# Spectral resolution of the ocean‘s Lorenz energy cycle

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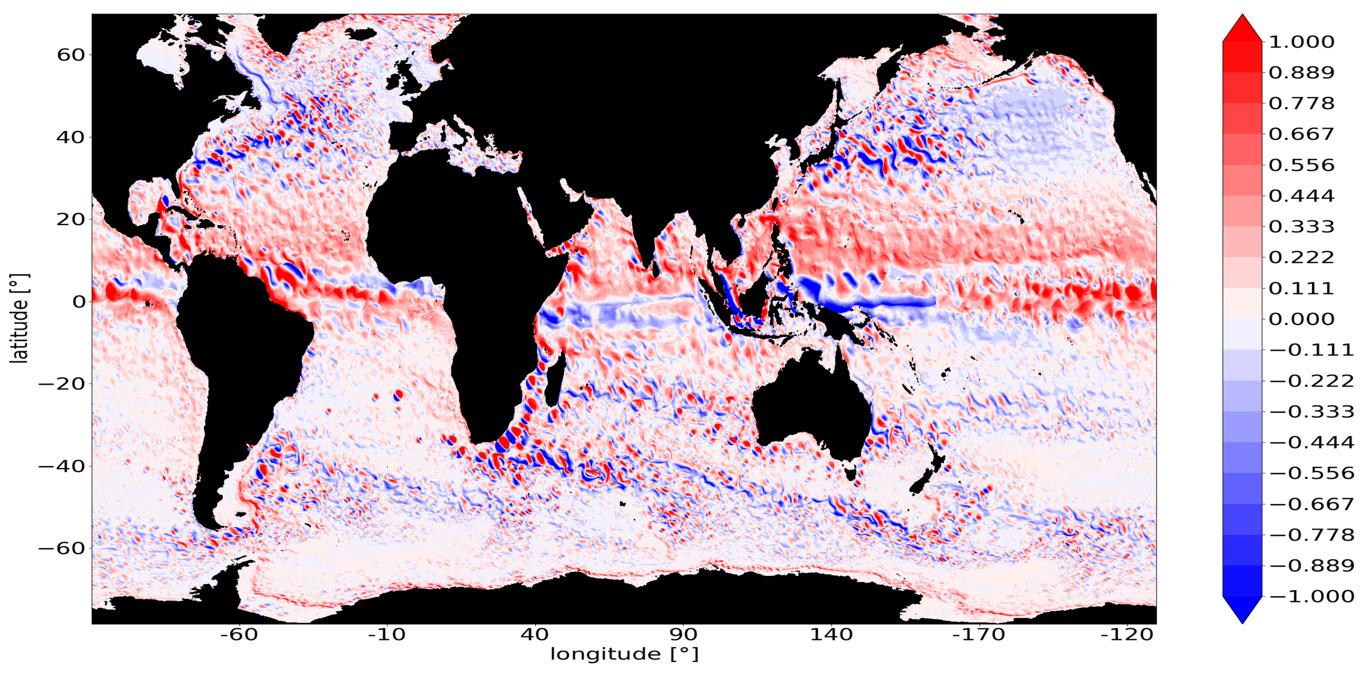
## Motivation & Theory



*Snapshot of relative vorticity $dv/dx - du/dy [s^{-1}]$ in the surface layer of the 1/10° x 1/10° POP ocean model in pyom configuration.*

$$\partial_t e = \underbrace{-\Re\left[\overline{\frac{1}{\rho_0}\partial_z \hat{p}' \hat{w}'^*}\right]}_{1} \underbrace{+\Re\left[\overline{\hat{w}'^* \hat{b}'}\right]}_{2} \underbrace{-\Re\left[\overline{\hat{\mathbf{u}}_h'^* \cdot \widehat{(\bar{\mathbf{u}}\cdot\nabla_h)\mathbf{u}_h'} + \hat{\mathbf{u}}_h'^* \cdot \widehat{(\mathbf{u}'\cdot\nabla_h)\mathbf{u}_h'}}\right]}_{3} \underbrace{-\Re\left[\overline{\hat{\mathbf{u}}_h'^* \cdot \widehat{(\mathbf{u}'\cdot\nabla_h)\bar{\mathbf{u}}_h}}\right]}_{4}$$

