Energetically consistent, resolution aware, parameterization of ocean mesoscale eddies

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The Problem

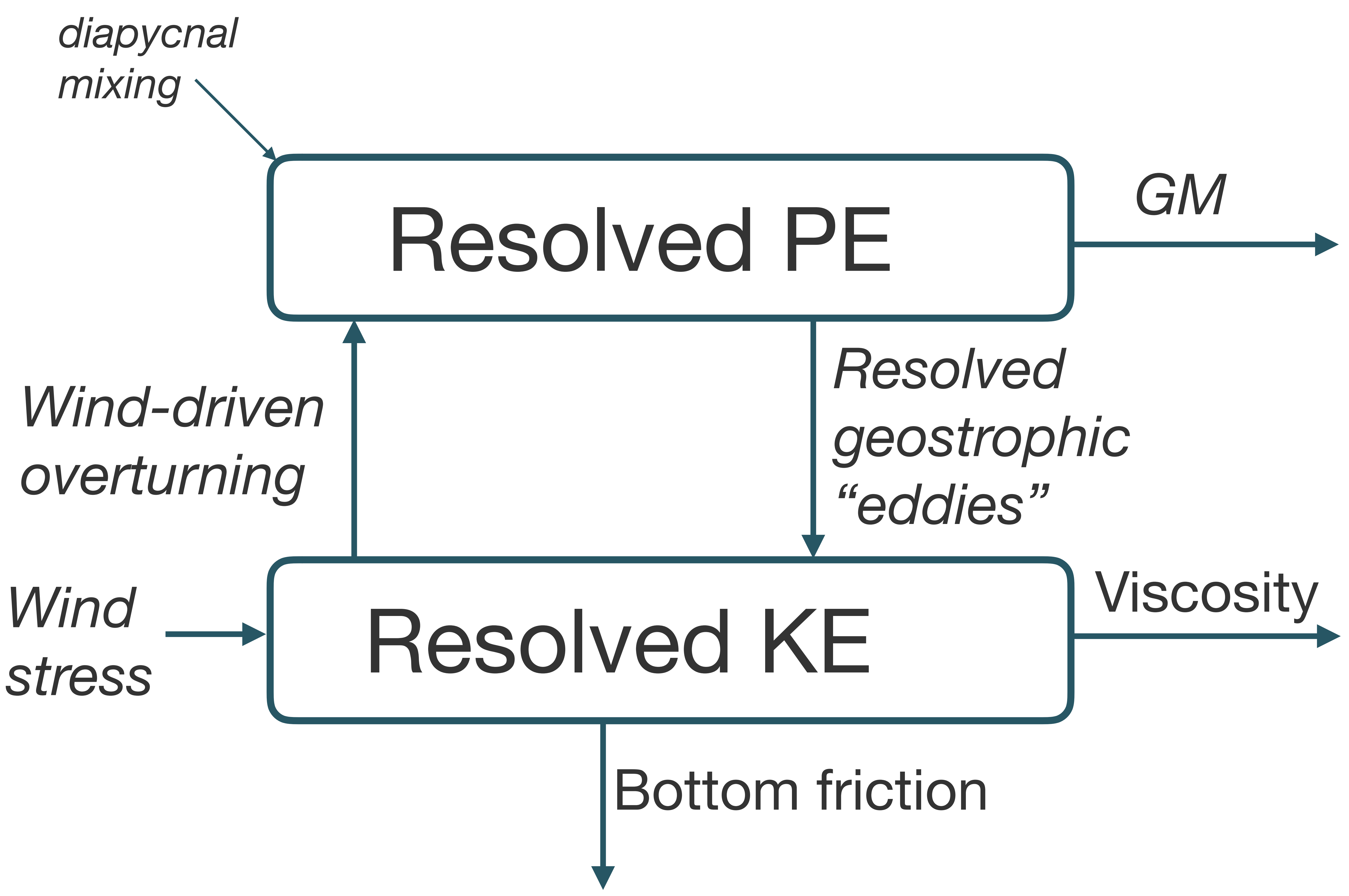
- Model resolutions between ~ 1-1/8th degree occupy awkward “grey zone” where mesoscale “eddies” are (barely) permitted but not properly resolved

- Challenging to leverage this resolution regime, arguably because existing parameterizations are overly dissipative for eddy permitting simulations.

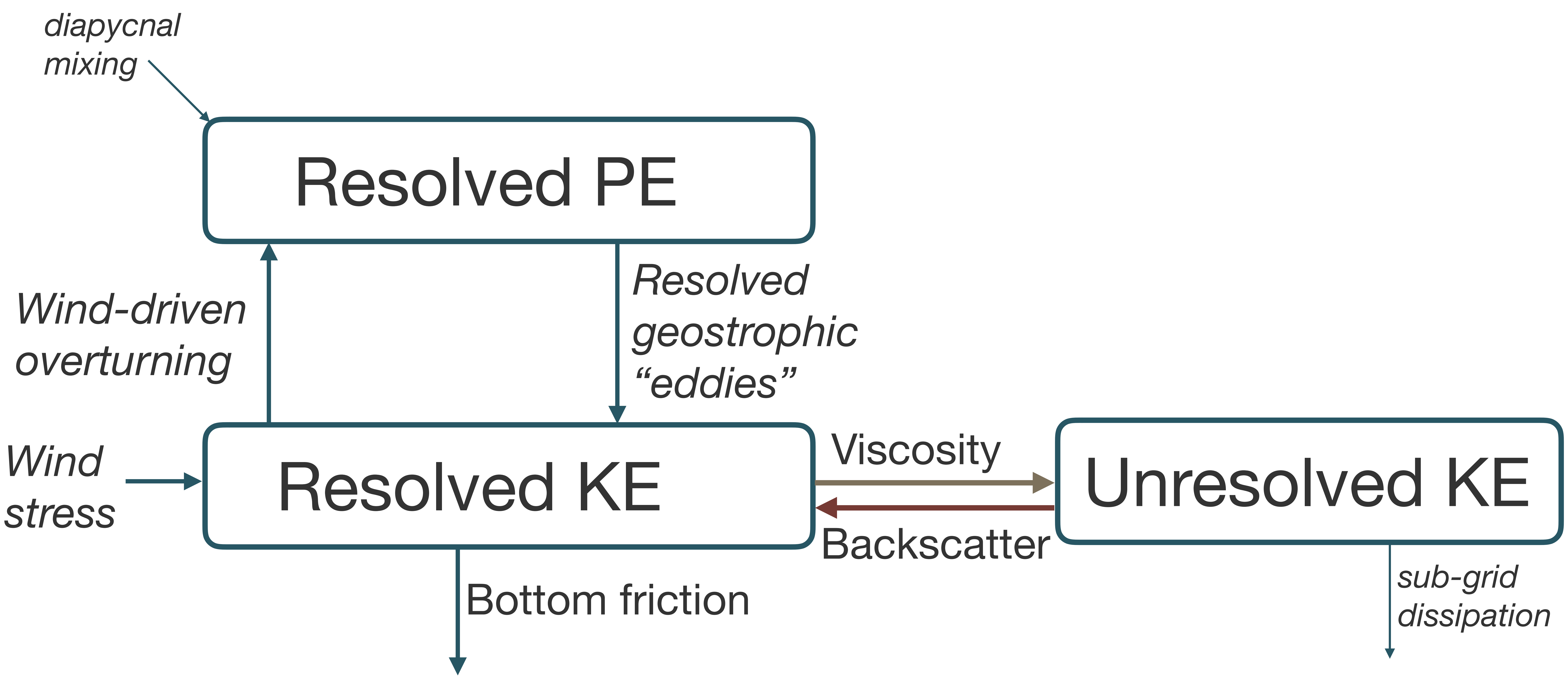
- Current “state of the art” is to treat models as either “eddying” or “non-eddying” in a binary manner (potentially switching within domain - e.g. Hallberg 2013)

- Noting that there exists a continuum of (transient and standing) eddy scales, can we do better than that?

