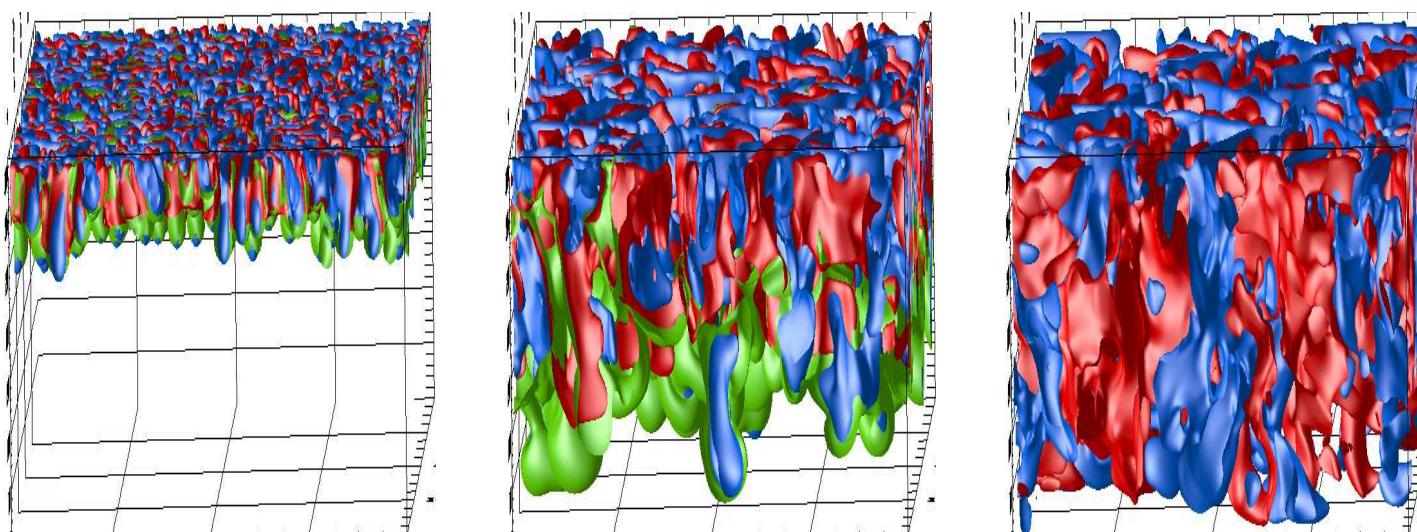


Small Scale Processes in the Ocean

Achim Wirth

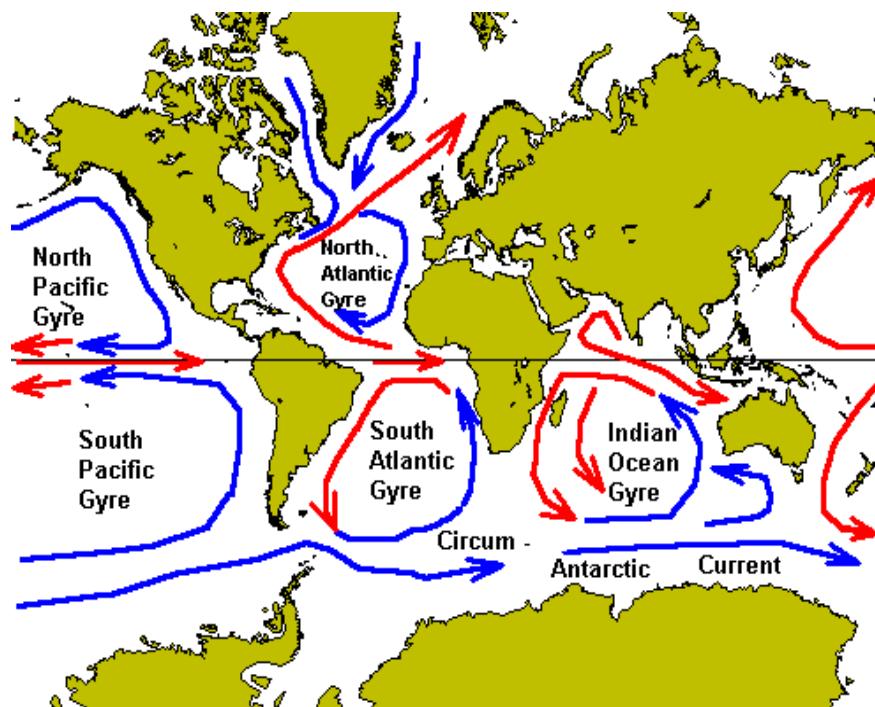
MEOM / LEGI Grenoble / CNRS



Ocean Circulation

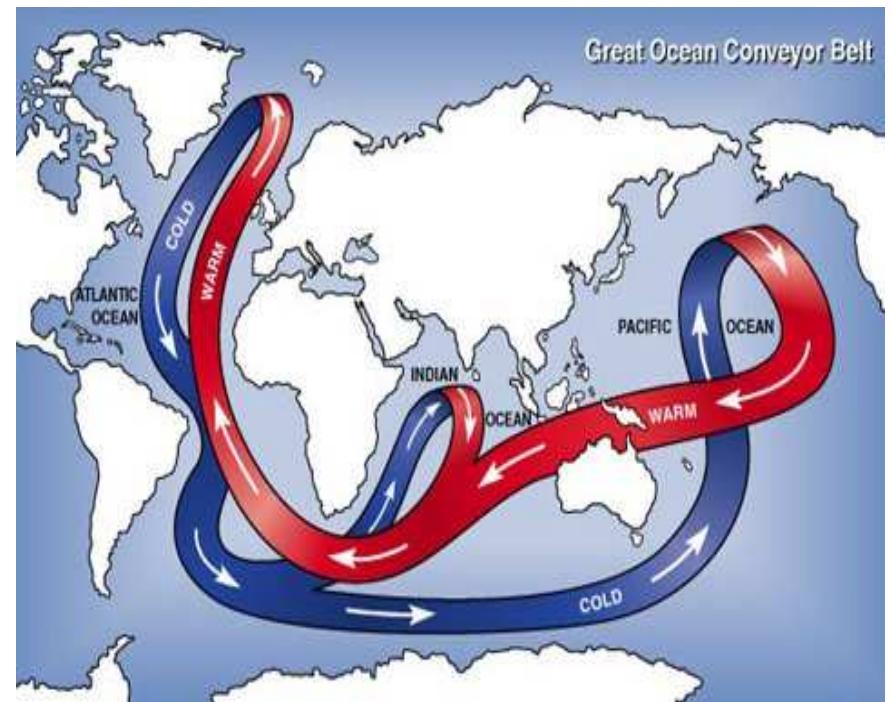
Gyre

“weather”