$e$ eddy kinetic energy (EKE)

$$e(t,\mathbf{k},z) = \Re\left[\frac{1}{2}\hat{\mathbf{u}}_h'^* \cdot \hat{\mathbf{u}}_h'\right]$$

1. Pressure work
2. Baroclinic eddy production (BC)
3. Divergence of the EKE flux ($\nabla \cdot EKE_{flux}$)
4. Barotropic eddy production (BT)

$$\partial_t EPE_k = \underbrace{-\frac{1}{N^2}\Re\left[\overline{\hat{b}'^* * \widehat{(\bar{\mathbf{u}}_h\cdot\nabla_h)b'} + \hat{b}'^* * \widehat{(\mathbf{u}_h'\cdot\nabla_h)b'}}\right]}_{5} \underbrace{-\frac{1}{N^2}\Re\left[\overline{\widehat{b'\mathbf{u}_h'\cdot\nabla_h)\bar{b}}}\right]}_{6} \underbrace{-\Re\left[\overline{\hat{w}'^* \hat{b}'}\right]}_{2}$$

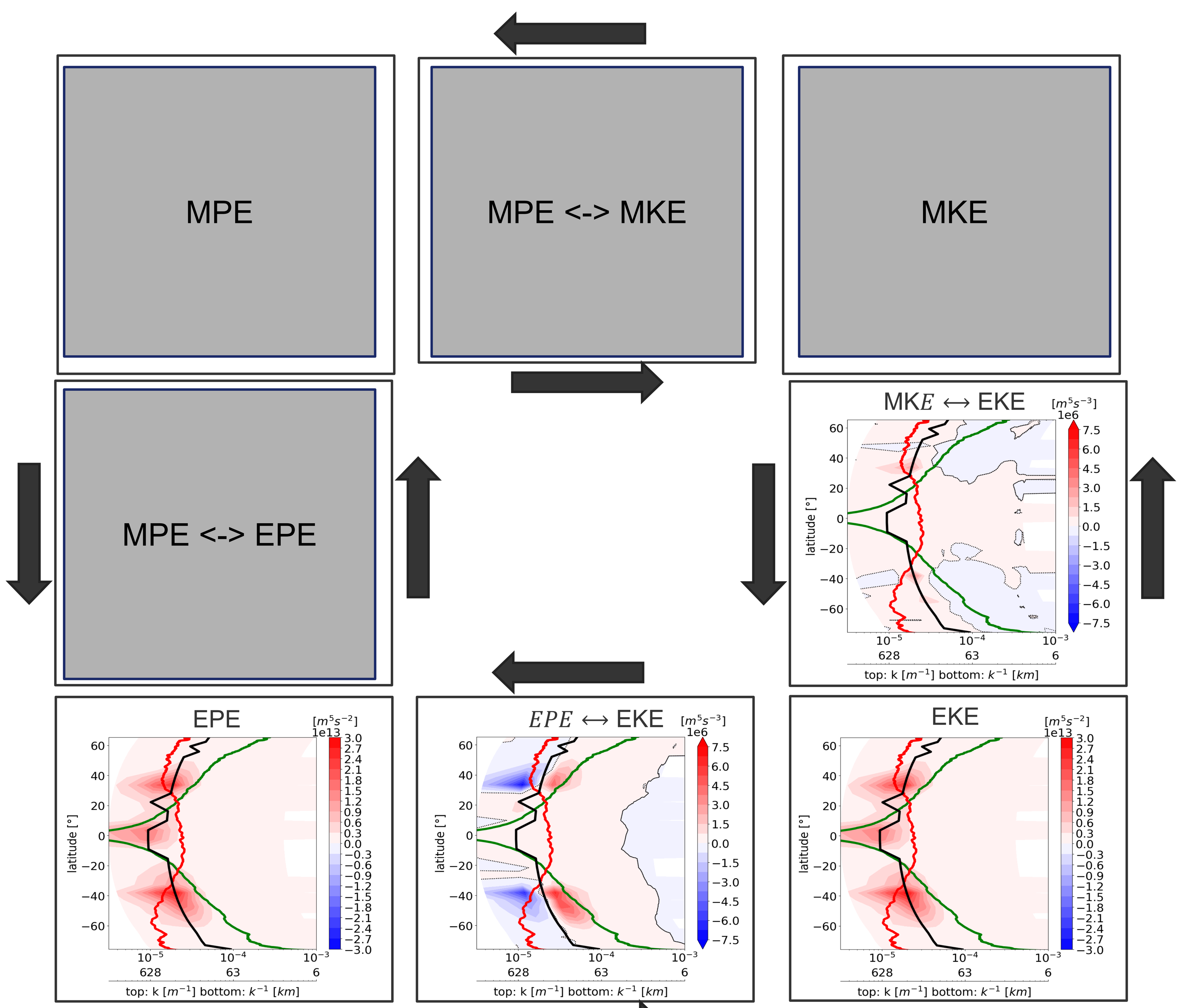
eddy available potential energy (EPE)

