Parameterizing Subgrid-Scale Eddy Effects Using Energetically Consistent Backscatter

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Introduction:

In the near future we expect the resolution of many IPCC-class ocean models to enter the "eddy-permitting" regime. At this resolution models can produce reasonable eddy-like disturbances, but can still not properly resolve eddies at all relevant scales. Adequate parameterizations representing sub-grid eddy effects are thus necessary. Most eddy-permitting models presently employ some kind of hyper-viscosity, which causes a significant amount of energy dissipation. However, in a regime of geostrophic turbulence**, only enstrophy, but almost no energy, should be dissipated by interior viscosity** (Jansen and Held, 2014). As a result of the artificial energy sink associated with viscous parameterizations, the eddy fields in eddy permitting models are generally not energetic enough. To overcome this problem we propose to introduce an energy "backscatter" term, which balances the spurious energy dissipation by hyperviscosity.

Backscatter formulation:

Prognostic sub-grid EKE equation:

$$\partial_t e = \boxed{\dot{e}_{\nu_4}} - \boxed{\dot{e}_{back}} - \boxed{\nabla \cdot \mathbf{F}}$$

Hyper-viscous dissipation: $\dot{e}_{\nu_4} = -\sum_i \nu_4 \nabla \mathbf{u}_i \cdot \nabla^3 \mathbf{u}_i$

Backscatter (via neg. visc.): $\dot{e}_{back} = \sum_i -\nu_2 |\nabla \mathbf{u}|^2$

Subgrid EKE transp. (here diffusion): $\mathbf{F} = -K_e \nabla e$

- In steady state, energy budget ensures balance between viscous dissipation and backscatter!
- Sub-grid EKE dissipation, as well as more realistic EKE transport can be added.

Backscatter here formulated via negative viscosity:

$$\nu_2 = -c\Delta\sqrt{e}$$

Δ = grid-scale

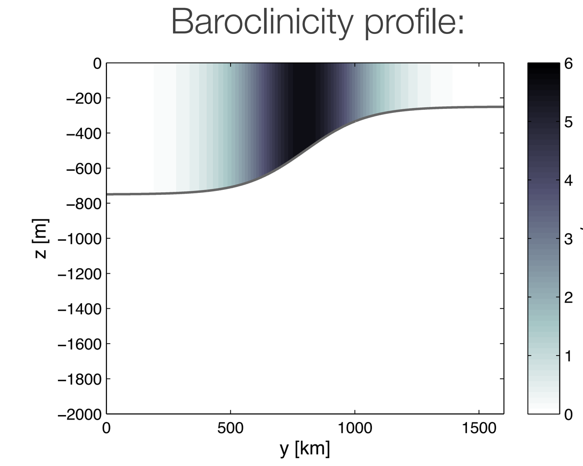
c = O(1) constant (here c=0.4)

- Negative (Laplacian) viscosity returns energy at larger scales than dissipation by biharmonic viscosity => Ensures enstrophy dissipation

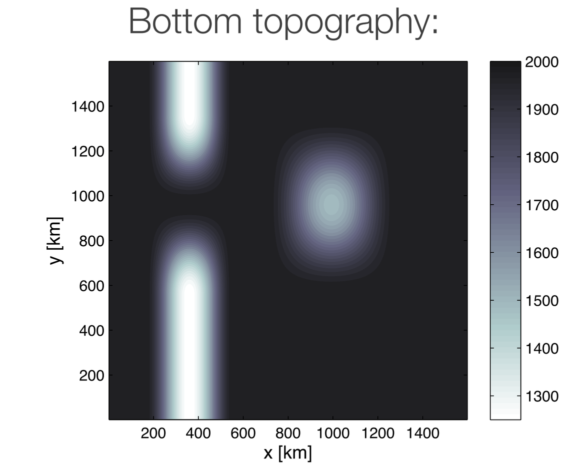
Idealized Model:

MOM6 dynamical core in idealized two-layer channel configuration:
("Southern Ocean-like" parameters)

Restoring to zonally-symmetric Baroclinicity profile:

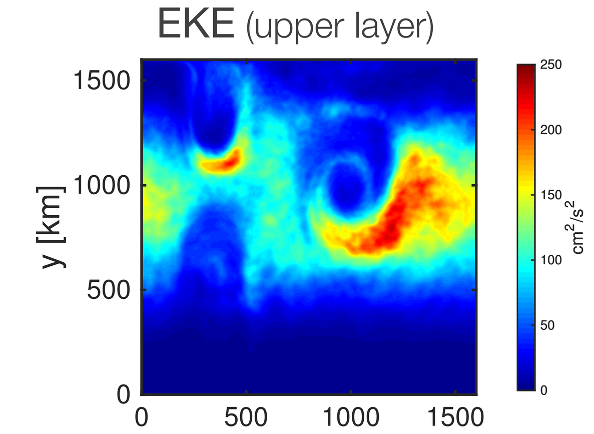


Bottom topography:

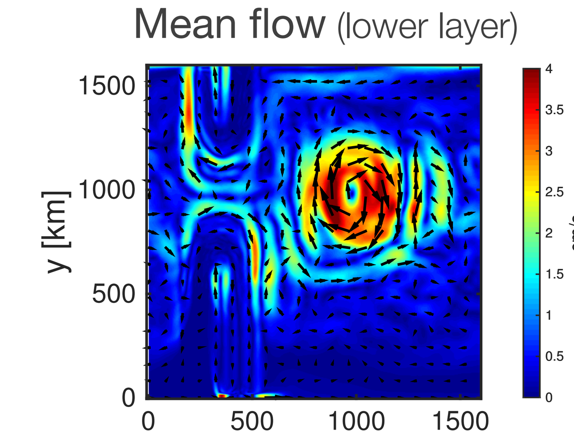


High resolution (3.2 km):

EKE (upper layer)

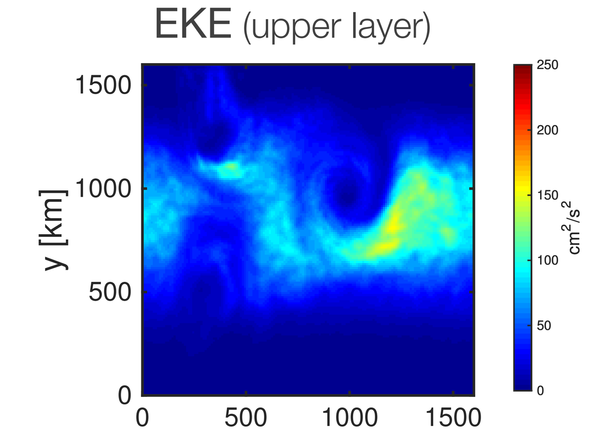


Mean flow (lower layer)

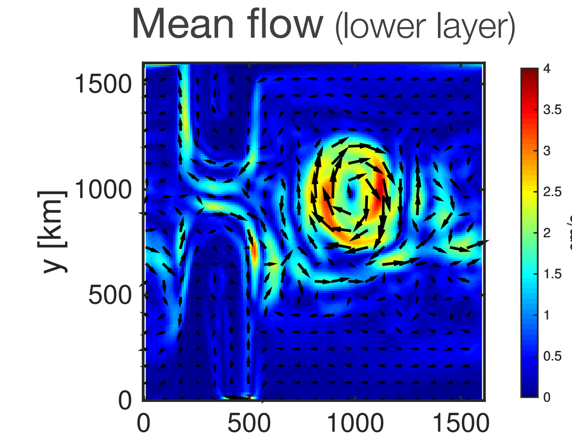


"Eddy permitting" (10 km):

EKE (upper layer)

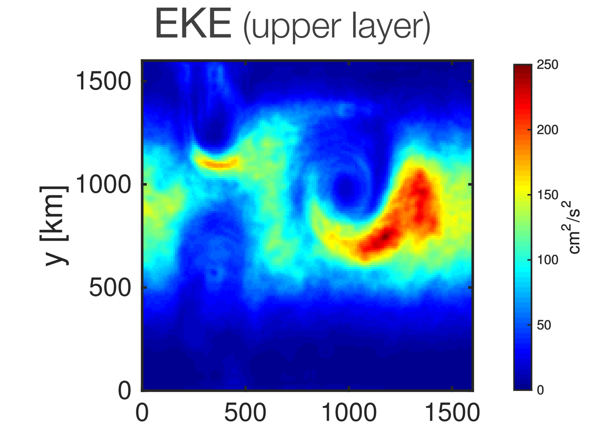


Mean flow (lower layer)

