Physical-Biogeochemical Interactions in the CESM

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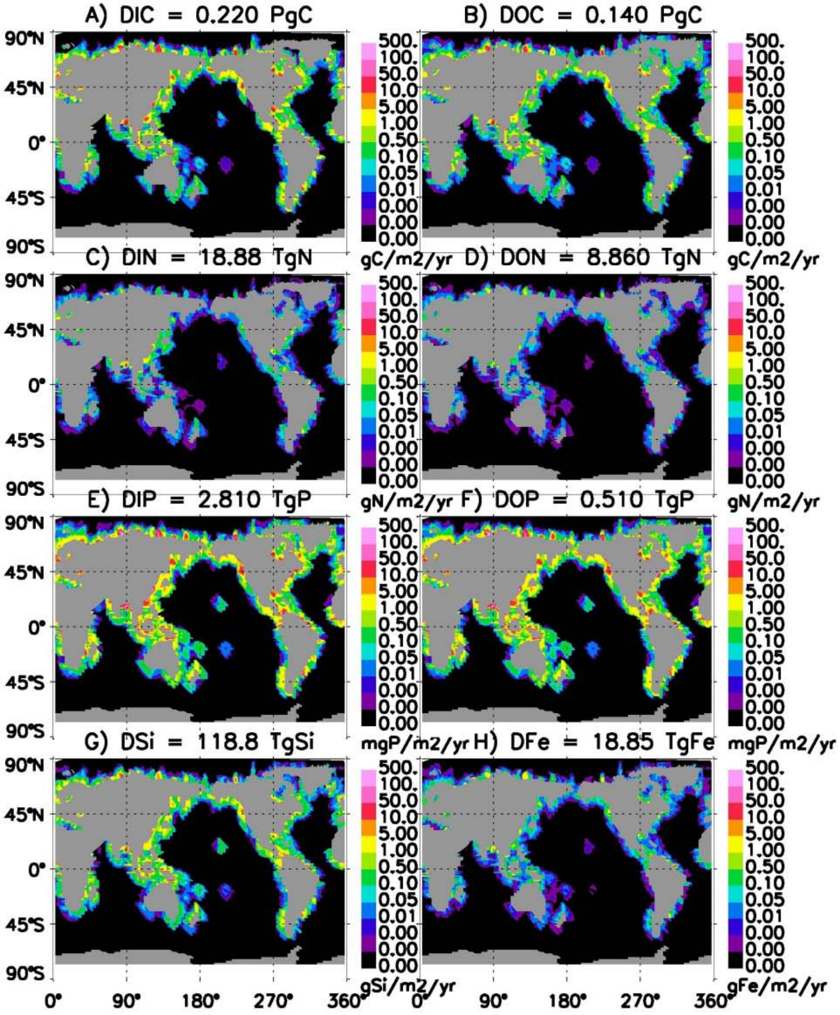
Talk Outline

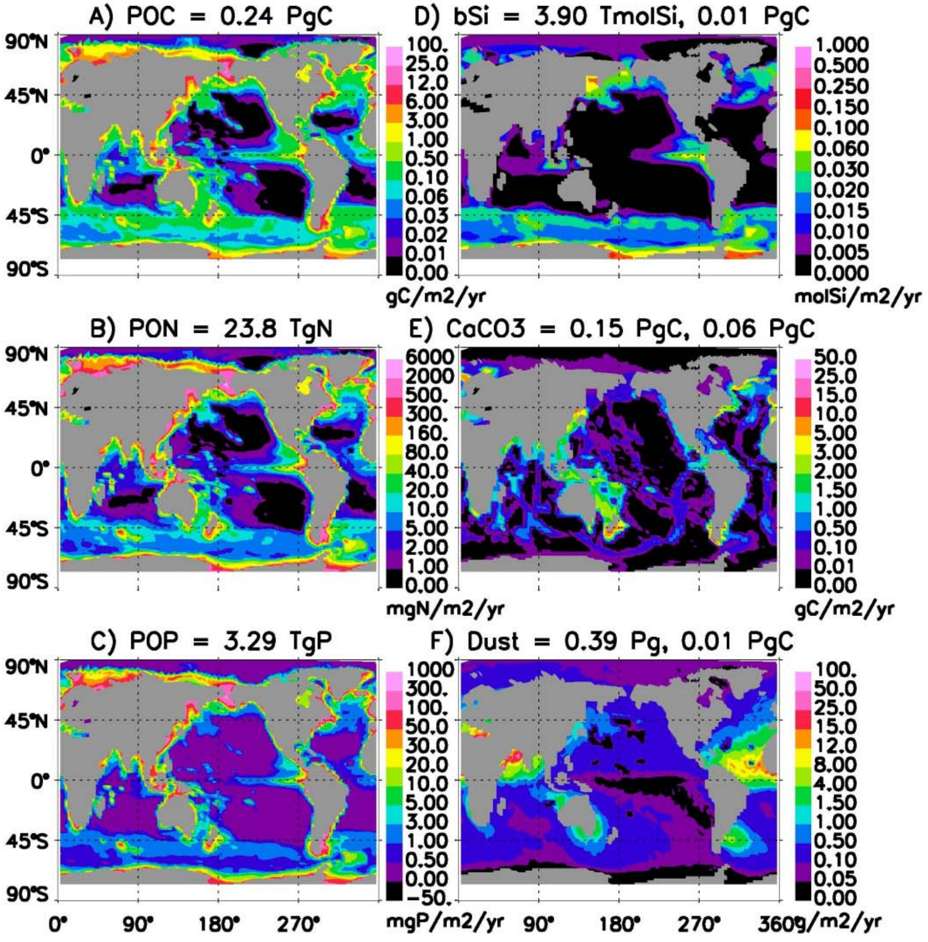
1) **The CESM oxygen problem.**
2) **Excessive AA**BW formation in X3 simulations.
3) Mixing hot spots important for biogeochemistry.
4) Diapycnal mixing at high latitudes and biogeochemistry.

All simulations had active ocean-ice (GIAF, gx3v7) with weak surface salinity restoring (needed for NADW),
100 year spin-up with standard physics,
followed by 100 year simulation with CESM 1.2 biogeochemistry,
and physics modifications, except where noted otherwise.



River Nutrient Inputs

Climatological nutrients from global Nutrient Export from WaterSheds (NEWS) models. Spatial pattern follows river water inputs.

