

On the Dynamics of Oceanic Gravity Currents

Achim Wirth

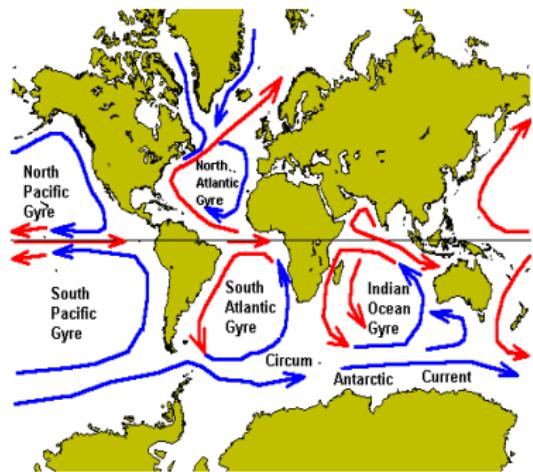
équipe MEIGE

LEGI / CNRS

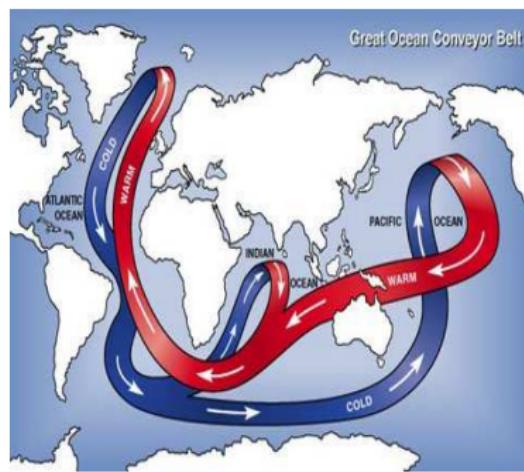
ENS, 3 mai, 2013

Ocean Circulation

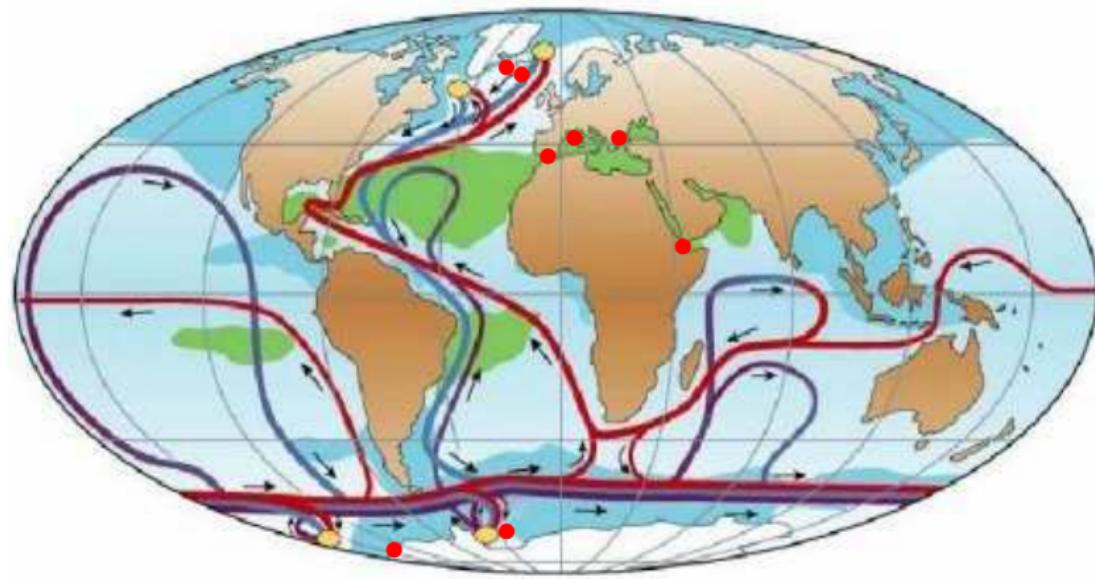
Gyre
“weather”



Overturning
“climat”



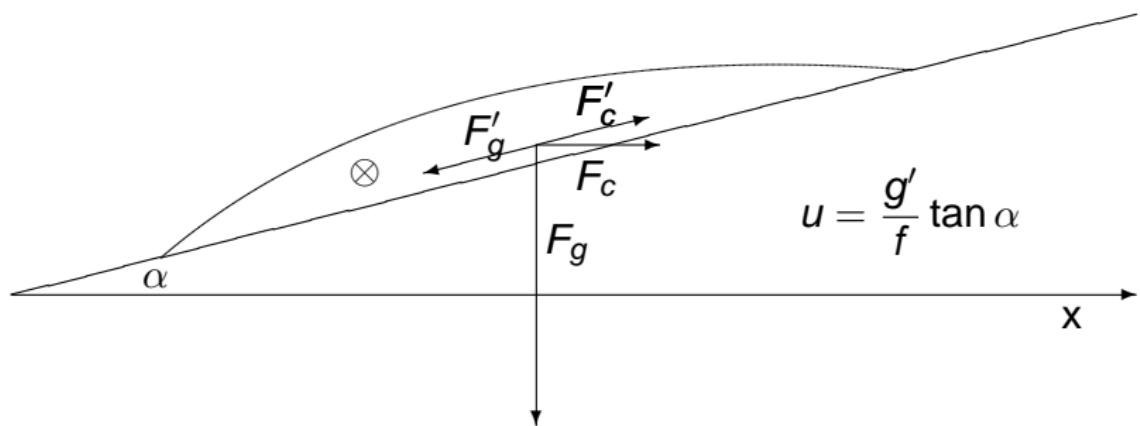
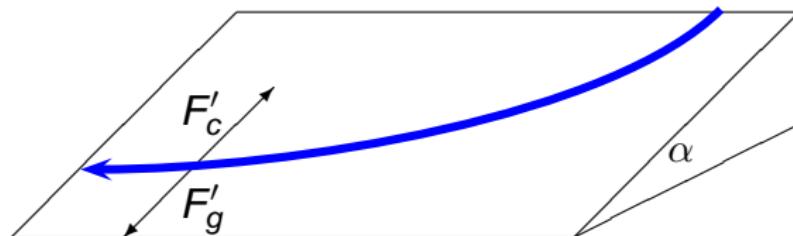
Gravity Current



