Southern Ocean biases

Matthew C. Long
Gokhan Danabasoglu, Peter Gent, and William Large

Climate and Global Dynamics Division
National Center for Atmospheric Research

CESM Ocean Model Working Group meeting

16 Jan 2014

Outline

Southern Ocean biases

Weak tracer uptake
(CFCs,C_{ant})

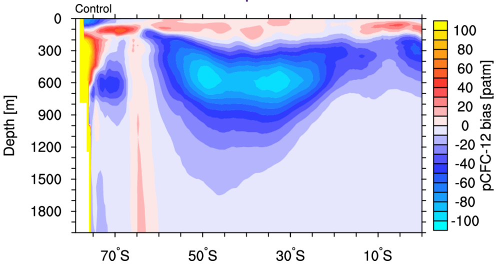
Shallow mixed layer depths

Hypotheses:

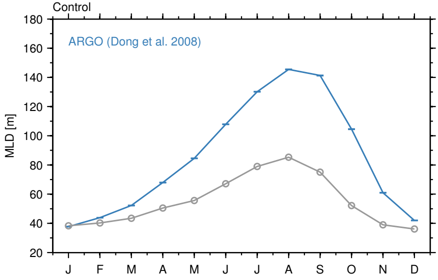
Problems with:

1. missing forcing;
2. vertical physics;
3. mesoscale mixing.

Zonal-mean pCFC-11 bias



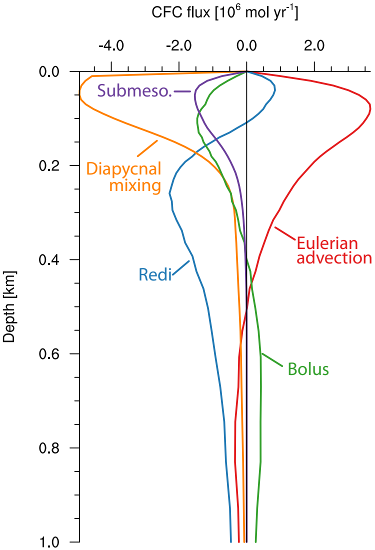
Regional-mean mixed layer depths



Mechanisms controlling uptake in the Southern Ocean

Vertical CFC11 transport

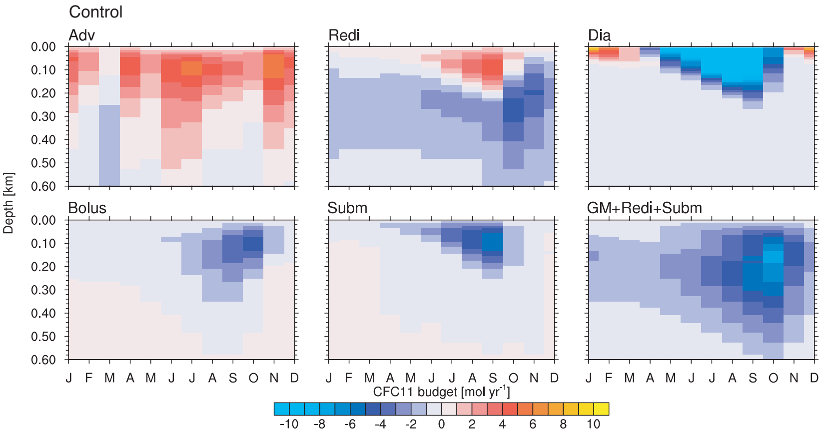
within Antarctic Circumpolar Current



- GM-bolus term opposes Eulerian-mean advection;
- Diapycnal mixing and isopycnal diffusion (Redi) dominate transport into the interior.

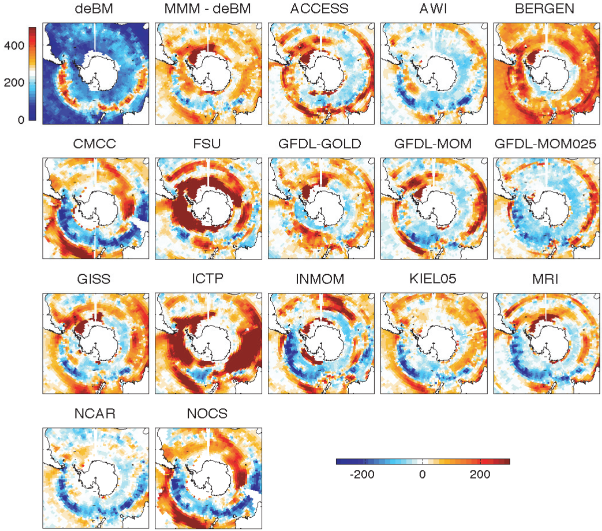
Seasonal handoff: boundary layer to isopycnal mixing

Vertical fluxes in ACC



Missing physics?

