Energetically Consistent Parameterization of Sub-Grid Eddies in Eddy-Permitting Ocean Models

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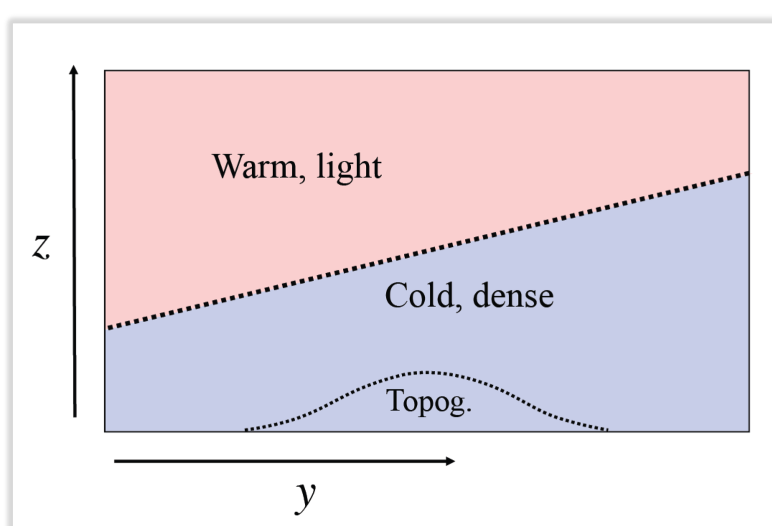
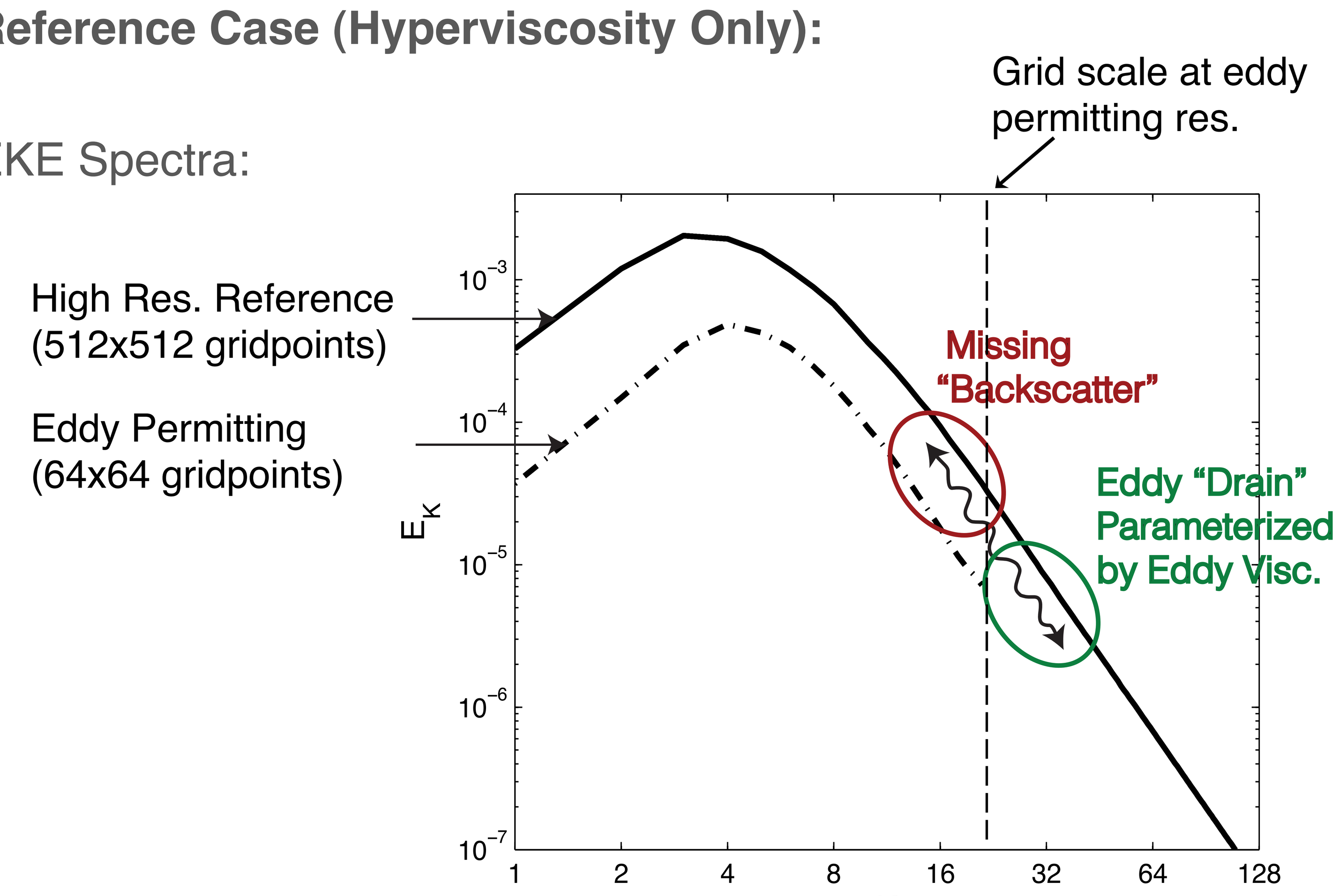
Introduction:
In the near future we expect the resolution of many IPCC-class ocean models to enter the “eddy-permitting” regime. At this resolution models can produce reasonable eddy-like disturbances, but can still not properly resolve eddies at all relevant scales. Adequate parameterizations representing sub-grid eddy effects are thus necessary. Most eddy-permitting models presently employ some kind of hyper-viscosity, which is shown to cause a significant amount of energy dissipation. However, comparison to higher resolution simulations shows that **only enstrophy, but almost no energy, should be dissipated below the grid-scale.** As a result of the artificial energy sink associated with viscous parameterizations, the eddy fields in eddy permitting models are generally not energetic enough.