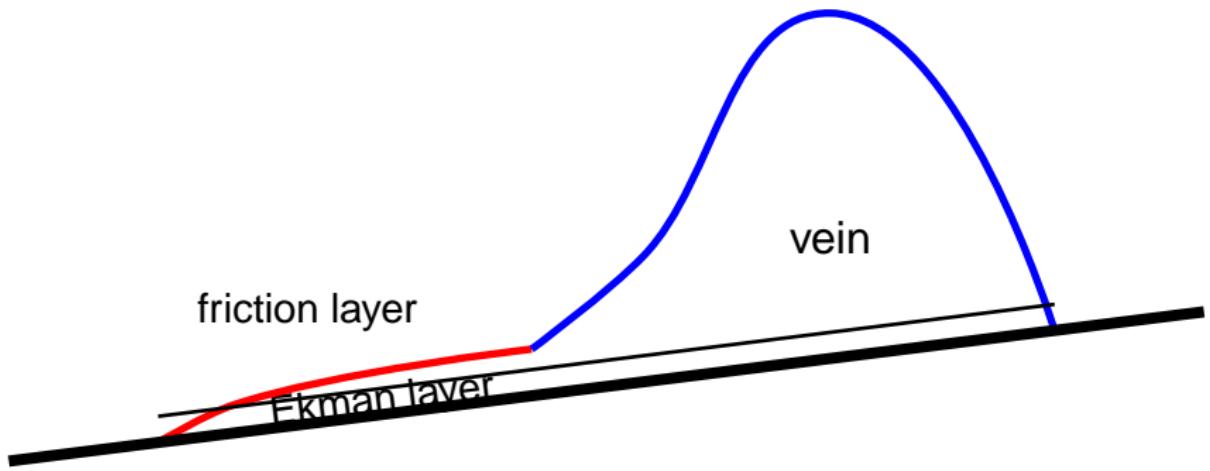
(Rahmstorf, Nature 2002)

- Surface
- Deep
- Bottom
- Salinity > 36 ‰
- Salinity < 34 ‰
- Deep Water Formation