September mixed layer depth: Obs and biases in CORE-forced runs

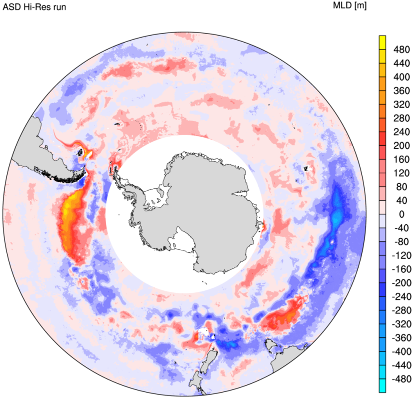


Downes et al. in prep

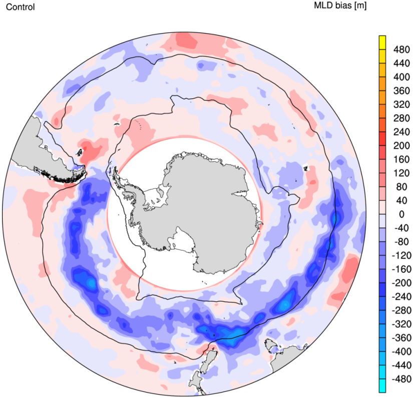
Hi-res ML biases

August-October MLD biases

CESM Hi-res (0.1°)



CESM standard (1°)



0.25° Community Atmosphere Model (CAM5, spectral element)

0.1° Parallel Ocean Program (POP2, 62 levels)

Vertical physics: K profile parameterization

Monin-Obukhov similarity theory

The vertical variation of turbulence characteristics in the **'surface layer'** depends only on the surface momentum flux (u^*), buoyancy flux (B_f), and distance from the boundary (d).

Key parameters

$$u^* = (|\tau_0|/\rho_0)^{1/2}$$
friction velocity

$$S^* = -\overline{ws_0}/u^*$$
scalar fluctuation scale

$$L = {u^*}^3/(\kappa B_f)$$
Monin-Obukhov length

Stability functions

$$\phi_m(\zeta) = \frac{\kappa d}{u^*}\frac{\partial U}{\partial z} \text{ (momentum)}$$

$$\phi_s(\zeta) = \frac{\kappa d}{S^*}\frac{\partial S}{\partial z} \text{ (scalar)}$$

are nondimensional and relate momentum and scalar fluxes to mean gradients, expressed as a function of the stability parameter: $\zeta = d/L$.

Vertical physics: K profile parameterization

Turbulent fluxes

$$\overline{wx}(d) = -K_x\left(\frac{\partial X}{\partial z} - \gamma_x\right)$$

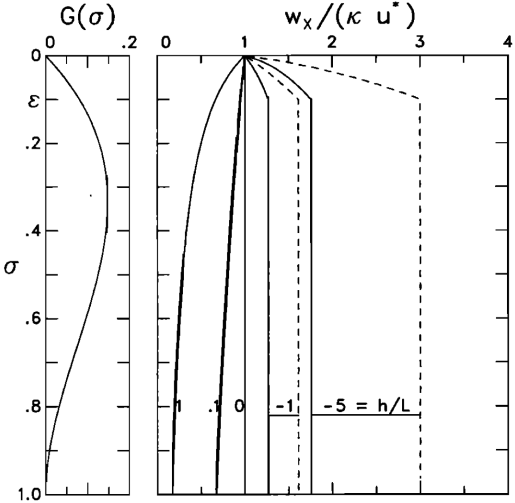
Diffusivity ($K \sim U \cdot L$)