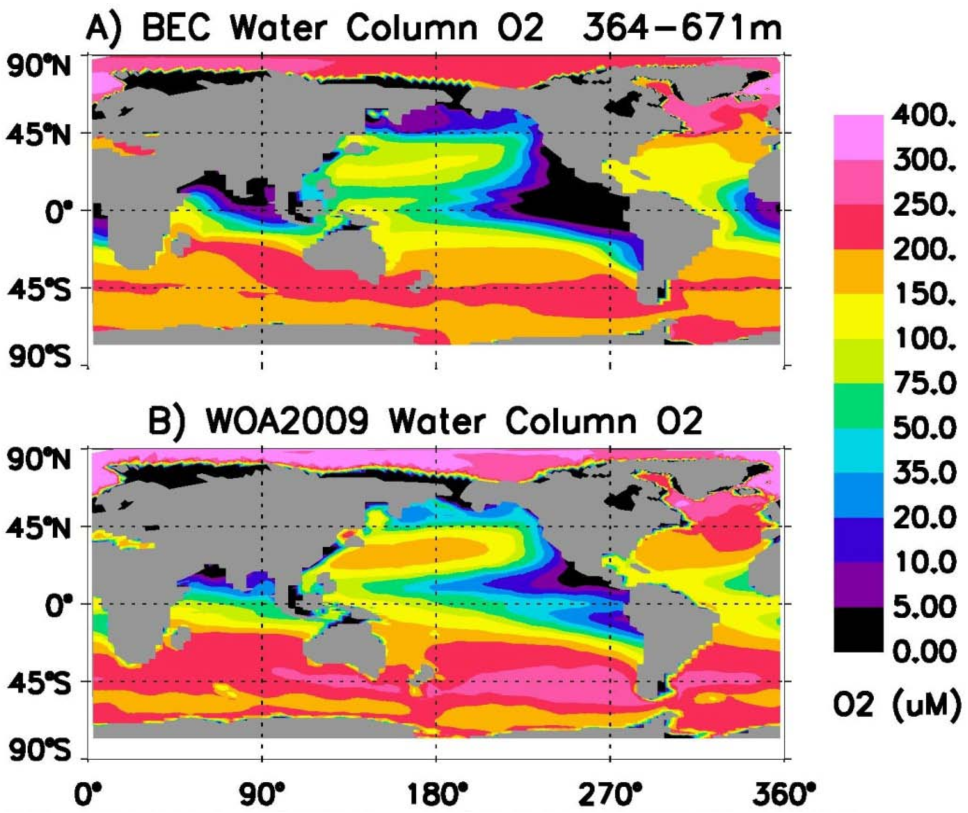


BGC Sediment Fluxes

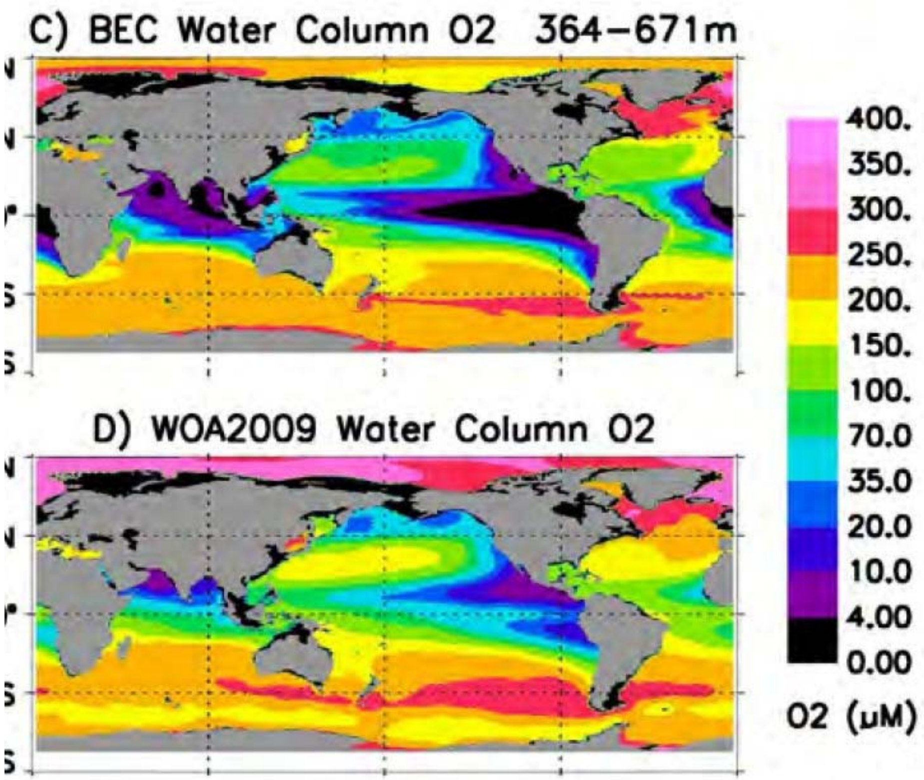
Simple sediment biogeochemical fluxes.

Losses of alkalinity, phosphorus and silicon are ~balanced by input from rivers.

Also includes sedimentary denitrification.

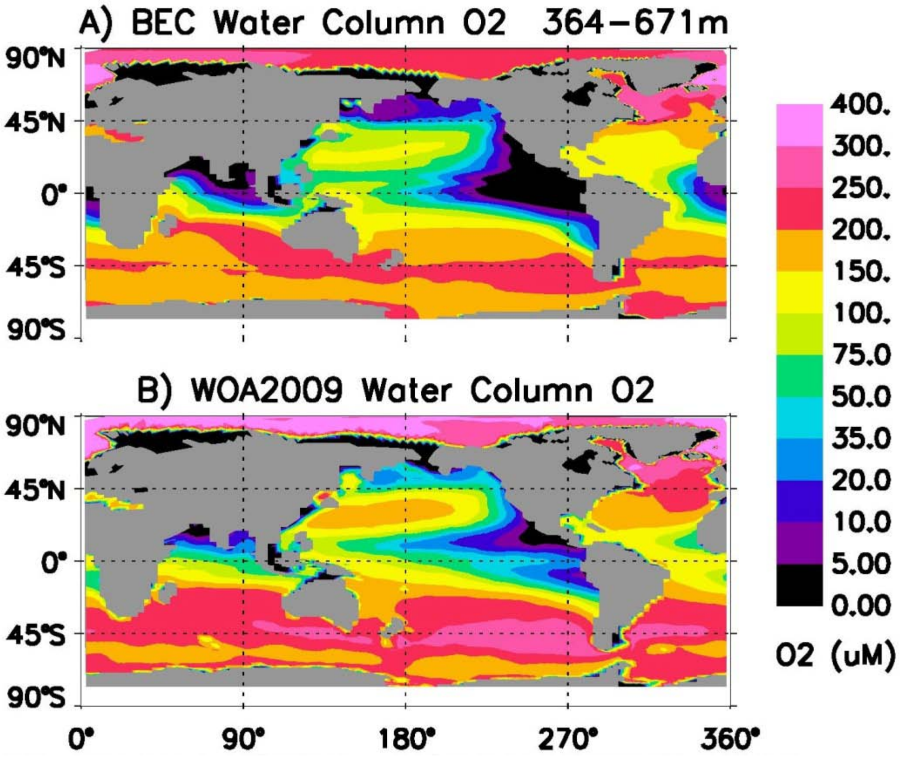


CESM 1.0 gx3v7

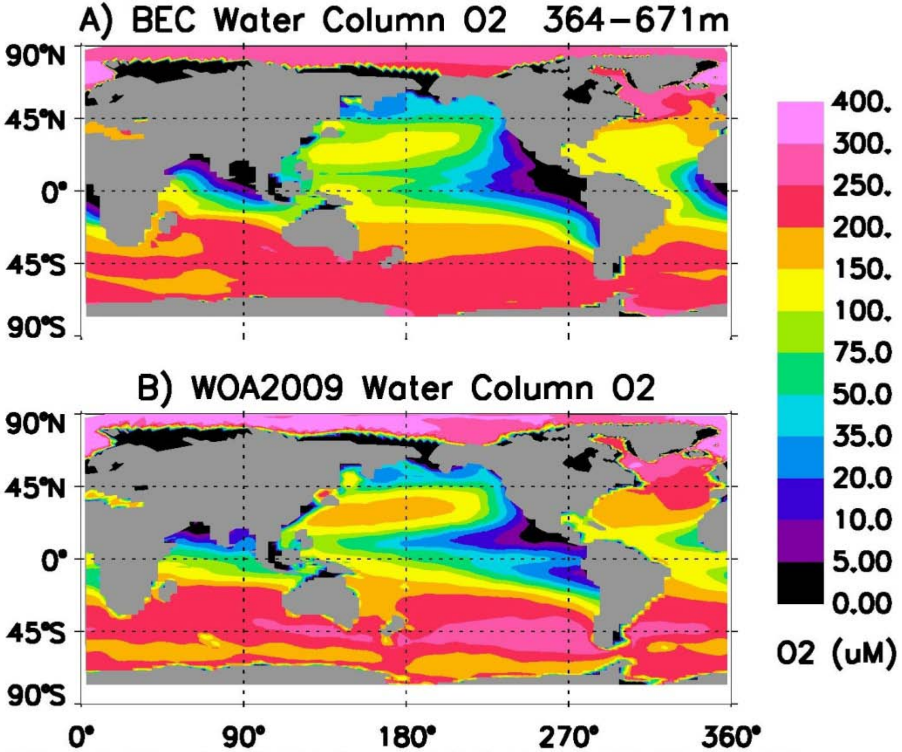


CESM 1.0 gx1v6

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



CESM 1.0 gx3v7

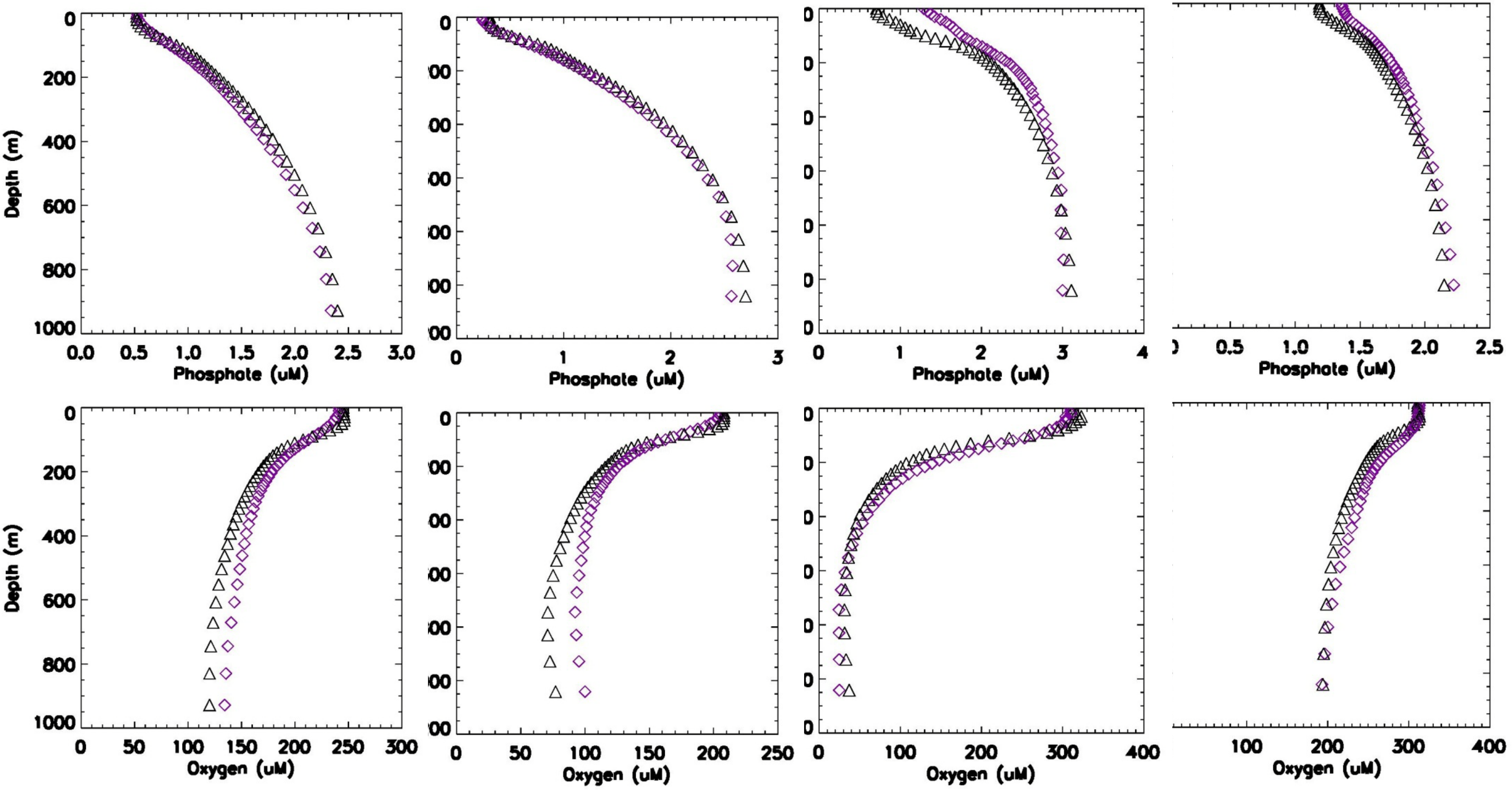


CESM 1.2 gx3v7

Negative oxygen biases greatly reduced, but still present with CESM 1.2 BEC code.

