Geometry and Energetics of Ocean Mesoscale Eddies and Their Rectified Impact on Climate (GEOMETRIC)

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Goal: Develop a framework for parameterising and interpreting eddy-mean flow interaction that preserves the relevant symmetries and conservation laws

1. GEOMETRIC eddy framework

(Marshall et al., 2012)

- residual-mean momentum equation

$$\frac{\partial \overline{\mathbf{u}}}{\partial t} = \ldots - \nabla \cdot \mathbf{E} + \text{forcing} - \text{dissipation}$$

- consistent eddy energy equation

$$\frac{\partial E}{\partial t} = \nabla \cdot (\ldots) + \overline{\mathbf{u}} \cdot \nabla \cdot \mathbf{E} + \text{forcing} - \text{dissipation}$$

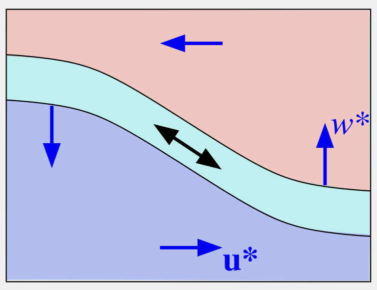
- eddy stress tensor **E** includes eddy Reynolds and form stresses
- dimensional size of **E** set by eddy energy E
- all remaining unknowns are dimensionless and ≤ 1 in magnitude and measure the anisotropy and direction of the eddy fluxes (analogous to eddy variance ellipses)
- if we neglect Reynolds stresses, GEOMETRIC is equivalent to Gent and McWilliams (1990) with an eddy diffusivity

$$\boxed{\kappa = \alpha \frac{N}{\partial \overline{b}/\partial y} E \qquad (|\alpha| \leq 1)}$$

2. Implementation in OGCMs

(Mak et al., 2018)

- employ existing Gent and McWilliams code with prescribed diffusivity profile
- solve prognostic equation for depth-integrated eddy energy, E
- rescale eddy diffusivity profile to match GEOMETRIC energy constraint



$$\psi_0 = \kappa_0(z)\frac{\nabla b}{N^2} \qquad \lambda = \frac{\int E\, dz}{\int N|\psi_0|\, dz}$$

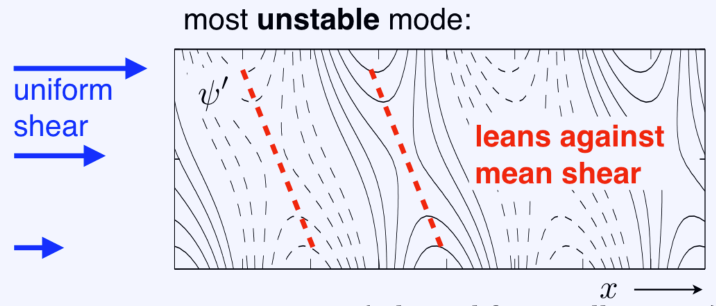
$$\psi = \lambda \kappa_0(z) \frac{\nabla_h b}{N^2}$$

$$\mathbf{u}* = \frac{\partial \psi}{\partial z}, \qquad w* = -\nabla_h \cdot \psi$$

3. Proofs of concept

- reproduces **dimensional Eady growth rate**

(Marshall et al., 2012)