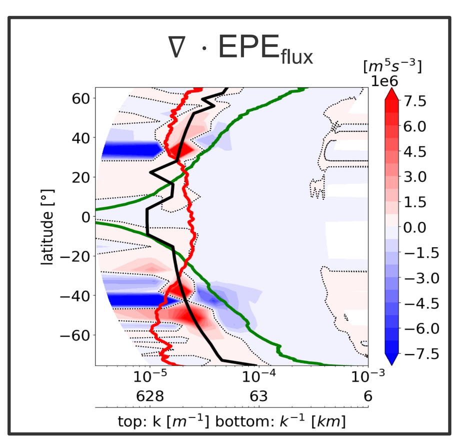
$$EPE_k(t,\mathbf{k},z) = \Re\left[\frac{\hat{b}'^* * \hat{b}'}{2N^2}\right]$$

5. Divergence of the EPE flux ($\nabla \cdot EPE_{flux}$)
6. Exchange with mean available potential energy

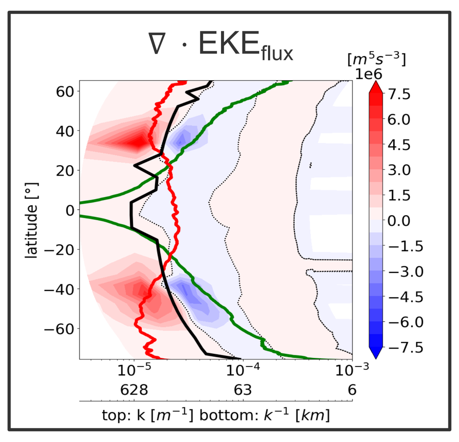
## Results

### Resolving the spectral LEC



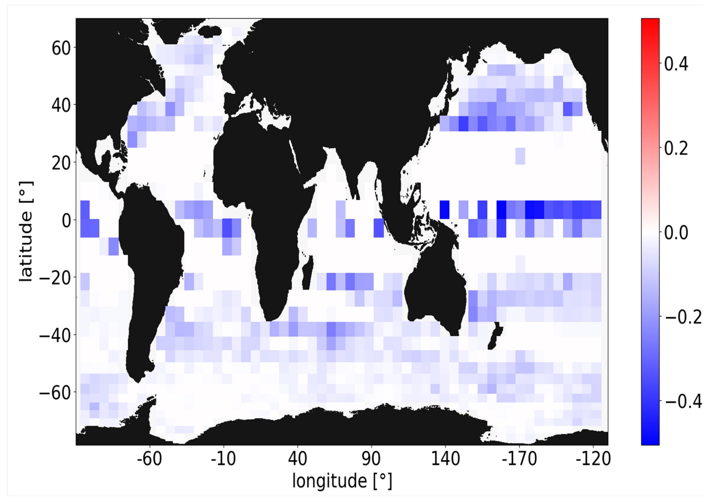




$L_{rossby}^{-1}$ — $L_{rhines}^{-1}$ — $k_{EKEmax}$

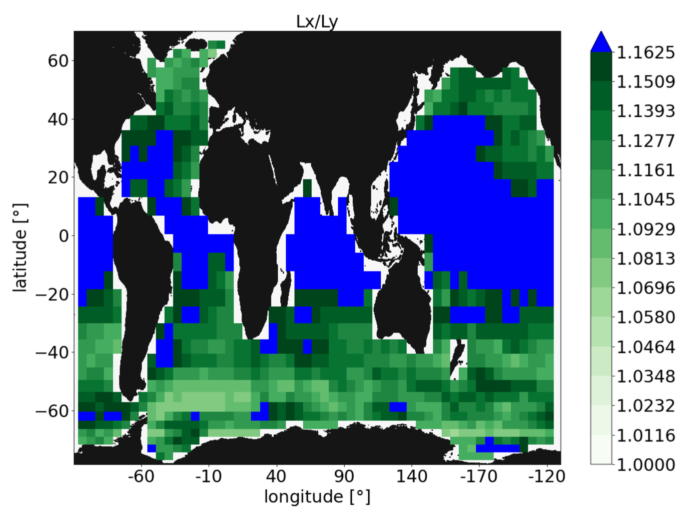



*Vertically and zonally integrated Terms of the LEC as a function of latitude and horizontal wavenumber magnitude k. Also shown are first baroclinic Rossby radius (green line), Rhines scale (red), and maximum of EKE (black).*

