

# Ocean Convection

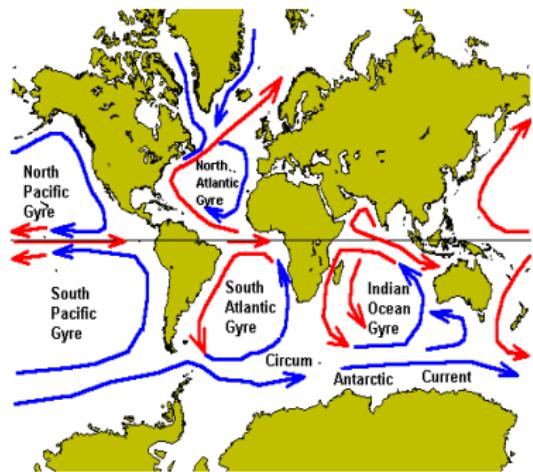
Achim Wirth

LEGI / CNRS

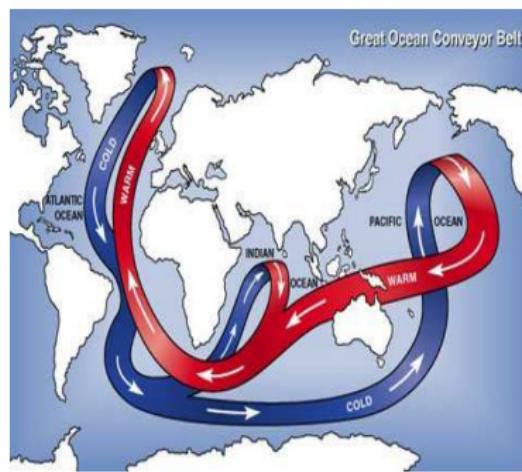
Aussois, Dec 13, 2011

# Ocean Circulation

Gyre  
“weather”



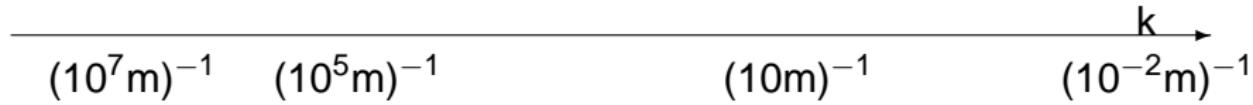
Overturning  
“climat”