$$K_x(\sigma) = w_x(\sigma)\, h\, G(\sigma)$$
$$(\sigma = d/h)$$

Velocity scale

$$w_x(\sigma) = \frac{\kappa u^*}{\phi_x(\sigma h/L)}$$

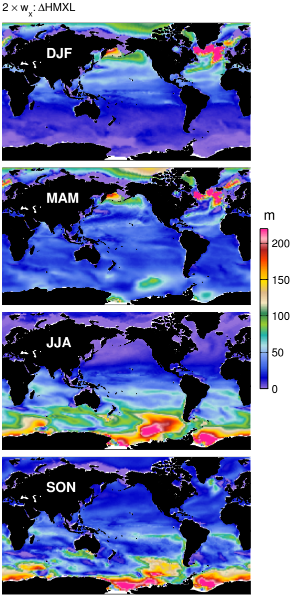
$$(\zeta = d/L = \sigma h/L)$$

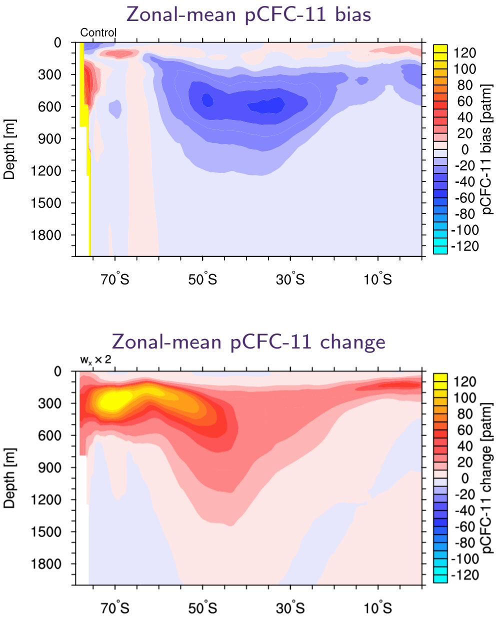


"In unstable conditions the turbulent velocity scales beyond the surface layer are assumed to remain constant at their $\sigma = \epsilon$ values. Without this constraint, unstable w_x values would become very large..."

Large et al. 1994

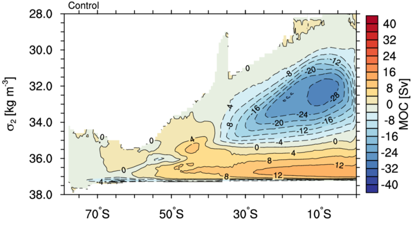
Sensitivity to doubling w_x



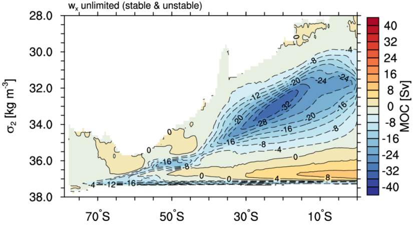


Sensitivity to $\epsilon = 1$ (removing limits)

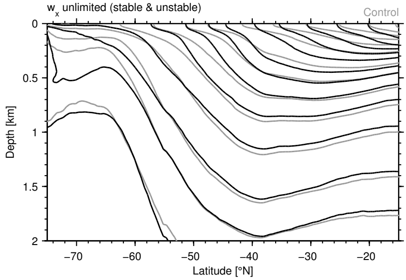
Control



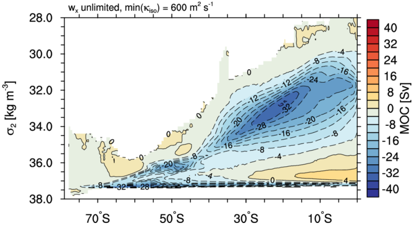
Unlimited



Zonal-mean σ_0



Unlimited with GM-Redi change



Representing w_x: Nondimensional flux profiles

"[A]cceptable fits to available data..."[1]

Stable

$\phi_m = \phi_s = 1 + 5\zeta$ $\quad 0 \leq \zeta$

Unstable (momentum)

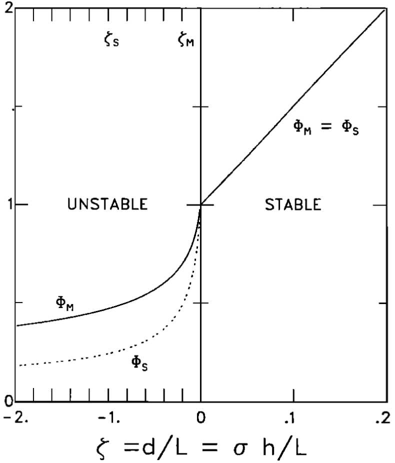
$\phi_m = (1 - 16\zeta)^{-1/4}$ $\quad \zeta_m \leq \zeta \leq 0$