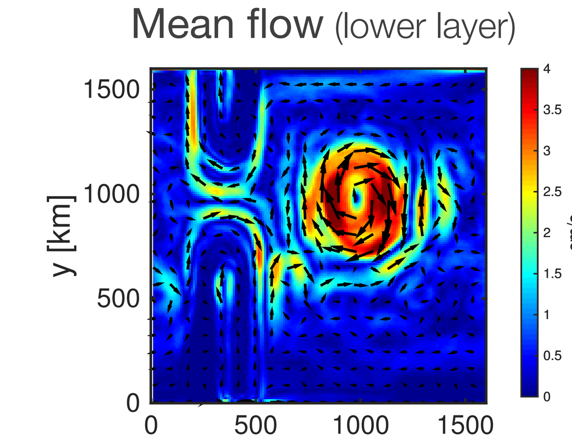


"Eddy permitting" (10 km) + backscatter:

EKE (upper layer)

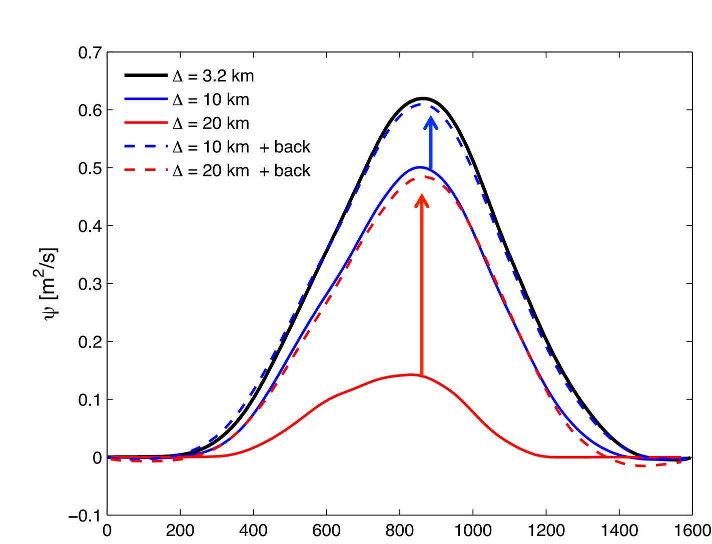


Mean flow (lower layer)