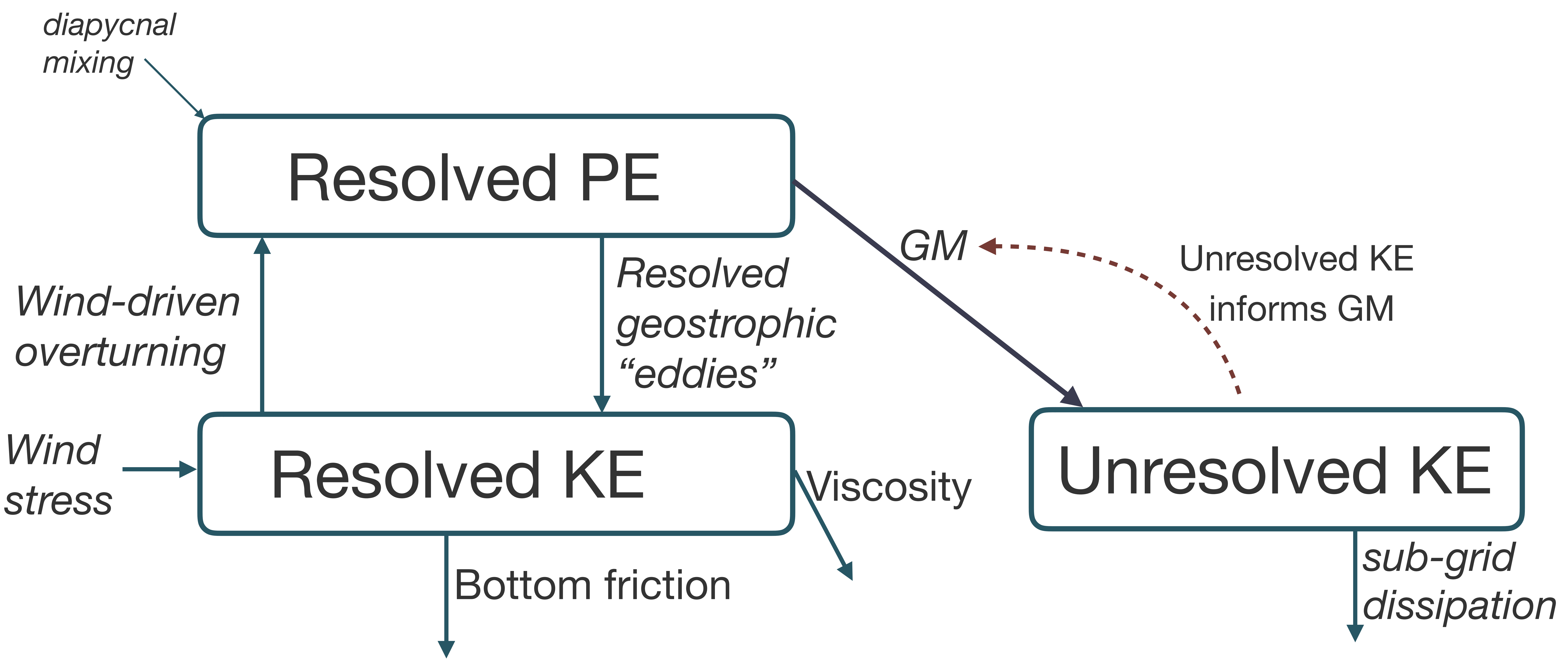
Energetics in Ocean models



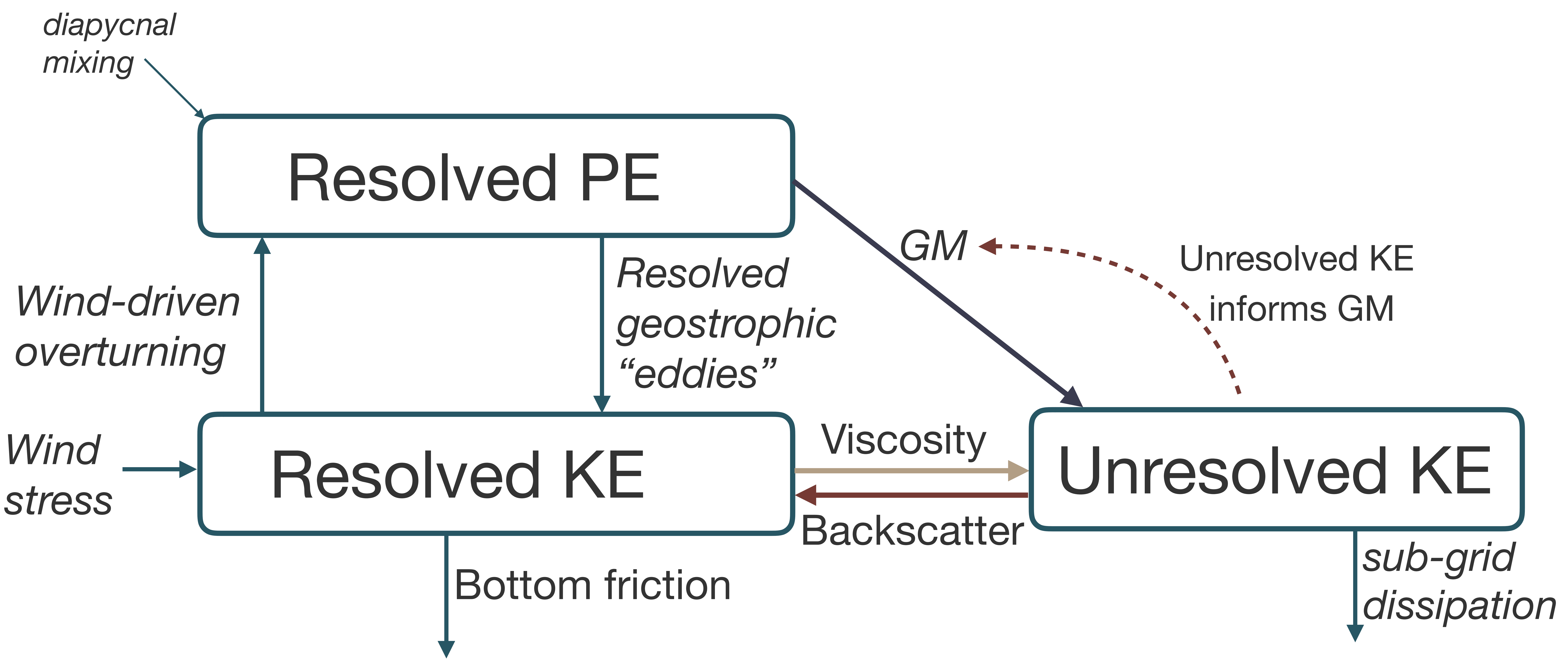
Energetics in Ocean models
"Backscatter" (e.g. Jansen et al. 2015)