### Distribution of BC<0



*Average of $BC_{norm} = \frac{BC(k)dk}{\int |BC(k)|dk}$ for $k < k_{EKEmax}$ shows where BC<0 takes place. Apart from the equator it is limited to regions poleward of 30°*




*Ratio of zonal and meridional eddie scales shows the anisotropy of the eddie field*

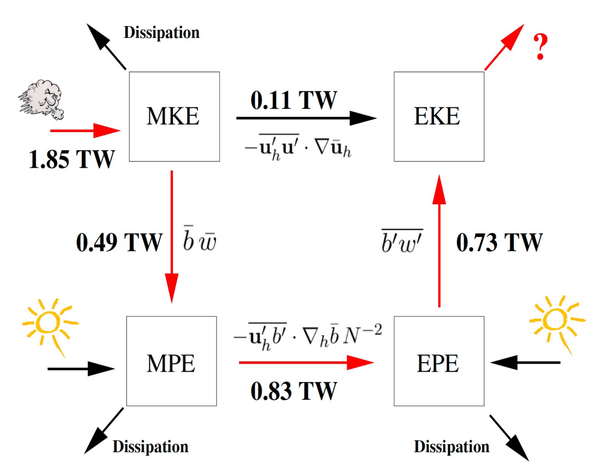
$$(k_x, k_y) = \frac{\int \mathbf{k} E(\mathbf{k}) k_h^{-2} dk}{\int E(\mathbf{k}) k_h^{-2} dk}$$

$$(L_x, L_y) = (2\pi/k_x, 2\pi/k_y)$$

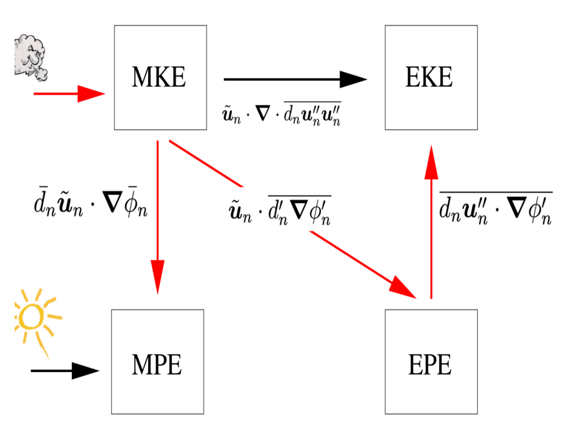
- BC < 0 takes place in the isotropic turbulence regime
- There the eddie scales are isotropic
- The eddies are not affected by energy transfer to Rossby waves and zonal jets (Theiss 2004, Eden 2007, Tulloch 2011)

