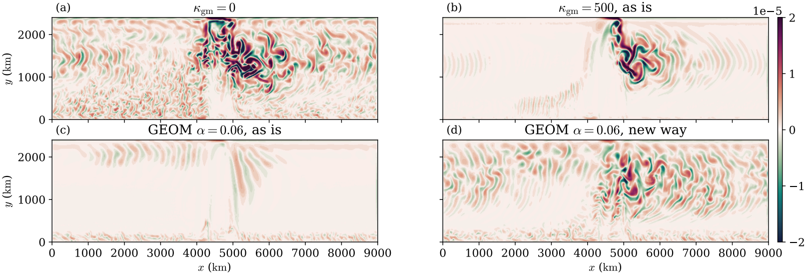
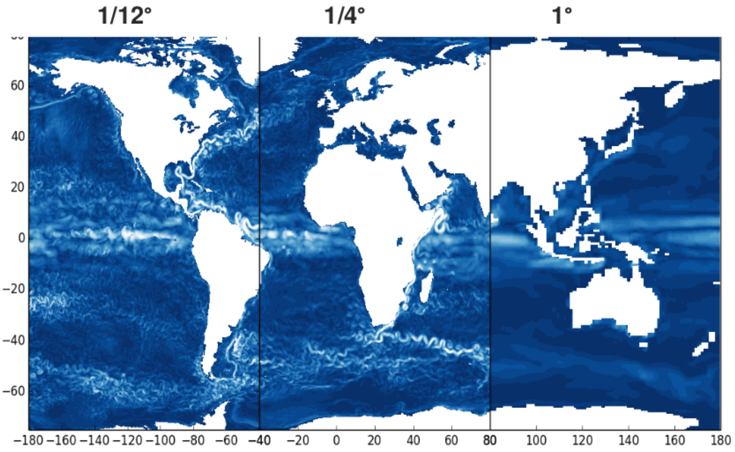
Mesoscale eddy parameterisation in numerical 'grey zone' ocean models



J. Mak, J. R. Maddison, D. P. Marshall, X. Ruan, Y. Wang & L. Yeow

Eddy permitting models

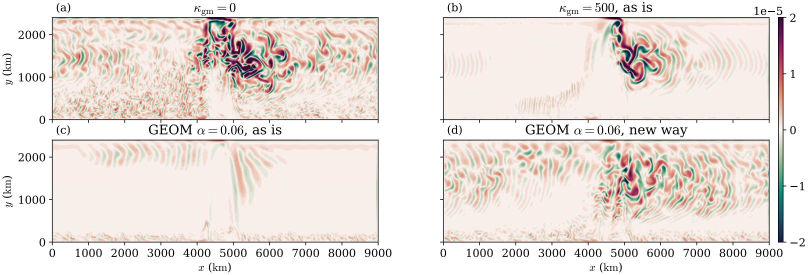


Q. to parameterise, or not to parameterise?

figure from Helene Hewitt (UKMO)

GM-based schemes in eddy permitting models

- problems with using GM-based schemes?

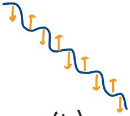


Rationale for behaviour

option 1 : use ρ

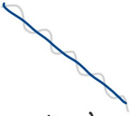
$$u^* = -\nabla \times (K_{pm} S)$$

$$S = |\nabla_H \rho|^2 / N^2$$



$\rho(t_n)$

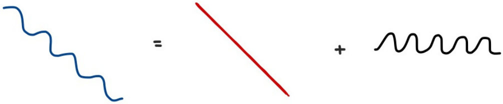
$\longrightarrow$



$\rho(t_{n+1})$

Idea

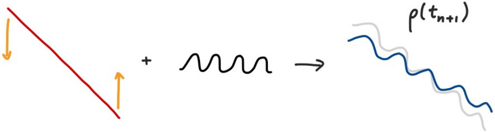
option 2 : use filter



$$\rho(t_n) = \rho_{large}(t_n) + \rho_{small}(t_n)$$

$$u^*_L = -\nabla \times (K_{pm} S_L)$$

$$S_L = |\nabla_H \rho_{large}|^2 / N^2$$



Key ingredients

1. some splitting into a large and small-scale field

   → diffusion-based **horizontal** filter based on

$$(1 - L^2\nabla_H^2)^M \Theta_L = \Theta,$$

   → cf. implicit solve of diffusion equation; $M \geq 2$ allows L to be interpreted as a filtering length-scale (closely related to Matérn auto-covariance)