$\phi_m = (1.26 - 8.38\zeta)^{-1/3}$ $\quad \zeta < \zeta_m$

Unstable (scalar)

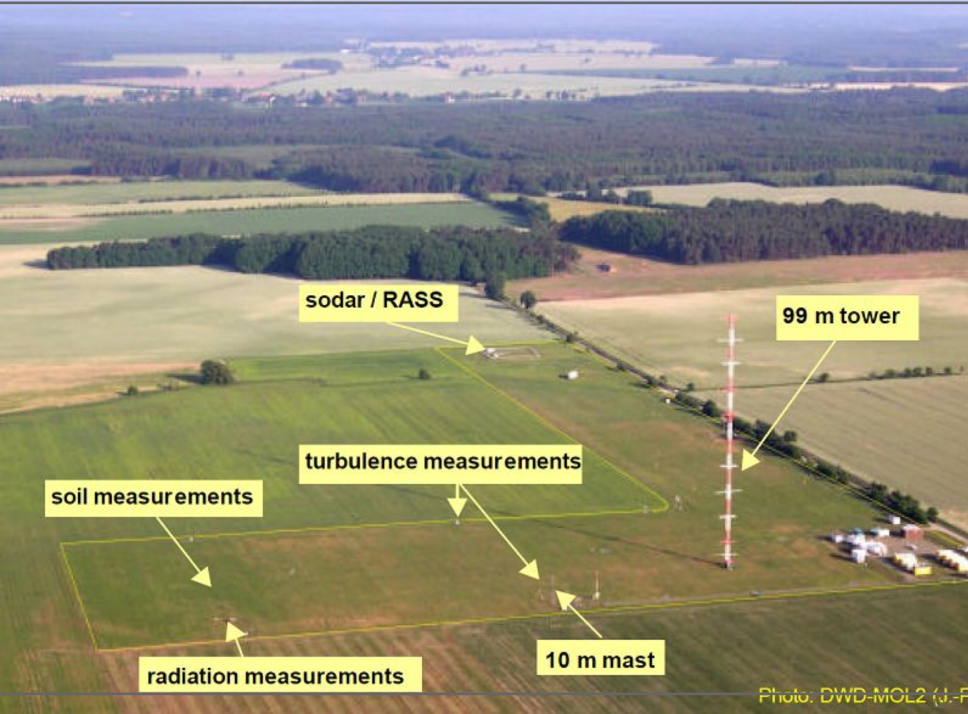
$\phi_s = (1 - 16\zeta)^{-1/2}$ $\quad \zeta_s \leq \zeta \leq 0$

$\phi_s = (-28.86 - 98.96\zeta)^{-1/3}$ $\quad \zeta < \zeta_s$

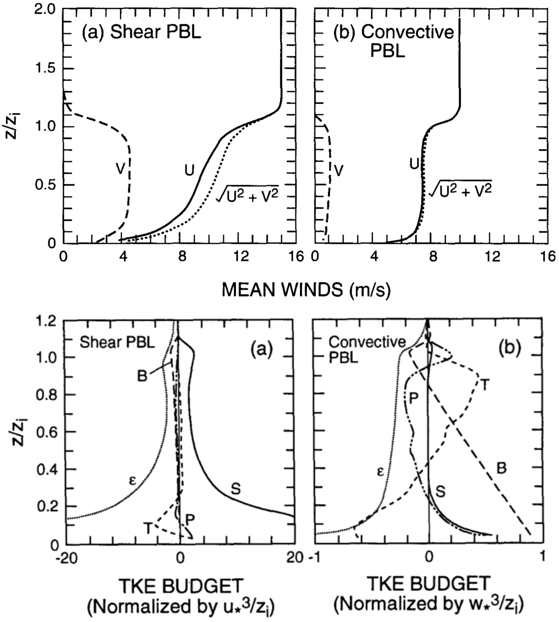


Large et al. 1994

[1] *Large et al. 1994*


sodar / RASS
99 m tower
turbulence measurements
soil measurements
10 m mast
radiation measurements
Photo: DWD-MOL2