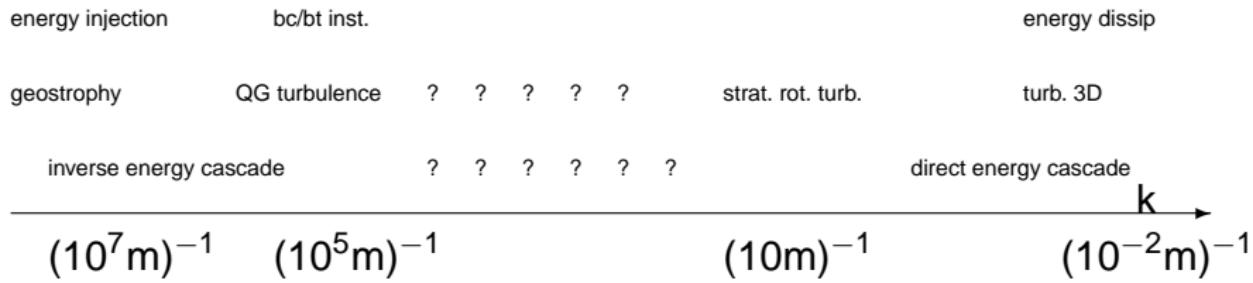
## Ocean Dynamics by Scale

energy injection

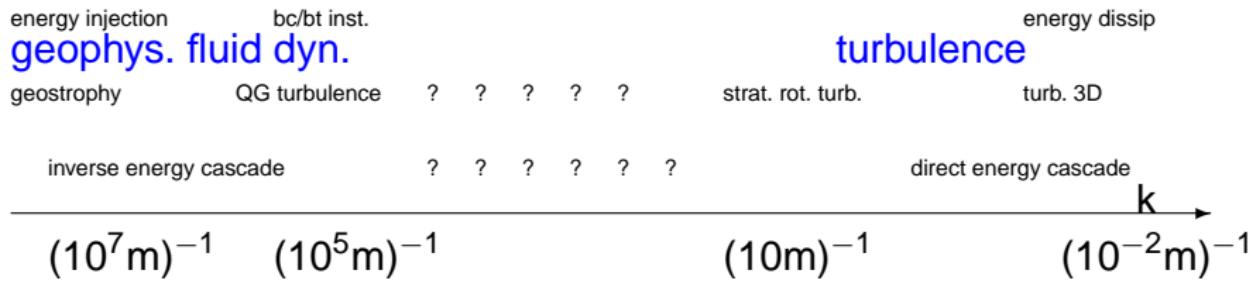
energy dissip



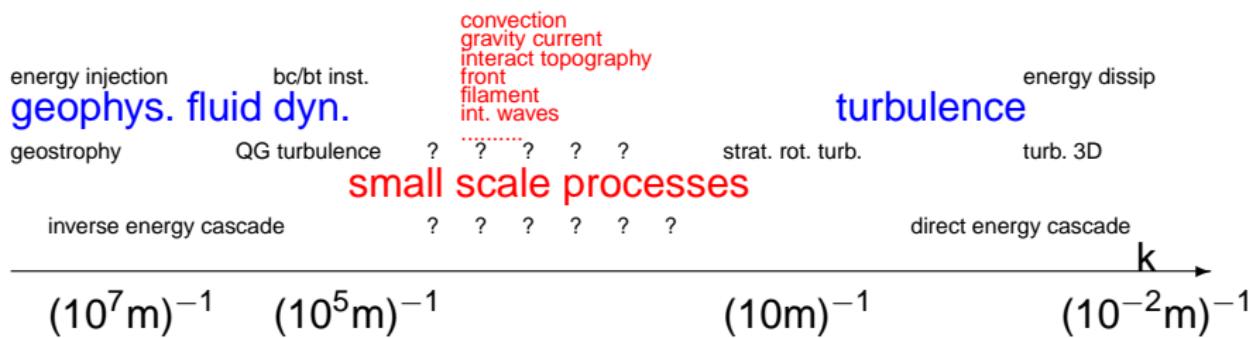
## Ocean Dynamics by Scale



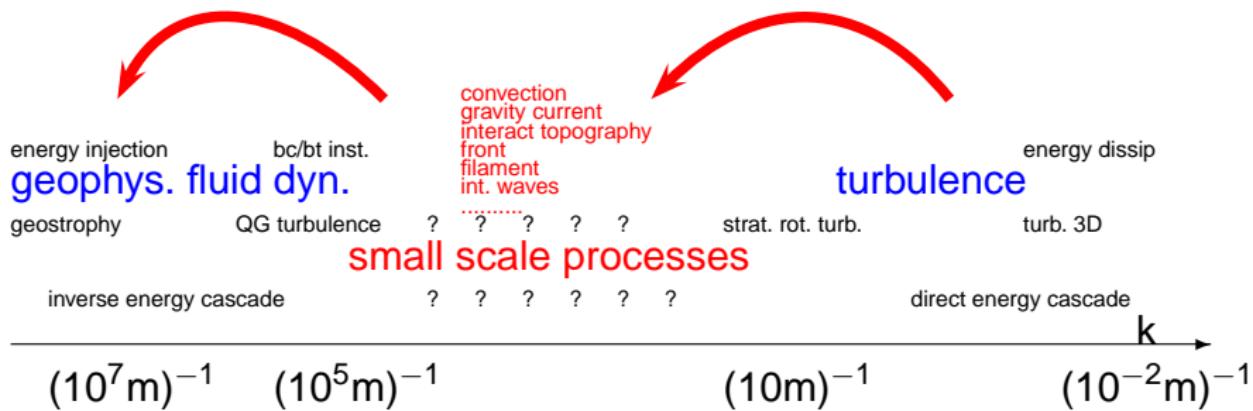
# Ocean Dynamics by Scale



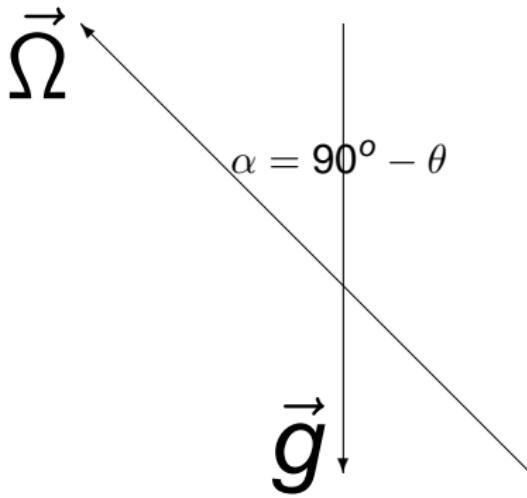
## Ocean Dynamics by Scale

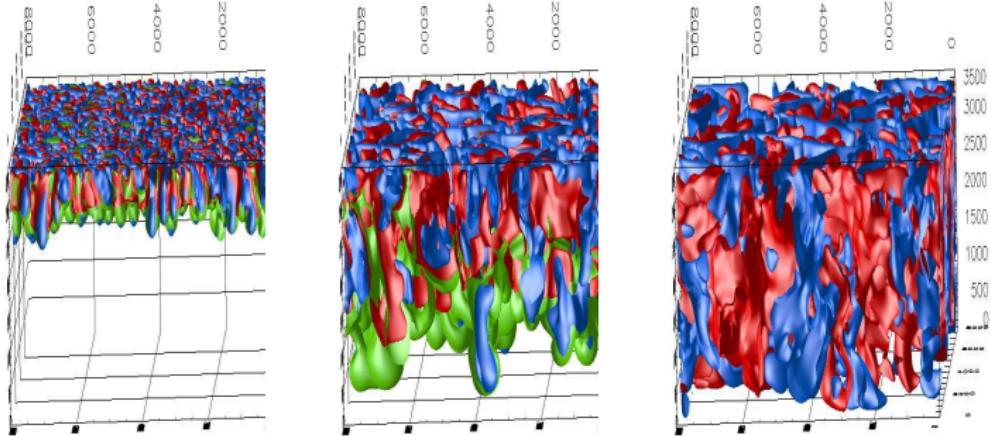


## Ocean Dynamics by Scale



## Non-vertical Axis of Rotation





Bi-periodic domain ( $8\text{km} \times 8\text{km} \times 3.5\text{km}$ )

Isothermal ocean

Forcing : 250, 500, 1000  $\text{W/m}^2$

Latitude : North pole, Gulf of Lions ( $45^\circ\text{N}$ )

Numerical resolution :  $256 \times 256 \times 224$  points