   → $M = 2$, $L = 100$ km here

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3. numerical implementation

   → NEMO, minor re-piping of data if letting $\boldsymbol{u}^*$ act on everything

Key ingredients: use with GEOMETRIC

$$\kappa_{\mathrm{gm}} = \alpha \frac{\int E \, \mathrm{d}z}{\int (M^2/N) \, \mathrm{d}z} \qquad [\kappa_{\mathrm{gm}} = \kappa_{\mathrm{gm}}(x, y, t)]$$

$$\frac{\partial}{\partial t} \int E \, \mathrm{d}z + \nabla_H \cdot \left((\widetilde{\boldsymbol{u}}^z - c_{\mathrm{ros}} \boldsymbol{e}_x) \int E \, \mathrm{d}z \right) = \int \kappa_{\mathrm{gm}} \frac{M^4}{N^2} \, \mathrm{d}z - \lambda \int E \, \mathrm{d}z + \kappa_E \nabla_H^2 \int E \, \mathrm{d}z,$$

(recently merged into NEMO 4.2 trunk; with thanks to Andrew Coward NOC)

4. energy consistency?

   $\rightarrow$ non-trivial things to be aware of, but basically use large-scale field information where applicable

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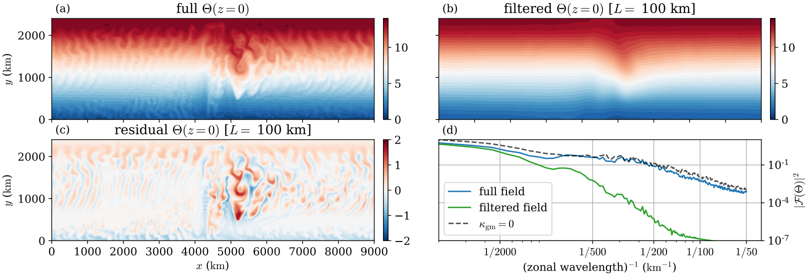
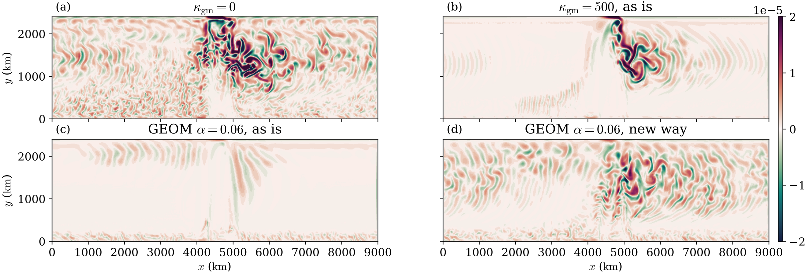
Q. **CONSTANT total eddy energy with changing resolution,**

parameterised + explicit = constant?

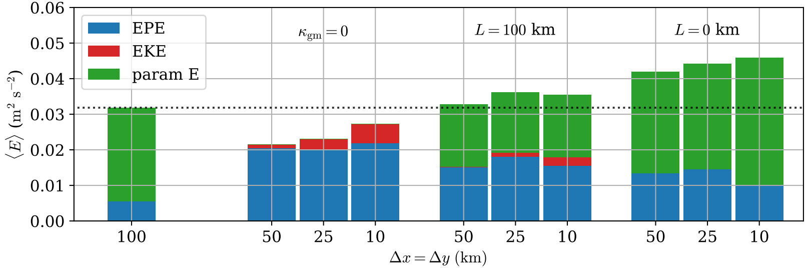
$\rightarrow$ fixed total energy but represented in different forms?

Some results: reduced damping





Some results: energy constancy?



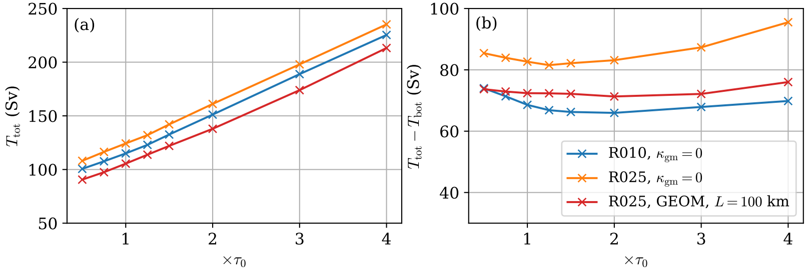
- **FIXED** GEOMETRIC parameter choice, $\alpha = 0.06$, $\lambda^{-1} = 80$ days (filtering with $L = 100$ km)

  $\rightarrow$ almost energy constancy with changing resolution?