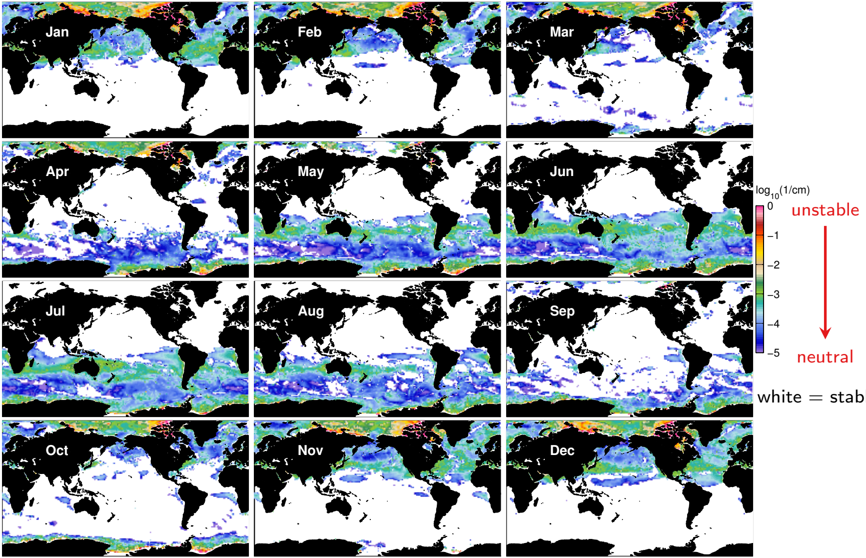
Hypothesis: surface layer depth is a function of stability regime



Moeng & Sullivan 1994

Unstable to near neutral regions

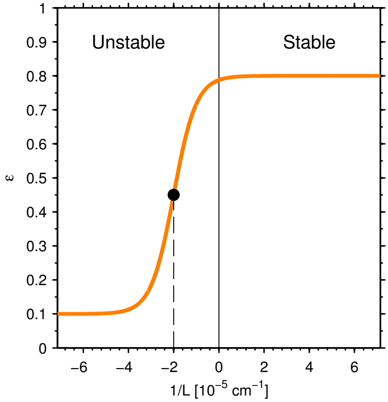
Stability parameter ($1/L < 0$)