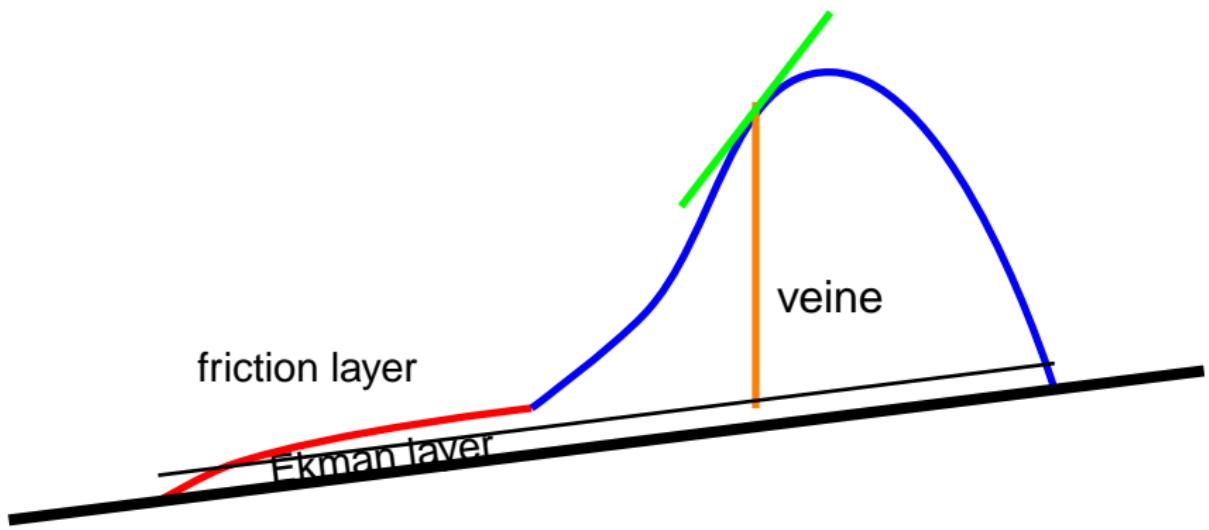
Geostrophy



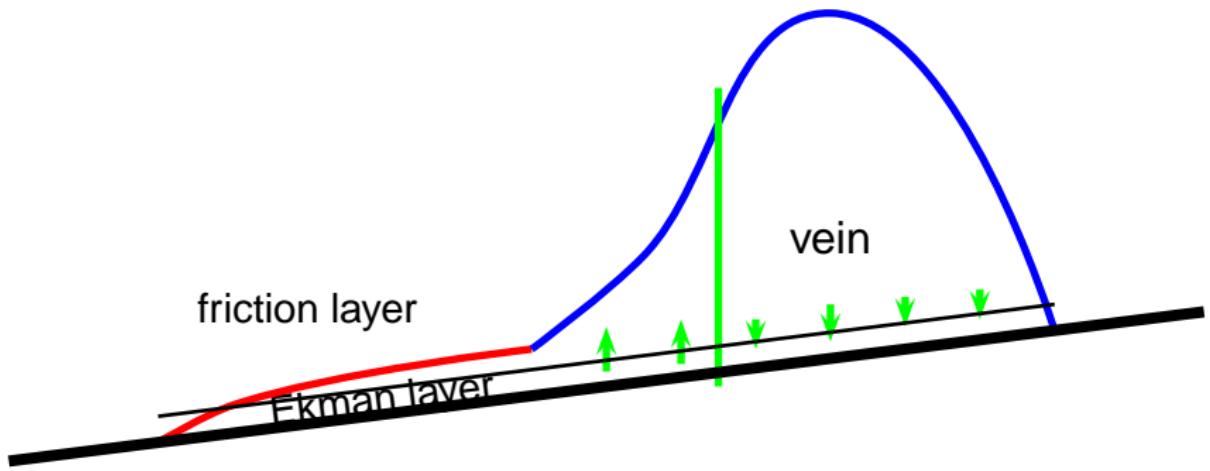
Forced Geostrophy



Forced Geostrophy



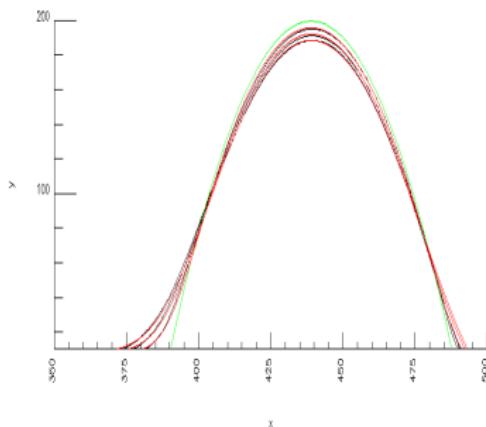
Forced Geostrophy



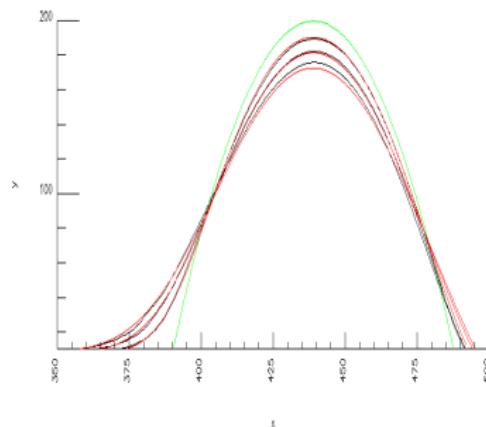
Heat Equation

$$\partial_t h = -\partial_x U_{Ek} = \frac{\delta}{2} \partial_x v_{geo} = \frac{\delta g'}{2f} \partial_{xx} h = \partial_x (\kappa_H \partial_x h)$$

24h



60h



Friction

... determines the dynamics of oceanic gravity currents.
The frictional processes can not be explicitly represented
in today's (and tomorrow's) ocean models

$$\tau + c_D |\mathbf{u}|$$

linear Rayleigh friction (τ)

quadratic drag law (c_D)

?

roughness of the ocean floor ?

variability of roughness ?

multiscale roughness (bio) ?

roughness type “k” vrs. “d” ?

orientation of roughness elements ?

suspension of sediments ?

tidal currents ?

waves ?

retroaction of currents on roughness ?

And : “The matter is far from being understood” Jiménez, Ann.
Rev. Fluid Mech. (2004).

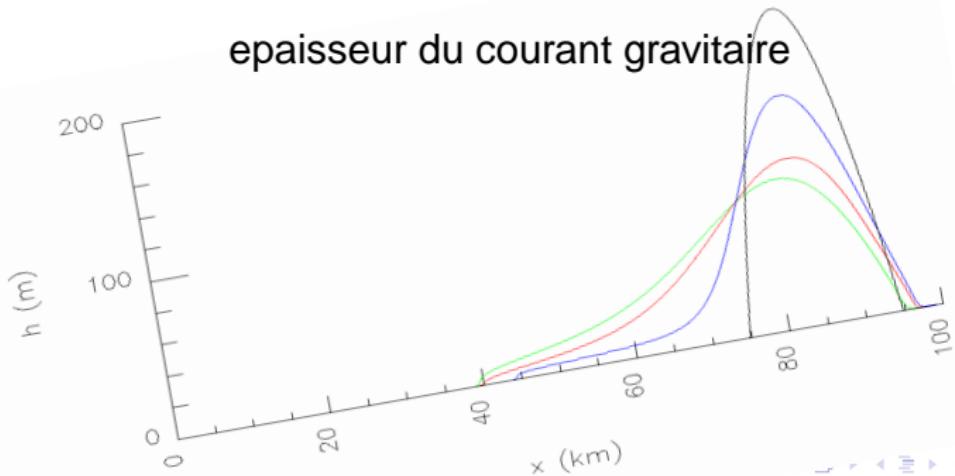
How do we find REAL bottom-friction

- ▶ Optimist : Study non-hydrostatic PBL-dynamics.
- ▶ Realist : Use data-assimilation to determine friction parameters from obs. (that we do not have).

Evolution temporelle SW

$$\begin{aligned}\partial_t u + u \partial_x u - fv + g'(\partial_x h + \tan \alpha) &= -Du + \nu \partial_x^2 u, \\ \partial_t v + u \partial_x v + fu &= -Dv + \nu \partial_x^2 v, \\ \partial_t h + u \partial_x h + h \partial_x u &= \nu \partial_x^2 h, \\ D = D(x, t) &= \frac{1}{h}(\tau + c_D |\mathbf{u}|).\end{aligned}$$

épaisseur du courant gravitaire



Procédure d'Estimation

Vecteur d'état augmenté (contient les paramètres) :

$$\mathbf{x}(x, t) = (h(x, t), u(x, t), v(x, t), \tau, c_D) \quad (1)$$

Outil : EnKF (Ensemble Kalman Filter) :

$$\mathbf{x}_i^a = \mathbf{x}_i^f + \mathbf{K} \left(h^{obs} + \epsilon_i - \mathbf{H} \mathbf{x}_i^f \right) \quad (2)$$

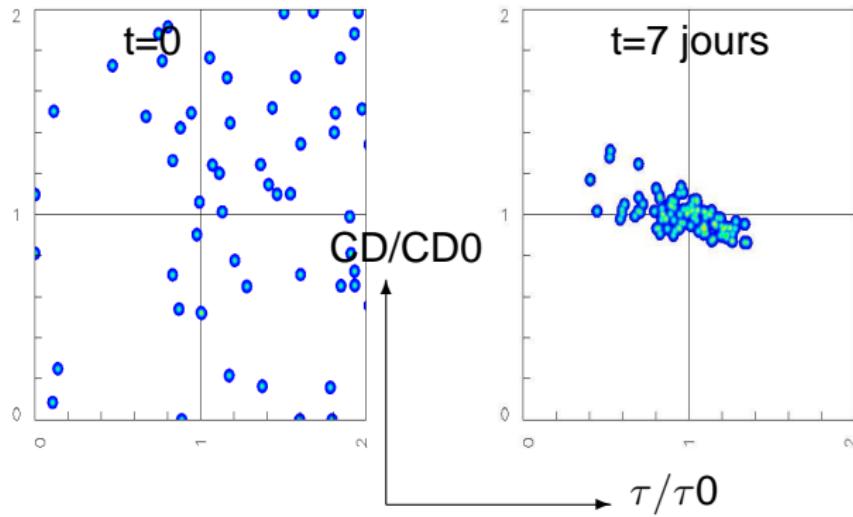
$$\mathbf{K} = \mathbf{P} \mathbf{H}^T (\mathbf{H} \mathbf{P} \mathbf{H}^T + \mathbf{W})^{-1} \quad (3)$$