## Ongoing Work

### Difficulty #1: Definition of energy cycle




*Lorenz energy cycle (averaging on z-levels)*



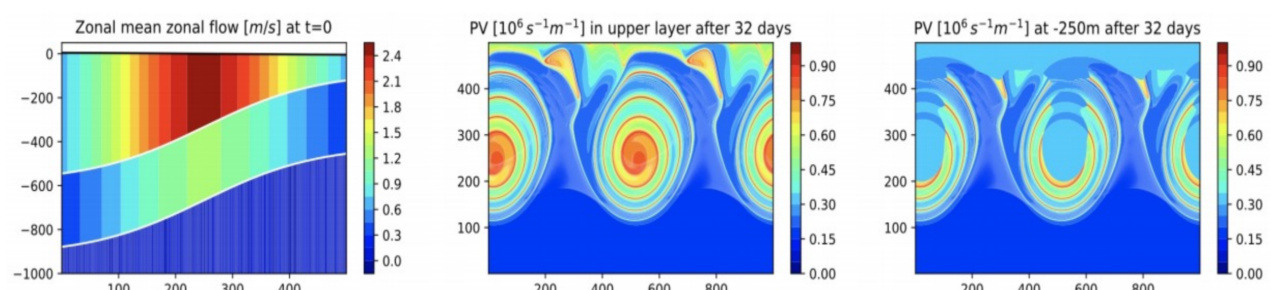

*Blecks energy cycle (isopycnal thickness weighted averaging)*

### Difficulty #2: Definition of available potential energy

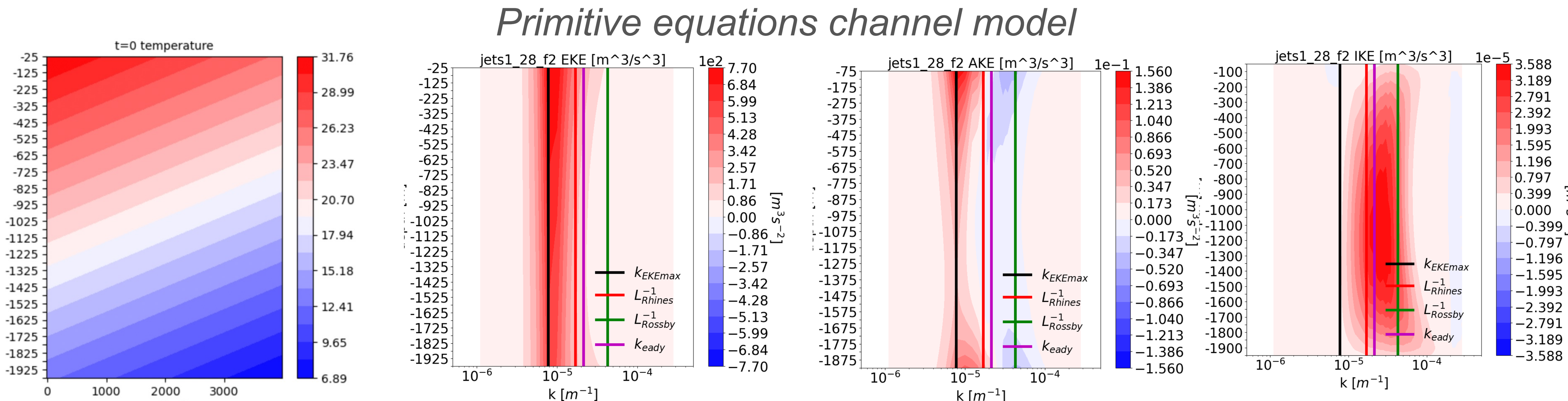
$EPE = \bar{b'^2}/(2N^2)$ $\quad MPE = \bar{b}^2/(2N^2)$

### Solution: Idealized models

*Z-layered model*



*Primitive equations channel model*



*Temperature(y,z) t=0* *EKE(k,z)* *div $EKE_{flux}$ (k,z)* *BC(k,z)*

*Channel model with zonal jet generated by baroclinic instability –> no BC<0 yet*