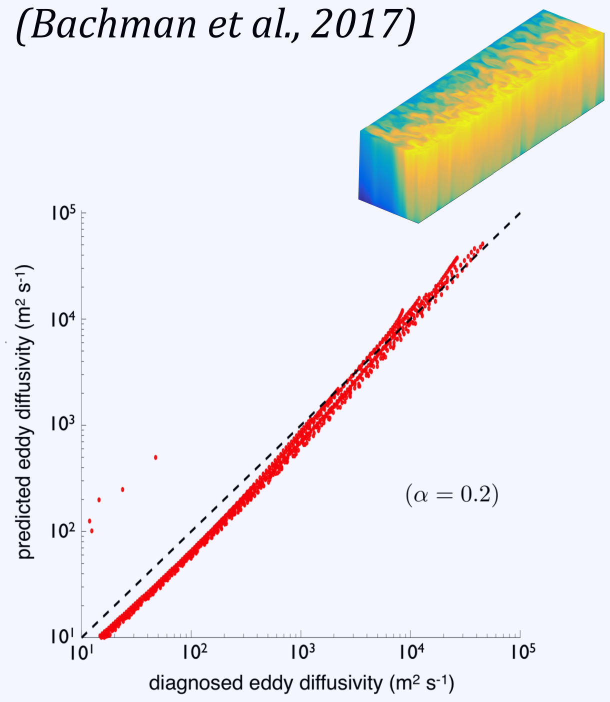


(adpated from Vallis, 2006)

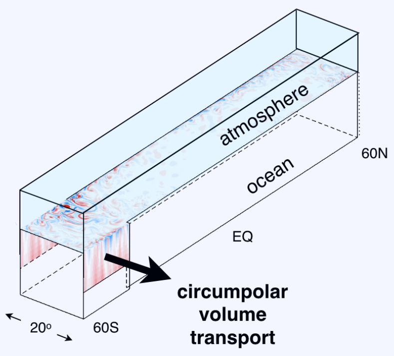
$$\frac{\partial}{\partial t}\iiint E\, dx\, dy\, dz = \boxed{\alpha \frac{f}{N}\frac{\partial \overline{u}}{\partial z}} \iiint E\, dx\, dy\, dz$$

Eady growth rate if α = 0.61 $(|\alpha| \leq 1)$

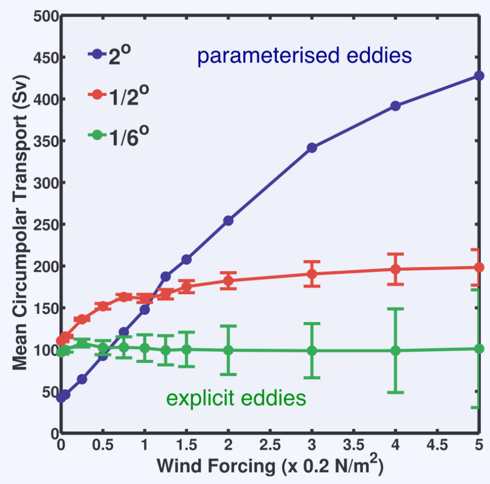
- **realistic eddy diffusivities** in nonlinear Eady problem *(Bachman et al., 2017)*

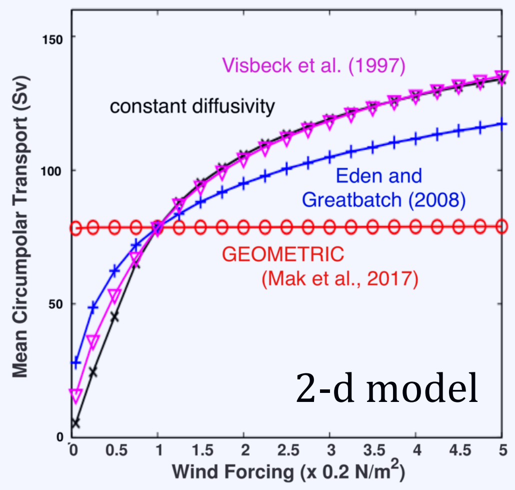


- reproduces **eddy saturation**, reduced sensitivity of circumpolar volume transport to surface wind stress found in models with explicit eddies *(Mak et al., 2017)*



(Munday et al., 2013)