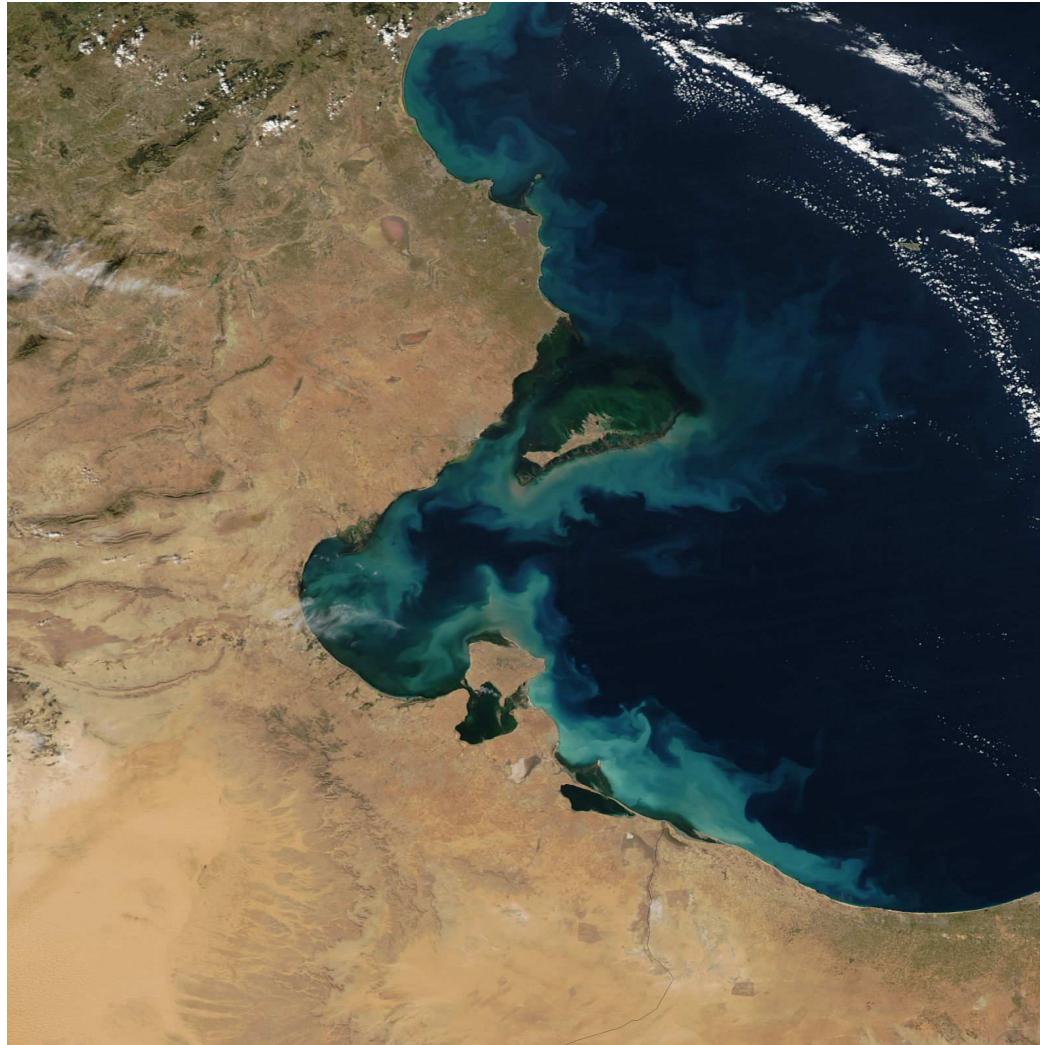


Overturning

“climat”