## Dimensionless Parameters

$$\text{Rayleigh Ra}_f = \frac{B_0 H^4}{\nu \kappa^2}$$

$$\text{Prandtl Pr} = \frac{\nu}{\kappa}$$

$$\text{Natural Rossby Ro}^* = \sqrt{\frac{B_0}{f^3 H^2}}$$

Angle  $\theta$

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$$\text{Rayleigh Ra}_f = \frac{B_0 H^4}{\nu \kappa^2}$$

Lohse & Toschi 2003 ; Gibert et al. 2006

$$\text{Prandtl Pr} = \frac{\nu}{\kappa}$$

$$\text{Natural Rossby Ro}^* = \sqrt{\frac{B_0}{f^3 H^2}}$$

Angle  $\theta$

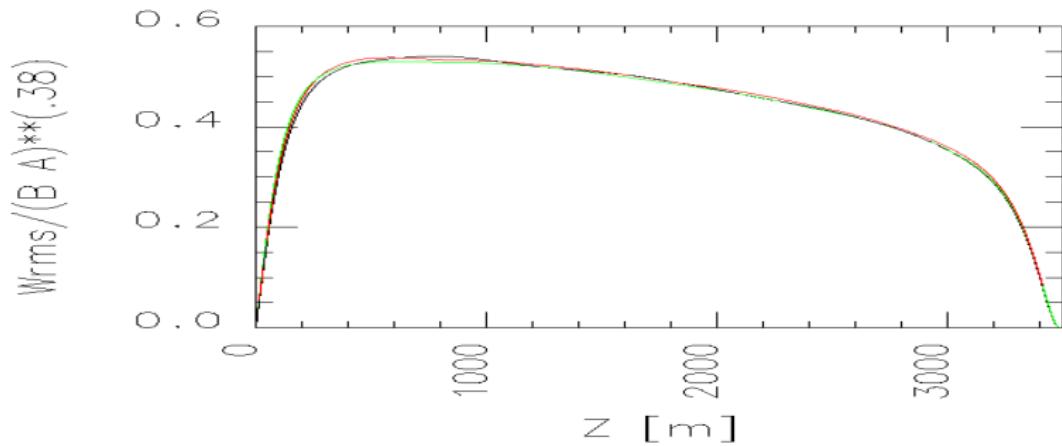
## The Experiments

exp.	surface heat flux	latitude
E01	1000 W/m <sup>2</sup>	90°
E03	500 W/m <sup>2</sup>	90°
E04	250 W/m <sup>2</sup>	90°
E31	1000 W/m <sup>2</sup>	45°
E33	500 W/m <sup>2</sup>	45°
E34	250 W/m <sup>2</sup>	45°