Increasing isopycnal mixing in general reduces the low-latitude O_2 biases. Anisotropic GM? EUC and eastern boundary currents bring oxygen to the eastern Pacific.

CESM 1.2 Mean Vertical Profiles - Oxygen and Phosphate



Global Profile 25S-25N NPac (45-60N) SO (45-60S)

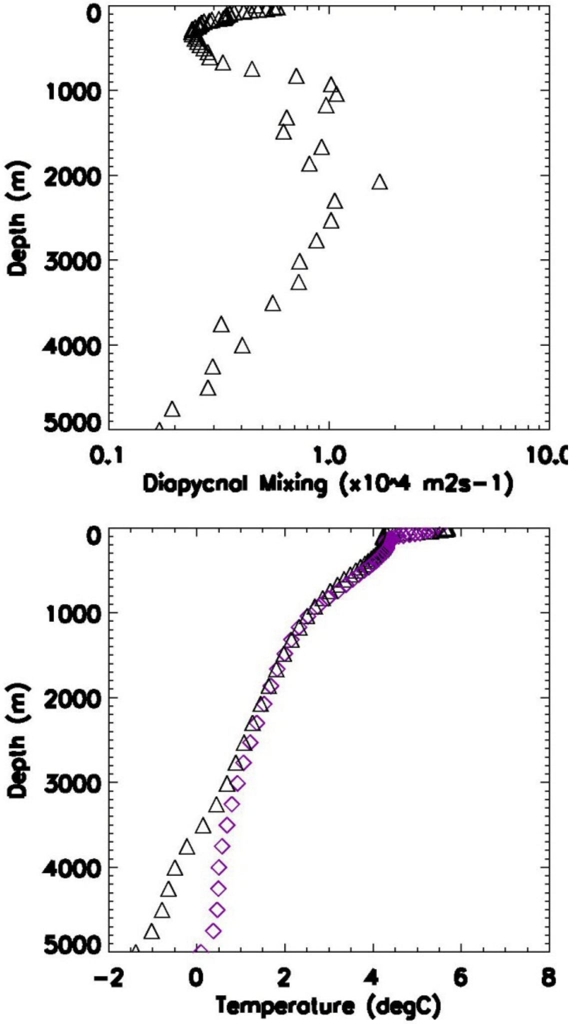
Black Triangle = CESM, Purple Diamond = Observed

Excessive AABW Formation in Ocean-Ice X3 Simulations

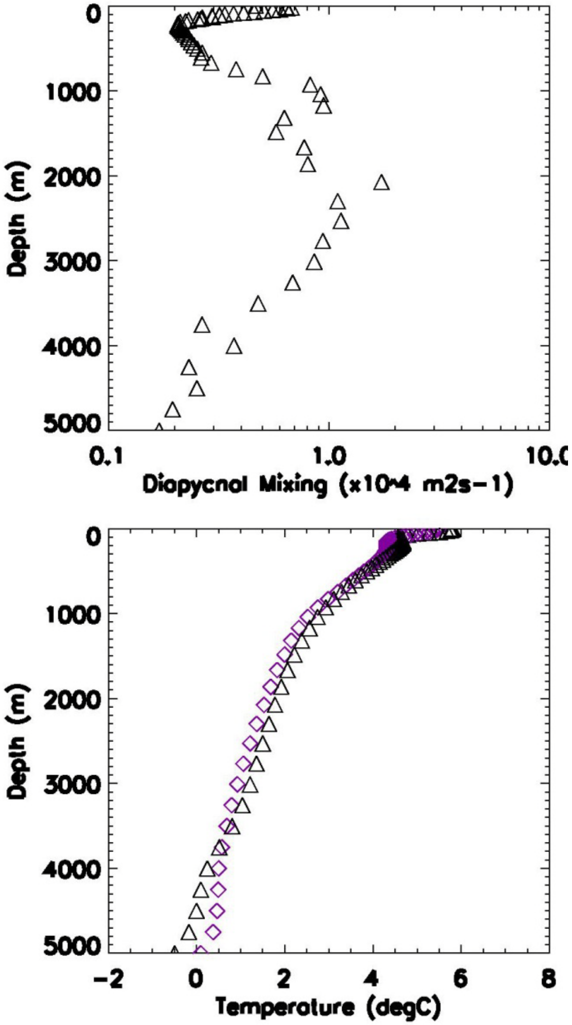
In the X3 model, active ocean-ice simulations too much AABW forms, leading to cold temperature, high-nutrient biases in the deep ocean (not seen in X1).

Seems to be due to ocean-ice interactions and low % sea ice cover in the Southern Ocean (problem largely disappears with prescribed sea ice cover). Tidal mixing in Ross and Weddell Seas also likely plays a role.

Mean Southern Ocean (45-60S) Vertical Profiles Kv and T



GIAF salinity restoring



CIAF prescribed sea ice

Deep ocean nutrients are biased by high AABW formation.