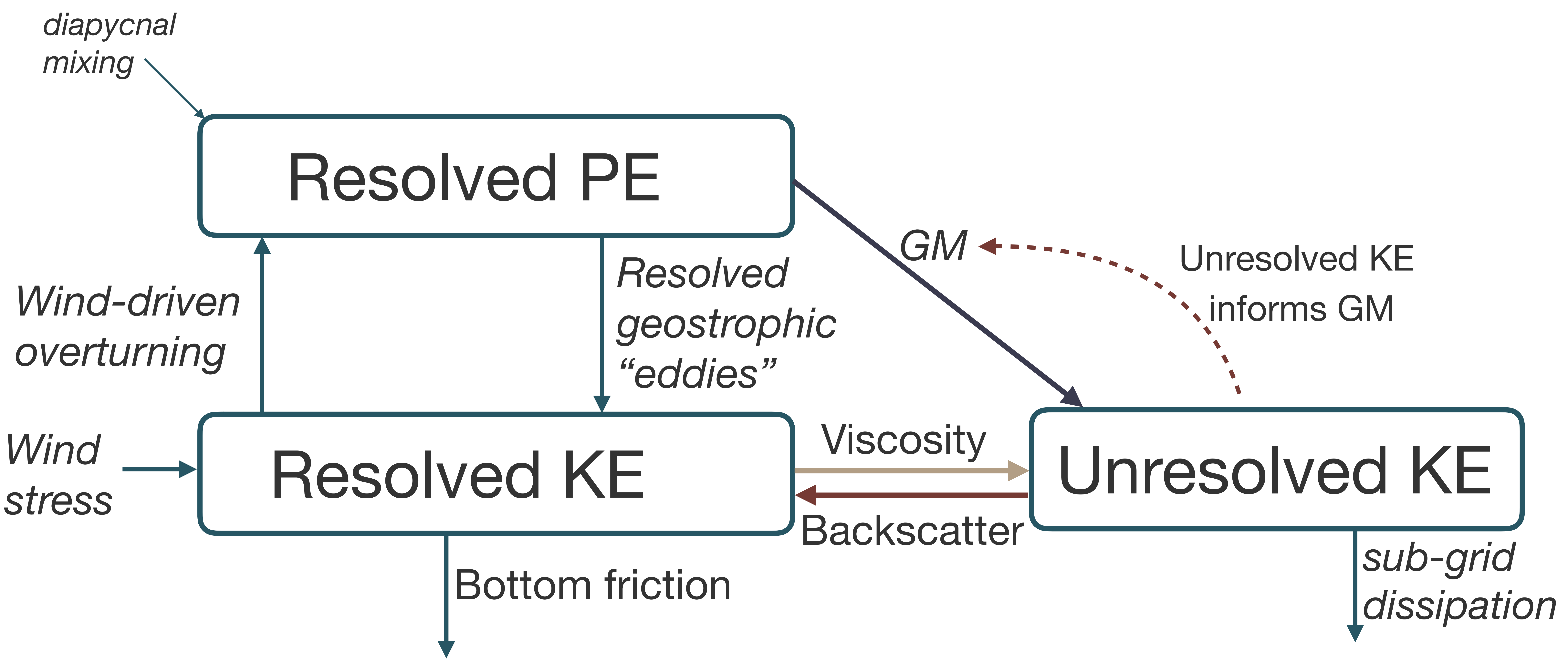
Energetics in Ocean models
"Energy budget-based GM" (e.g. Eden and Greatbatch 2008)



Energetics in Ocean models
Putting it all together

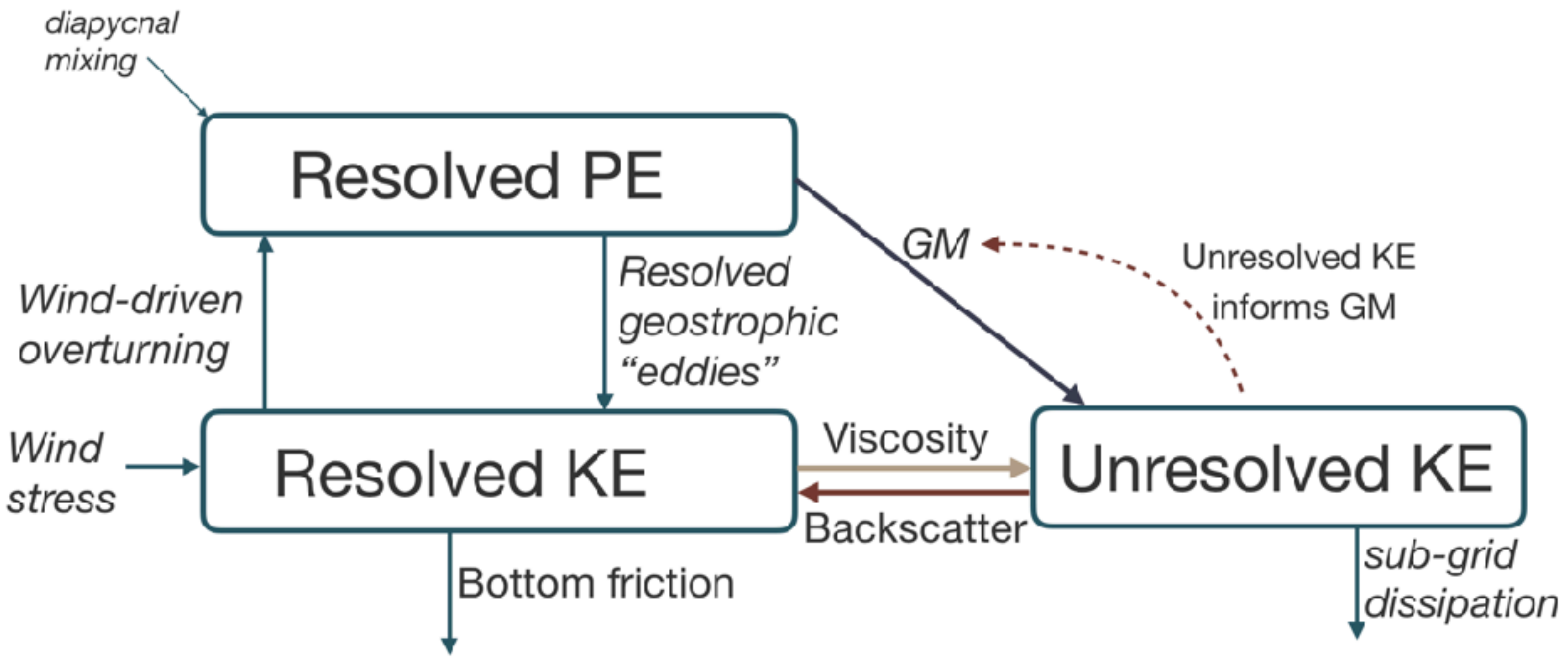


Energetics in Ocean models
Putting it all together



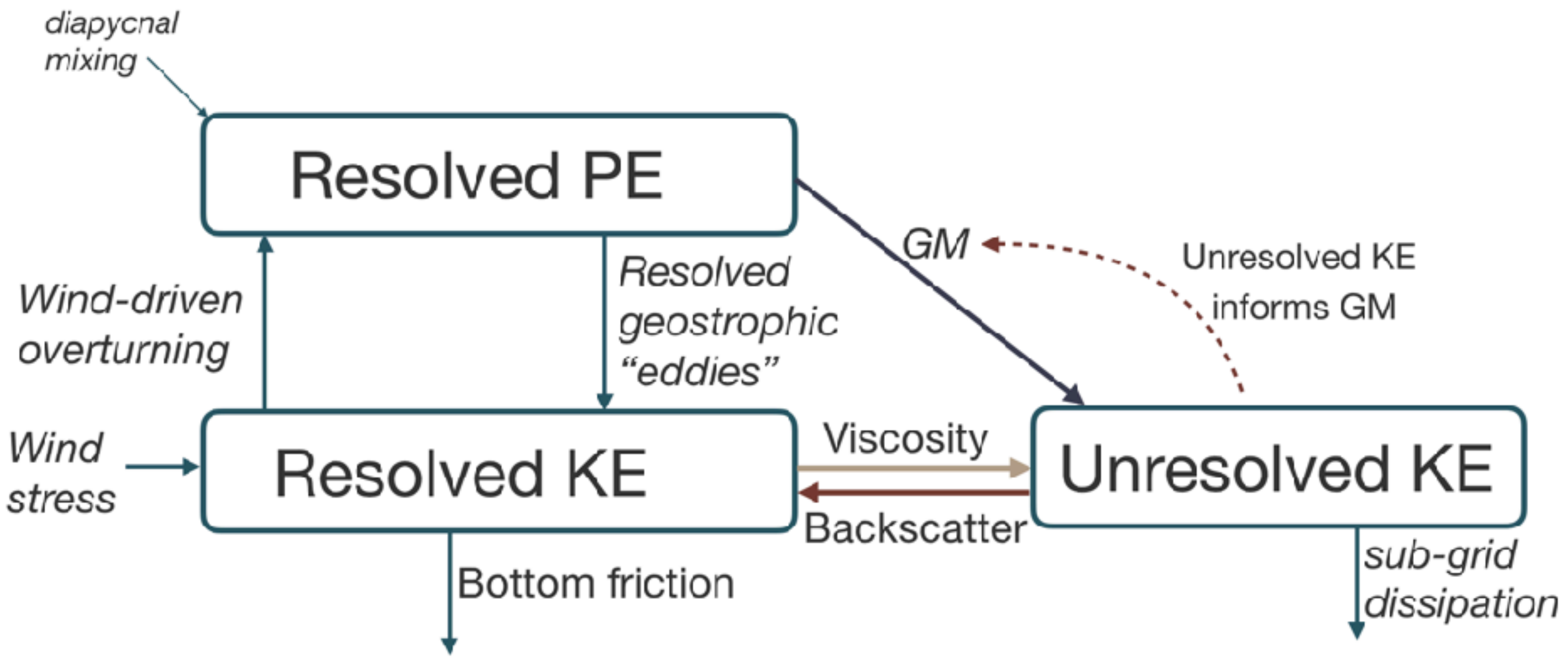
see also: Bachman 2019, Ocean modelling

Energetics in Ocean models
Equations



$$\partial_t e = \boxed{\dot{e}_{GM}} \boxed{+ \dot{e}_{\nu_4}} \boxed{- \dot{e}_{\nu_2}} \boxed{- \dot{e}_{diss}} + \frac{1}{H}\nabla \cdot (H\mathbf{F_e})$$

