The Role of Eddy Mixing Suppression for the Ventilation in the Southern Ocean

Asher Riaz[1], Maxim Nikurashin[1], Andreas Klocker[1], Simon Wotherspoon[1], Nathan Bindoff[1], and Peter Strutton[1]

[1]IMAS

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Abstract

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Asher Riaz[1,2], Andreas Klocker[1,3], Maxim Nikurashin[1,3], Nathaniel L. Bindoff[1,2,3]
Peter G. Strutton[1,3], Simon Wotherspoon[1,2]
[1] Institute for Marine and Antarctic Studies, University of Tasmania, Hobart, Australia, [2] CSIRO Oceans and Atmosphere, Hobart, Australia
[3] ARC Centre of Excellence For Climate Extremes, Hobart, Australia

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Abstract : In climate-ocean models, eddy mixing coefficients are often constant in space and time. However, observations, advances in theory, and high-resolution-eddy-resolving ocean models have revealed significant variability in the strength of isopycnal mixing both spatially and temporally. A theory that includes the effect of mean flow suppression has been developed by [1] it has a strong impact on tracer uptake and ventilation. This theory is used in offline calculations by [1, 2, 4] but has not been implemented as a parameterization in an ocean model and in this study we implement it for the first time in an ocean model [3]. The parameterisation is tested in a non-eddy-resolving ocean model, demonstrating passive ventilation of a tracer as a function of depth and latitude. The first main result is this parameterization improves the mean state of the ocean. The other result is this parameterisation improves the sensitivity of tracer uptake to changing winds.

1. Model Description and Experiments

- We use pyOM – python ocean model [3]. The domain size is 1000km x 2000km x 2984m with 38 vertical layers. The meridional extent roughly equates to 42°S to 62°S in the Southern Ocean. The setup is identical to [2].
- Two different horizontal resolutions are used, for high-resolution (HR) 1/10° and for coarse-resolution (CR) 1°.

Experiment no.	Wind $[\mathrm{N\,m^{-2}}]$	KGM $[\mathrm{m^2s^{-1}}]$	KREDI $[\mathrm{m^2s^{-1}}]$
1	0.1	100	500
2	0.1	100	= Ko
3	0.1	100	= KFN
4	0.2	300	500
5	0.2	300	= Ko
6	0.2	300	= KFN
7	0.3	600	500
8	0.3	600	= Ko
9	0.3	600	= KFN
10	0.1	300	500
11	0.1	300	= Ko
12	0.1	300	= KFN
13	0.2	1000	500
14	0.2	1000	= Ko
15	0.2	1000	= KFN

Table 1. All the 15 CR experiments used in this study with different parameterizations for KGM (eddy advection) and KREDI (eddy diffusion) where KFN expression taken from [4]

2. Model Forcing

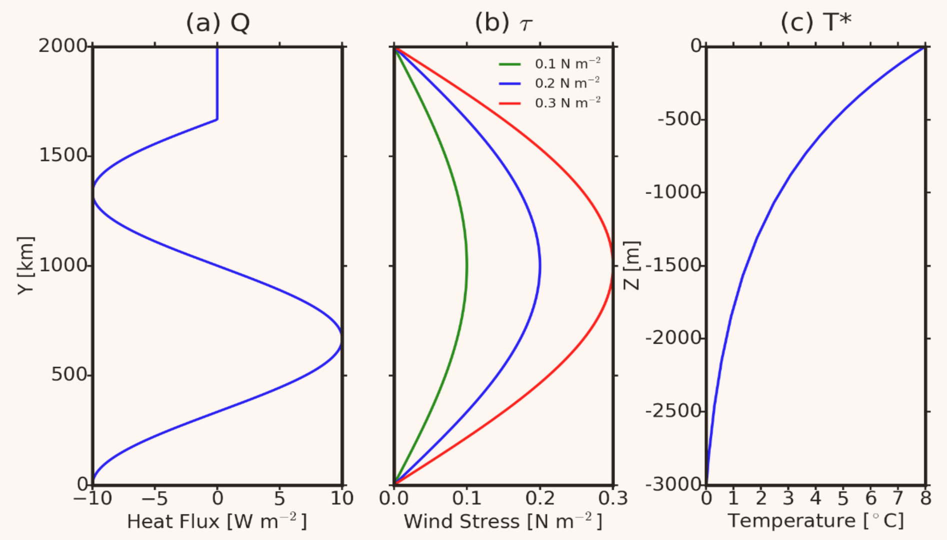

Fig. 1. Model forcing components. (a) Surface heat flux (positive into ocean), (b) wind stress and (c) northern boundary temperature restoring profile

- Tracer is forced at surface with 6h time restoring.
- Tracer is restored to zero in the sponge layer.
- No other mixing scheme e.g KPP applied to tracer.