$$\mathbf{P} = \frac{1}{m-1} \sum_{i=1}^m (\mathbf{x}_i^f - \langle \mathbf{x}^f \rangle)(\mathbf{x}_i^f - \langle \mathbf{x}^f \rangle)^T, \quad (4)$$

Choix des valeurs initiales pour l'ensemble des paramètres ?

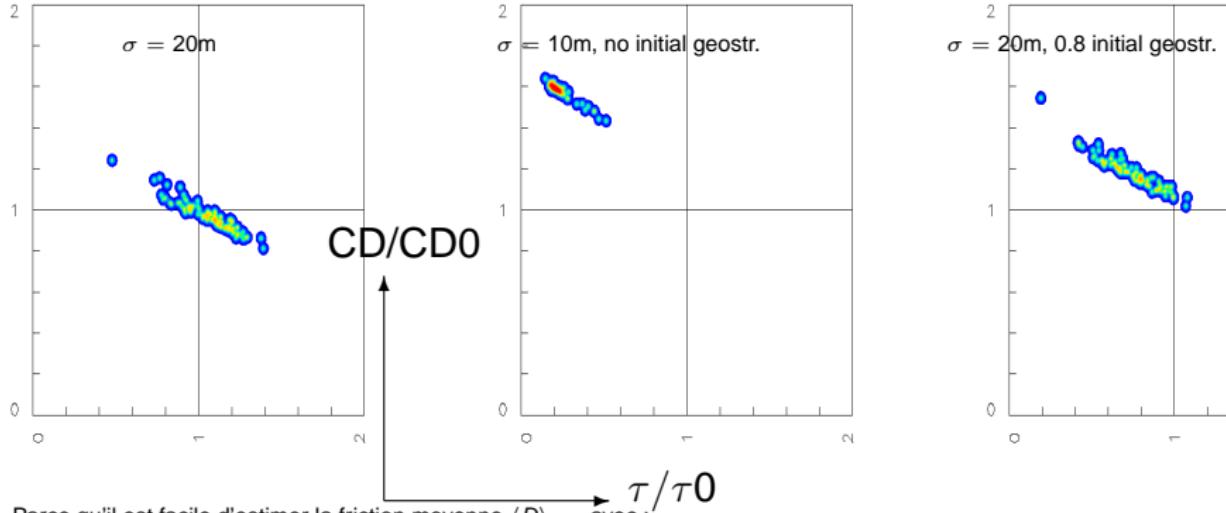
Peut-on estimer r et c_D en observant seulement $h(x)$?

Assimilation toutes les heures avec un erreur d'observation de
 $10m$, $\tau_0 = 5 \cdot 10^{-4} \text{ ms}^{-1}$, $c_{D0} = 5 \cdot 10^{-3}$



Oui !

Pourquoi l'ensemble est-il aligné ?



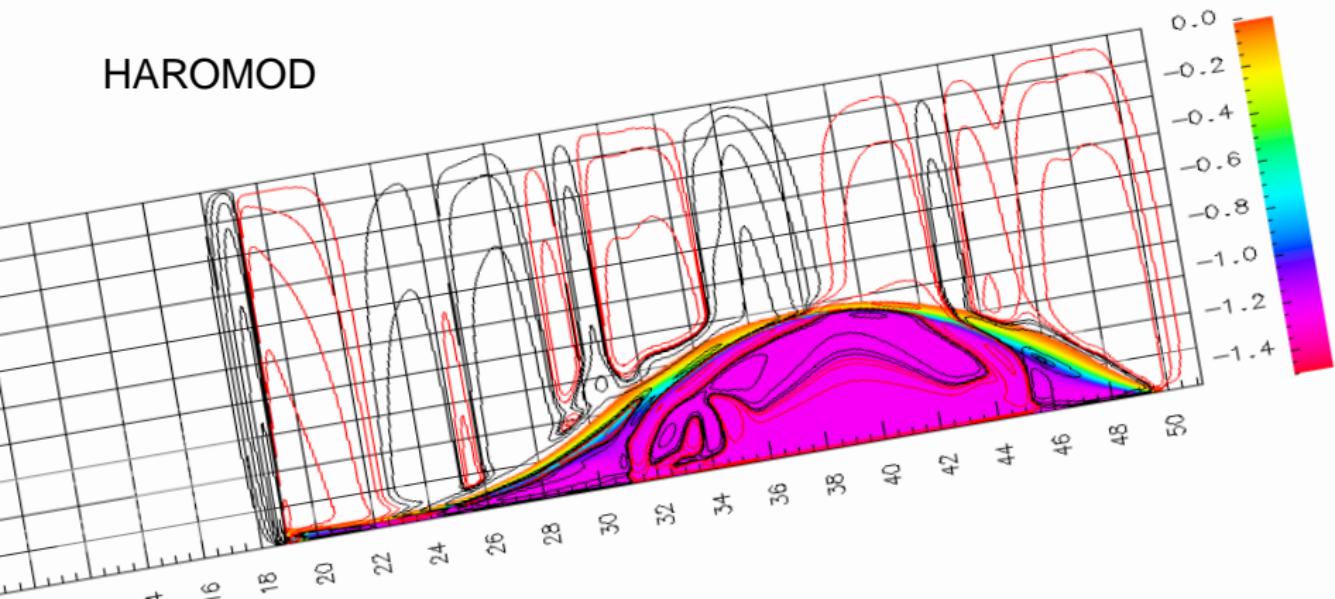
Parce qu'il est facile d'estimer la friction moyenne $\langle D \rangle_{x,t}$, avec :

$$D = (\tau + c_D |\mathbf{u}|)$$

mais il est plus difficile de distinguer entre friction de Rayleigh linéaire et un loi de trainée quadratique. Nous avons une projection rapide sur une "variété lente" correspondant à $\langle D \rangle_{x,t} = \text{const.}$ suivi d'une convergence lente à l'intérieur de la "variété lente."

