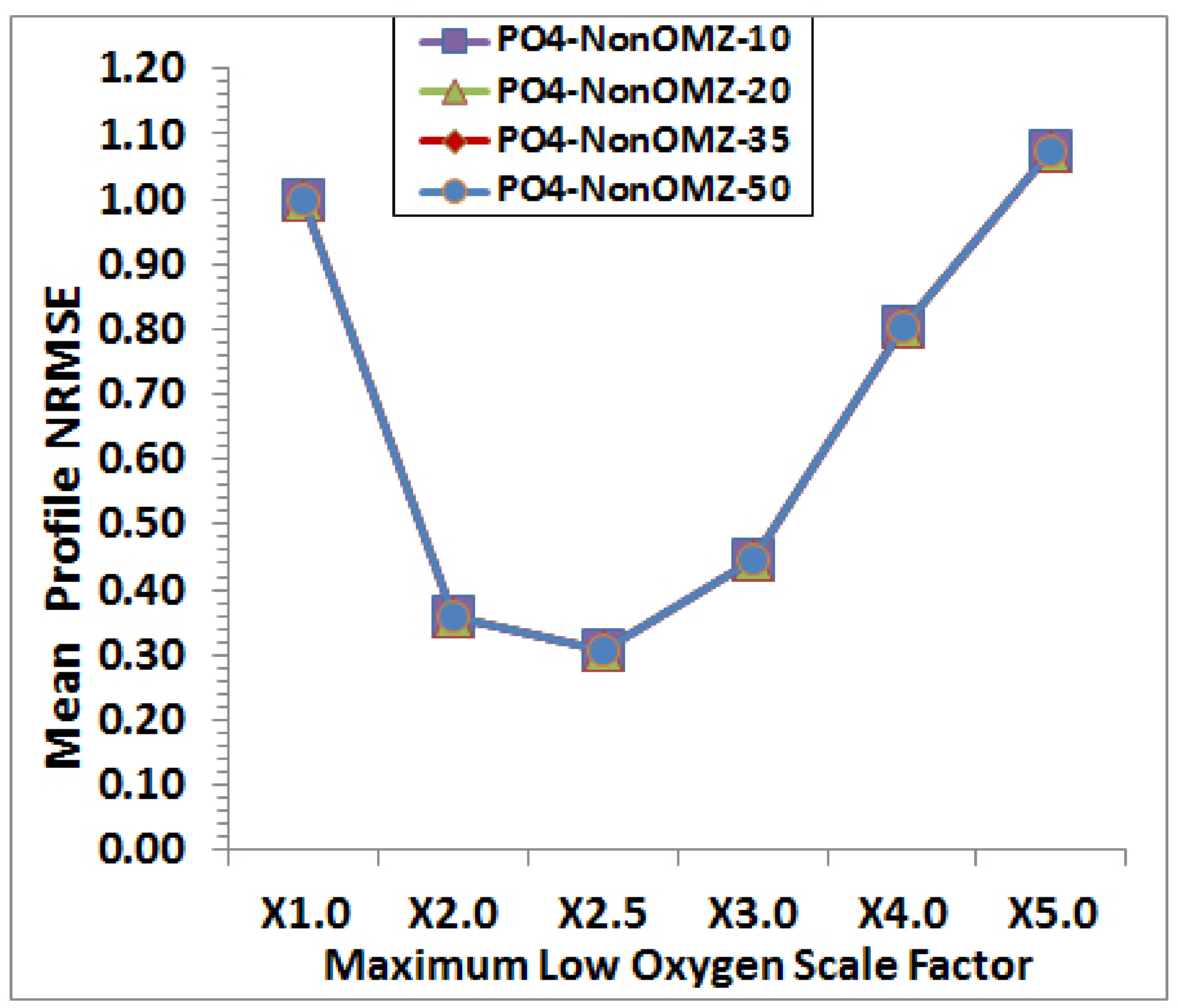
Some plots show the effect of using different cutoff values (10, 35, and 50 μM). Results are insensitive to value chosen.