Model:
- 2-layer doubly-periodic, beta-plane QG model
- 1000 km x 1000 km domain
- k_d^{-1} = 12 km
- Linear bottom drag (τ_D = 25 d)
- (Asymmetric) Gaussian “bump” topography
- “Leith” hyper-viscosity

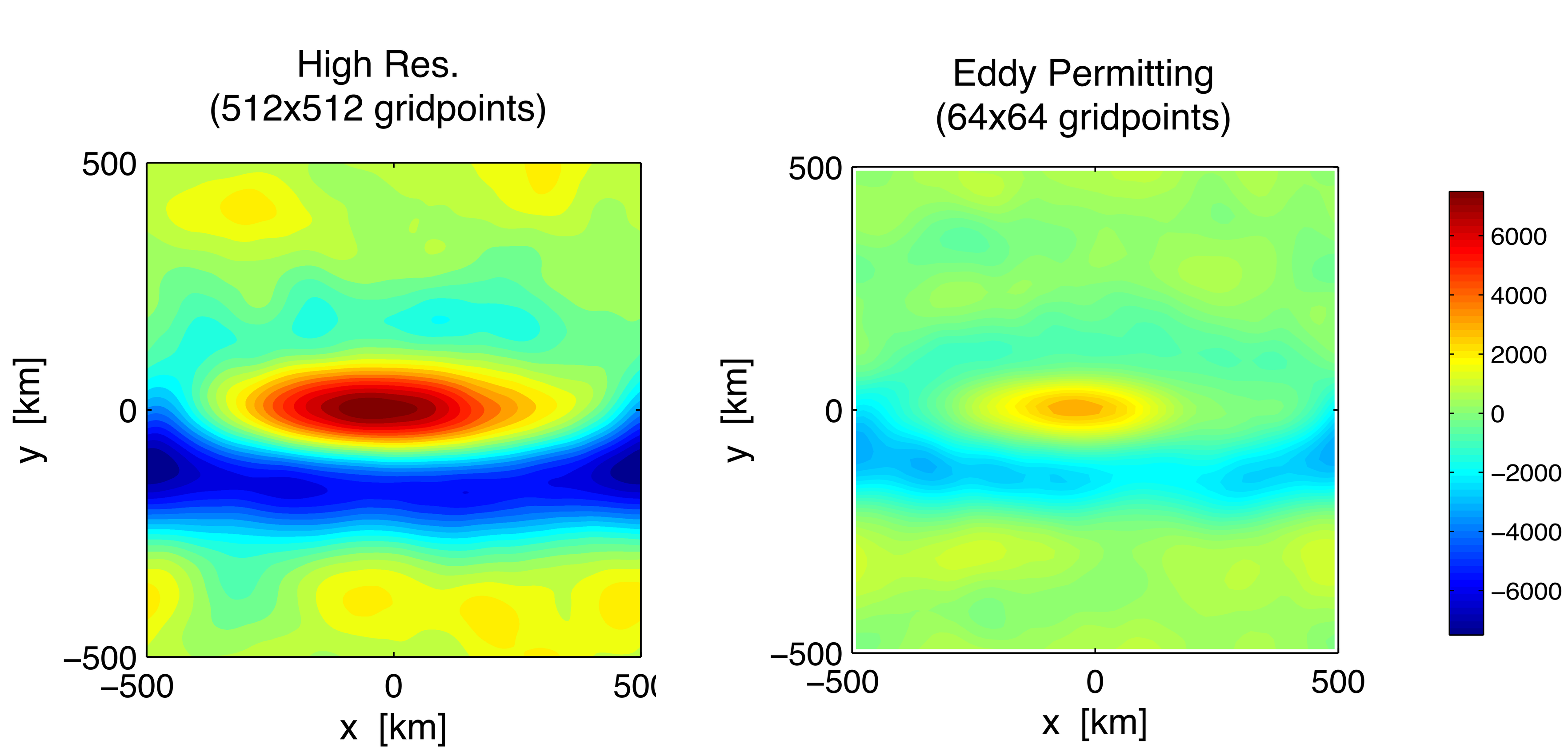


Reference Case (Hyperviscosity Only):

EKE Spectra:



Mean Flow (Lower Layer Streamfunction):



Problem:
(Hyper-)viscous parameterizations cause spurious energy dissipation in eddy-permitting simulations.
=> Too low EKE level => generally poor performance

Solution:
Energy “backscatter” to maintain adequate eddy energy level.

$$\frac{\partial}{\partial t}\int E dV = \ldots \quad -\int \nu |\nabla \xi|^2 dV \quad + \int \psi \times \mathrm{forc}\, dV$$

Choose forcing such that: $\int \psi \times \mathrm{forc}\, dV = 0.9 \int \nu |\nabla \xi|^2 dV$

Factor Accounts for frictional diss. at sub-grid scales (1.0 for conservative flow)

2 simple versions of forcing to enforce energy conservation:

1. White noise vorticity forcing:

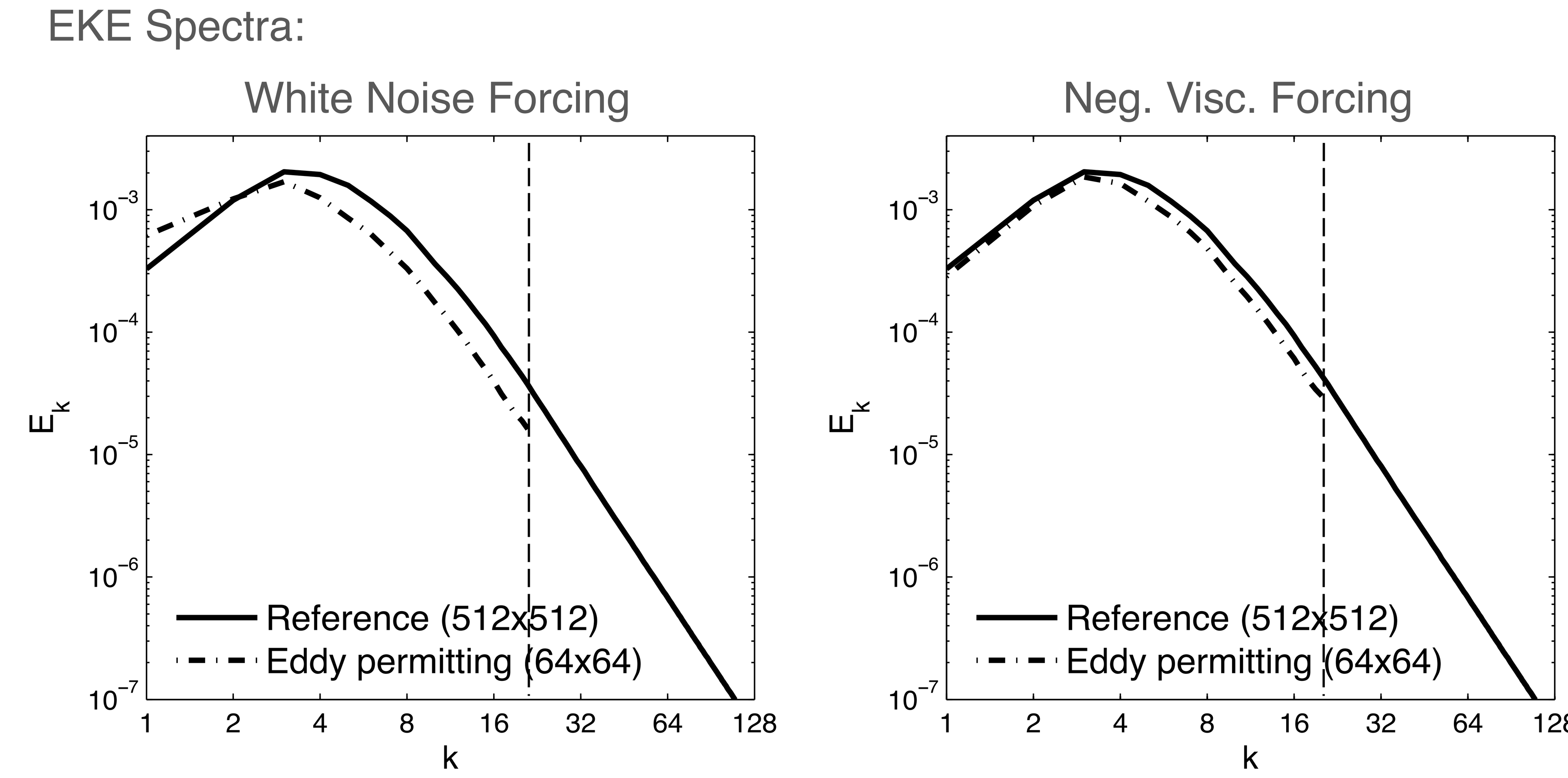
$$\mathrm{forc} = A(t) n \quad \text{where} \quad \langle n(\mathbf{x}_1, t_1)\eta(\mathbf{x}_2, t_2)\rangle = \delta(\mathbf{x}_1 - \mathbf{x}_1)\delta(t_1 - t_2)$$