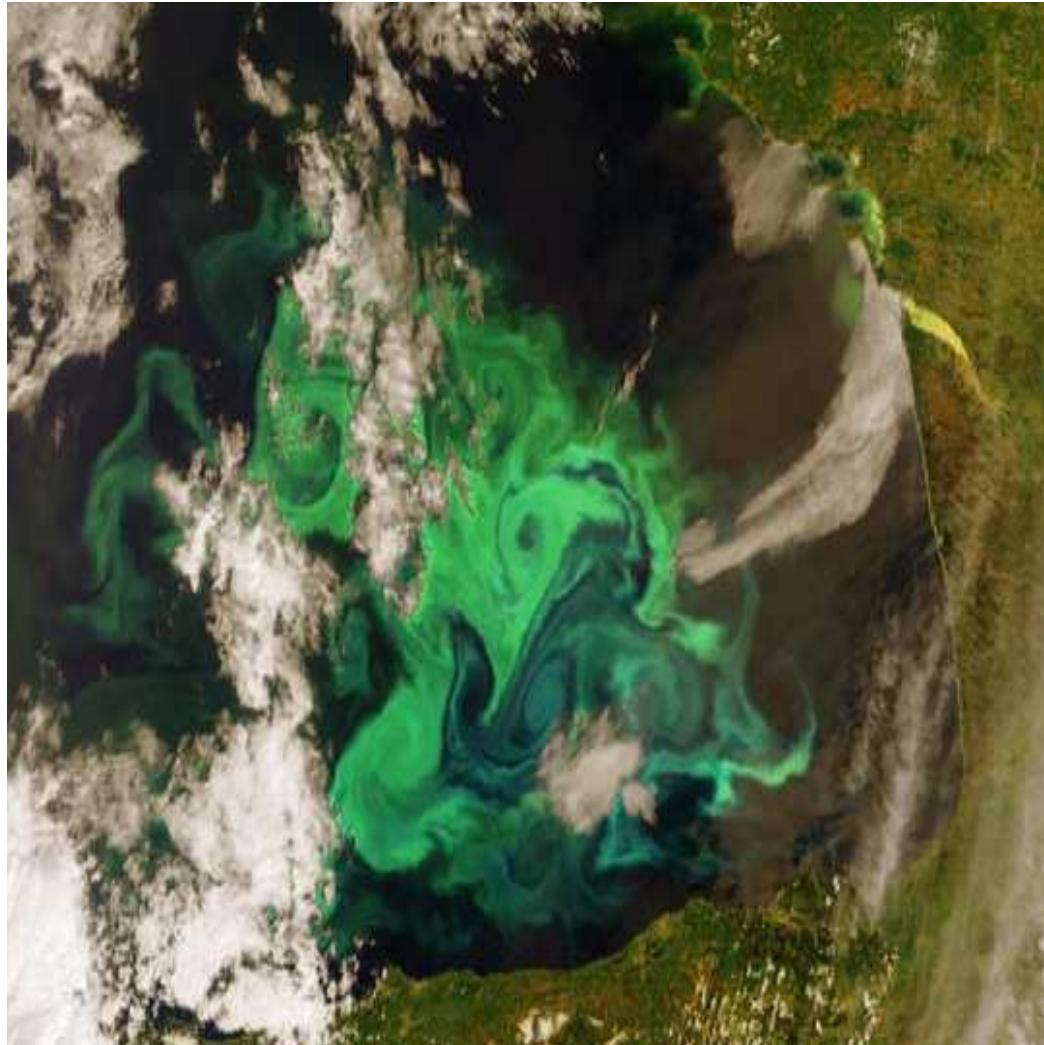
Small Scales



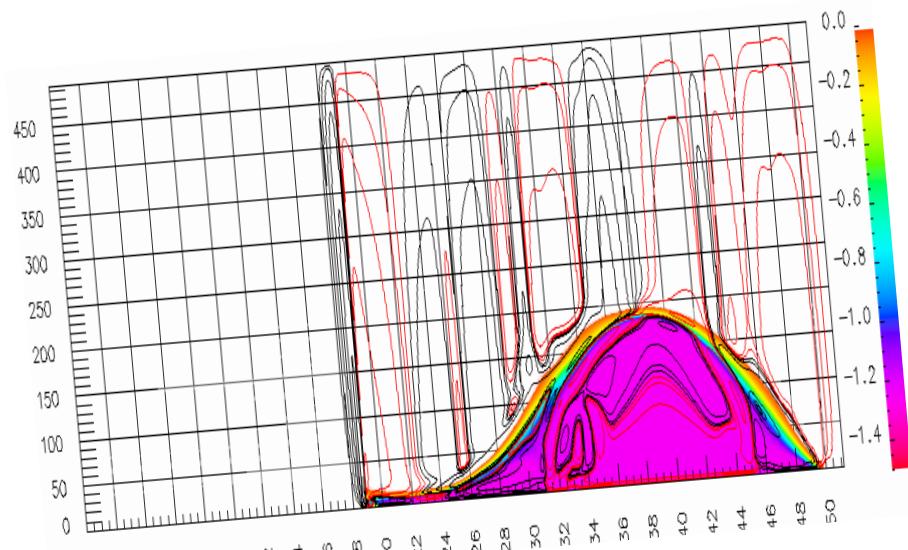
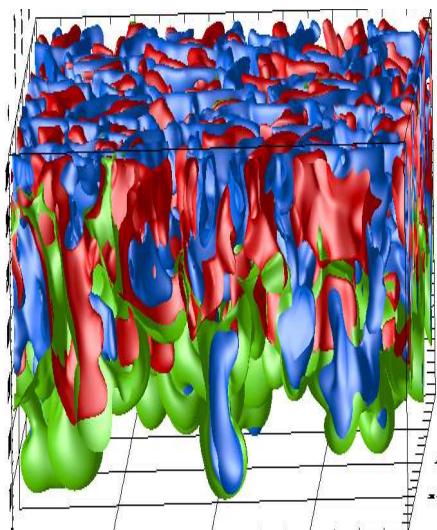
Small Scales