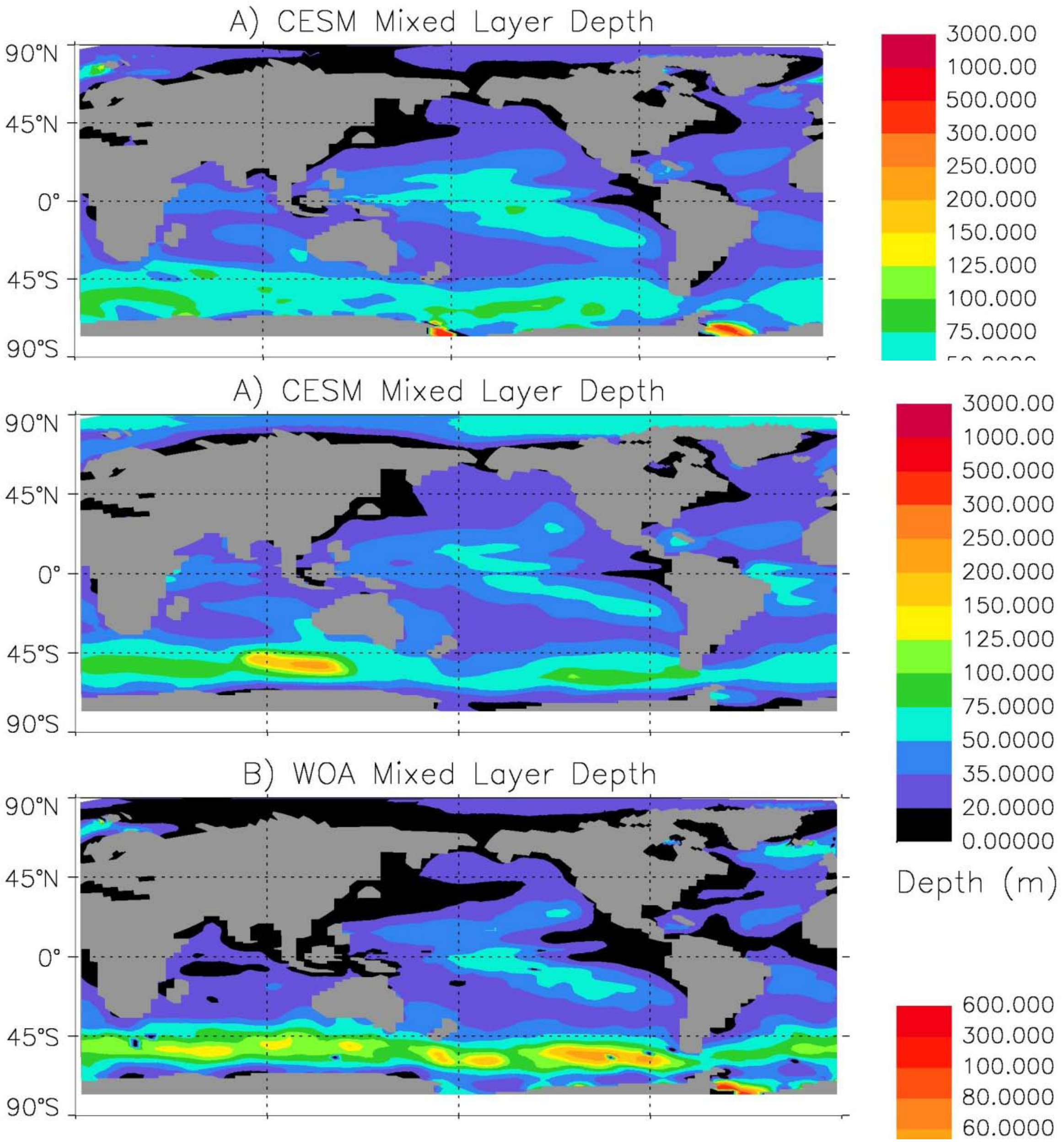
Annual Mean Mixed Layer Depths

GIAF

salinity restoring

CIAF

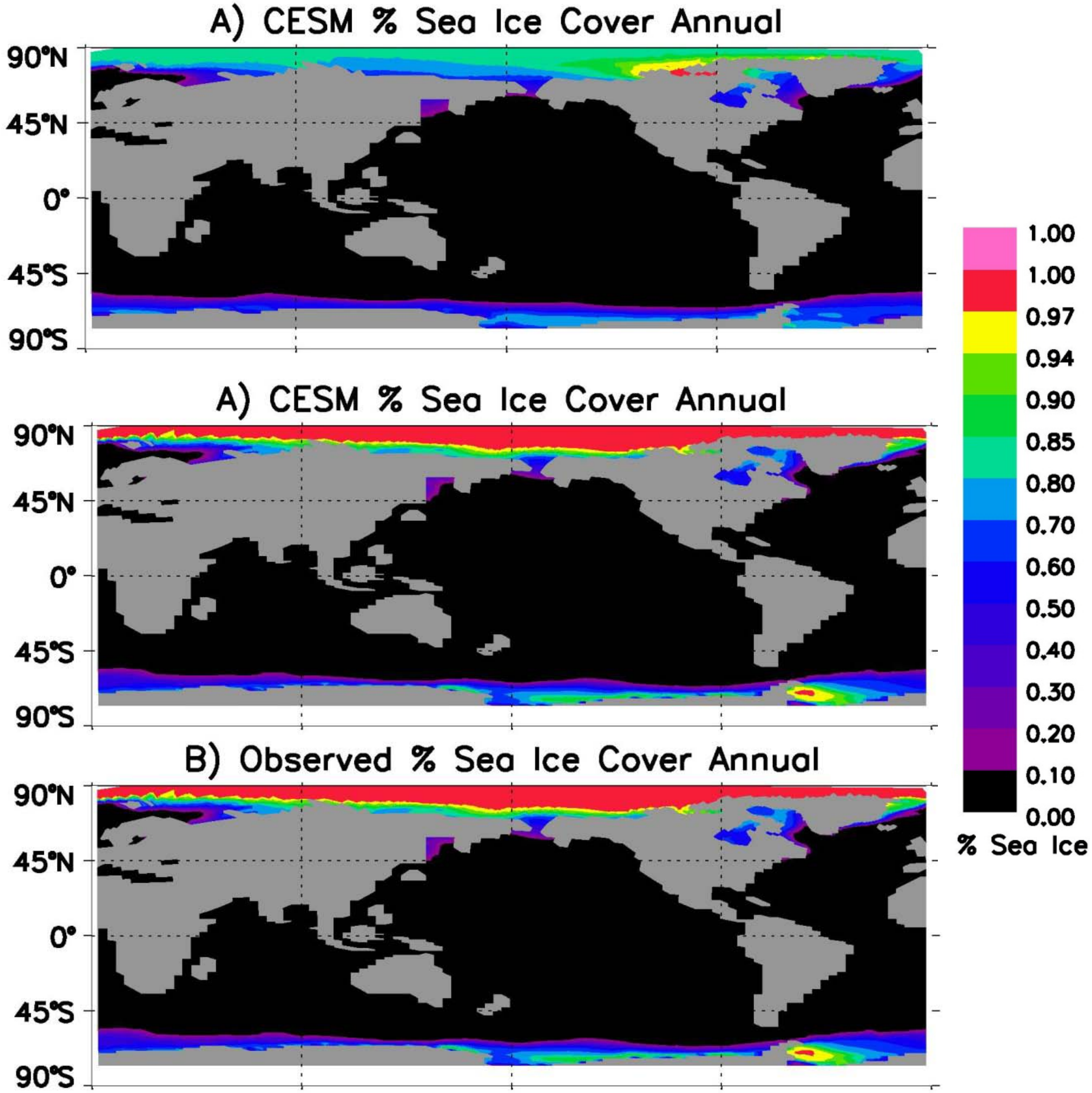
prescribed sea ice



Annual Mean Percent Sea Ice Cover

GIAF salinity restoring

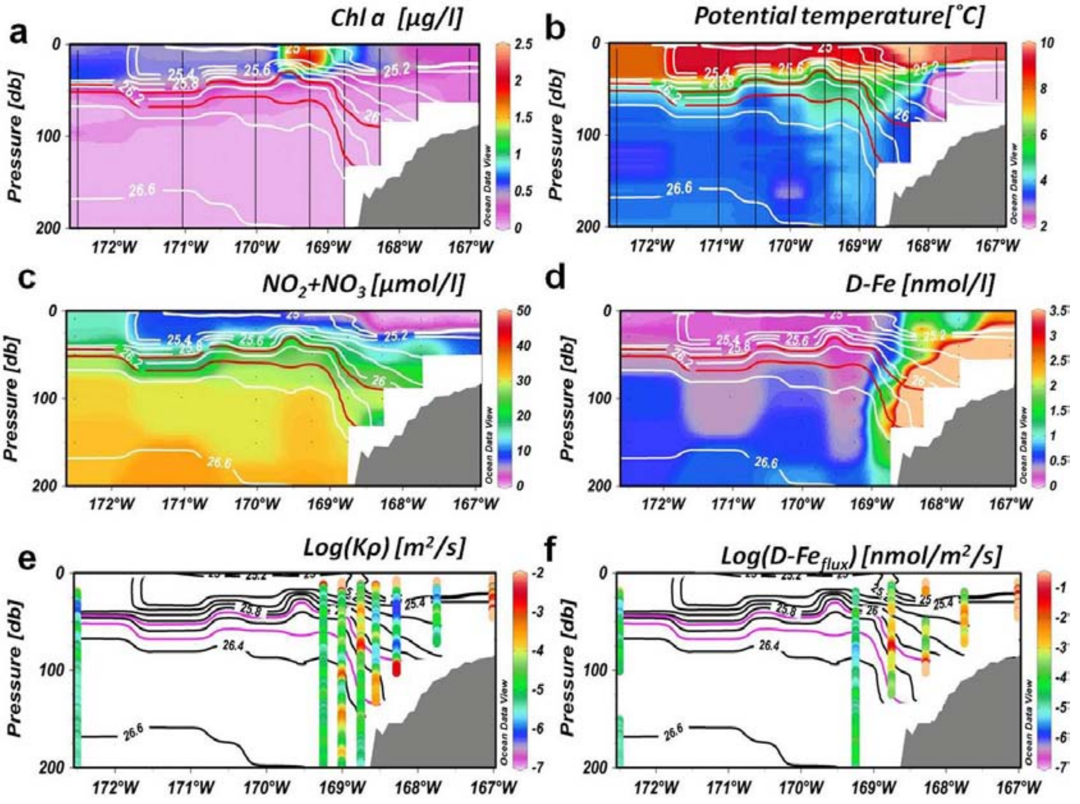
CIAF prescribed sea ice



CESM >80N = 0.9705, Obs >80N = 0.9705

There is field evidence supported by modeling studies for strong diapycnal mixing in the subarctic N. Pacific in the vicinity of the Kuril Islands (impacts NPIW formation) and the Bering Sea shelf break (i.e., Watanabe et al., 1994; Kawasaki and Hasumi, 2010; Itoh et al., 2011; Tanaka et al., 2012).

These mixing hot spots in the upper ocean are missing in CESM (X1 and X3).