# Which régime ?

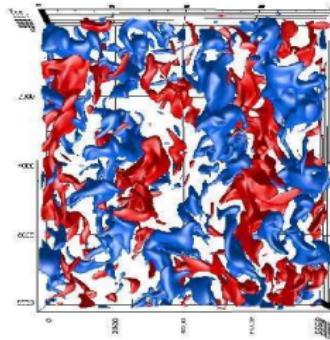
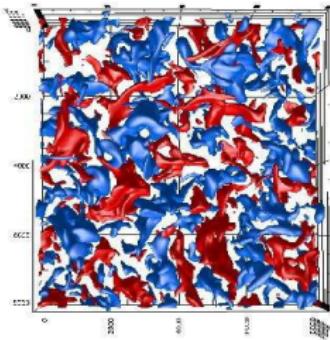
## Rotation (Heton) vs. 3D Turbulence ?

- ▶  $H_{rot} = \sqrt{B_0/f^3}$   $\leadsto u_{rot} = (B_0/f)^{1/2}$
- ▶  $H = H$   $\leadsto u_{3D} = (B_0 H)^{1/3}$



So, can we neglect rotation (atmosphere) ?

# Plume Ensembles



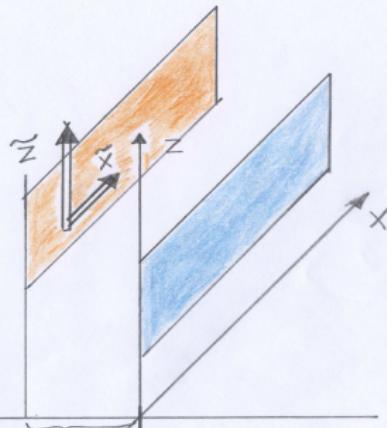
**FIG.:** Isosurfaces of vertical velocity  $w = \pm 0.05 \text{ m s}^{-1}$  (+ red, - blue) looking upward from the ocean floor (x to the right, y downward) at the end of the experiments  $t = 168\text{h}$

## Theorem of Taylor-Proudman-Poincaré

$$2(\Omega_y \partial_y + \Omega_z \partial_z) \begin{pmatrix} u \\ v \\ w \end{pmatrix} = \frac{g}{\rho_0} \begin{pmatrix} \partial_y \rho \\ -\partial_x \rho \\ 0 \end{pmatrix}$$

Colin de Verdière 2002, Un fluide lent entre deux sphères en rotation rapide  
les théories de la circulation océanique,  
*Annales Mathématiques Blaise Pascal*, 9, 245–268.)

## Analysis of correlation



$$\text{corr}_w(\tilde{x}, \tilde{z}) = \frac{\langle (w(P) w(P(\tilde{x}, \tilde{z}))) \rangle}{\sqrt{\langle w(P)^2 \rangle \langle w(P(\tilde{x}, \tilde{z}))^2 \rangle}}$$