Downward flux of sinking organic matter in the OMZs



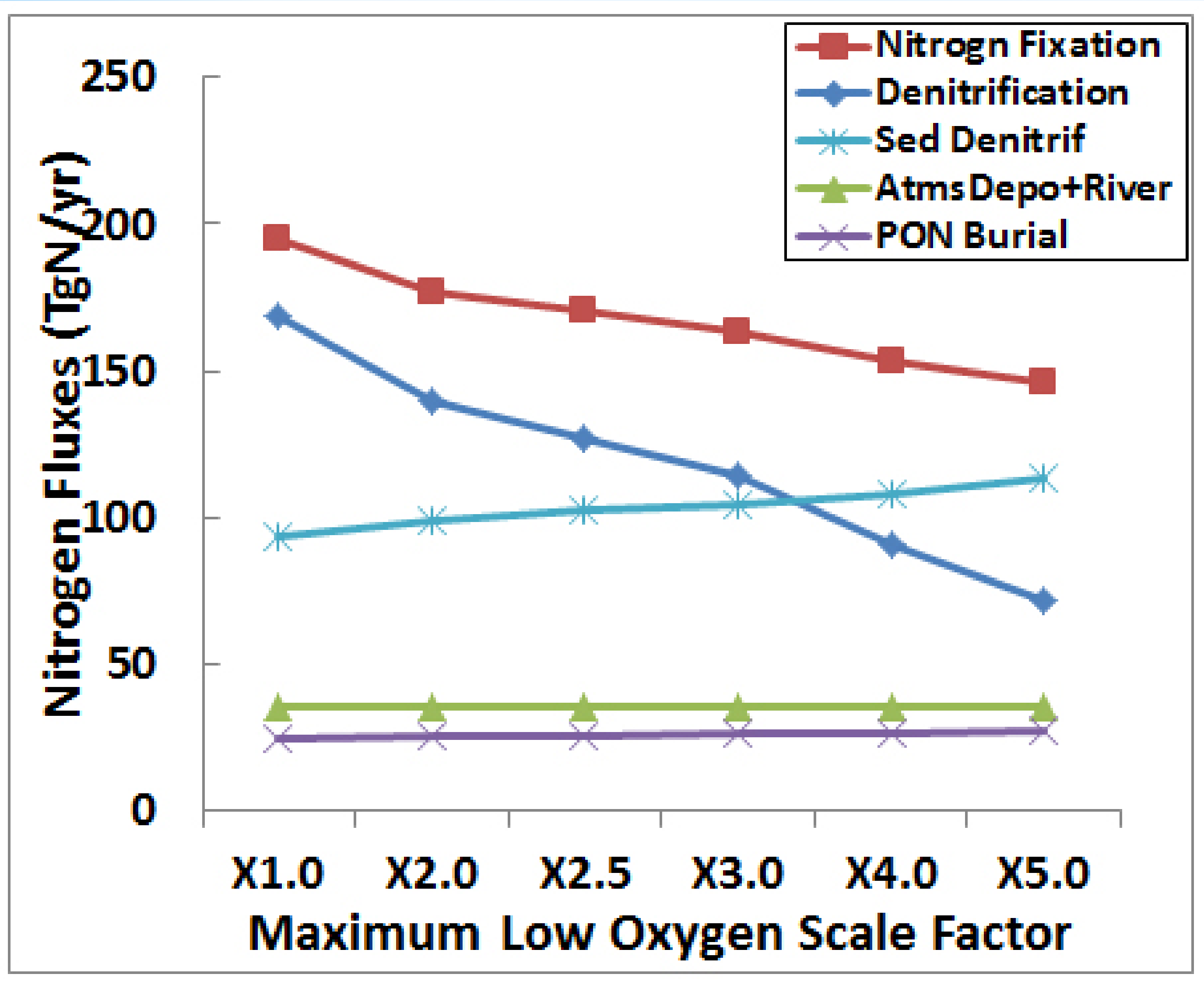
Normalized rmse in the mean PO4 profile in OMZ regions (30S-30N). RMSE error for each case divided by rmse from X1 case (no O_2 effect on length scale), using different cutoff values for OMZ.