Tanaka et al., 2010

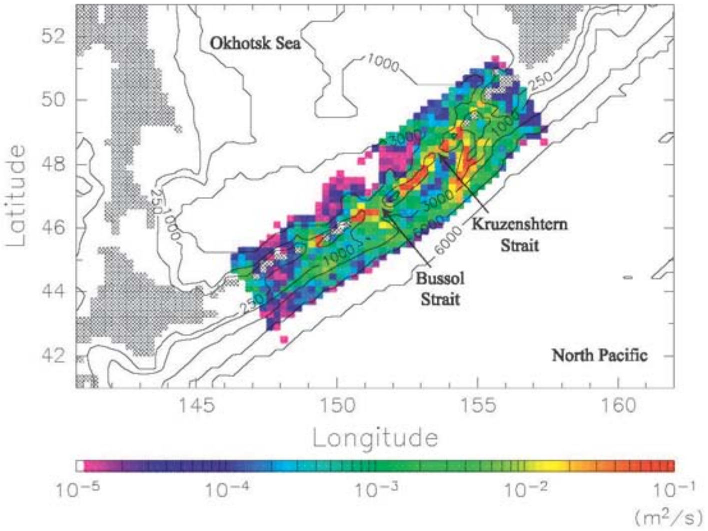
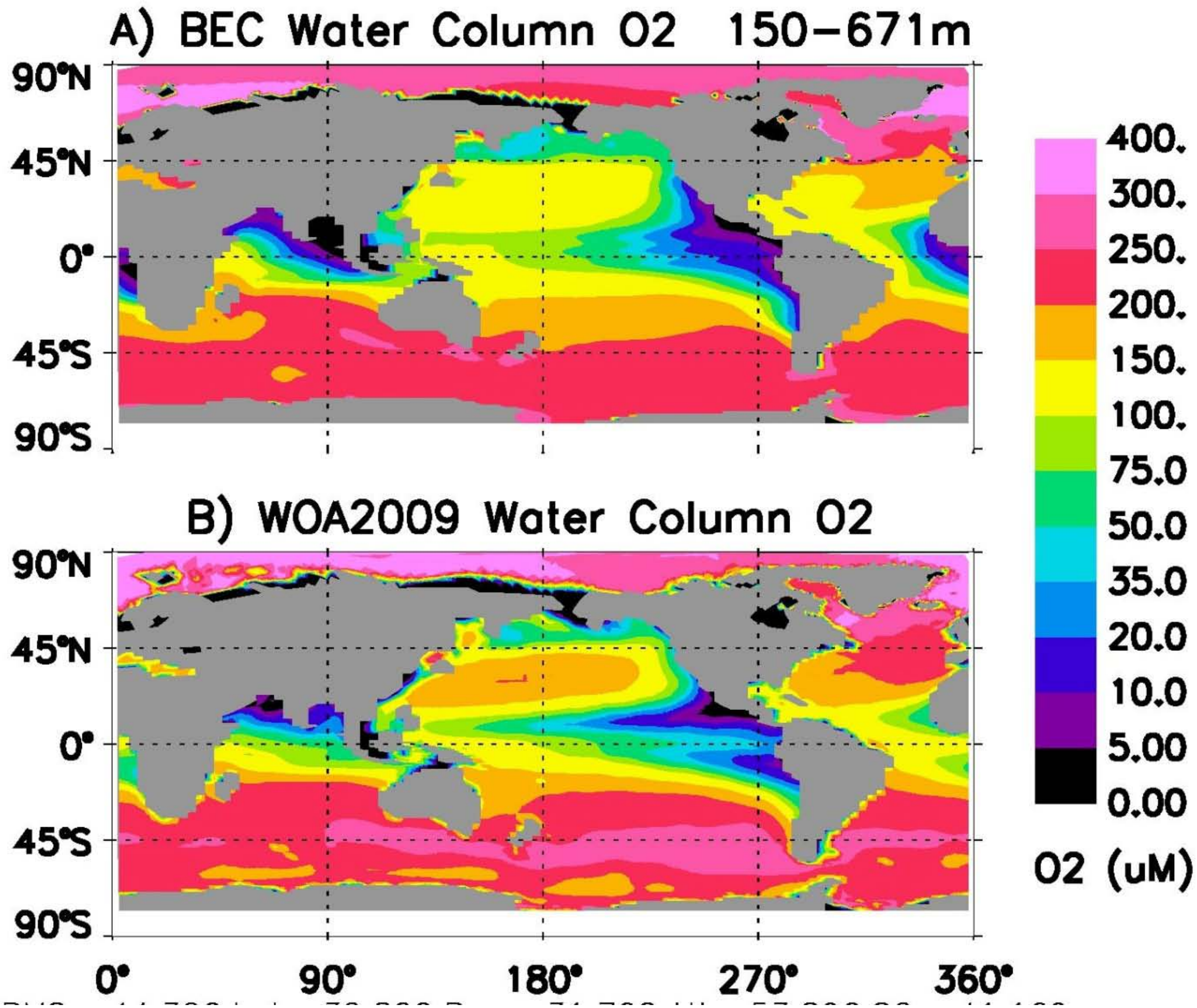
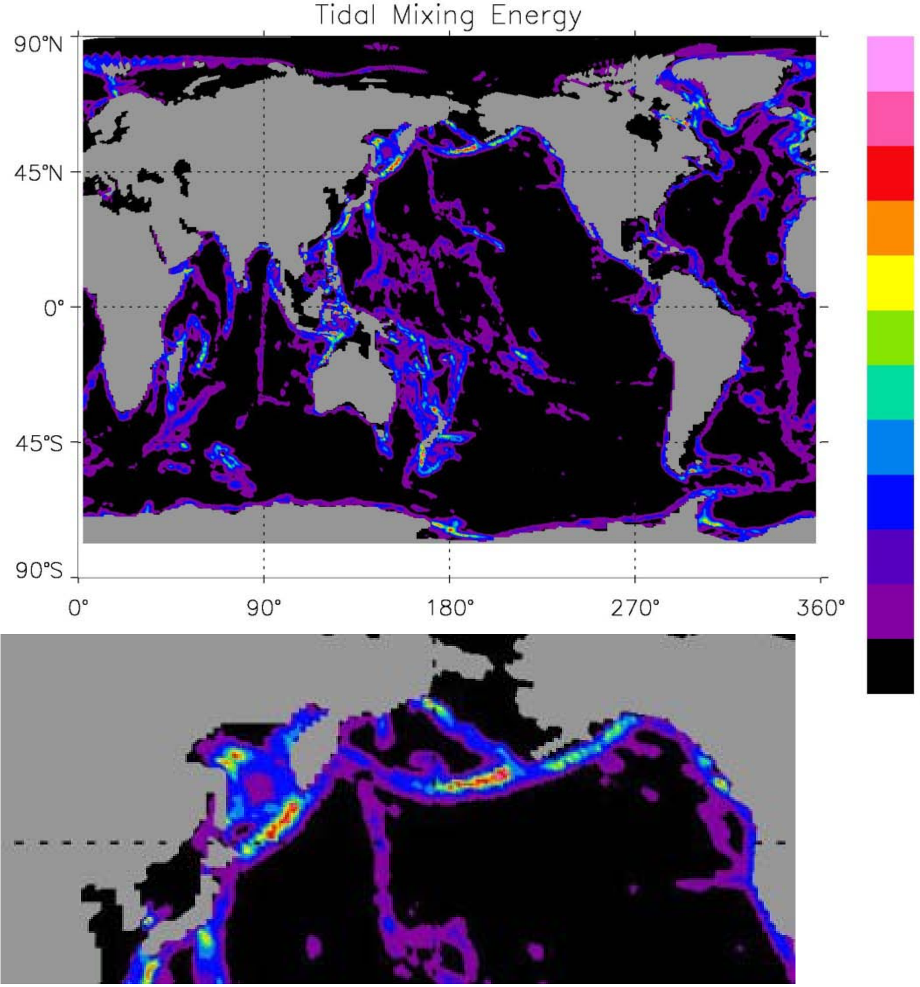


FIG. 1. Map view of the depth-averaged diapycnal diffusivity obtained by Tanaka et al. (2007, 2010). Superimposed are contours of bottom topography.

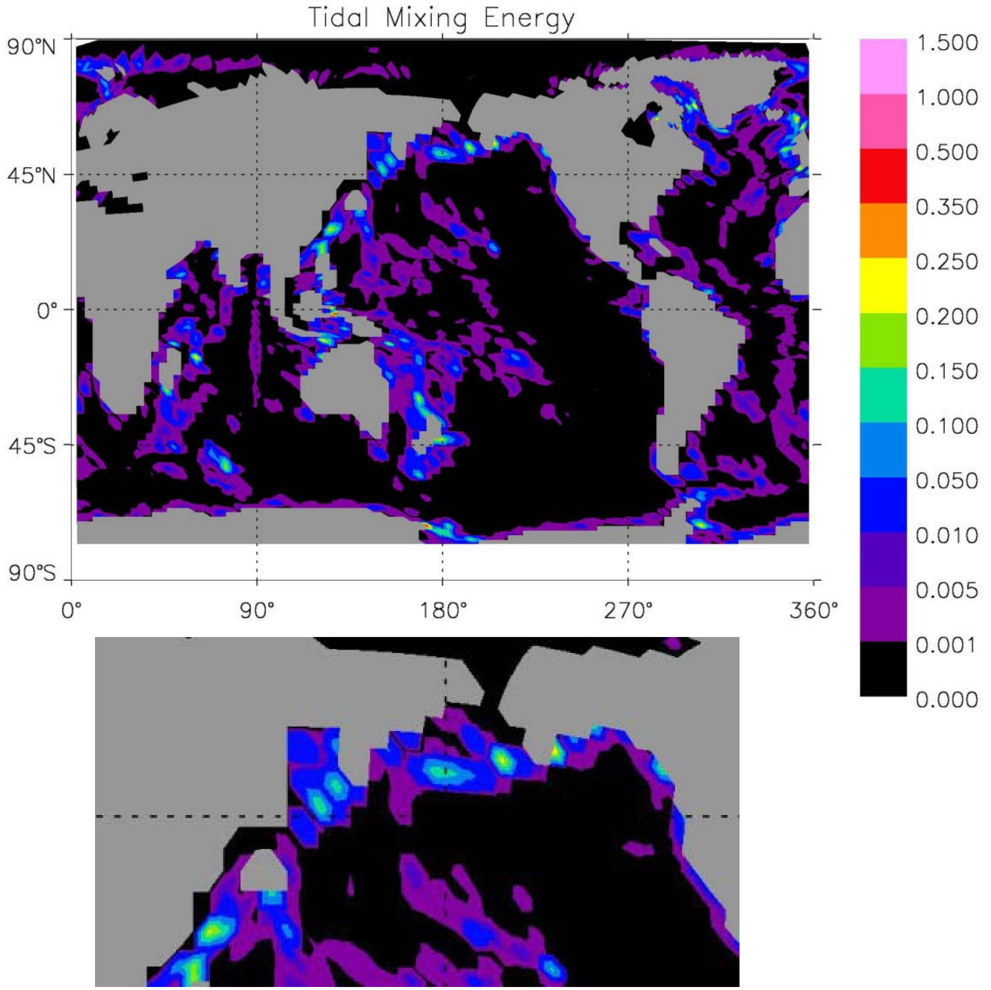
Tanaka et al., 2006



Note elevated O_2 at depth in the observed oxygen (lower panel) at these mixing hot spots, missing in CESM.