# Signature of the Taylor-Proudman-Poincaré theorem

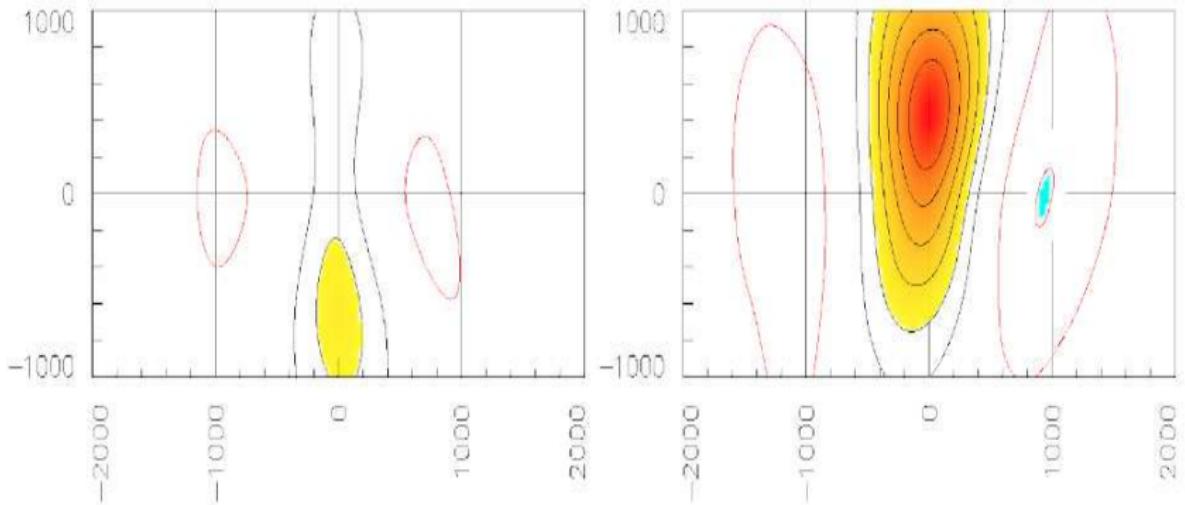


FIG.:  $C_y(500 \text{ m}, W)$  E34.

## Simple Plume Model

$$\begin{pmatrix} -\tau & f & -F \\ -f & -\tau & 0 \\ F & 0 & -\tau \end{pmatrix} \begin{pmatrix} u \\ v \\ w \end{pmatrix} = \begin{pmatrix} 0 \\ 0 \\ g' \end{pmatrix}$$

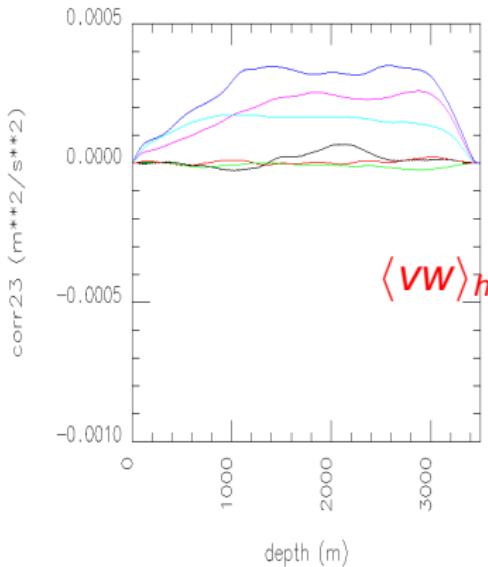
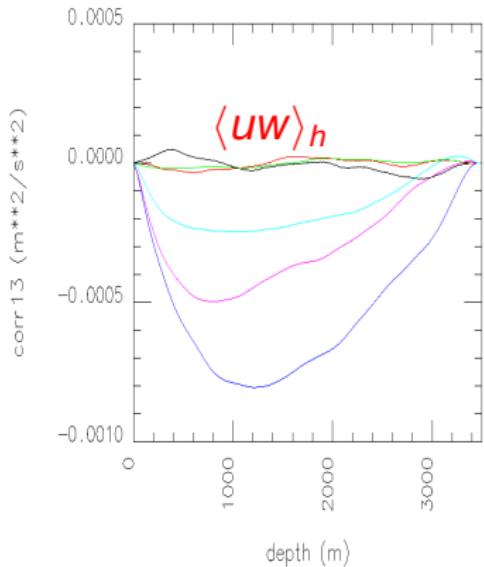
Solution :

$$\begin{pmatrix} u \\ v \\ w \end{pmatrix} = \tilde{c} \begin{pmatrix} \tau F/f^2 \\ -F/f \\ -1 - \tau^2/f^2 \end{pmatrix},$$

with  $\tilde{c} = g'f^2/((f^2 + F^2 + \tau^2)\tau)$  plume speed,  
 $\tau$  (friction time) $^{-1}$ .

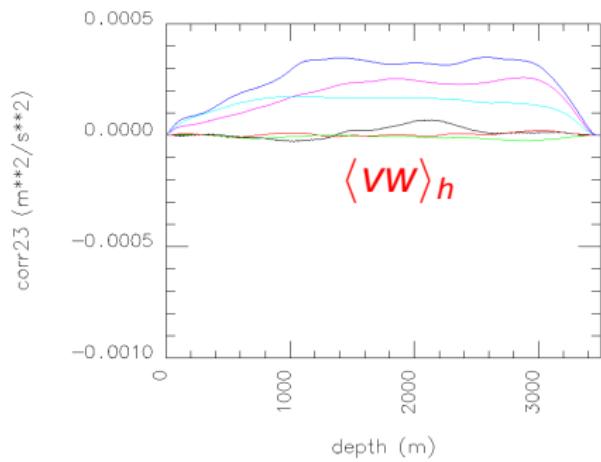
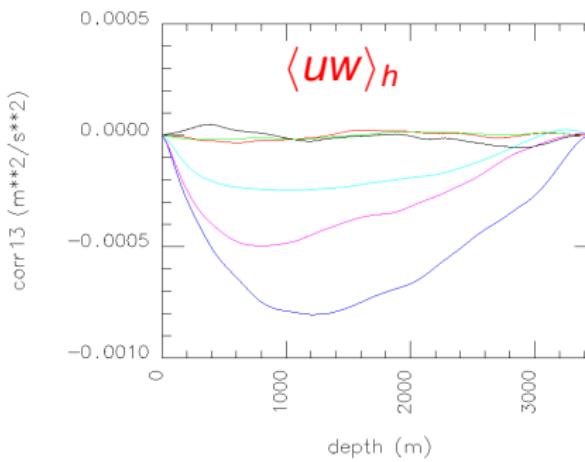
# First Order Moments (I)