Energetics in Ocean models
Equations



$$\nu_4 = (c_{smag}|D| + \tau_{\nu_4}^{-1})\Delta^4$$

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Energetics in Ocean models
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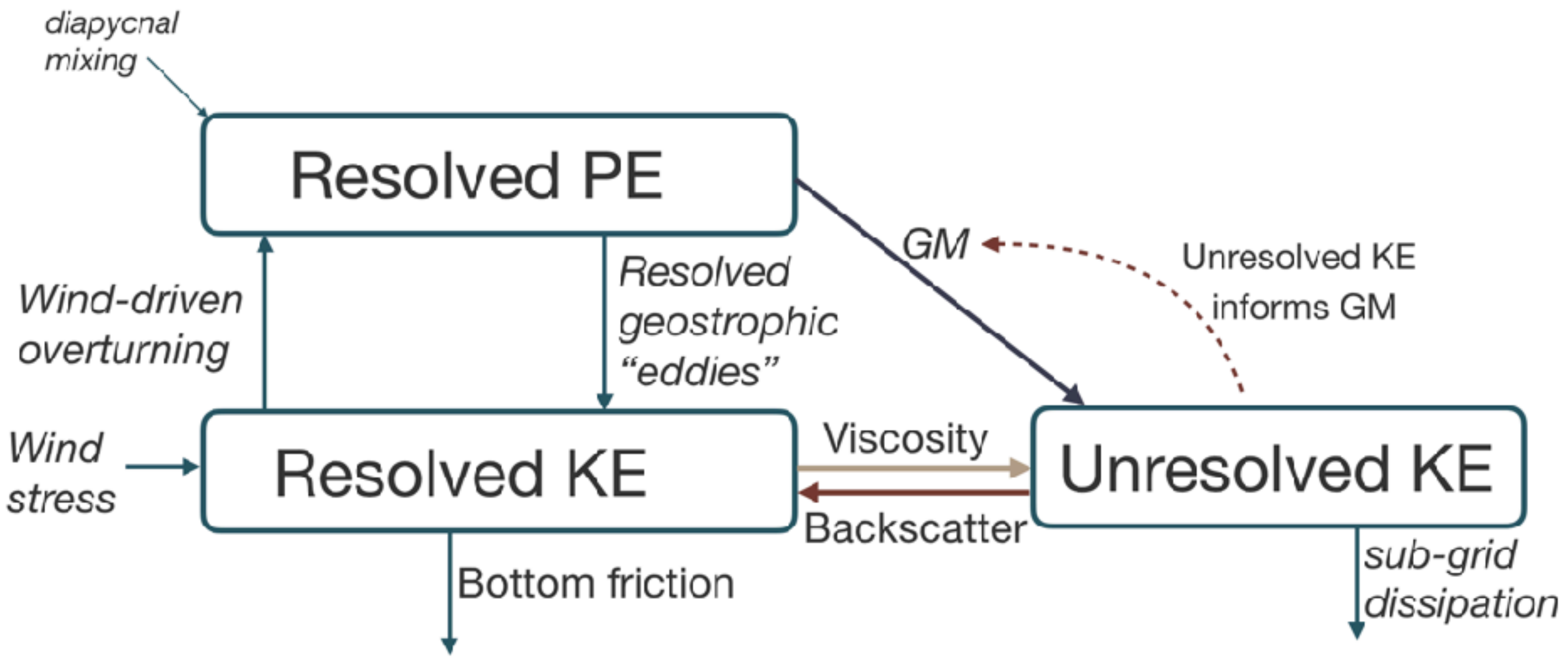

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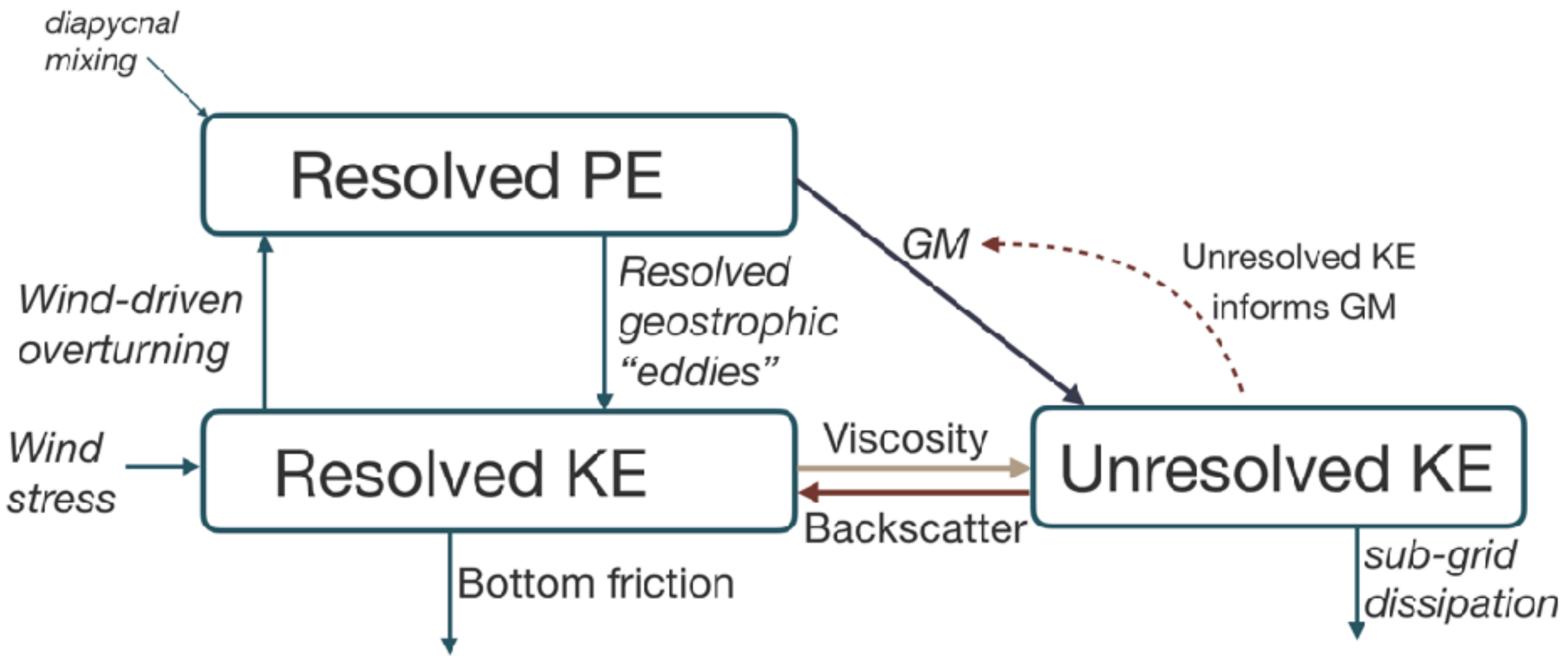
$$\boxed{\nu_4 = (c_{smag}|D| + \tau_{\nu_4}^{-1})\Delta^4}$$

$$\boxed{K_{GM} = -\nu_2 = \alpha\sqrt{2e}\,L_{mix}\,R(\Delta k_d)}$$

$$L_{mix} = \min(\Delta, L_{\beta *})$$

$$R(\Delta k_d) = \left[1 + \left(\frac{\Delta k_d}{\pi}\right)^{-2}\right]^{-1}$$