Tidal mixing energy gx1v6

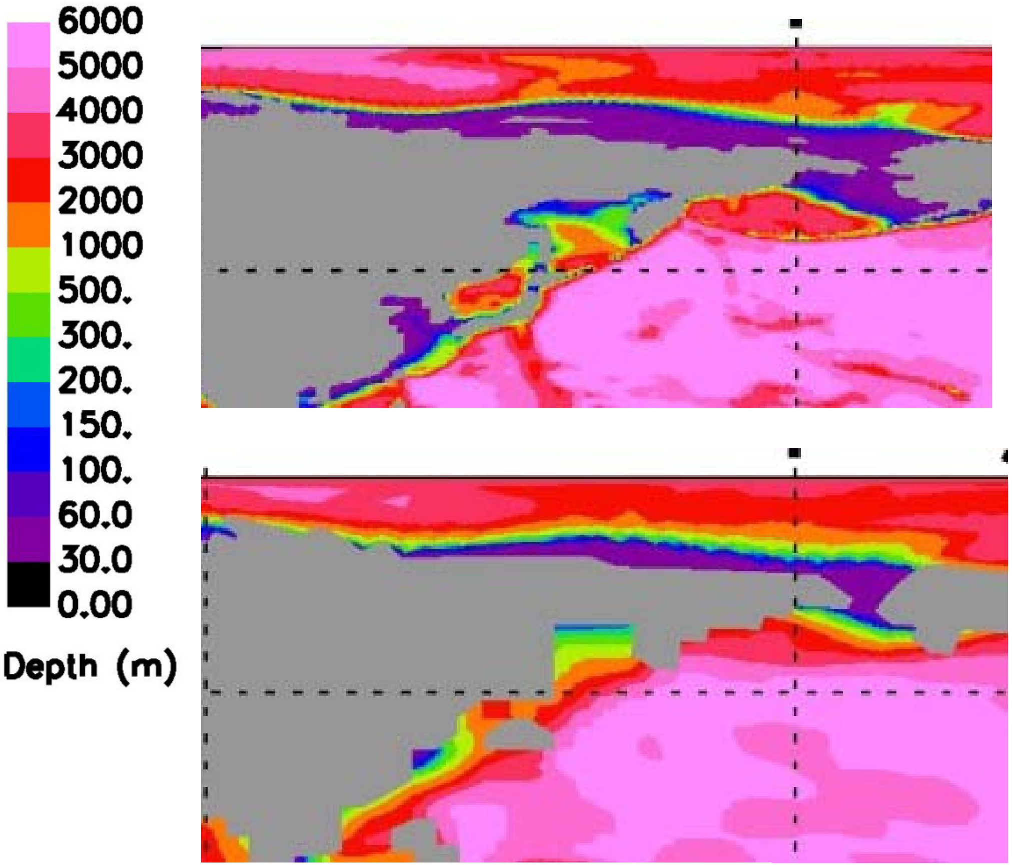


Tidal mixing energy gx3v7

Two Problems in due to grid resolution:

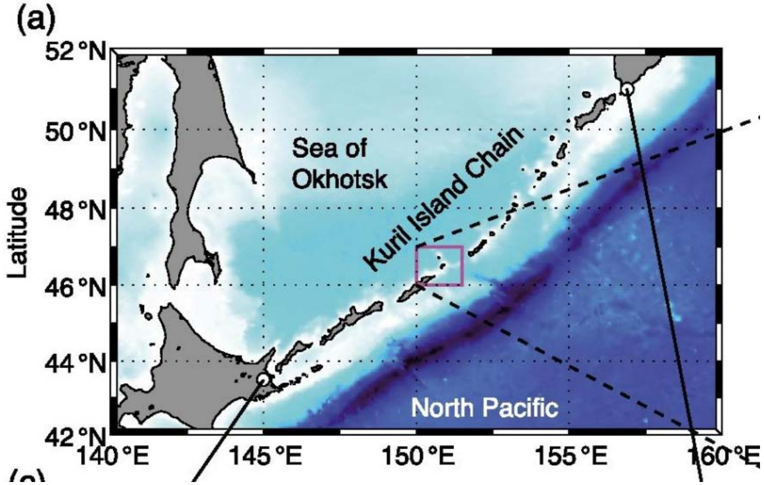
1) Smoothing has nearly erased the mixing hot spots (gx3).

2) Energy present is too deep in the water column (both).



Depth gx1v6

Depth gx3v7



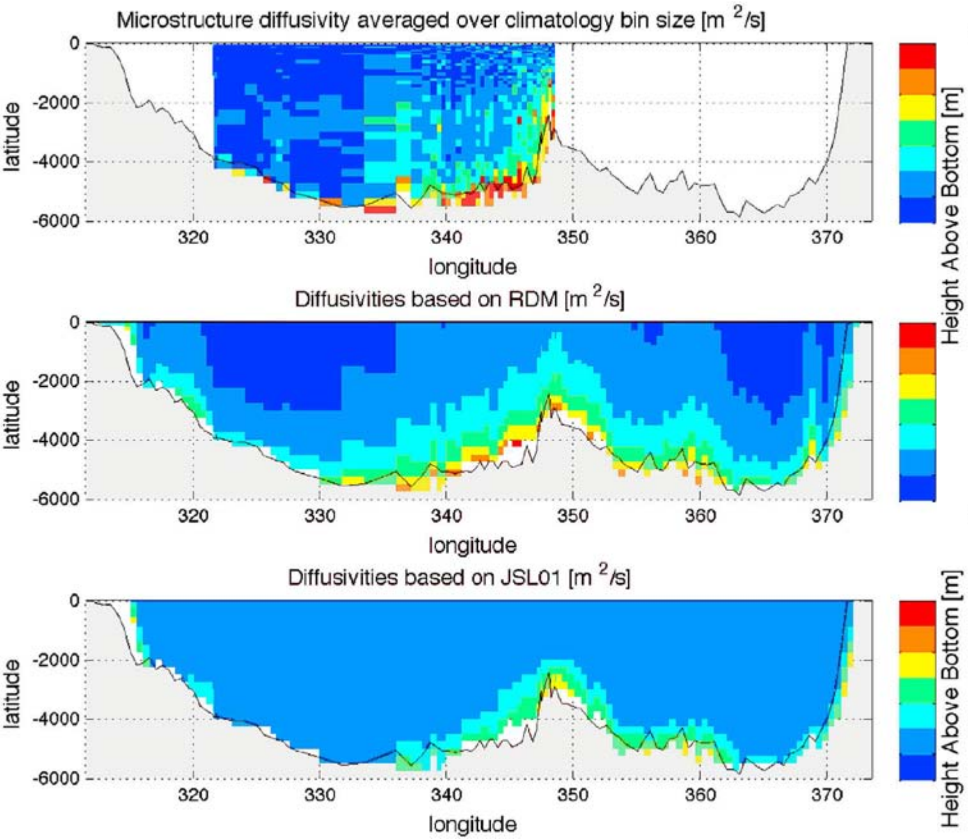
Actual bathymetry has chain of islands that reach the surface.

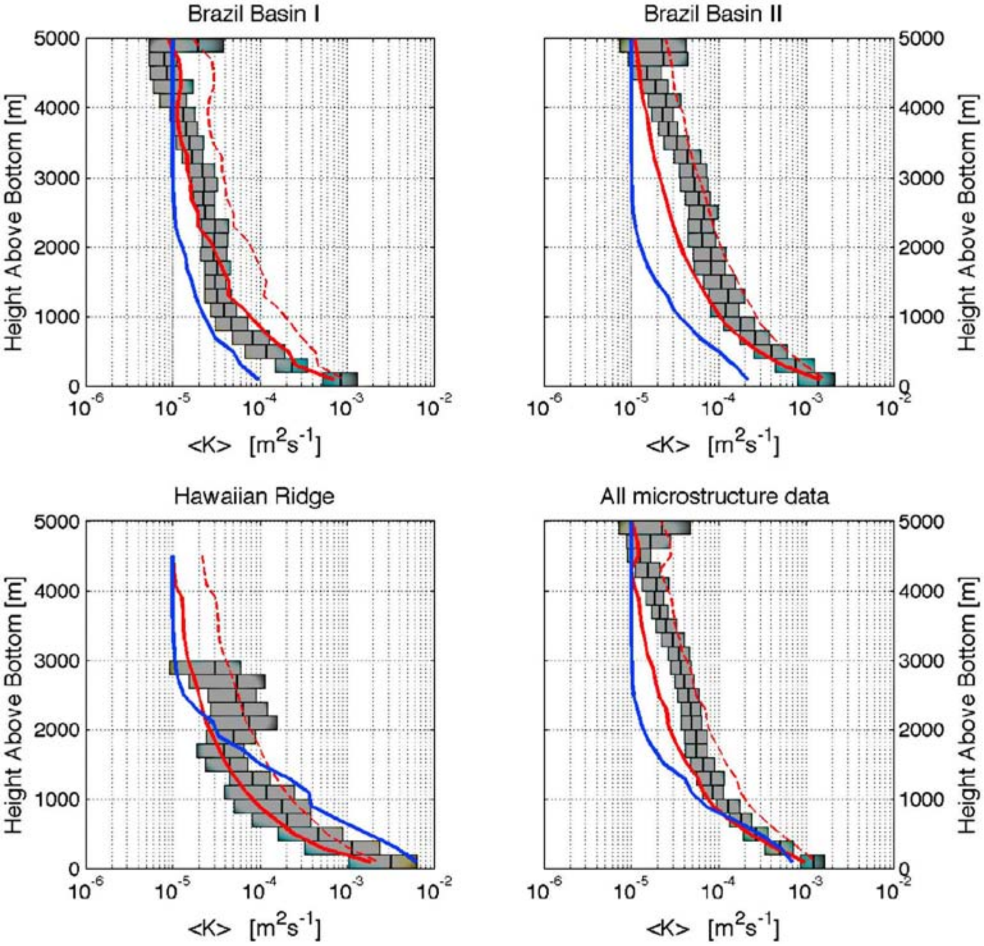
Vertical structure of mixing should reflect this somehow.

Tidal mixing in the CESM is a function of bottom roughness and the breaking of tide-generated barotropic waves, the vertical extent of the mixing is based on an exponential curve with fixed 500m length-scale.

Recent work by Decloedt and Luther (2010; 2012) suggests that this length scale should vary spatially as a function of the strength of the rough-bottom generated mixing (with height above bottom inversely related to mixing energy).