$$\begin{aligned}\partial_t \langle u \rangle_h &= -\partial_z \langle uw \rangle_h + f \langle v \rangle_h + \nu \partial_z^2 \langle u \rangle_h \\ \partial_t \langle v \rangle_h &= -\partial_z \langle vw \rangle_h - f \langle u \rangle_h + \nu \partial_z^2 \langle v \rangle_h\end{aligned}$$



## First Order Moments (II)

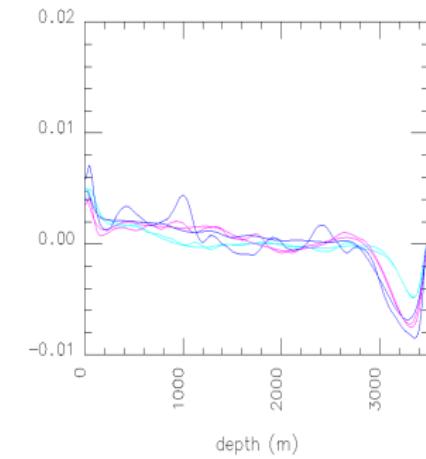
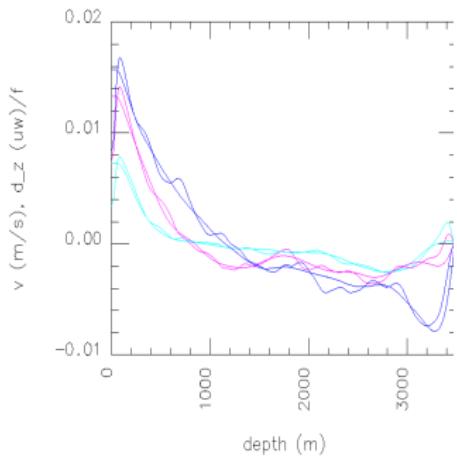
$$\begin{aligned}\partial_t \langle u \rangle_h &= -\partial_z \langle uw \rangle_h + f \langle v \rangle_h + \nu \partial_z^2 \langle u \rangle_h \\ \partial_t \langle v \rangle_h &= -\partial_z \langle vw \rangle_h - f \langle u \rangle_h + \nu \partial_z^2 \langle v \rangle_h\end{aligned}$$



## First Order Moments (III)

$$f\langle v \rangle_{h,t} = \partial_z \langle uw \rangle_{h,t}$$

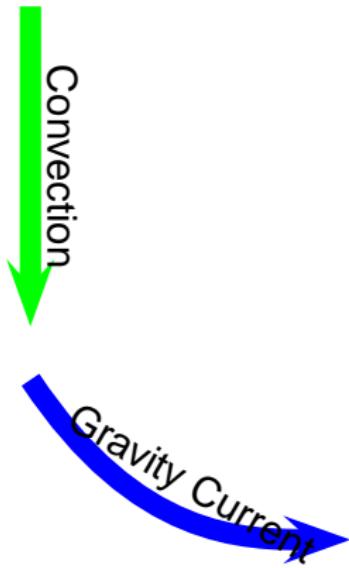
$$f\langle u \rangle_{h,t} = -\partial_z \langle vw \rangle_{h,t}$$



## Conclusions Conclusions :

- ▶ Tilt of rotation vector more important than rotation !
- ▶ Tilt stretches structures along the axis of rotation
- ▶ Tilt generates a local overturning circulation
- ▶ Tilt increases horizontal mixing
- ▶ Tilt does NOT change stratification (allows for a param. for density structure indep. of tilt)
- ▶ Forget about HOM

## Conclusions



## Conclusions & Perspectives