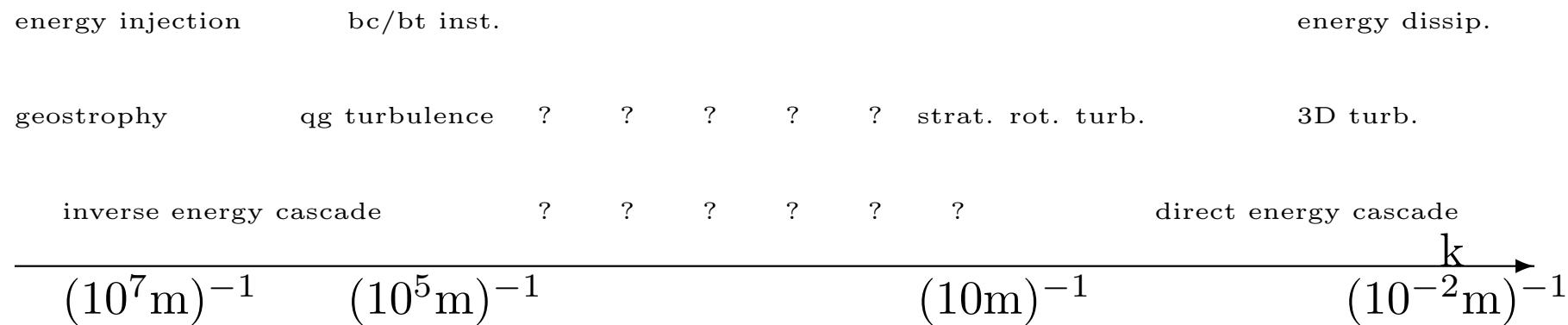
Small Scales



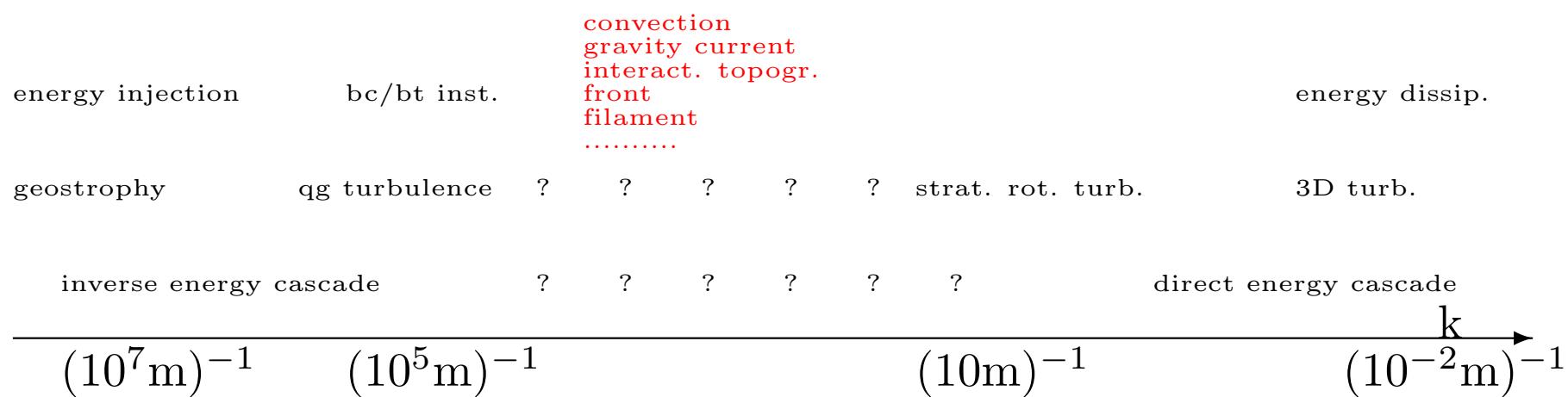
Small Scales



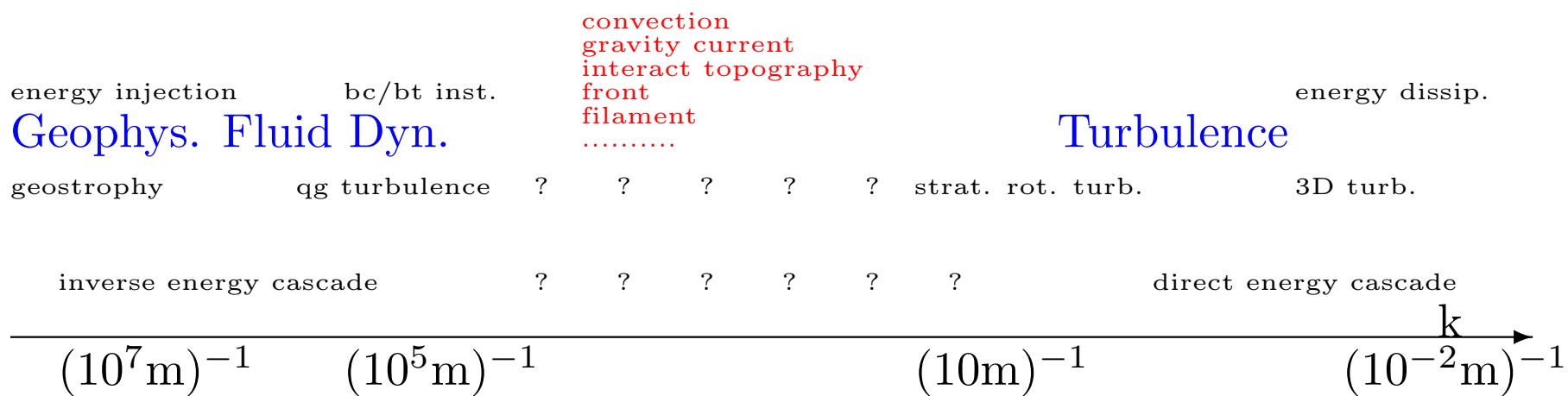
Ocean Dynamics by Scale



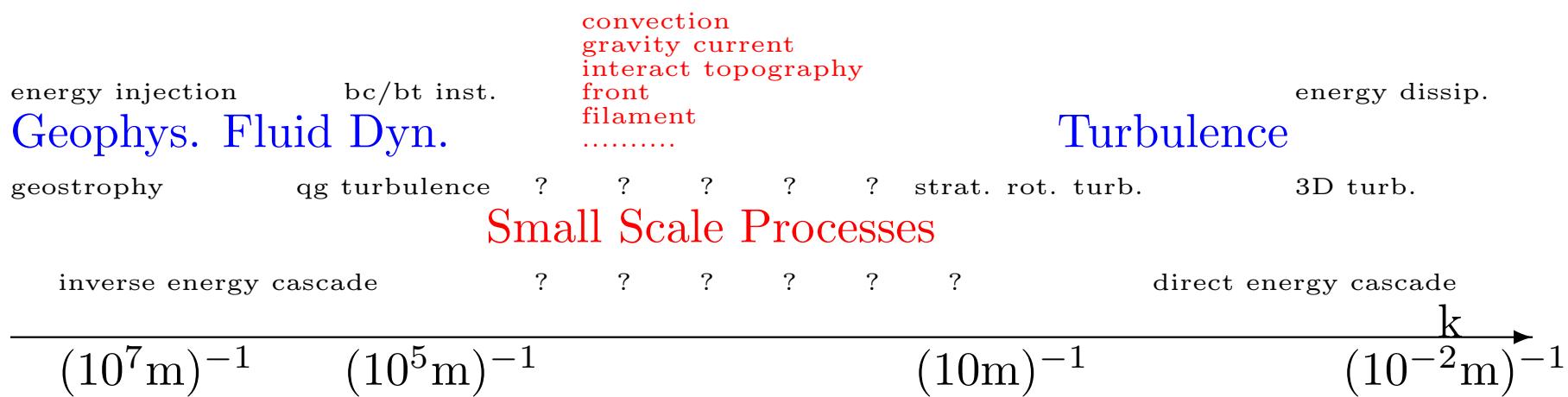
Ocean Dynamics by Scale



Ocean Dynamics by Scale



Ocean Dynamics by Scale

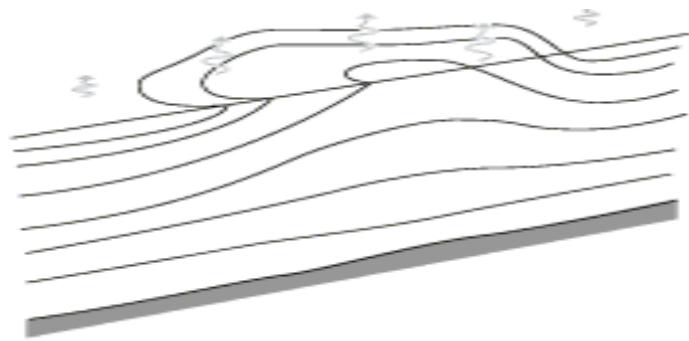


Ocean Deep Convection

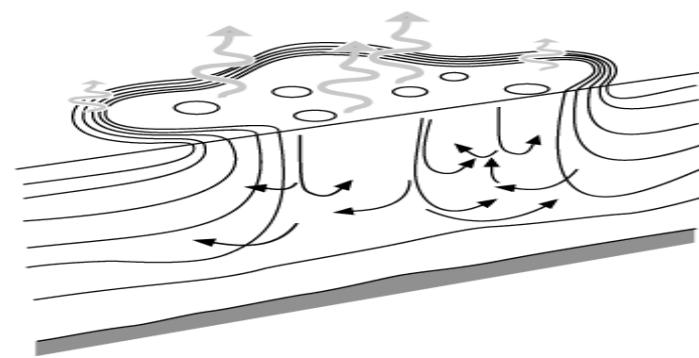
Known Ocean Deep Convection Sites



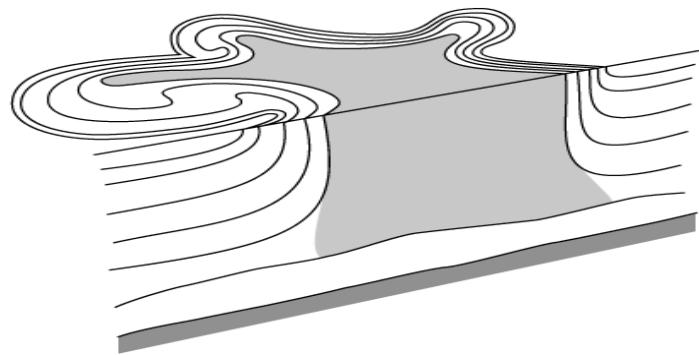
Convection



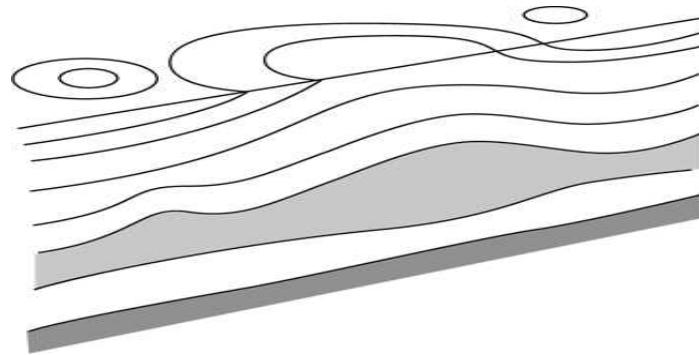
preconditioning



convection

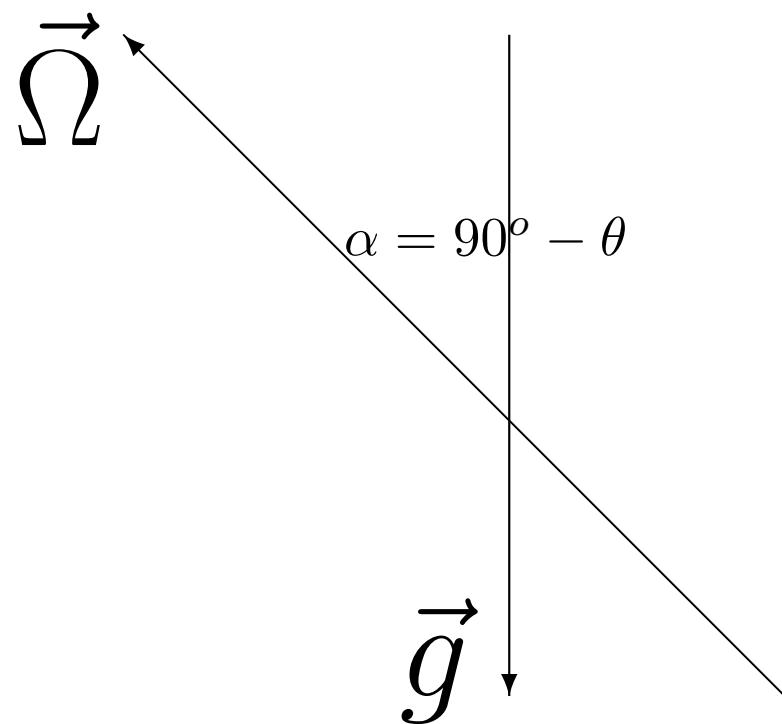


restratification 1

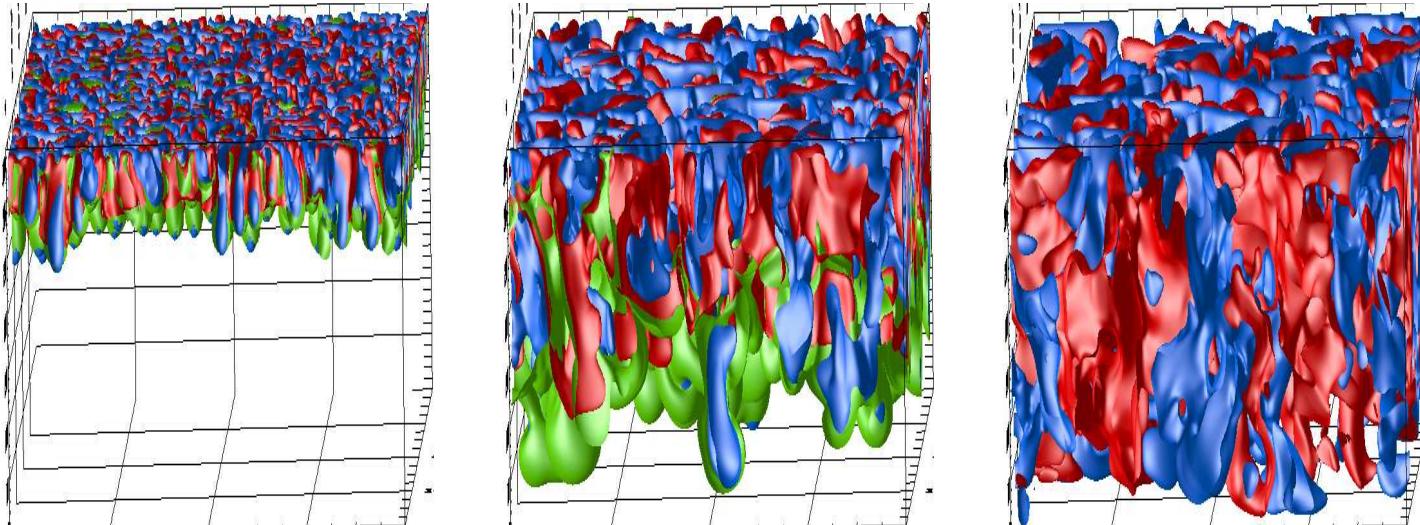


restratification 2

Non-vertical Axis of Rotation