3. Energetically Consistent Model

- Energetic consistency is an important feature of the pyOM model [3]. This implies that even for non-eddy-resolving experiments, this model can track and estimate the eddy energy budget.

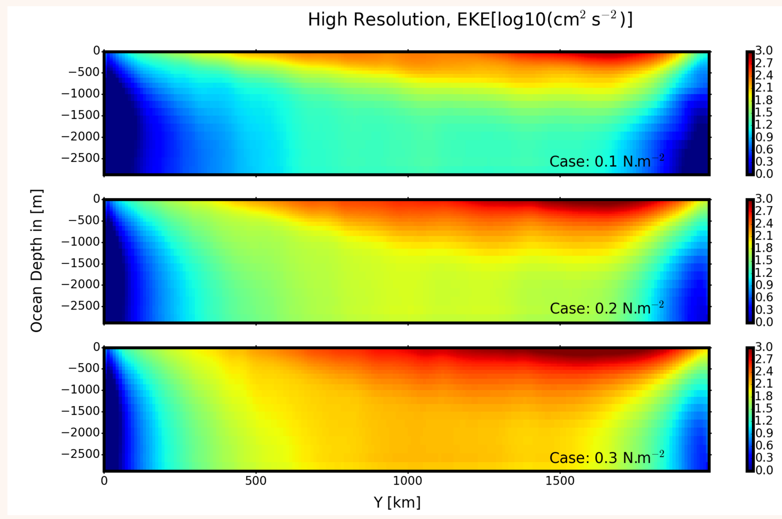

Fig 2. Log10 of the EKE from 1/10°

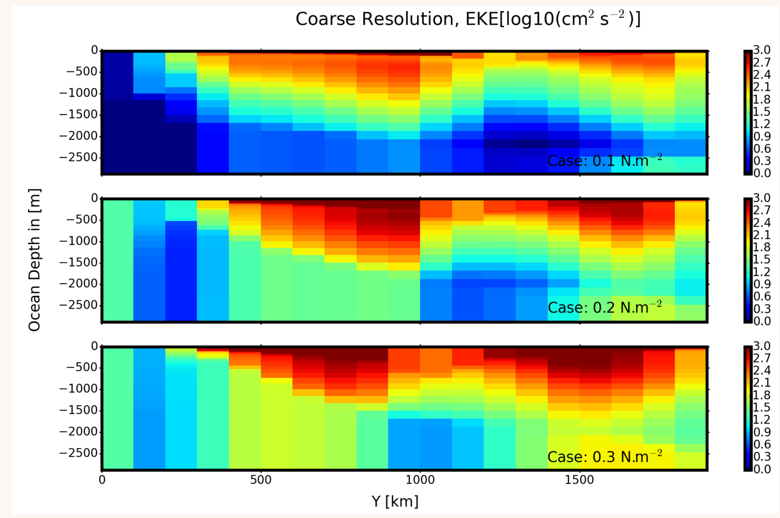

Fig 3. Log10 of the EKE from 1°CR model provides estimate of eke at coarse resolution of 1°

4. Eddy Mixing Suppression

Following [4] we take the expression of KFN:

$$\mathrm{KFN} = \frac{K_0}{1+\frac{k^2}{\gamma^2}(\bar{U}-c)^2}$$

$K_0 = \Gamma * \sqrt{2EKE} * L$, (unsuppressed diffusivity), L is eddy scale and Γ is the mixing efficiency constant = 0.35, we get :

$$\mathrm{KFN} = \frac{\Gamma*\sqrt{2EKE}*L}{1+\frac{k^2}{\gamma^2}(\bar{U}-c)^2}$$

Here, $k = \frac{2\pi}{L}$, (wave number), $\gamma = \frac{\sqrt{2EKE}}{2(\Gamma)L}$, (eddy decorrelation time scale), $\bar{U}$, (mean flow), $c = \beta * L_d^{\,2}$, (eddy phase speed), β is change of Coriolis with latitude and L_d is the Rossby radius of the deformation.