The alternative empirical mixing scheme proposed by Decloedt and Luther is only a function of bottom bathymetry. The RDM also varies the length scale of mixing up the water column spatially as a function of the strength of bottom mixing.





Fixed 500m length scale leads CESM bottom mixing to decrease more quickly than observed with distance from the bottom (bottom panel in left figure, blue line in right panel) (from Decloedt and Luther, 2012). Inverse model estimates give much higher mean abyssal mixing rates than either the CESM or the RDM models. (?)

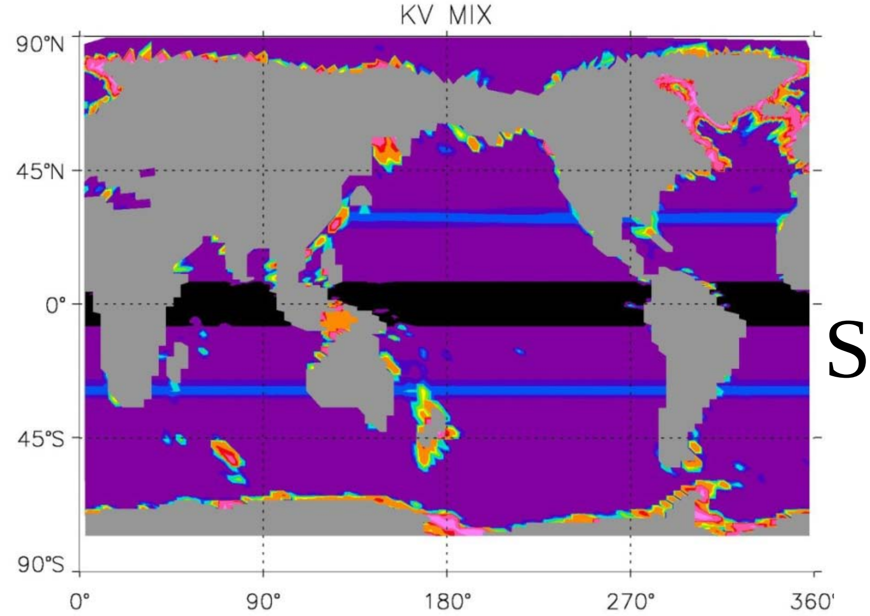
Next we compare 3 simulations with CESM 1.2 BEC:

1) STD - standard physics, but with fixed tidal mixing length scale
increased from 500m to 1000m.

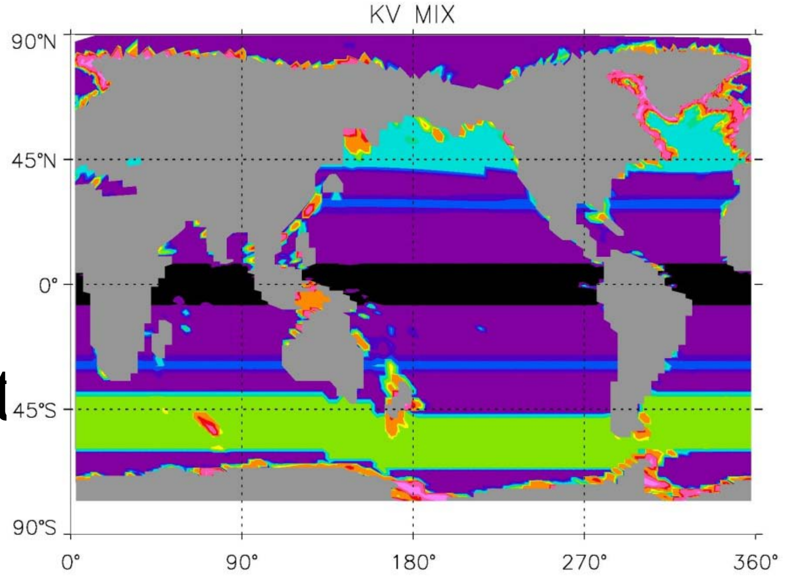
2) HiLat - tidal length increased 500m > 1000m, background diapycnal
mixing increased at high latitudes (40-65N/S),
by factor of 2 in N. Hemisphere (0.34 x 10^{-4} m^2/s),
by factor of 3 in S. Hemisphere (0.51 x 10^{-4} m^2/s).

3) SOBot - increased tidal mixing in Southern Ocean,
tidal mixing length 500m > 1000m,
mininum tidal energy of 0.05 W/m2 at depths < 3500m,
minimum tidal energy of 0.005 W/m2 at greater depths,
maximum tidal energy of 0.005 W/m2 > 65S.

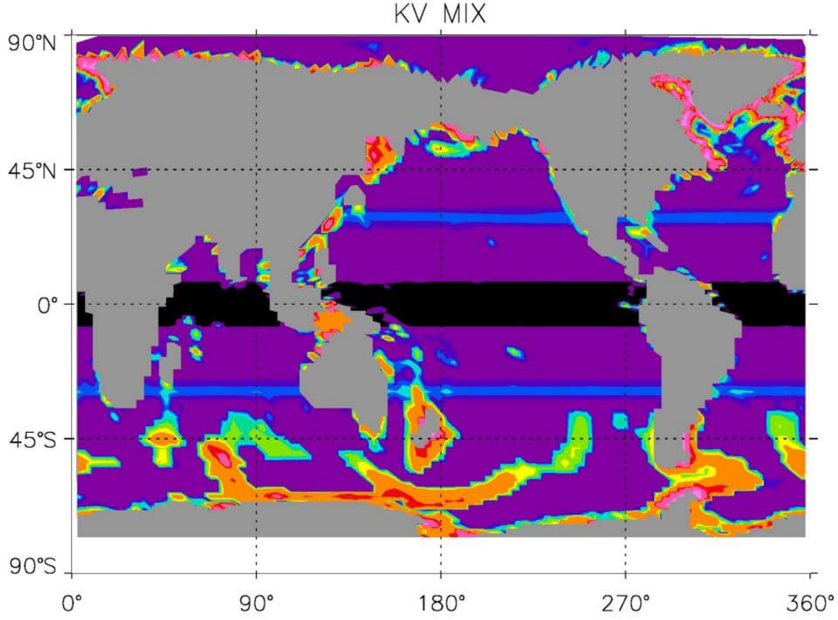
Mean Diapycnal Mixing (295-830m depth range)