Non-hydrostatic simulation :

HAROMOD



SW modifié

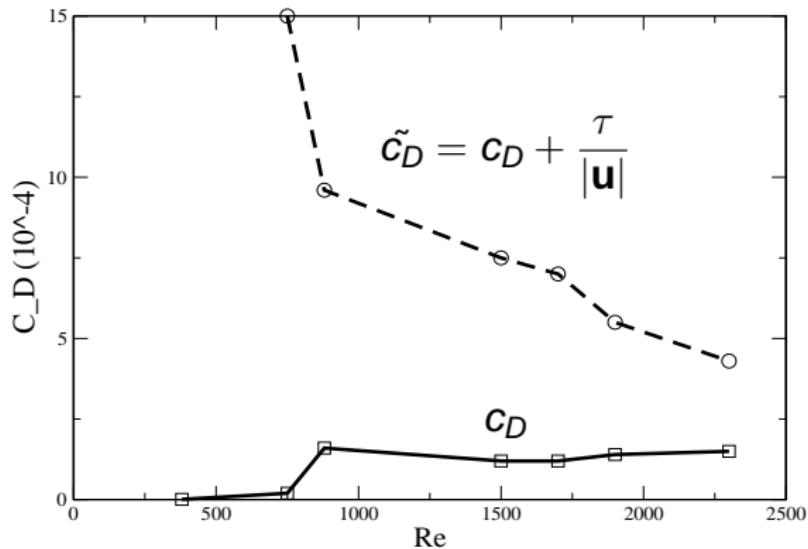
$$\begin{aligned}\partial_t u + \beta u \partial_x u - fv + g'(\partial_x h + \tan \alpha) &= -Du, \\ \partial_t v + \gamma u \partial_x v + fu &= -Dv,\end{aligned}$$

$$\beta = \frac{h \int_0^h u^2 dz}{(\int_0^h u dz)^2} > 1$$

$$\gamma = \frac{h \int_0^h uv dz}{\int_0^h u dz \int_0^h v dz} \approx 1/8$$

Data Assimilation :

Estimation of parameters and friction laws :
detection of transition from linear to quadratic law.

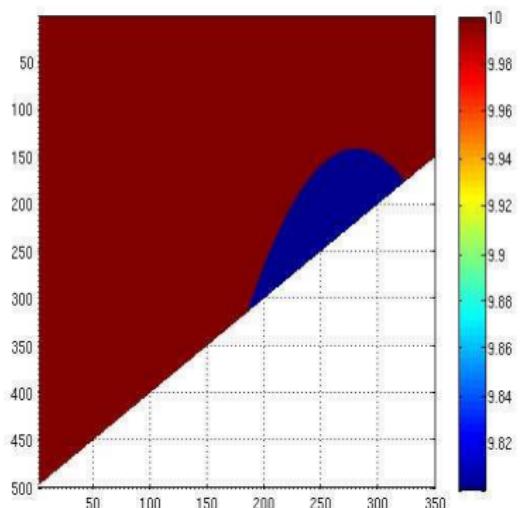


Plateforme Coriolis

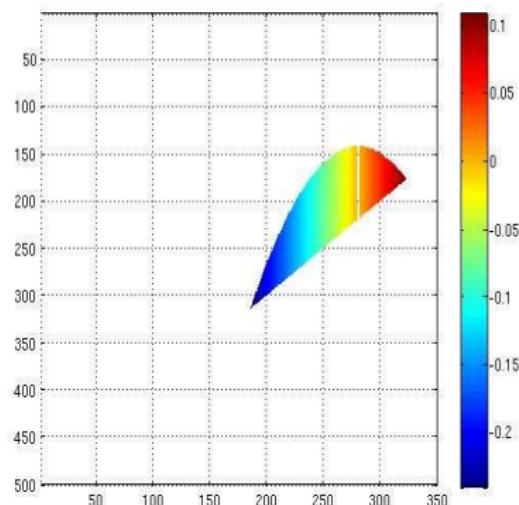


Initial Conditions

Temp

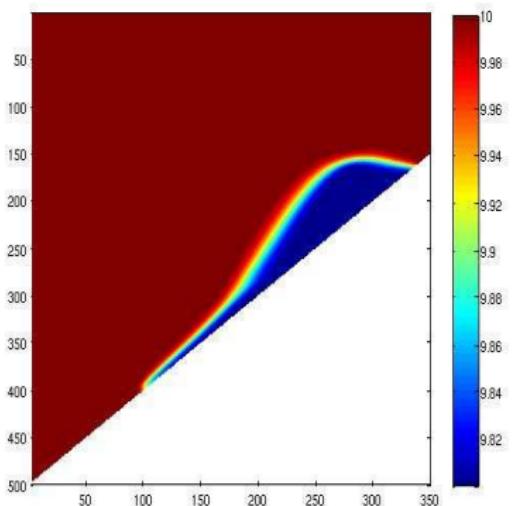


V_g

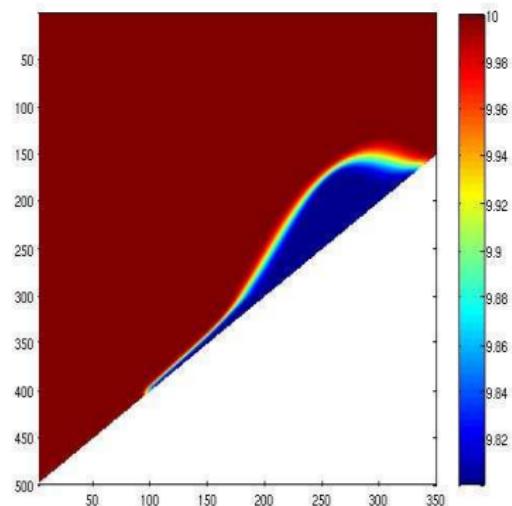


Reference Exp. (2D)