The Experiment



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

Isothermal ocean

Forcing: 250, 500, 1000 W/m^2

Latitude: North pole, Gulf of Lions (45°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 θ

Dimensionless Parameters

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

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Angle θ

Dimensionless Parameters

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

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 θ

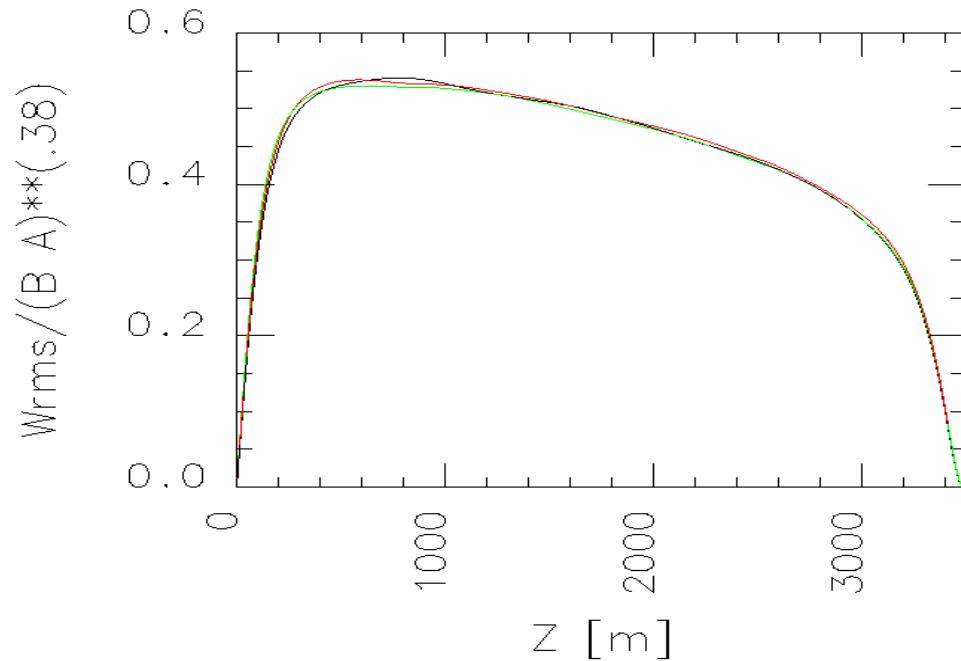
The Experiences

exp.	surface heat flux	latitude
E01	1000 W/m ²	90 ^o
E03	500 W/m ²	90 ^o
E04	250 W/m ²	90 ^o
E31	1000 W/m ²	45 ^o
E33	500 W/m ²	45 ^o
E34	250 W/m ²	45 ^o

Which régime ?