5. EKE and Equilibration

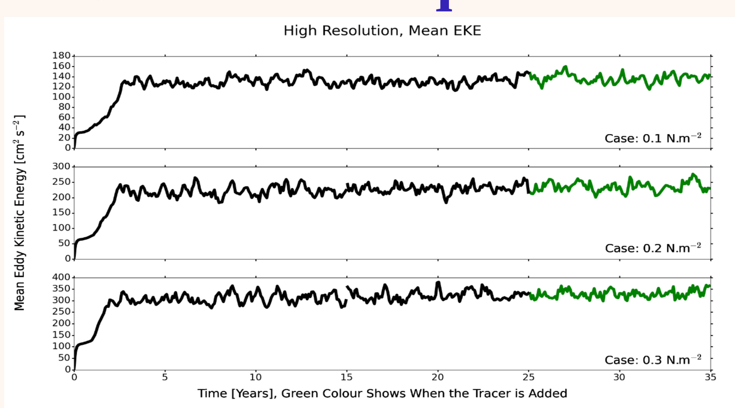

Fig 4. EKE of HR experiments green colour when tracer is added

6. Eddy suppression parameterization and improvement in the slopes of isotherms

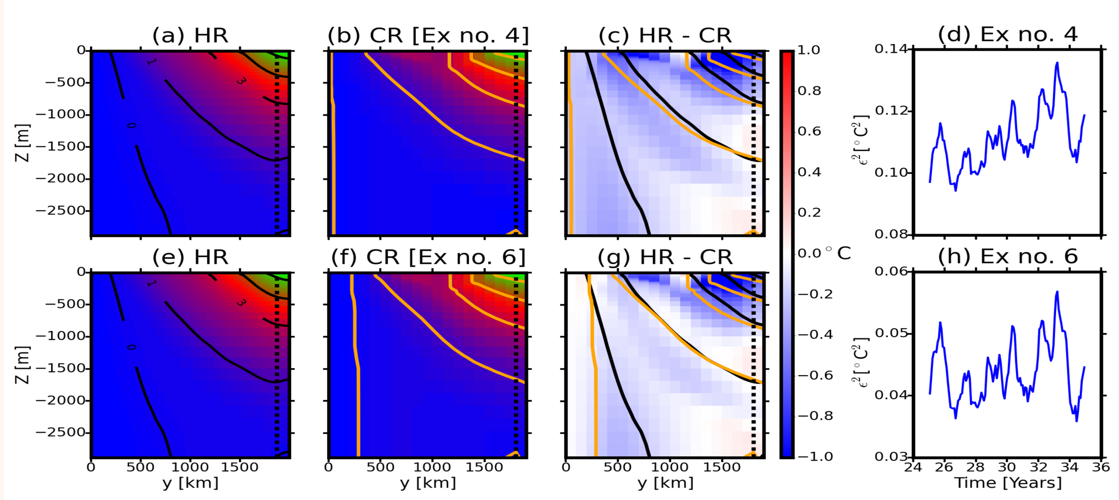

Fig. 5. (a) & (e) HR–zonally averaged temperature (same plots), black dotted lines show where sponge layer ends and black solid lines show isotherms of 0,1,3,5,7. (b) & (f) CR experiments no. 4 & 6, (c) & (g) temperature difference between HR and CR, (d) & (h) temperature misfit function = $(\mathbf{HR}-\mathbf{CR})^2$

7. Unsuppressed and Suppressed Diffusivities

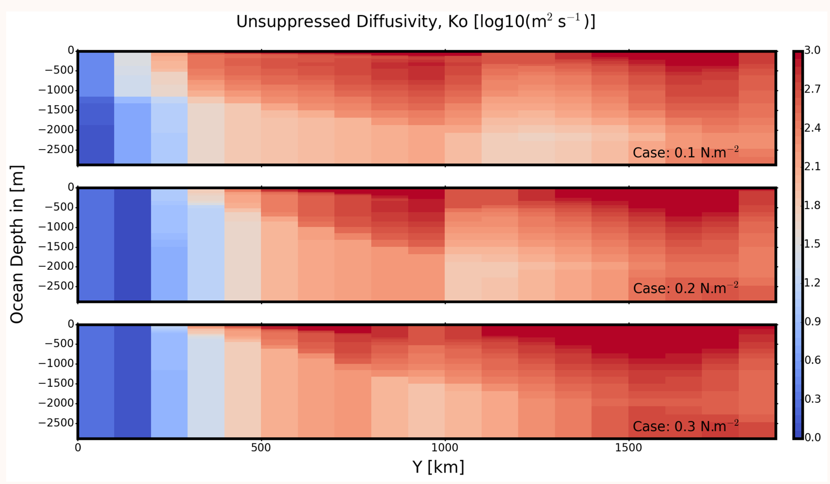

Fig 6. Log 10 of Ko Unsuppressed Diffusivity for experiments no. 2,5 and 8

- Magnitude of Ko increases with increasing winds, the maximum values are at the equatorward flank of the ACC (Antarctic Circumpolar Current), whereas Ko decreases towards the poleward flank Of the ACC.