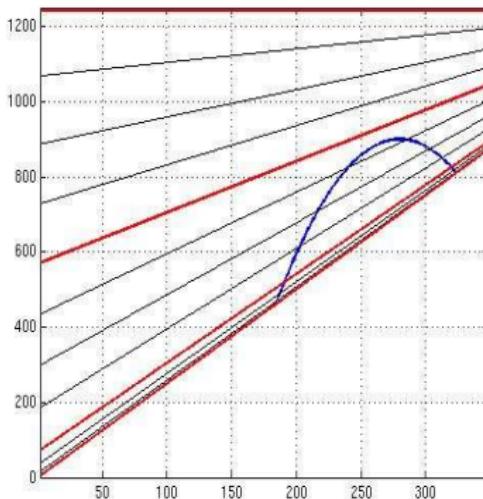
Z



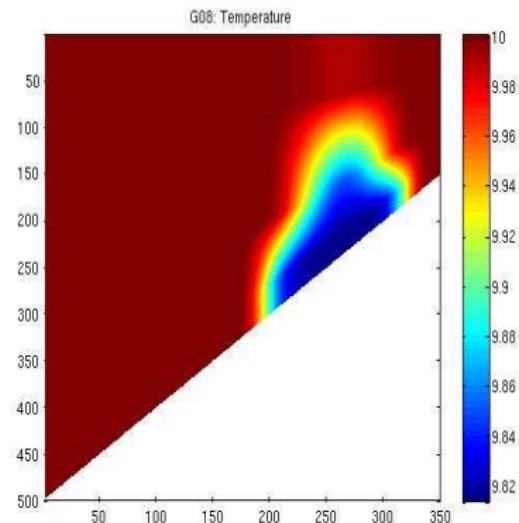
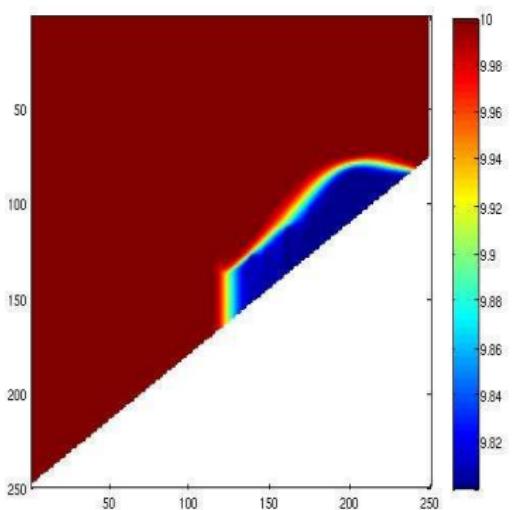
σ



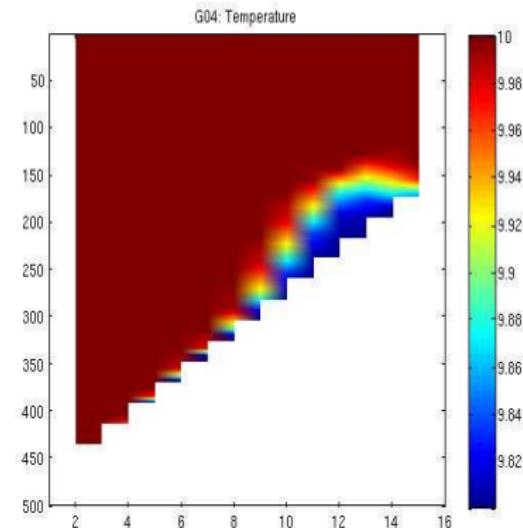
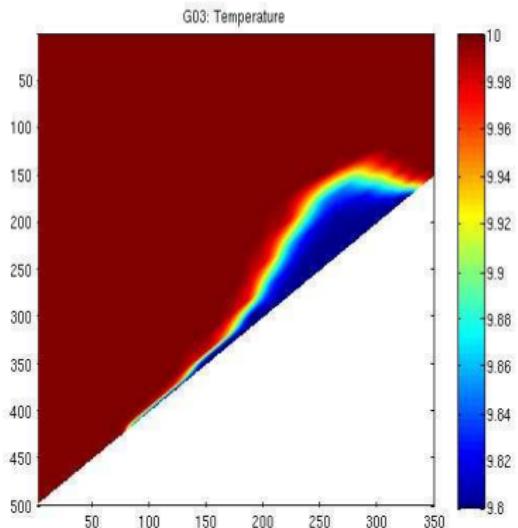
Grid σ



Convective Adjustment and Classic (2D)

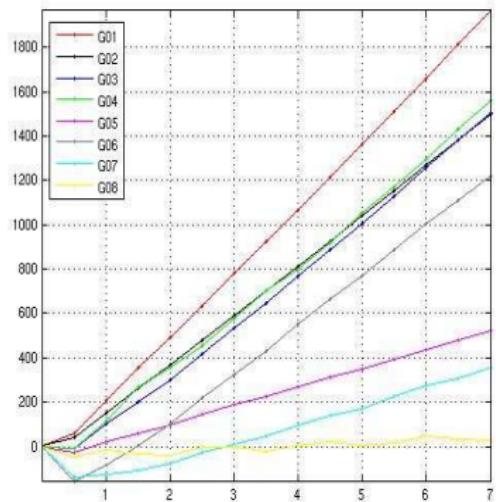


2+4+3 Levels (2D)