Energetics in Ocean models
Equations



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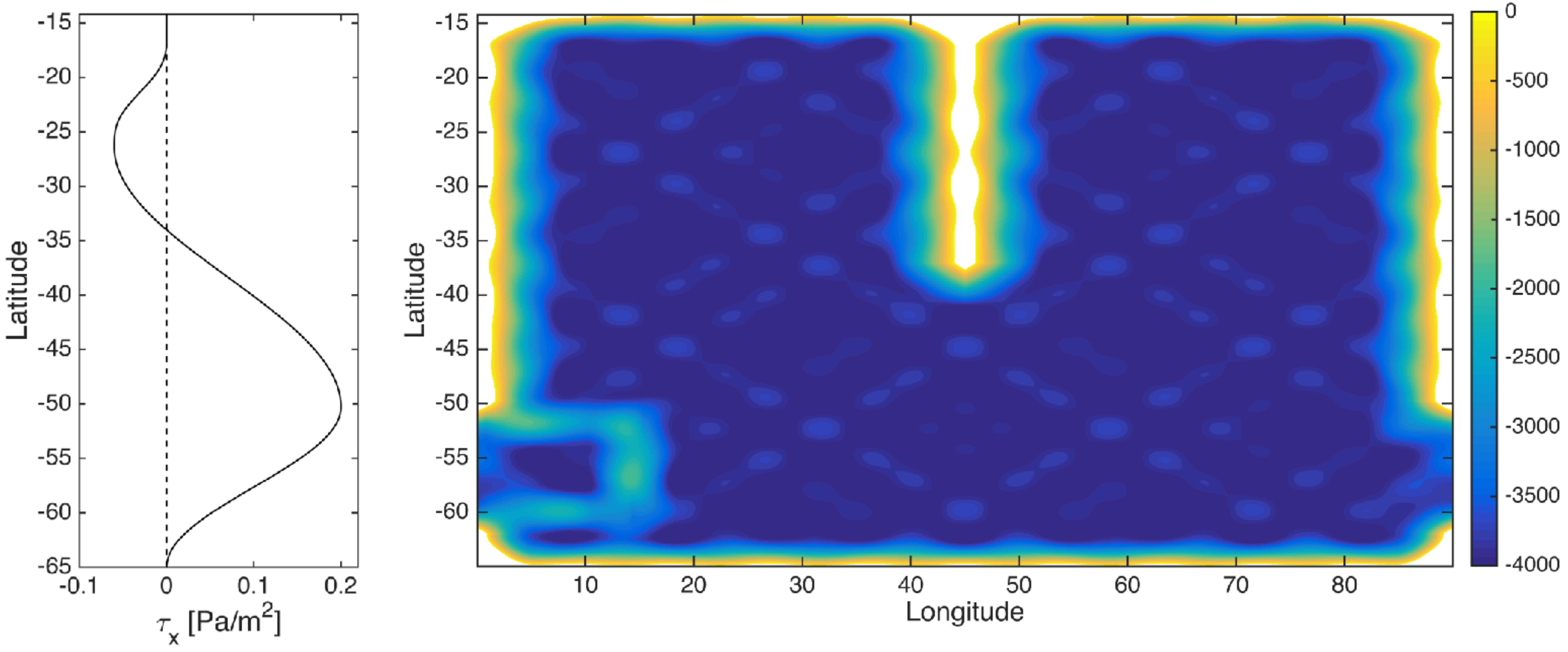
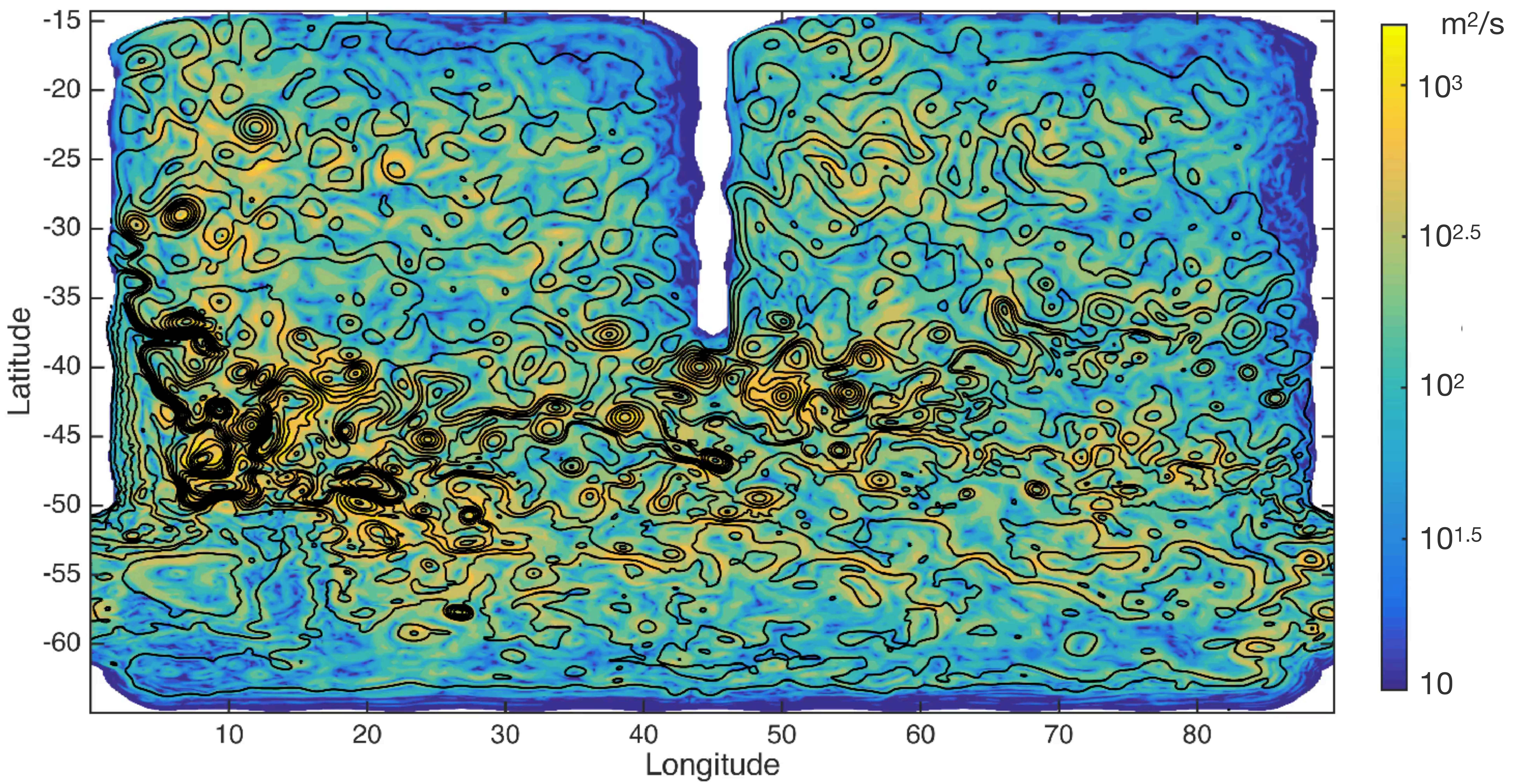
$$\dot{e}_{diss} = -c_d\sqrt{(e + \mathbf{u}_{bot}^2 + U_{bg}^2)}\;e$$

Neverland



- MOM6
- 6 isopycnal layers
- fully adiabatic

Neverland
A high resolution reference solution



Testing parameterizations

- We will here consider three different parameterizations:

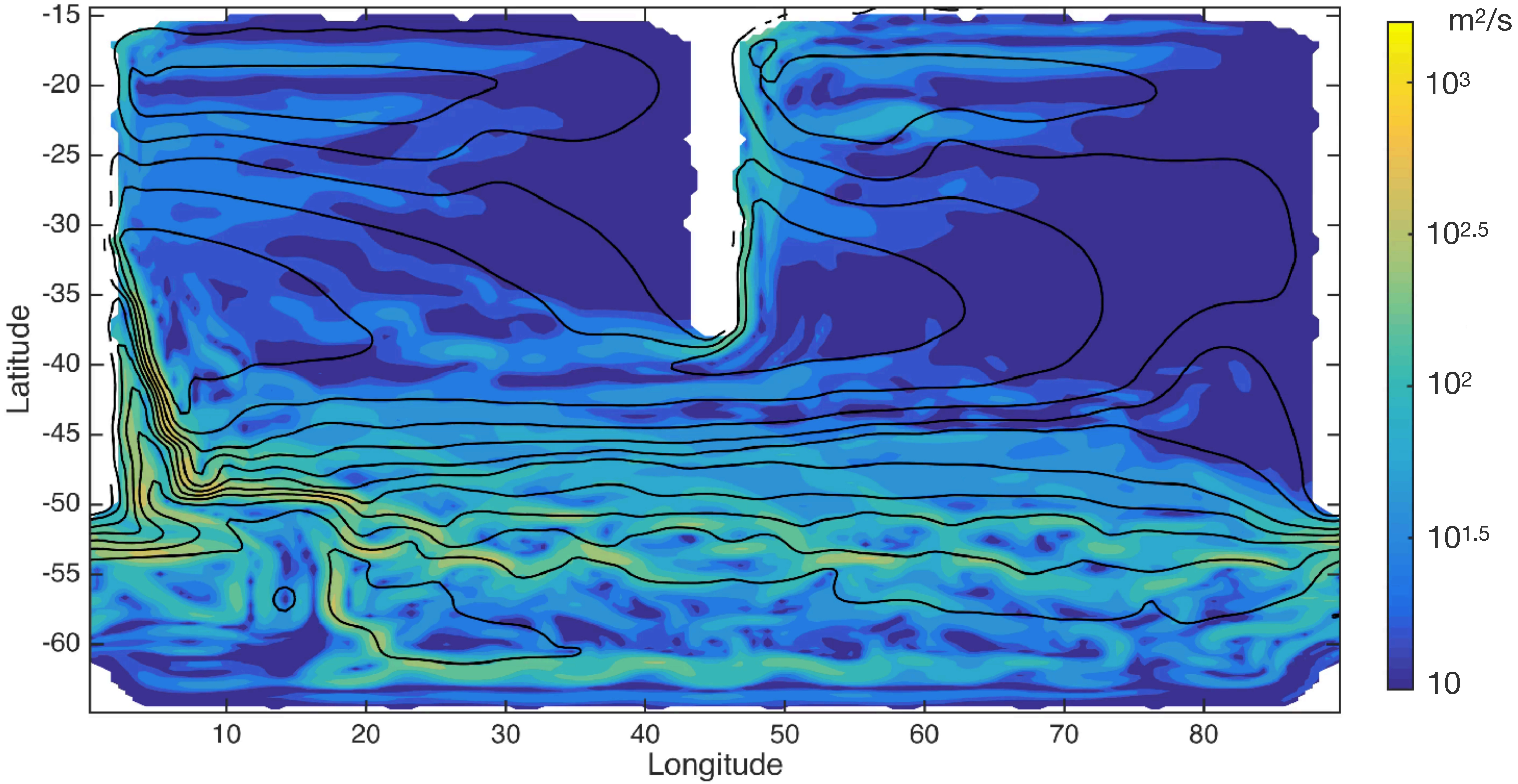
MEKE GM + Backscatter: $K_{GM} = -\nu_2 = \alpha\sqrt{2e}\,L_{mix}\,R(\Delta k_d)$ with $\alpha = 0.16$

Constant GM: $K_{GM} = const. = 1000\,m^2 s^{-1}$

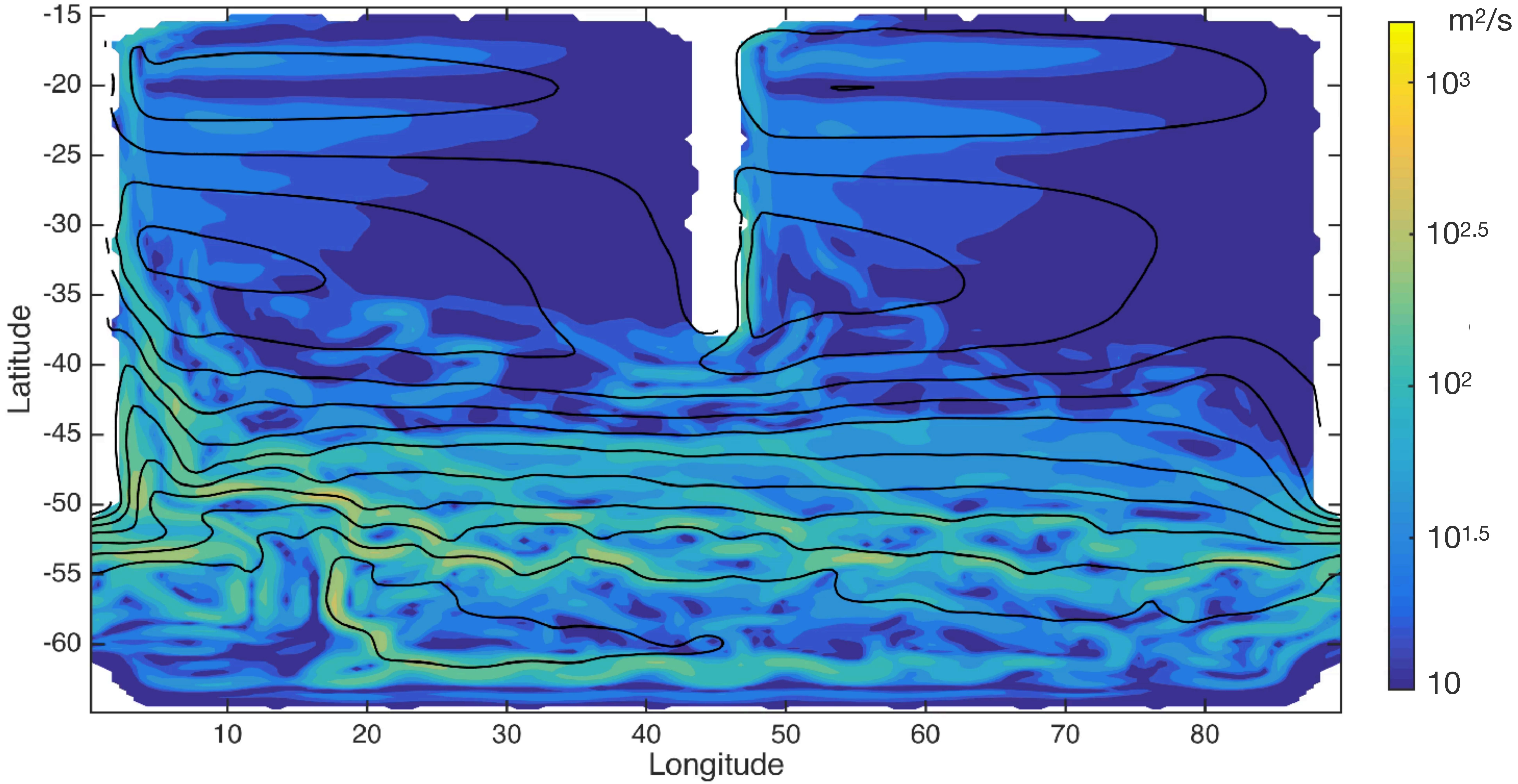
A “resolution aware” version of Visbeck (1997): $K_{GM} = \gamma s N \Delta^2$ with $\gamma = 1.1$

- In **all cases** one parameter is **tuned to match mean-state APE** from high-res simulation at 1/2^{o} resolution!