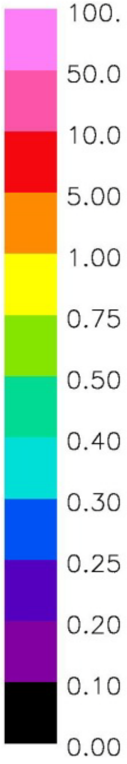
STD



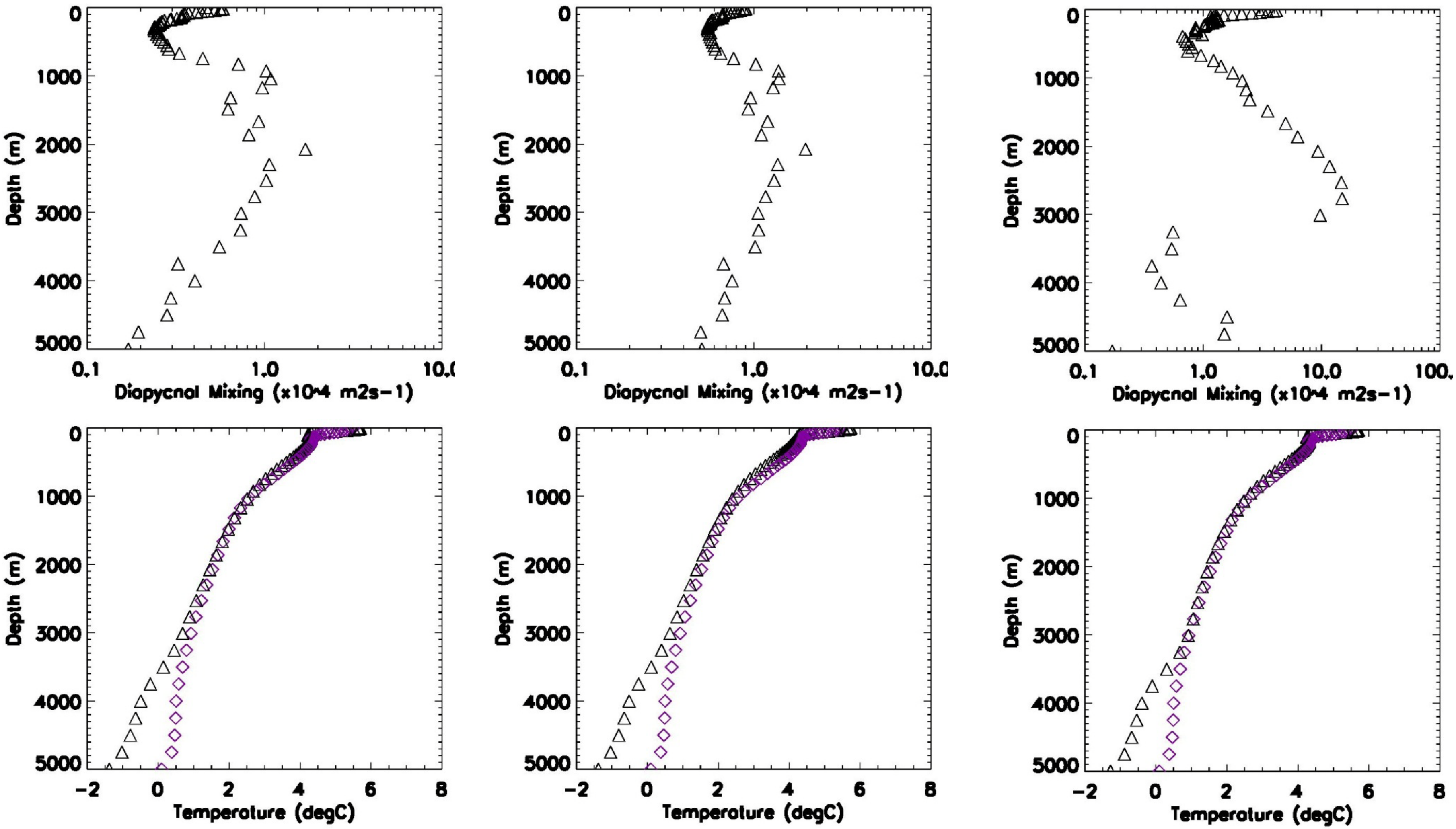
HiLat



SOBot

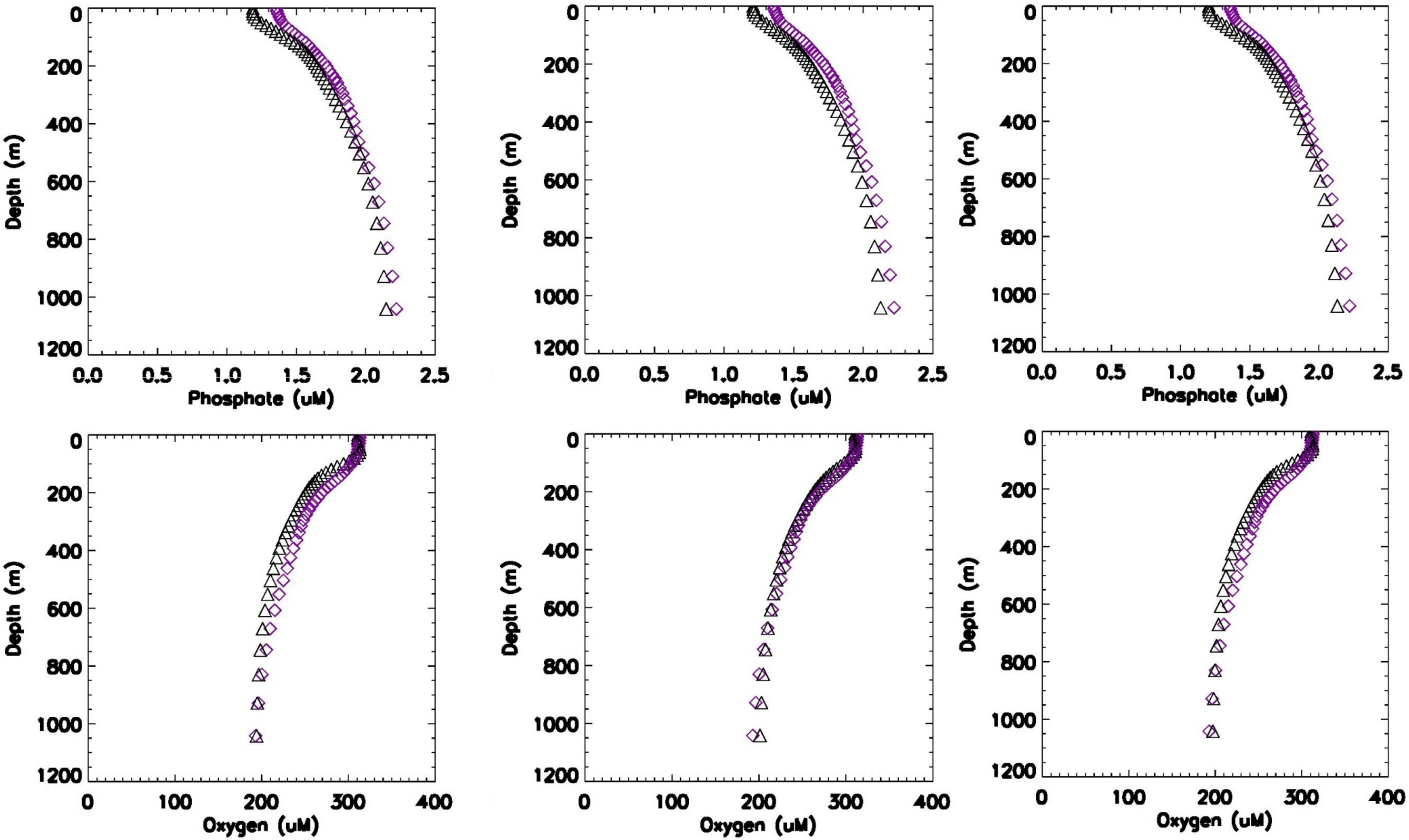


Mean Southern Ocean (40-65S) Kv and Temperature



STD HiLat SOBot

Mean Southern Ocean (40-65S) Phosphate and O_2

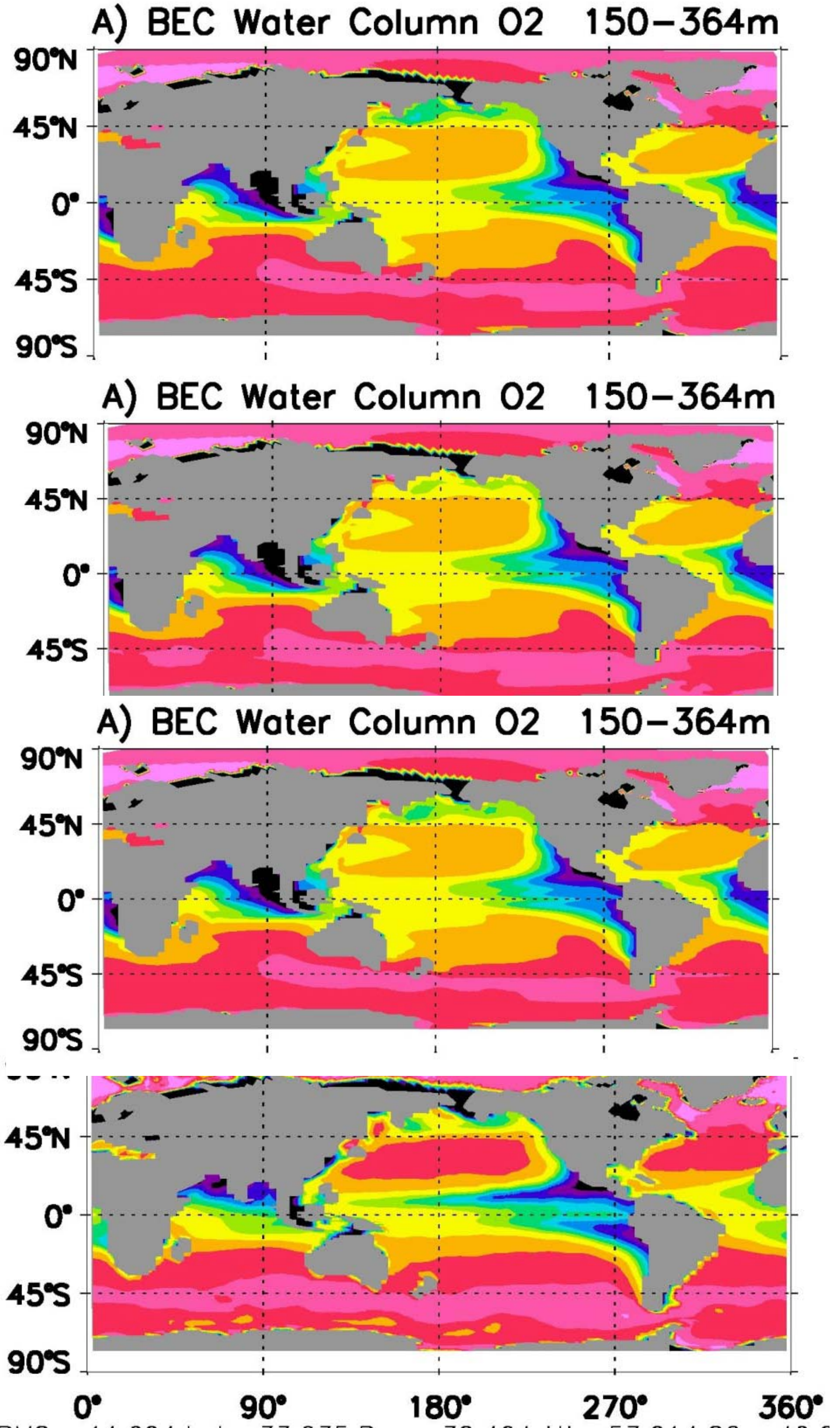


STD

HiLat

SOBot

Oxygen (150-364m)



STD

HiLat

SOBot

OBS

Conclusions

1) Excessive AABW formation in X3 model. Increasing tidal length scale to 1000m made this worse. Shorter length scale for strong mixing areas might help (haven't tried this yet).

   How to get more sea ice cover (X3 North and South)?

2) Include spatially varying length scale for bottom mixing that accounts for actual bathymetry (i.e. Kuril islands/straits)?

3) Need to include include stronger bottom mixing (particularly above rough bathymetry) in the Southern Ocean (where eddies and ACC fronts interact with bathymetry).

4) Need stronger upper-ocean diapycnal mixing in the subarctic North Pacific and Southern Ocean. Perhaps partly through background Kv, with some combination of bottom mixing, inertial mixing, Langmuir mixing, deeper winter mixed layers, etc.. SO mixed layers get much deeper with surface restoring of temperature..

5) Anisotropic GM might help reduce remaining low-latitude O_2 biases, that still cause problems for biogeochemistry. We need a version of this working in the CESM (please!).