Rotation (Heton) vs. 3D Turbulence ?

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



So, can we neglect rotation (atmospherer)?

Plume Ensembles

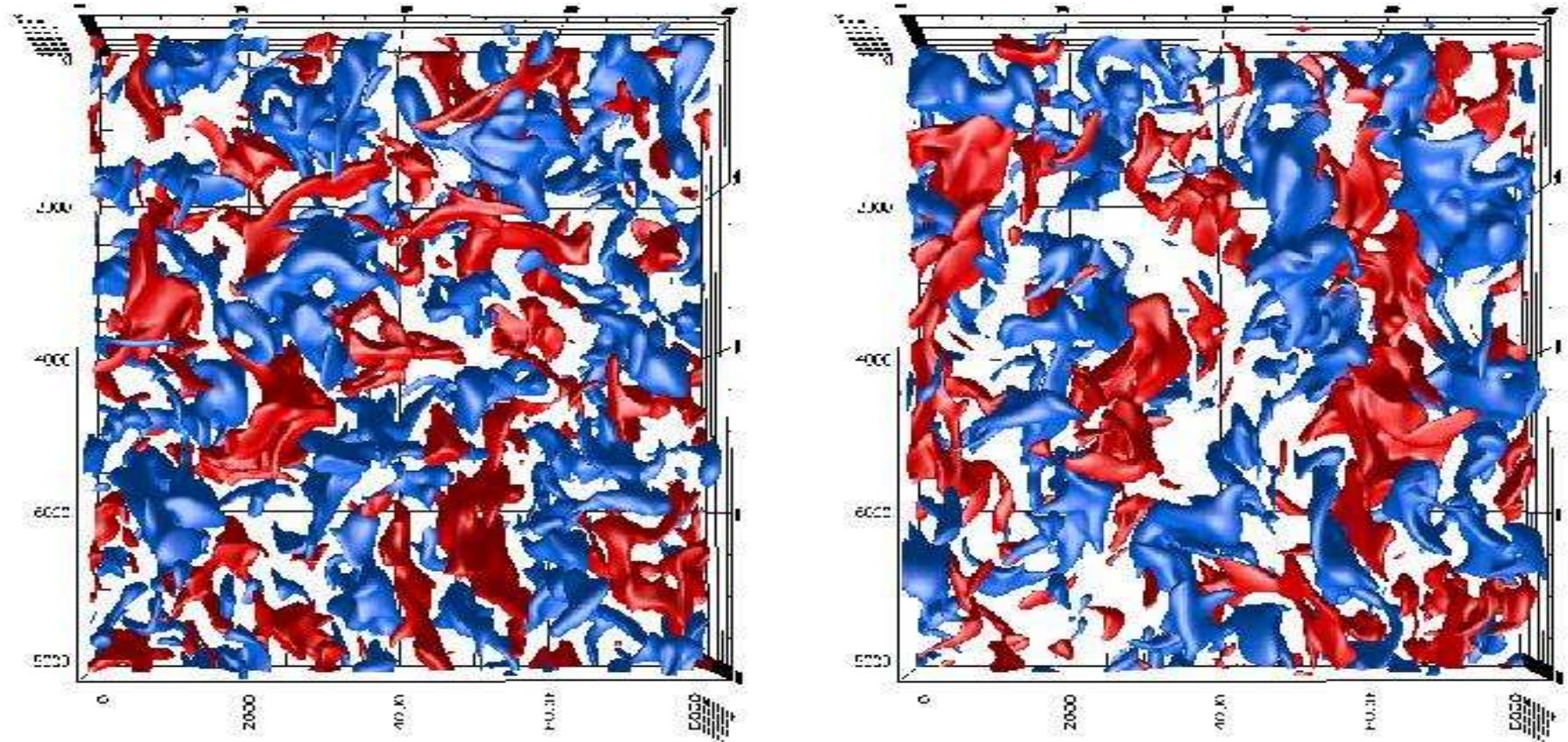


Figure 1: Isosurfaces of vertical velocity $w = \pm 0.05 \text{ m s}^{-1}$ (+ red, - blue) looking upward from the ocean floor (x to the right, y downward) at the end of the experiments $t = 168\text{h}$

Theorem of Taylor-Proudman-Poincaré

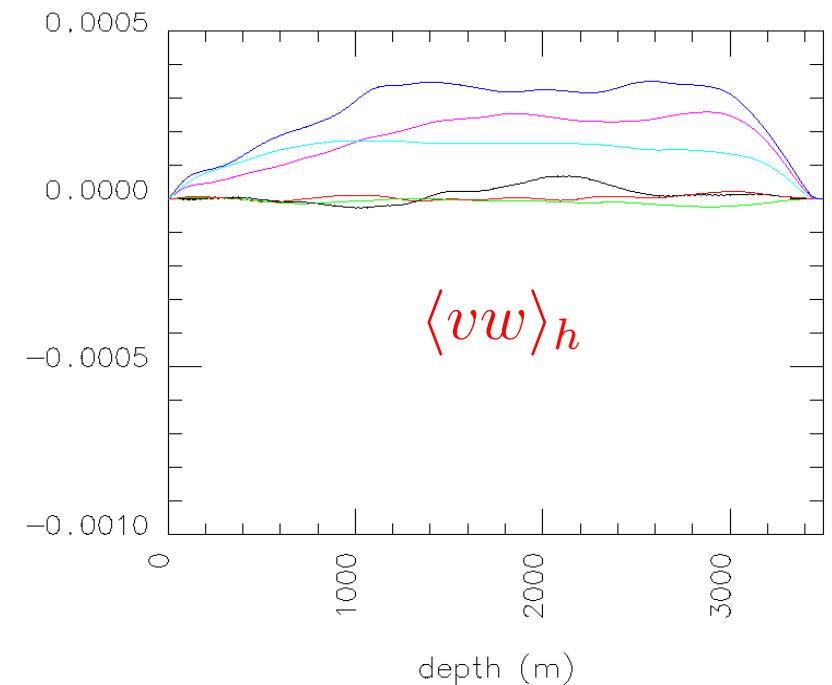
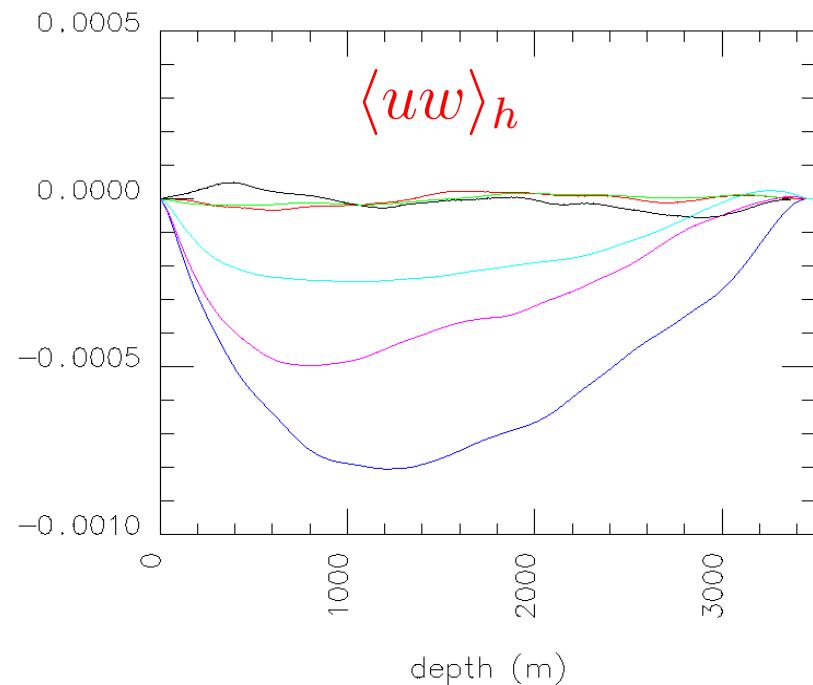
$$2(\Omega_y \partial_y + \Omega_z \partial_z) \begin{pmatrix} u \\ v \\ w \end{pmatrix} = \frac{g}{\rho_0} \begin{pmatrix} \partial_y \rho \\ -\partial_x \rho \\ 0 \end{pmatrix}$$

