# MESO-SCALE EDDY PARAMETERISATIONS, FORWARD APE CASCADE, AND DIAPYCNAL MIXING

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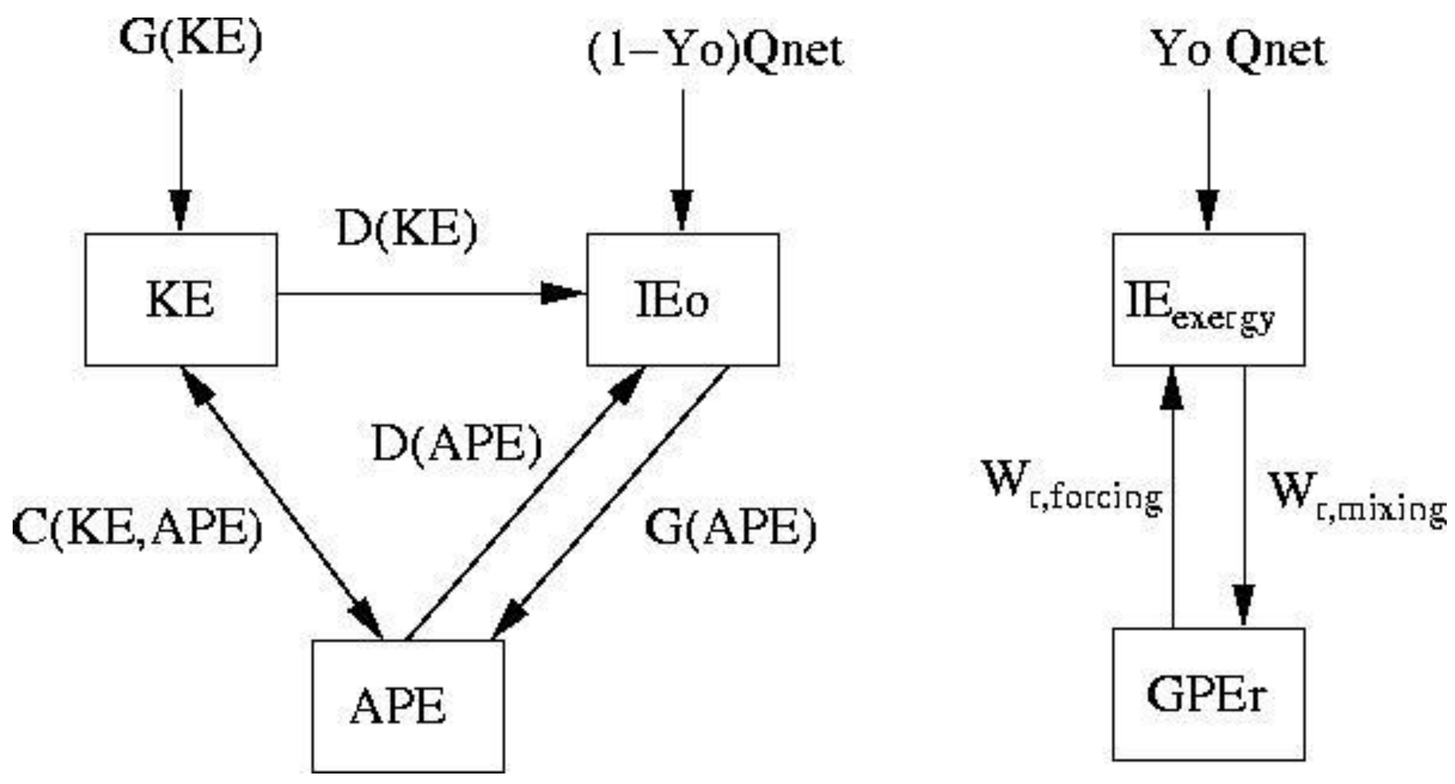
## 1.INTRODUCTION

Meso-scale eddy parameterisations, such as the well-known Gent/McWilliams (1990) parameterization, form a crucial component of modern Ocean Numerical General Circulation Models. Such parameterizations usually add a bolus velocity to the tracer advecting velocity, which are generally constrained so as to remove available potential energy (APE) adiabatically, i.e., without affecting the background Gravitational Potential Energy. The fate of the APE thus removed, and its possible link with diabatic turbulent diapycnal mixing has been an issue much debated over the past decade, e.g., Tandon and Garrett (1996). The purpose of this poster is to link GM-type parameterizations to the forward APE cascade and diapycnal mixing by using new results about the energetics of turbulent stratified fluids recently developed by Tailleux (2009) and Tailleux and Rouleau (2009).