2. Negative Viscosity:

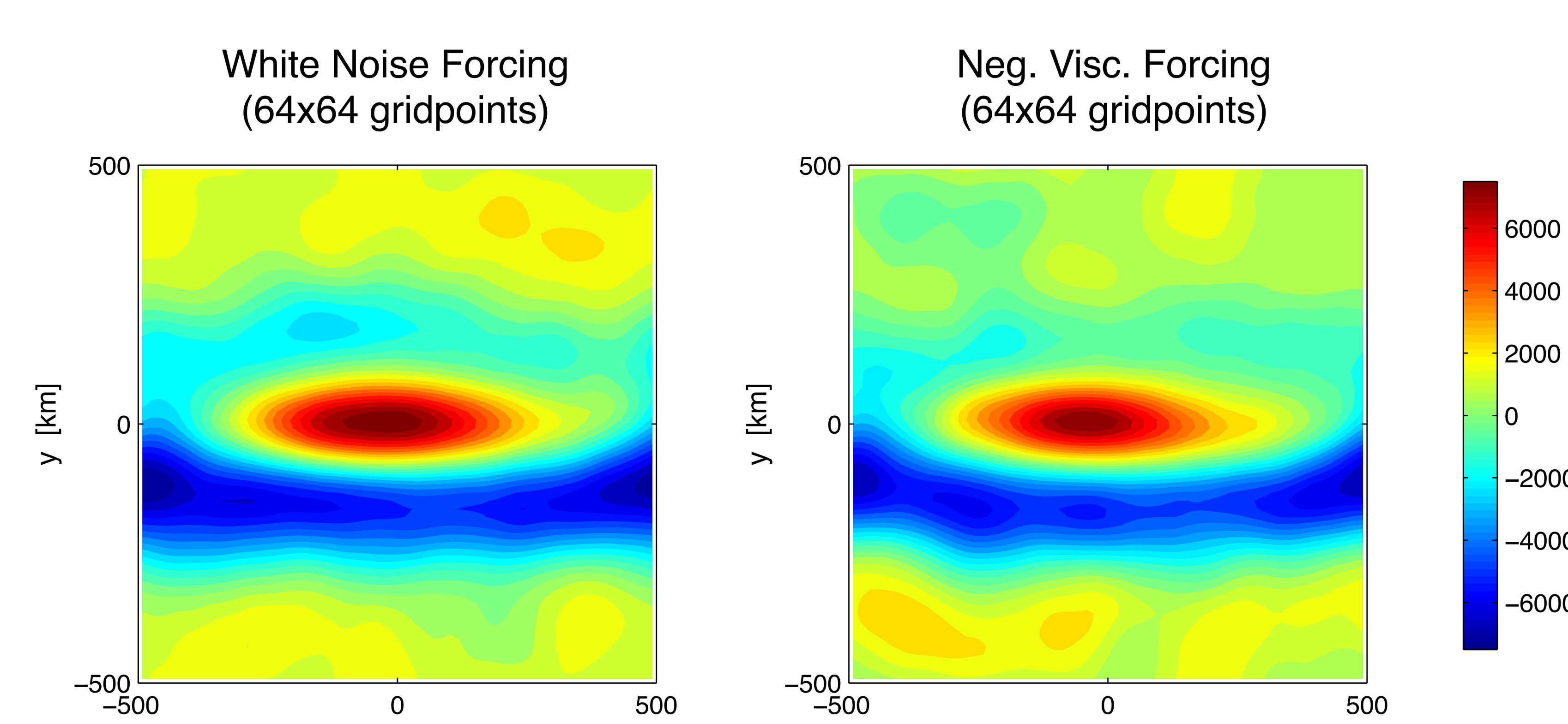
$$\mathrm{forc} = -A(t)\nabla^2 \xi$$

Results (with “Backscatter” Forcing):

EKE Spectra:



Mean Flow (Lower Layer Streamfunction):



Conclusions
- (Hyper-)viscous parameterizations required to dissipate enstrophy - but cause spurious energy dissipation in eddy-permitting regime.
- Energy “backscatter” can be used to maintain adequate eddy energy level in eddy-permitting simulations.
- For more details see:
  Jansen, M. F. and I. M. Held: Energetically consistent parameterization of subgrid-scale eddies, submitted to *Ocean Modeling*.

Outlook
- Implementation in primitive equation model (MOM6)
- Inhomogeneity requires “localish” energy conservation
  -> Use explicit sub-grid EKE equation (can use “MEKE” framework in MOM6)
- Combine with GM-type parameterization acting at non-eddying resolution – make fully scale adaptive