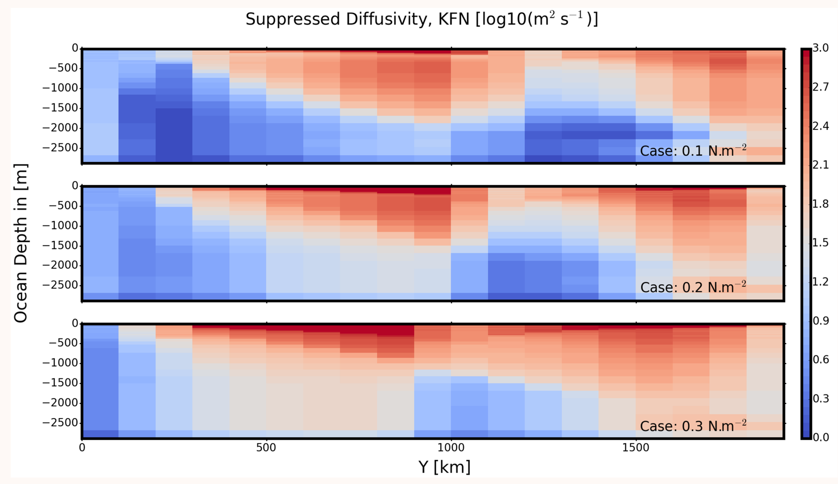

Fig 7. Log 10 of KFN Suppressed Diffusivity for experiments no. 3, 6 and 9

- On average for all three wind cases diffusivity is suppressed by a factor of 2. Whereas individually for case 0.1, 0.2 and 0.3 the KFN is suppressed by factor of 3, 2 and 1.5 respectively.

8. The Southern Ocean ventilation tracer response to climate change

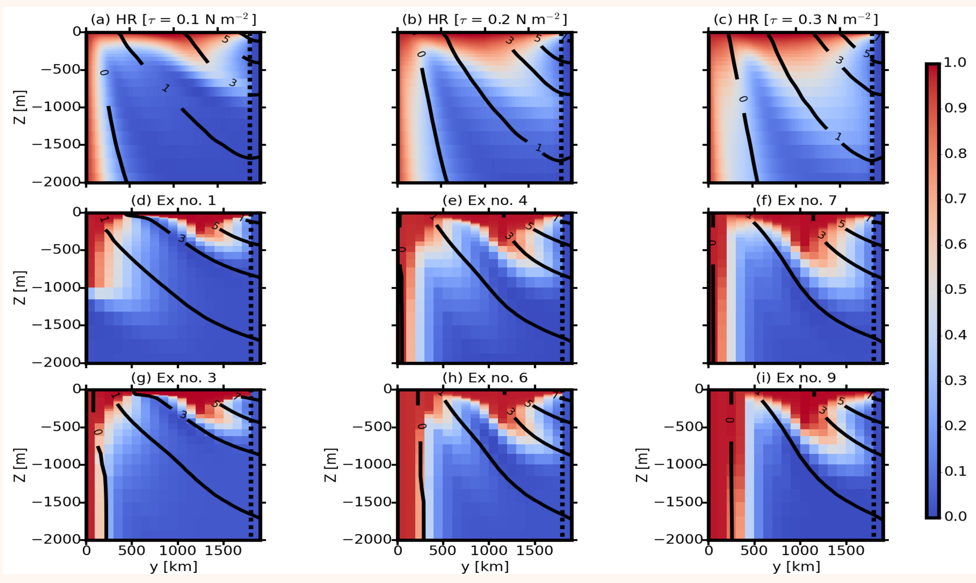

Fig 8. Tracer distribution. Top row: HR (3 winds). Middle row: KREDI = constant. Bottom row: KREDI = KFN. To avoid confusion KREDI = Ko not shown