## 2. ENERGETICS OF TURBULENT STRATIFIED FLUIDS

The energy conversions taking place in a turbulent stratified fluids are a controversial topic that was only resolved recently by Tailleux (2009, submitted to JFM). These are illustrated in Fig. 1




G(KE): Work rate done by the wind
G(APE): Work rate done by surface buoyancy fluxes
APE = Available Potential Energy
KE = Kinetic Energy
IEo = Dead Internal Energy
IEexergy = Exergy part of Internal Energy
GPEr = Background Gravitational Potential Energy
D(APE) = Diffusive dissipation rate of APE
D(KE) = Viscous dissipation rate of KE
C(KE,APE) = buoyancy flux
Qnet = Net surface heating and cooling rate
Wr,forcing = Rate of change of GPEr due to buoyancy forcing
Wr,mixing = Rate of change of GPEr due to molecular diffusion
Yo = Thermodynamic efficiency factor (much smaller than 1)

***Figure 1:*** *Energetics of a wind- and buoyancy driven turbulent ocean.*

Dynamics and Thermodynamics are coupled

$$W_{r,turbulent} = \xi\, D(APE), \qquad W_{r,forcing} \approx G(APE)$$

where ξ is a non-Boussinesq nonlinearity parameter. As a result, the work rates G(KE) and G(APE) are coupled as follows:

$$G(KE) = \frac{1+(1-\xi)\gamma_{mixing}}{\xi\,\gamma_{mixing}}\,G(APE) = \frac{1-\xi R_f}{\xi R_f}\,G(APE)$$

The case ξ=1 recovers Munk and Wunsch (1998)'s constraint on the mechanical energy sources of stirring required to sustain oceanic diapycnal mixing. The table displays the constraint on G(KE) assuming G(APE)=0.4 TW for different values of ξ and γmixing.

| | γmixing=0.2 | γmixing=0.5 | γmixing=1 |
|---|---|---|---|
| ξ=1 | 2 TW | 0.8 TW | 0.4 TW |
| ξ=0.5 | 4.4 TW | 2 TW | 1.2 TW |

## 3. SEPARATION INTO LARGE-SCALE & EDDY RESERVOIRS

Since numerical ocean models cannot resolve all scale of motions, understanding their energetics requires separating resolved and unresolved parts, as illustrated in Fig. 2.

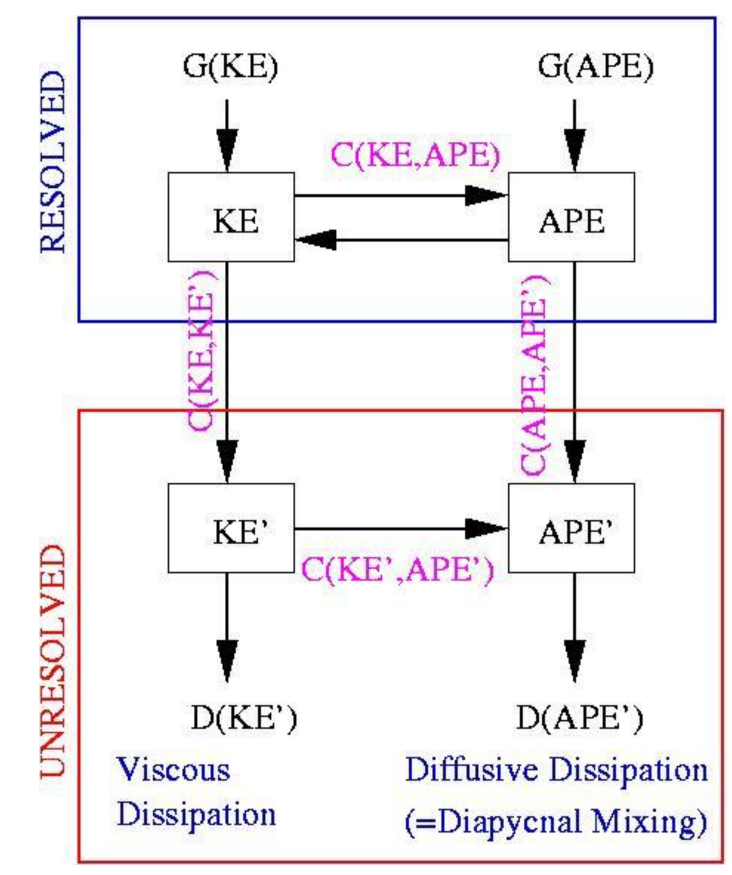



**Fig. 2**: *Energetics of wind- and buoyancy -driven Ocean illustrating the energy conversion taking place between the resolved and unresolved KE and APE reservoirs. Model "Viscous" dissipation is associated with the C(KE,KE') conversion, the meso-scale eddy parameterization associated with the C(APE,APE') conversion*

## 4. LINKS BETWEEN C(APE,APE') and D(APE')

Fig. 2 shows that all the APE cascaded toward smaller scales by the meso-scale eddy parameterization will be dissipated by molecular diffusion whenever C(KE',APE')>0, as occurs for instance in shear flow instability. Only if C(KE',APE')<0 is it possible for part of the cascaded APE to be eventually dissipated by viscous dissipation. Fig. 3 shows how the energy conversion rates of Fig. 2 when the assumed value of mixing efficiency is varied. The conversions are affected by the following parameters:

**Γape** : Fraction of large-scale APE being converted into large-scale KE
**Γke** : Fraction of large-scale KE being converted into large-scale APE
**Rf** : Bulk flux Richardson number for the oceans
**ξ** : Nonlinearity parameter linking D(APE) and Wr,turbulent for a nonlinear equation of state

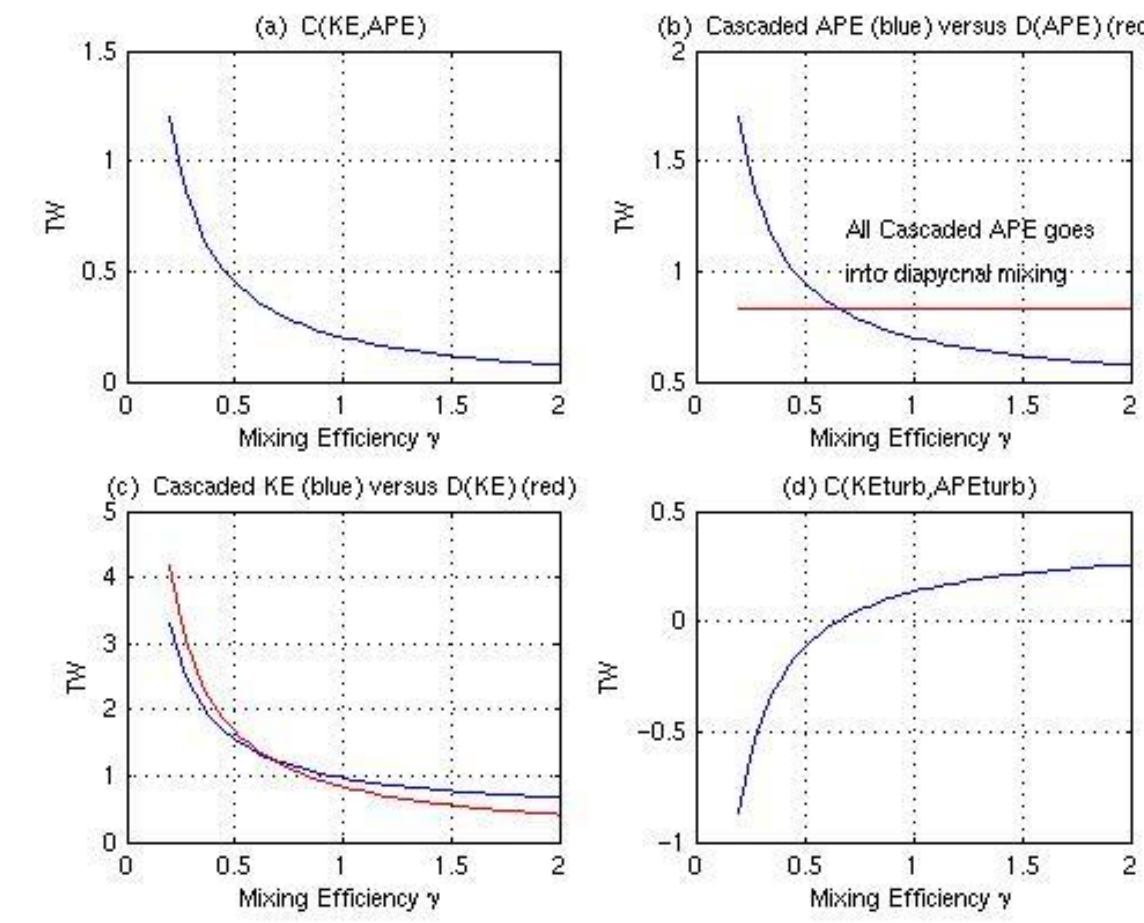



**Fig. 3**: *Energy conversion rates as a function of the Mixing efficiency, for the particular values G(APE)=0.5 TW , Γape=Γke=0.3, and ξ=0.8. Fixing the value of mixing efficiency then determines the value of G(KE) as well as of all the energy conversions. Panel (b) shows that when C(KE',APE') is positive, all the APE dissipated by the meso-scale eddy parameterization should go into turbulent diapycnal mixing. Note that the rate of KE dissipated by the forward KE cascade is very close to the total viscous dissipation rate.*

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**5. CONCLUSIONS** The meso-scale eddy parameterization is identified here with the forward APE cascade that drives turbulent diapycnal mixing, either partly or in totality, in the oceans. The APE cascade itself is reversible and adiabatic, so that it is physically required that the APE be removed adiabatically. Depending on the sign of the energy conversion C(KE',APE'), however, all or a fraction of the APE dissipated by the meso-scale eddy parameterization must be tied to diffusive dissipation and hence to the diapycnal mixing rate. How to do this is currently under investigation.