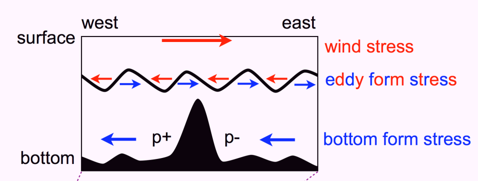




4. Understanding eddy saturation *(Marshall et al., 2017)*

- Momentum budget

  wind stress ~ eddy form stress



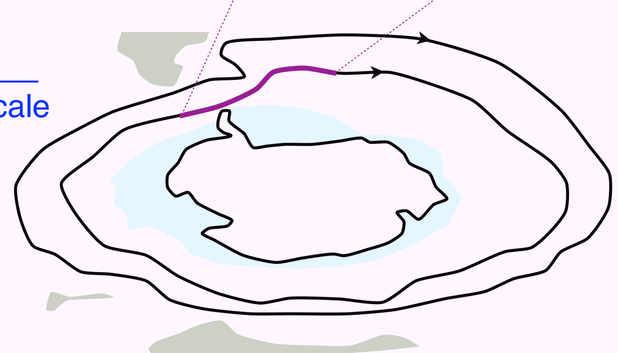
- Eddy energy budget

  eddy energy source ~ eddy energy sink

  $$\text{shear x } \cancel{\text{eddy energy}} \sim \frac{\cancel{\text{eddy energy}}}{\text{dissipation timescale}}$$

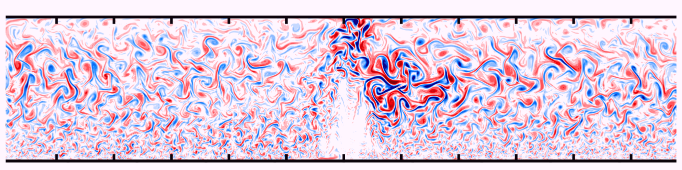
- GEOMETRIC closure

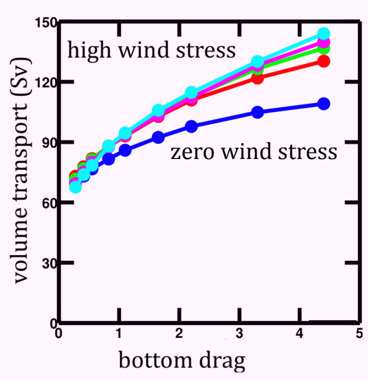
  eddy form stress ~ eddy energy



eddy energy ~ wind stress
shear ~ (dissipation timescale)$^{-1}$

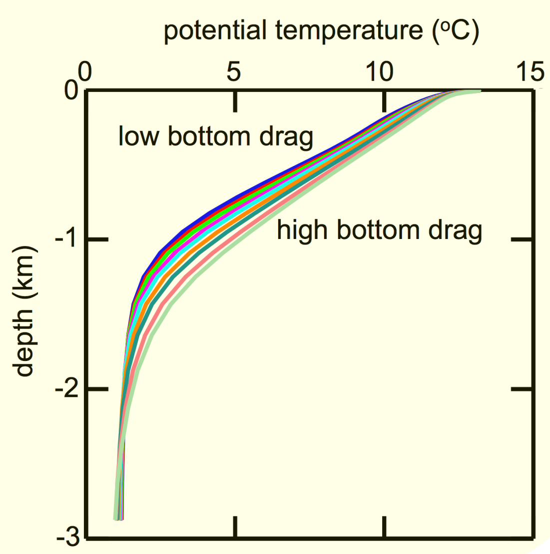
⇒ ACC transport independent of wind stress and increases with increased bottom drag!





5. Role of internal waves, diapycnal mixing?

- eddy energy dissipation time-scale is a key parameter in setting global stratification by setting tilt of isopycnals in the Southern Ocean
- important role for lee wave generation, diapycnal mixing, bottom drag?



(Marshall et al., 2017)

References

Bachman et al., 2017, *Ocean Modell.*, 109, 44–54 .
Gent and McWilliams, 1990, *J. Phys. Oceanog.*, 20, 150-155.
Eden and Greatbatch, 2008, *Ocean Modell.*, 20, 223-239.
Mak et al., 2017, *Ocean Modell.*, 112, 125-138.
Mak et al., 2018, *J. Phys. Oceanogr.*, submitted.
Marshall et al., 2012, *J. Phys. Oceanogr.*, 42, 539-557.
Marshall et al., 2017, *Geophys. Res. Lett.*, 44, 286–292.
Munday et al., 2013, *J. Phys. Oceanogr.*, 43, 507-532.
Vallis, G. K., 2006, Cambridge University Press, 745 pp.
Visbeck et al., 1997, *J. Phys. Oceanogr.*, 27, 381-402.