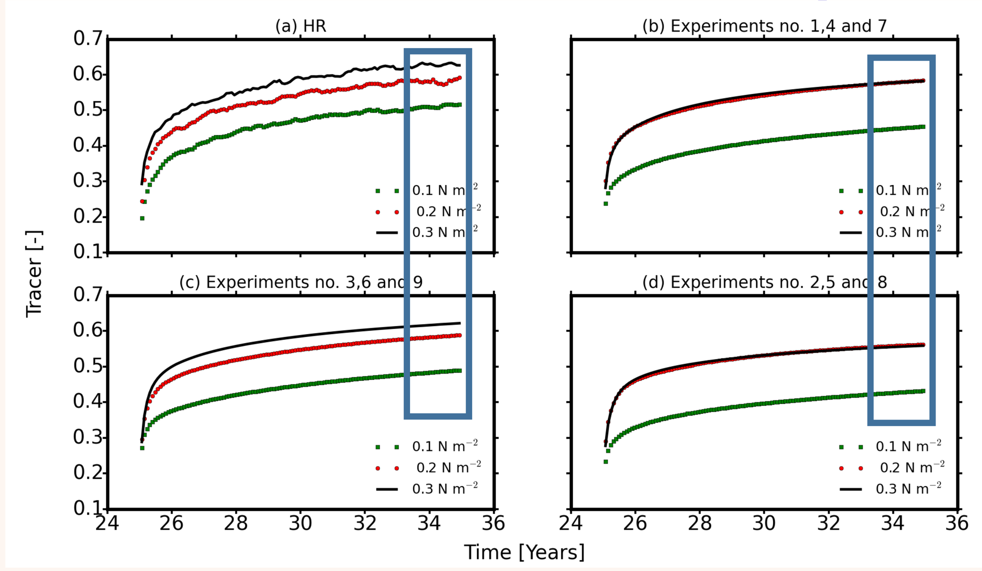

Fig 9. Time series of globally averaged-tracer concentration for (a) HR, (b) KREDI = constant, (c) KREDI = KFN and (d) KREDI = Ko

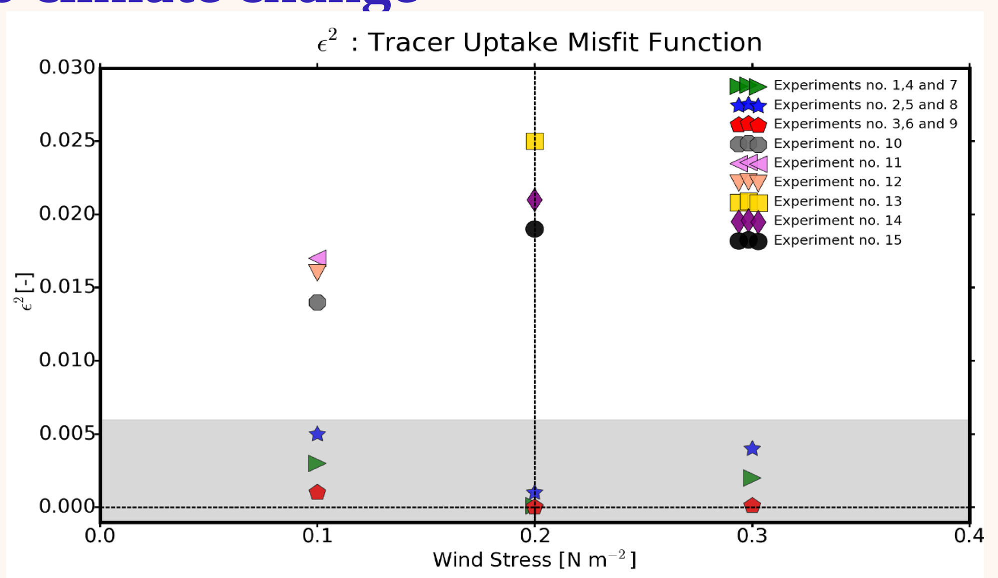

Fig 10. The tracer uptake misfit function $(\mathbf{HR}-\mathbf{CR})^2$. Black lines show reference experiments. Grey shaded area of the plot show experiments no. 1-9

9. TAKE HOME MESSAGE

- **Parameterization of KFN improves the mean state of the ocean by improving the slopes of isotherms.**
- **This parameterisation improves the sensitivity of tracer uptake to changing winds especially for the higher wind values.**
- **In future, implementing parameterization of KFN in CR global climate model will lead us to accurately forecast the carbon uptake by the global ocean.**

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Email : asher.riaz@utas.edu.au

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- [5](Riaz et al. The Role of Eddy Mixing Suppression for the Ventilation in the Southern Ocean, in prep).

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