(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.)

First Order Moments (I)

$$\partial_t \langle u \rangle_h = -\partial_z \langle uw \rangle_h + f \langle v \rangle_h + \nu \partial_z^2 \langle u \rangle_h$$

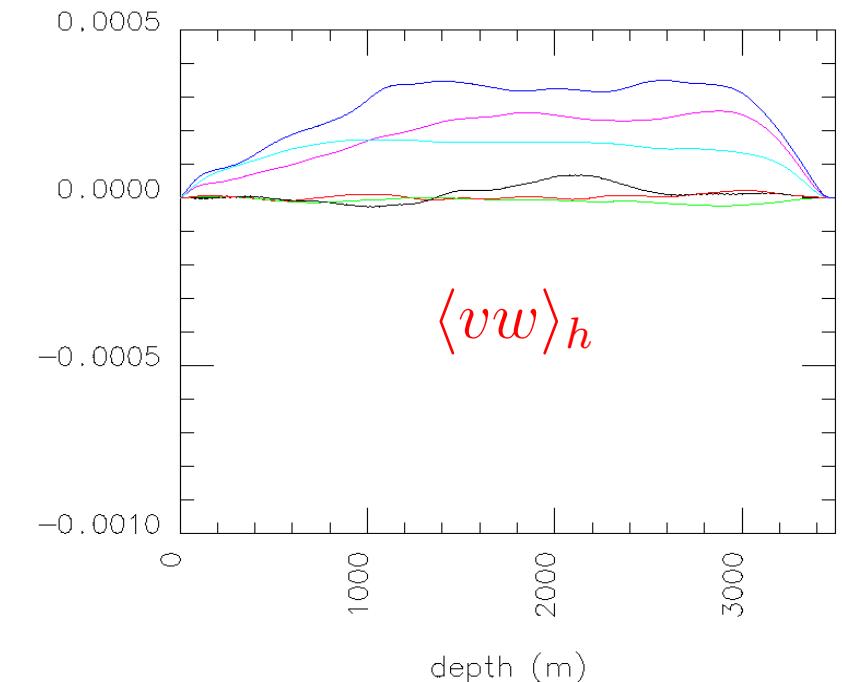
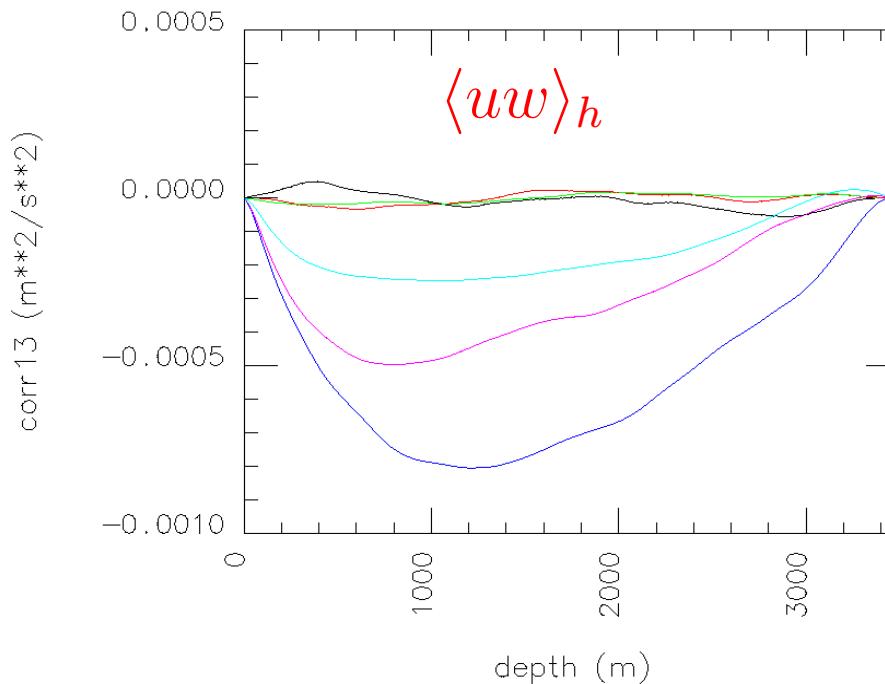
$$\partial_t \langle v \rangle_h = -\partial_z \langle vw \rangle_h - f \langle u \rangle_h + \nu \partial_z^2 \langle v \rangle_h$$



First Order Moments (II)

$$\partial_t \langle u \rangle_h = -\partial_z \langle uw \rangle_h + f \langle v \rangle_h + \nu \partial_z^2 \langle u \rangle_h$$