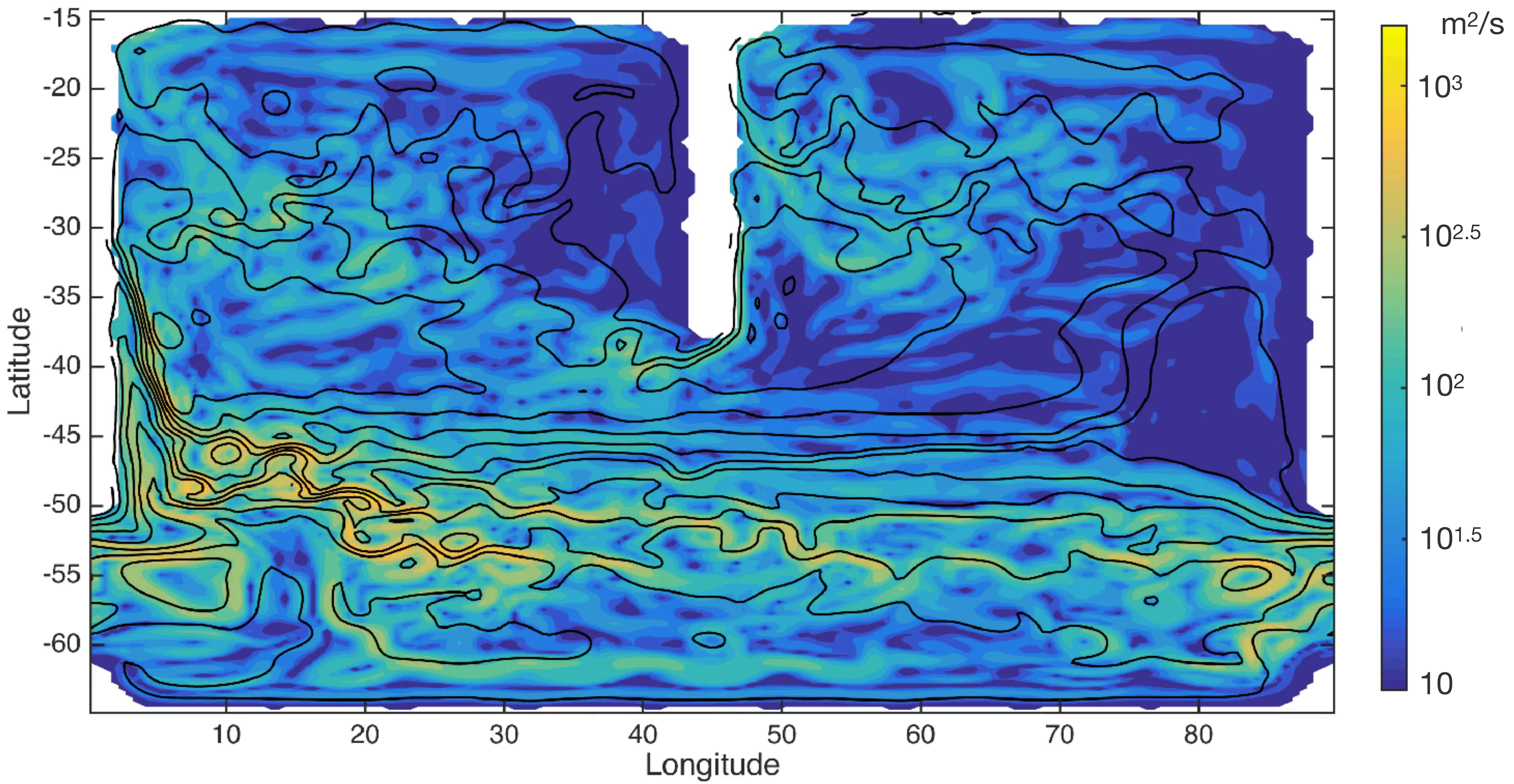
Results
Constant GM at 1/2 degree resolution



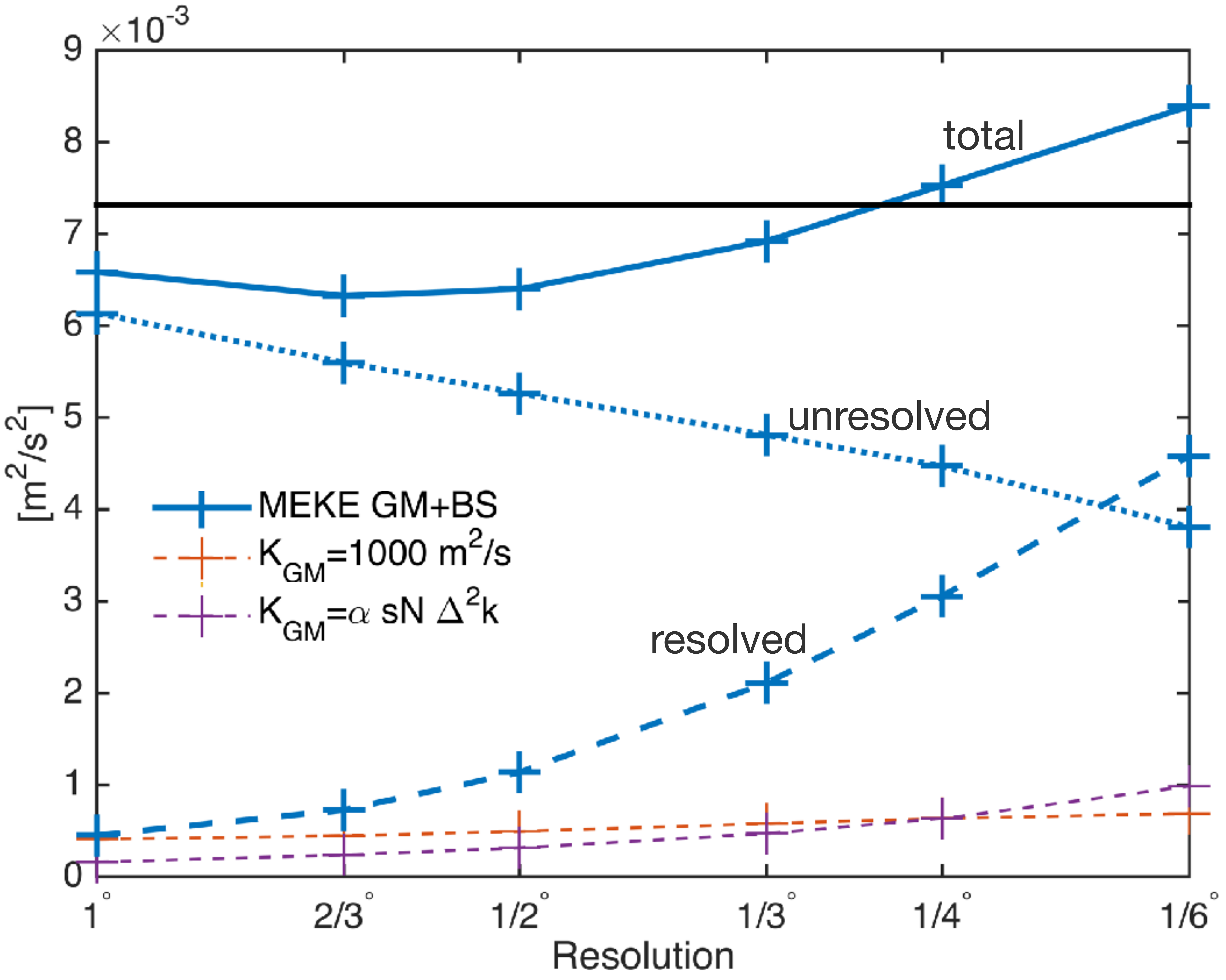
Results
“Visbeck” at 1/2 degree resolution



Results
Energy-budget based GM + backscatter at 1/2 degree resolution



Resolved and sub-grid KE as a function of resolution



Mean flow as a function of resolution
1) Metrics

Three metrics are here considered to quantitatively test mean state representation:

1) Mean-state APE: $$APE = \sum_n \iint g'_n \bar{\eta}_n^2 dxdy$$ (used to "tune" parameterizations)

2) Weighted interface height error: $$\epsilon^2 = \frac{1}{A} \sum_n \iint g'_n (\bar{\eta}_n - \bar{\eta}_{n_{1/16}})^2 dxdy$$

3) ACC transport: $$T_{ACC} = \sum_n \int (\overline{vh})_n dx$$

Mean flow as a function of resolution
2) Results

Conclusions

- Energy budget based mesoscale eddy closures can be useful if we account for energy “backscatter” to the resolved flow.