Downward flux of sinking organic matter in the OMZs

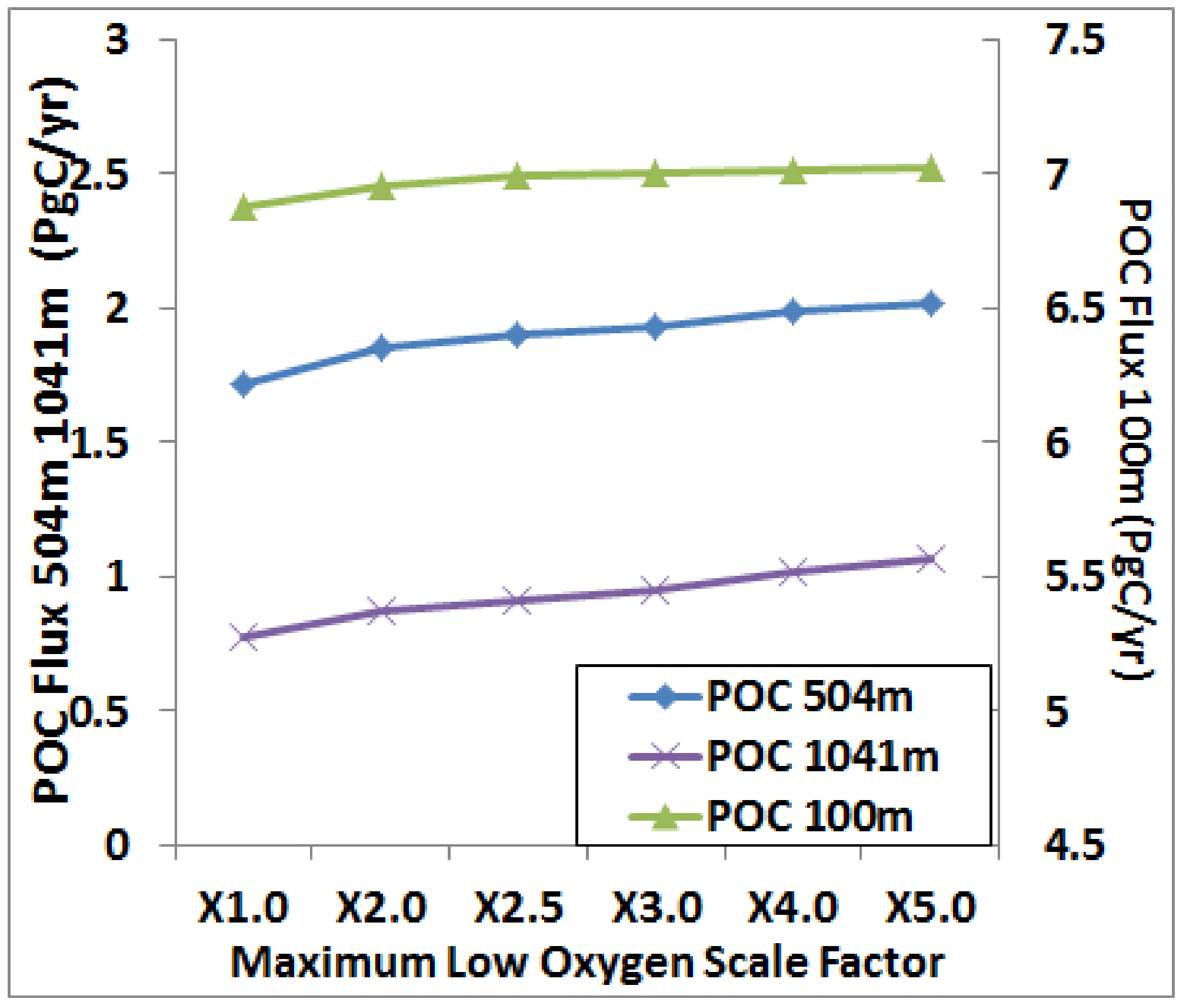


Normalized rmse for the mean PO4 profile in nonOMZ regions (30S-30N).

Downward flux of sinking organic matter in the OMZs



Downward flux of sinking organic matter in the OMZs



Sinking flux of carbon to the deep ocean increases by 18% with X2.5 scaling, and by 38% with X5.0 scaling.

Conclusions

I. Tidal mixing needs to account for 3D energy field to capture "hot spots" driven by sub-gridscale bathymetry (i.e., Kuril Islands).

II. Anisotropic GM may enhance zonal transport near the equator, reducing large BGC biases.

III. Deeper Southern Ocean mixed layers and vertical exchange needed to address multiple BGC biases.

IV. Results suggest remineralization length scales in the OMZs increase by a factor of 2-3, larger increases degrade nutrient simulations globally.

V. Expansion of the OMZs with climate change could lead to more efficient biological carbon export, providing a negative feedback.