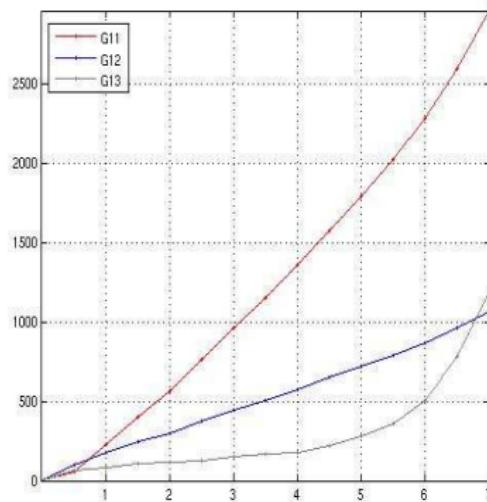


Down-slope transport

2.5D



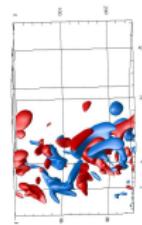
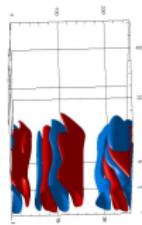
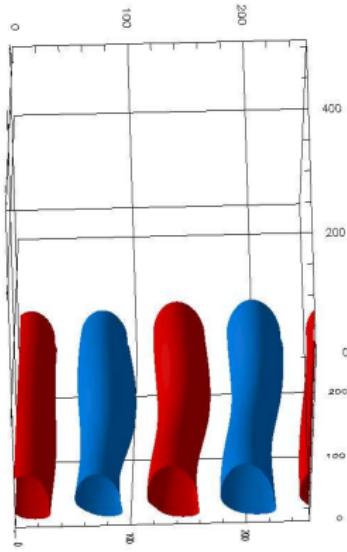
3D



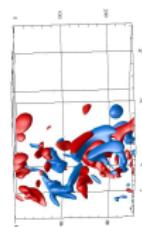
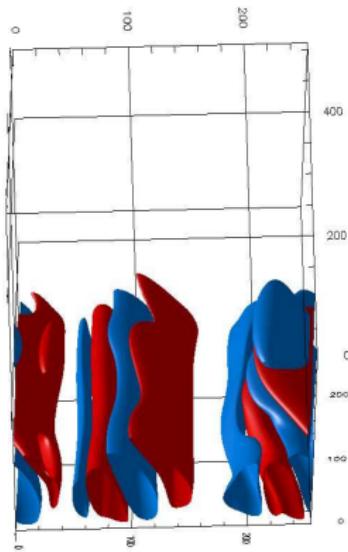
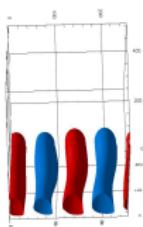
Conclusions Numerics

- ▶ The vertical resolution is key to correctly represent oceanic gravity currents.
- ▶ A few σ (< 6) levels in the bottom layer are sufficient.
- ▶ The refinement of the vertical resolution at the bottom is more important than at the surface.
- ▶ These results are NOT restricted to gravity currents.

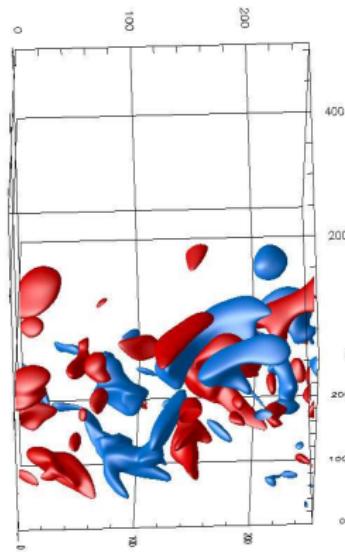
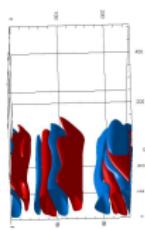
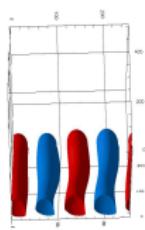
Coherent Structures



Coherent Structures



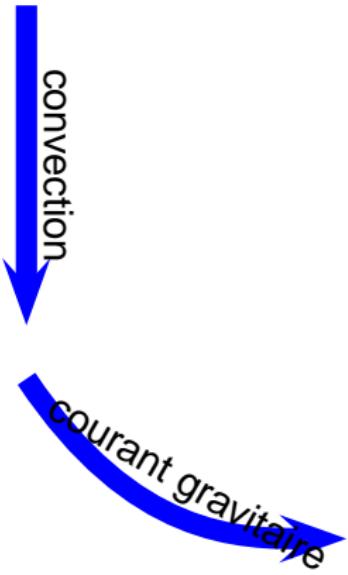
Coherent Structures



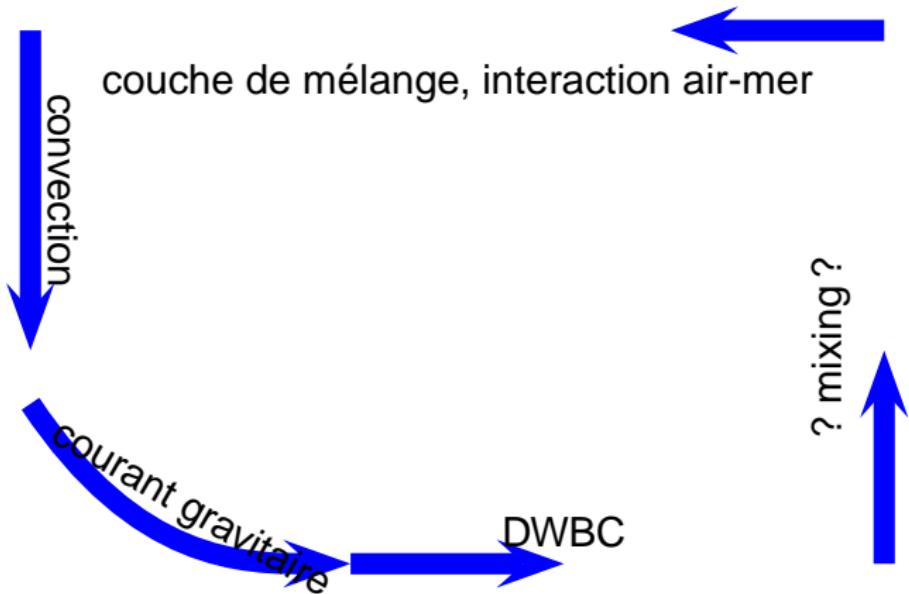
Couches d'Ekman

- ▶ Couches d'Ekman avec viscosité anisotrope (BLM 2010)
- ▶ Couches d'Ekman interfaciale (JPO 2011)