- Including backscatter can lead to significant improvements, particularly in barely eddy permitting “grey zone”:

  a) More energetic flow with improved internal variability

  b) Smooth connection between the non-eddying and eddy-resolving regimes, with

  c) Mean flow properties as good or better than GM (at relatively coarse res) or no GM (at higher res)

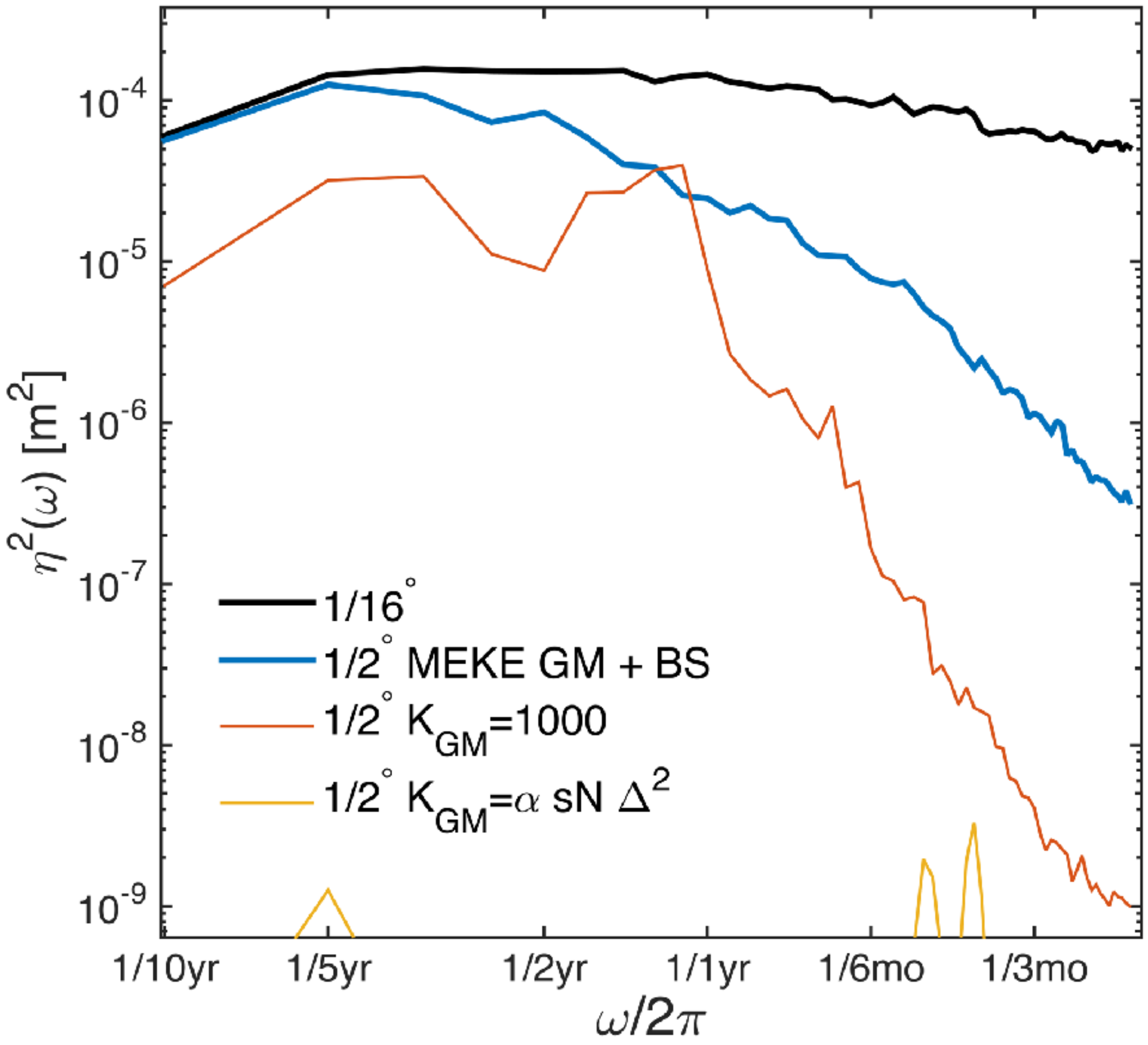
- Important questions (and room for improvement) remain, including:

  a) Vertical structure of eddy energy and fluxes

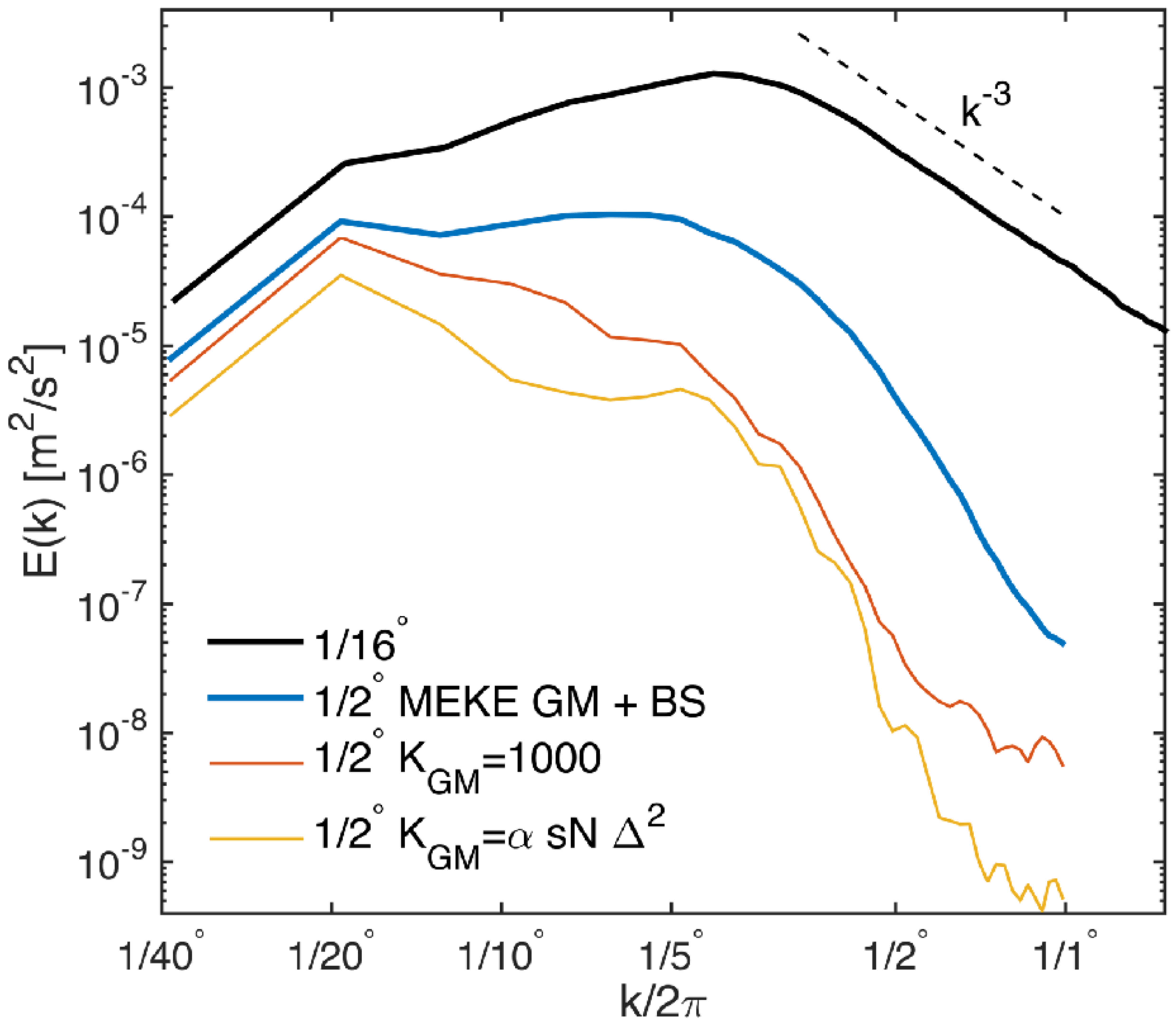
  b) Transport of (sub-grid) eddy energy

  c) Sub-grid dissipation?!

Variance spectra



Kinetic energy spectra



Mean Flow
SSH

Mean Flow
Isopycnal Depth (1027 kg/m³)

Mean Flow
Isopycnal Depth (1027.5 kg/m³)

Energy Budgets