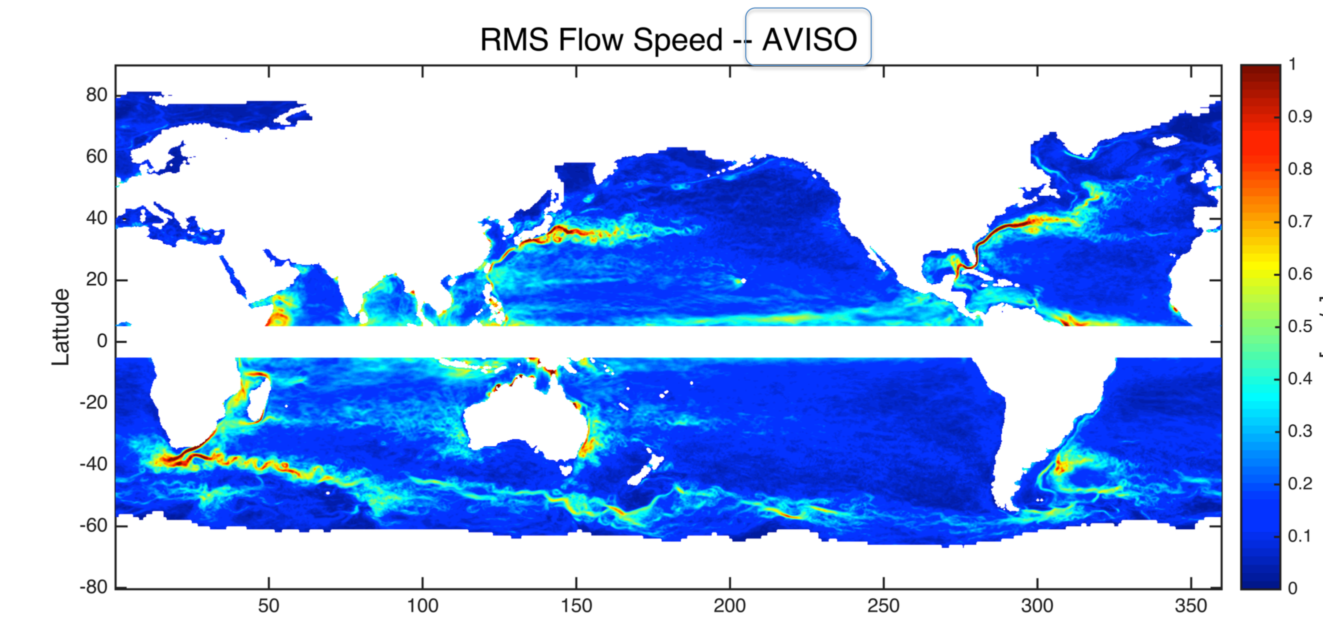
Overturning Circulation:

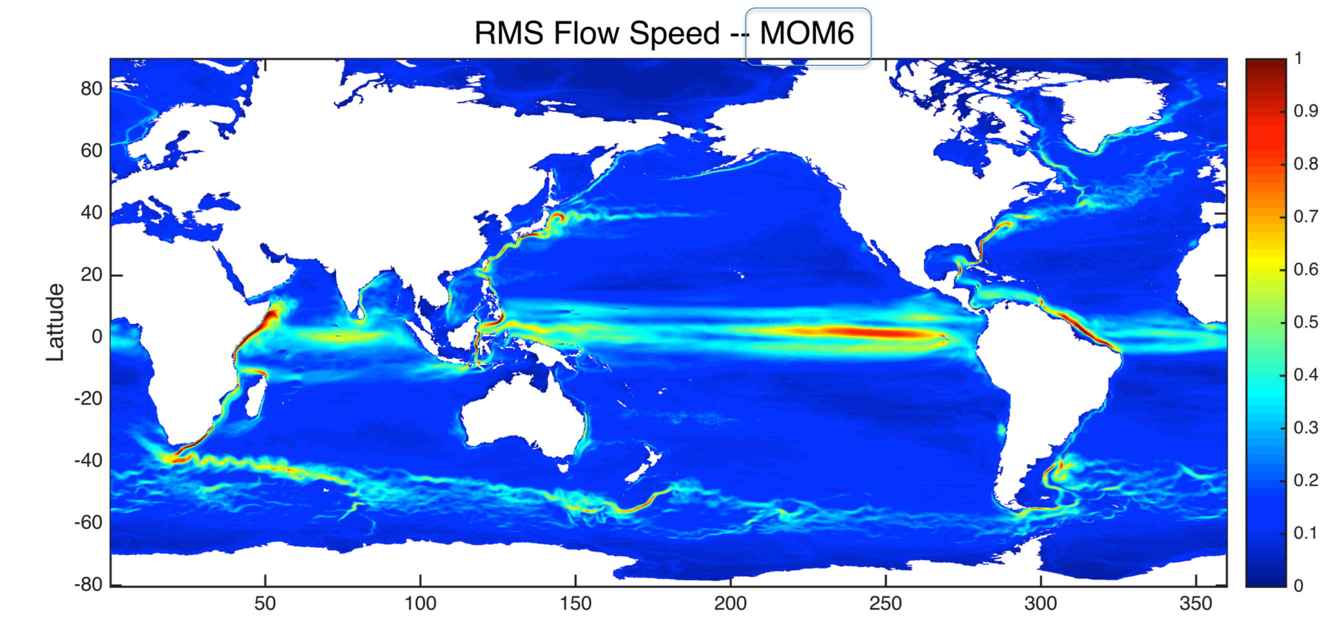
(here all eddy-driven)