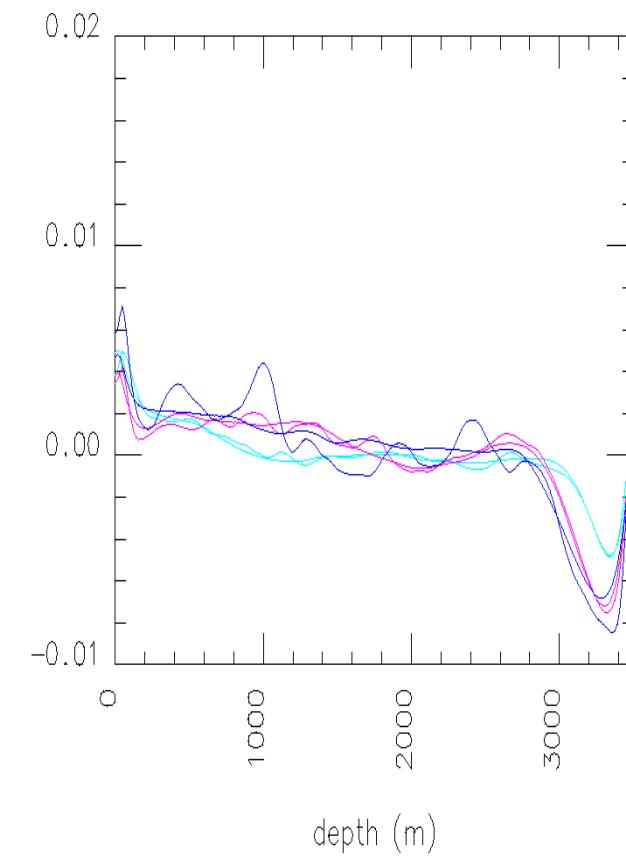
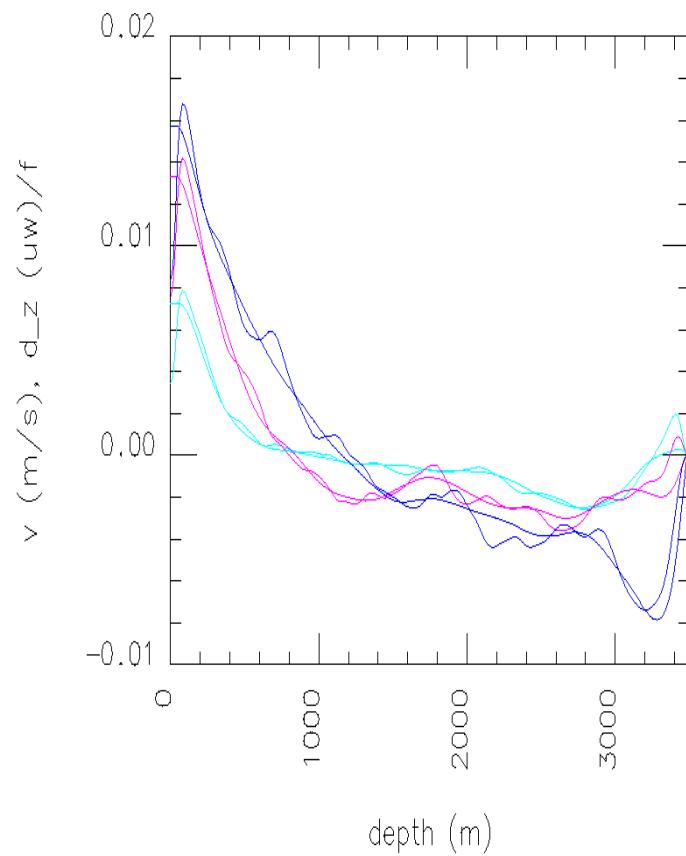
$$\partial_t \langle v \rangle_h = -\partial_z \langle vw \rangle_h - f \langle u \rangle_h + \nu \partial_z^2 \langle v \rangle_h$$



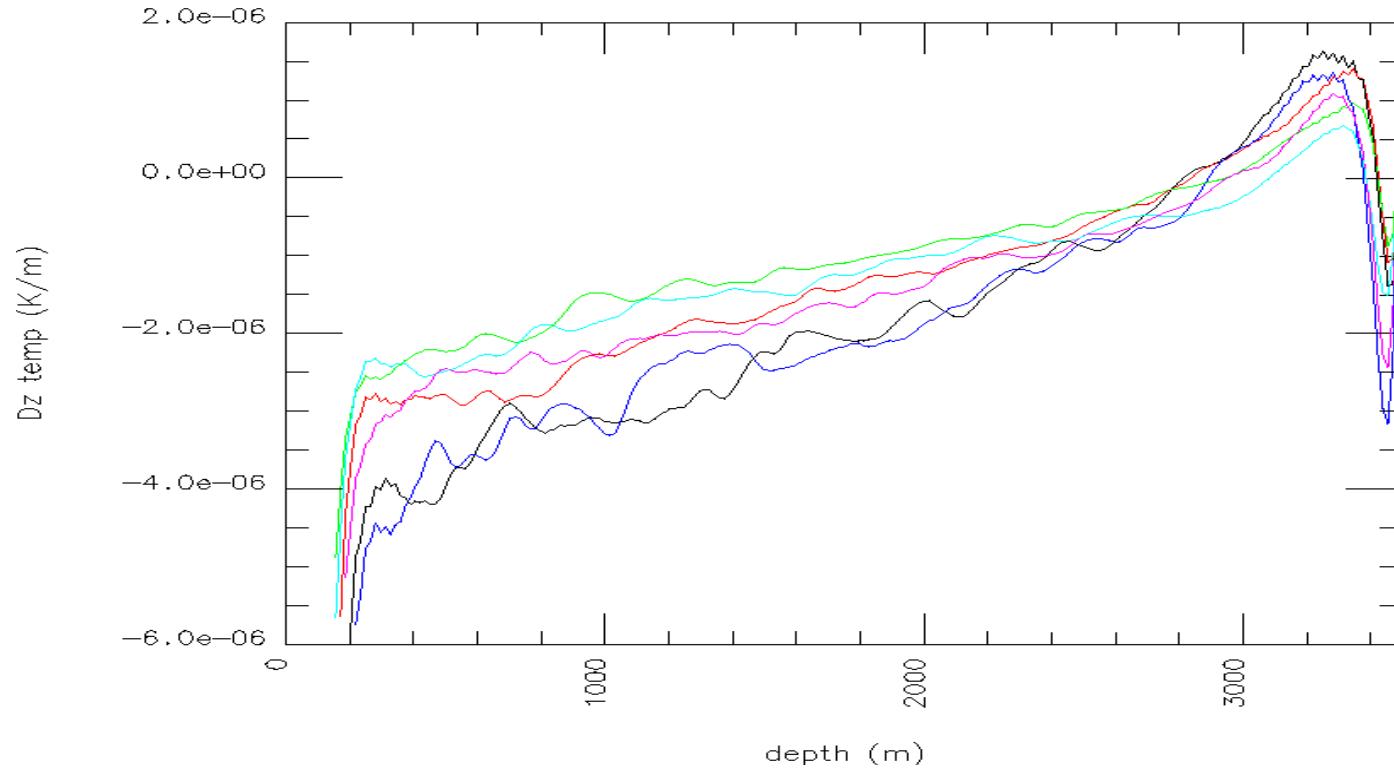
First Order Moments (III)

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

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



Stratification (independent of θ)



$$\kappa_Z(\alpha g \partial_z T - \gamma) = -\frac{B_0 z}{D}$$

param. (H, B)	(3500m, 1000W/m ²)	(1000m, 500W/m ²)	(350m, 500W/m ²)
$\kappa_Z \sim (H^4 B)^{1/3}$	$40 m^2/s$	$6 m^2/s$	$1.5 m^2/s$

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

Perspectives:

- Develop a parametrisation
- Observations, ~~Laboratory Experiments~~