  $\rightarrow$ seems robust with fixed α, λ^{-1} for sample calculations

  $\rightarrow$ R100 energy level could be tuned down with $\alpha \nearrow$, $\lambda^{-1} \searrow$?

Some results: mean state sensitivities



- varying wind forcing calculations, circumpolar transport

  $\rightarrow$ almost **eddy saturation** in thermal wind in GEOM + filtered calculations

  $\rightarrow$ no GM case looks good in terms of fluctuations, but has various issues in the mean state response

Conclusion

$$\boldsymbol{u}^* = -\nabla \times (\kappa_{\mathrm{gm}}\, \boldsymbol{s}), \qquad \boldsymbol{s} = \frac{\nabla_H b}{\partial b / \partial z},$$

Existing approaches:

- modifies κ_{gm} directly

  $\rightarrow$ control magnitude, but keep $\boldsymbol{s}$ and so $\boldsymbol{u}^*$ a full-scale field
- backscatter

  $\rightarrow$ damp first, then write it back in?

Here we ask for a large-scale $\boldsymbol{s}$:

- controls both magnitude and spatial variation of $\boldsymbol{u}^*$

  $\rightarrow$ keep the fluctuations, but add in a bit of GM

  $\rightarrow$ scale-aware energy levels, parameterised + explicit $\approx$ constant
- evidence for improved mean-state as well as sensitivities in eddy permitting channel models

Outlooks

Q. not inconsistent with backscatter, but don't need that much of it?

$\rightarrow$ not hitting the explicit eddies that much in the first place

Q. global model response in the physics

$\rightarrow$ interesting to see impact in Southern Ocean in ORCA025?

Q. impact on modelled biogeochemistry (EGU23-2513, **OS3.1, Thurs 2pm session, Room L2**, speaker: Xi Ruan)

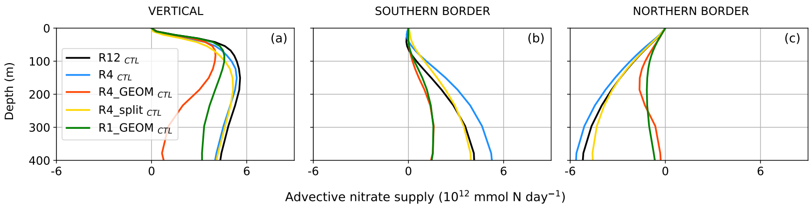
$\rightarrow$ no GM case, MOC too strong, nutrient supply and NPP too large

$\rightarrow$ GEOMETRIC + present approach damps the MOC a bit, reasonable nutrient supply and NPP

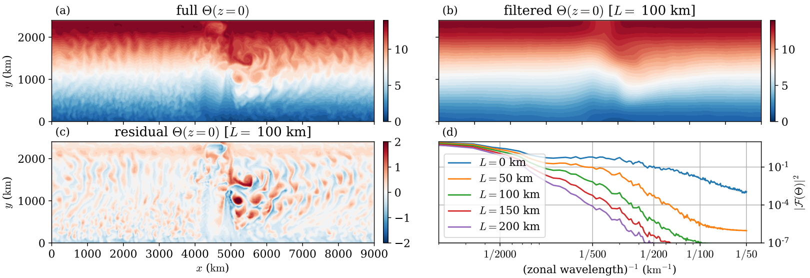
$\rightarrow$ (speculated) if only backscatter, drive a larger MOC, even larger discrepancy?

BGC response in NEMO gyre model

	NPP (CTRL)	NPP (CC)	ΔNPP (CC)	comment
R12	3.67	3.17	-13.8%	
R4	3.91	3.46	-11.5%	supply too large
R4 split	3.62	3.18	-12.2%	



Diffusive filter: $(1 - L^2\nabla_H^2)^2\Theta_L = \Theta$



- elliptic solve done here through Richardson iteration

  $\rightarrow$ could do e.g. CG given $(1 - L^2\nabla_H^2)$ is 'nice' for fixed grid spacing

  $\rightarrow$ convergence based on $\|\cdot\|_\infty$

- filter only every model **day** for cost reasons

  $\rightarrow$ large-scale field not expected to vary too fast anyway?

  $\rightarrow$ weak sensitivity to filtering frequency in sample calculations (for frequencies below a month)