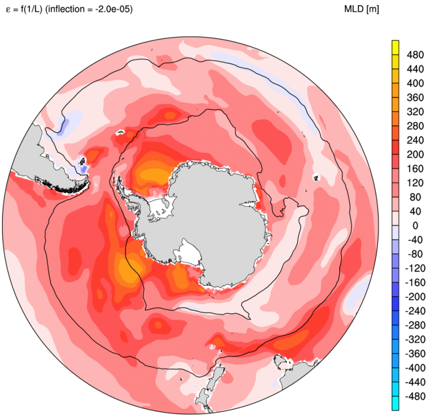
white = stable

Proposal: surface layer depth as a function of stability

Surface layer depth parameterization

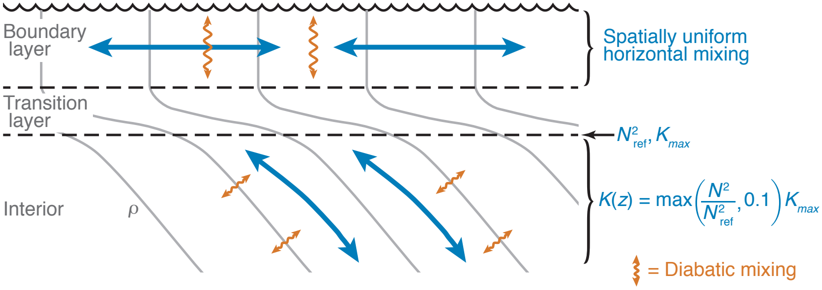


MLD change

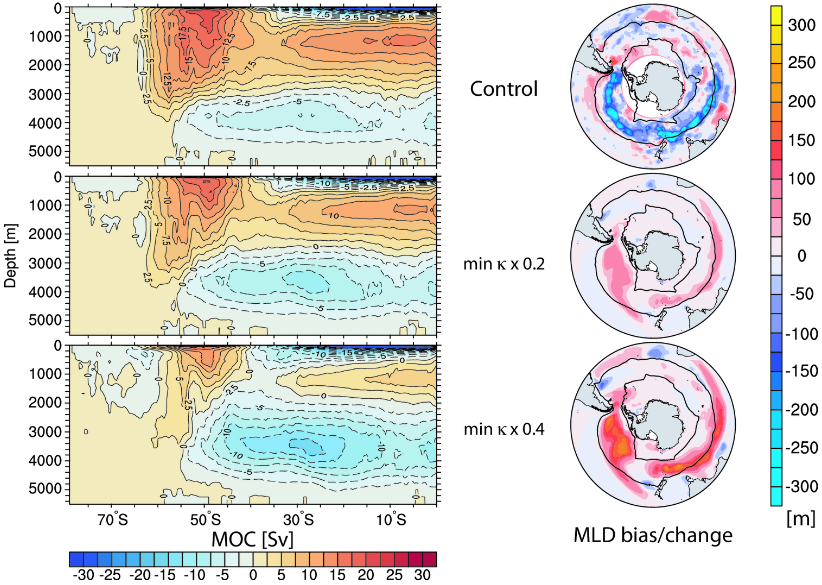


Prognostic thickness and isopycnal mixing coefficient

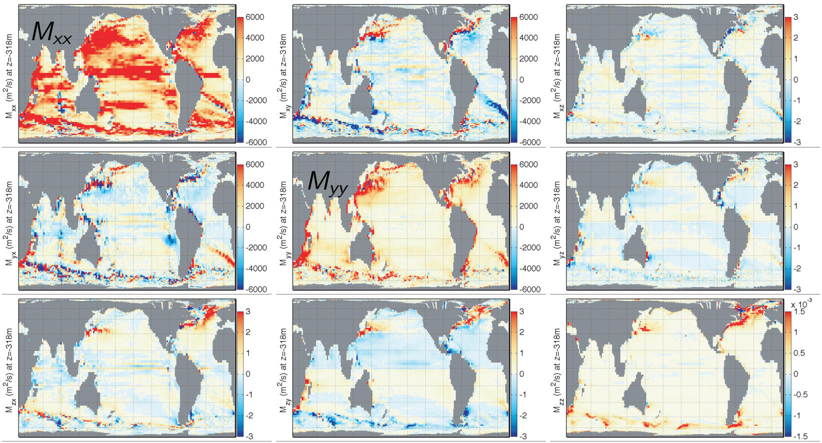
Horizontal uniformity in surface layer, attenuation with depth



Large-scale dynamics control mixed layer biases

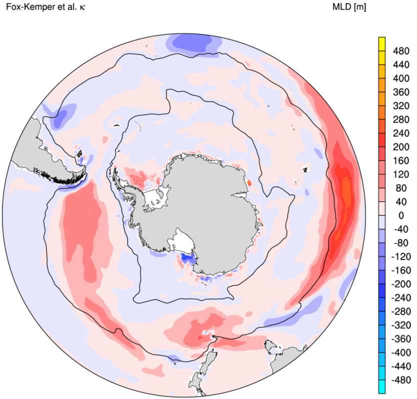


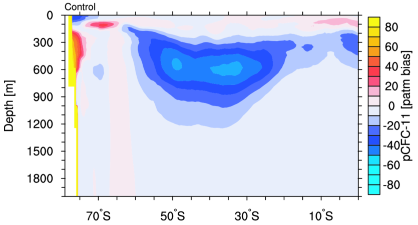
Mixing tensor diagnosed in hi-res POP

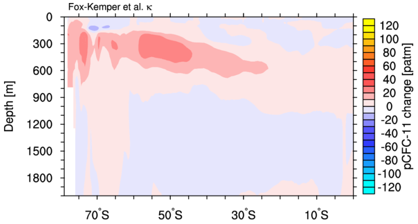


Fox-Kemper et al. 2013

Prescribed diffusivity results







Summary

- Model solutions are sensitive to turbulent velocity scale in KPP, which has weak observational constraints;
- Surface layer thickness is likely a function of the stability regime;
- Southern Ocean mixed layers are sensitive to deep isopycnal and thickness mixing; need improved scheme governing horizontal and vertical variation;
- Waves may be an important missing forcing.