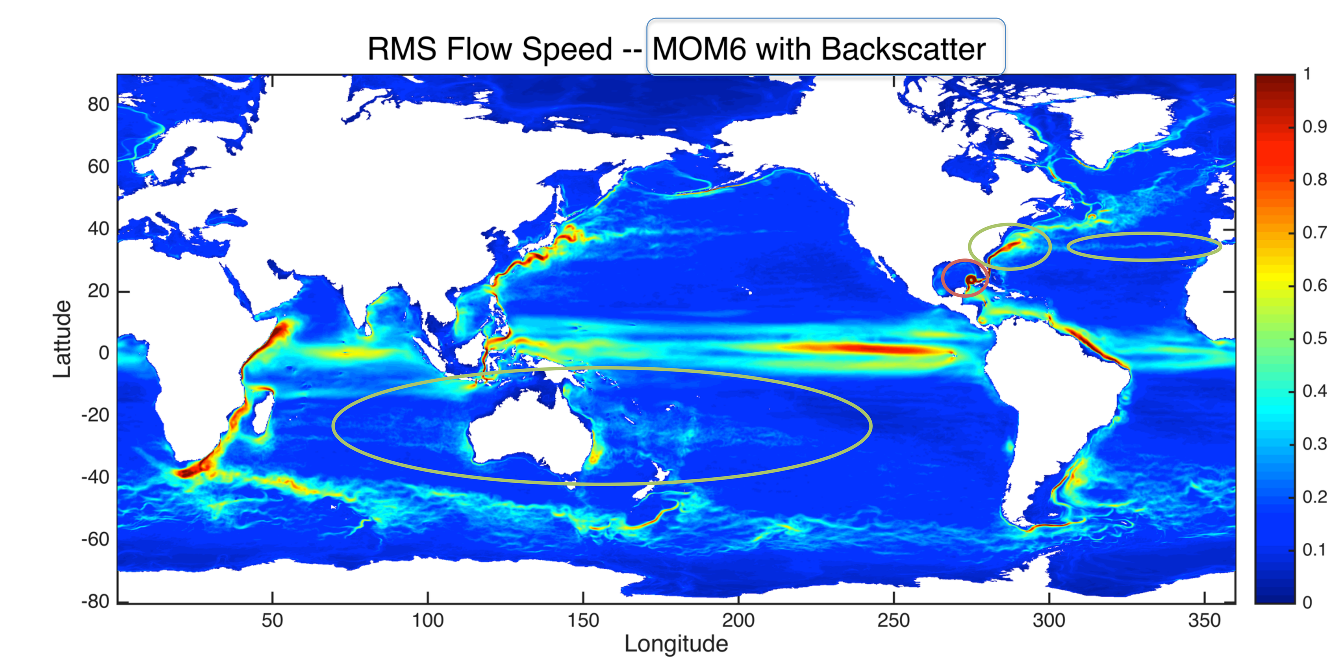


"Realistic" global setup:

MOM6 with CORE "normal year" forcing
(10 year simulations. Averages shown are last three years, and 2012-2014 AVISO.)







Conclusions / Outlook:

- Sub-grid EKE budget with negative viscosity backscatter can be used in idealized primitive equation model to greatly improve flow characteristics at eddy permitting resolution.
- Preliminary first results in global model are promising (but further analysis is needed)
- Issues that should be addressed:
  - Advection / transport of sub-grid EKE
  - Sub-grid dissipation (incl. large Ro flows => loss of balance => dissipation)
  - Vertical structure

Publications:

Jansen, M.F. and I.M. Held (2014): Parameterizing subgrid-scale eddy effects using energetically consistent backscatter. *Ocean Modeling*, 80, 36-48.

Jansen, M.F., Held, I.M., Adcroft, A.J., Hallberg, R. (2015), Energy budget-based backscatter in an eddy permitting primitive equation model. *Ocean Modelling*, 94, 15-26.