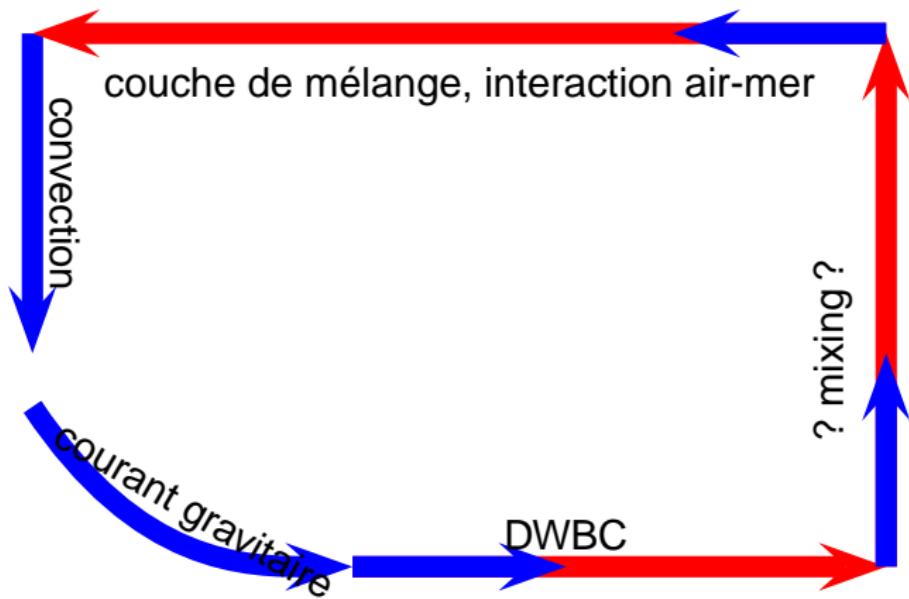
Conclusions



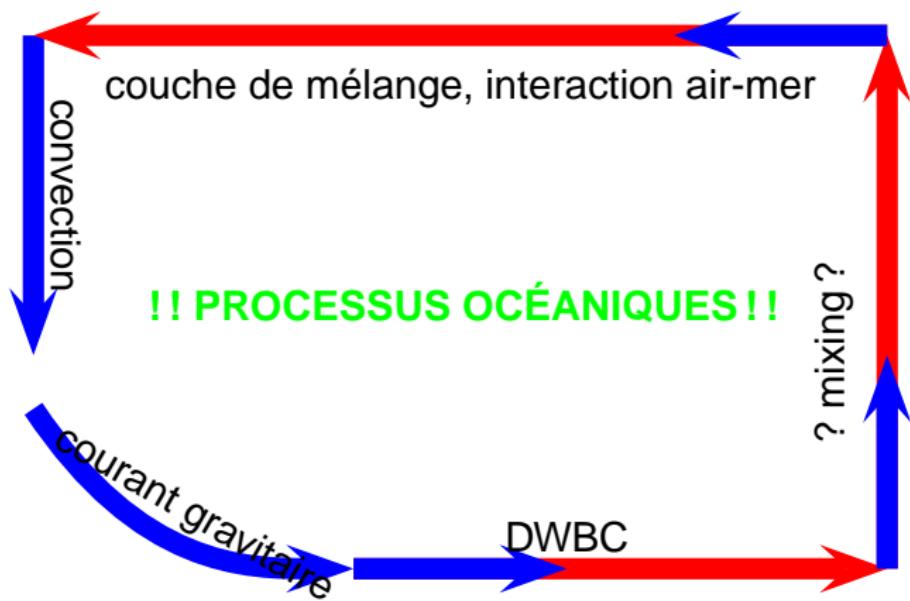
Conclusions



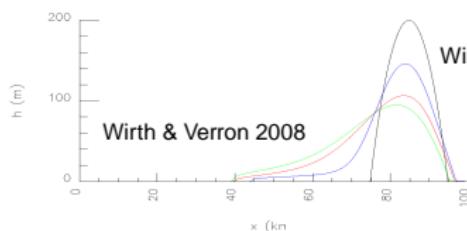
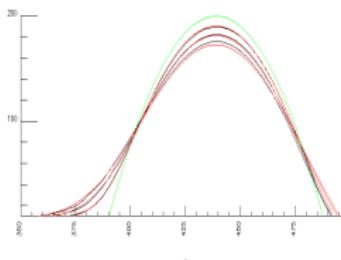
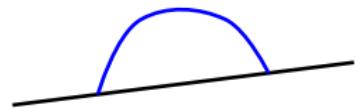
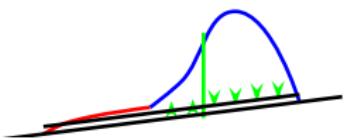
Conclusions & Perspectives



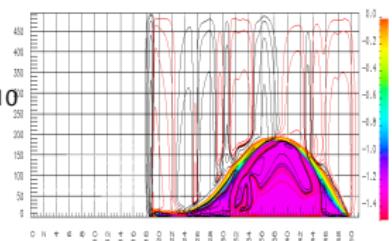
Conclusions & Perspectives



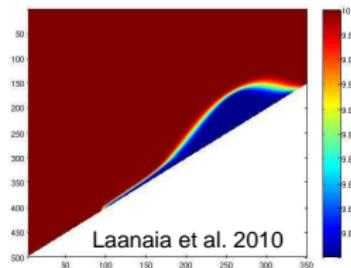
Courant gravitaire :



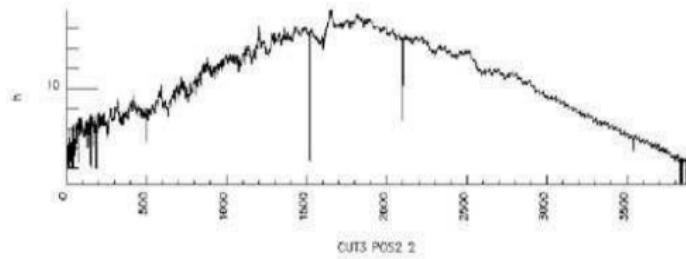
Wirth & Verron 2008



Wirth 2010



Laanaia et al. 2010



Etudes de processus

