

Dynamics of Oceanic Gravity Currents

Achim Wirth

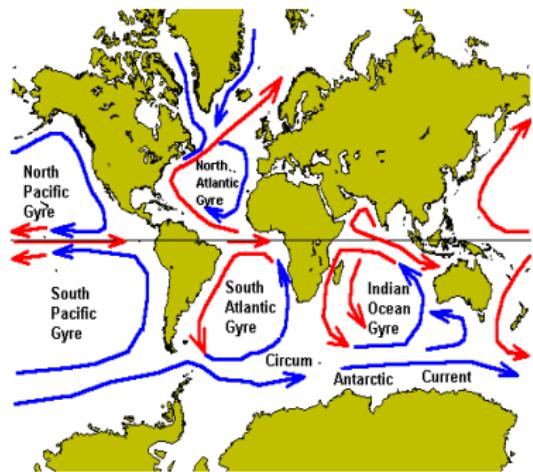
équipe MEOM

LEGI / CNRS

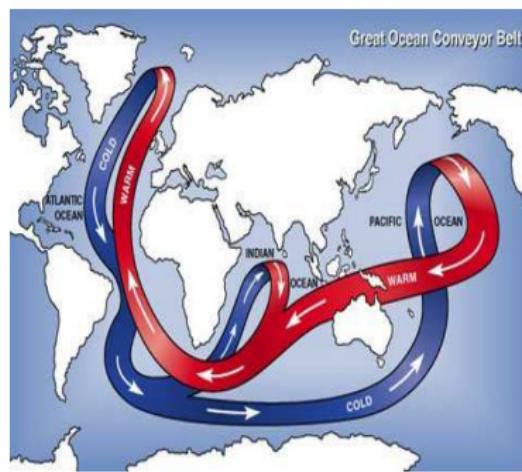
Roma 22/11/2010

Ocean Circulation

Gyre
“weather”



Overturning
“climat”



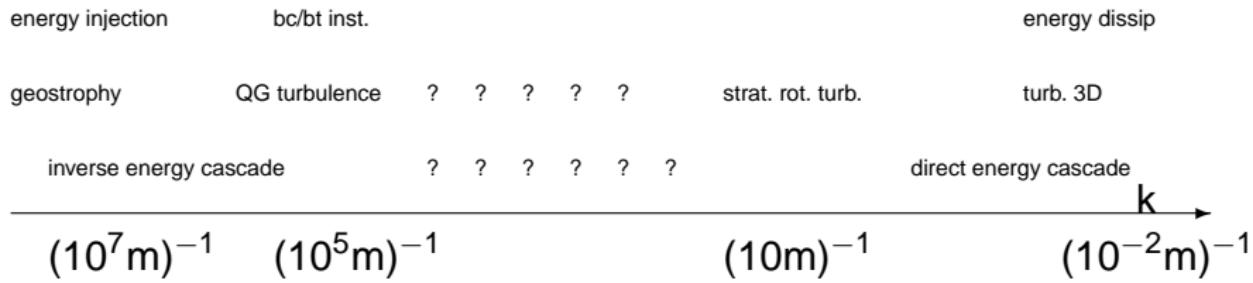
Ocean Dynamics by Scale

energy injection

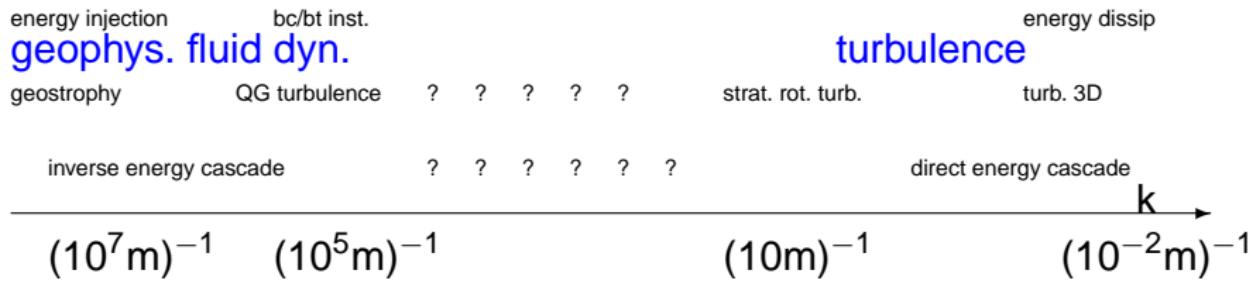
energy dissip



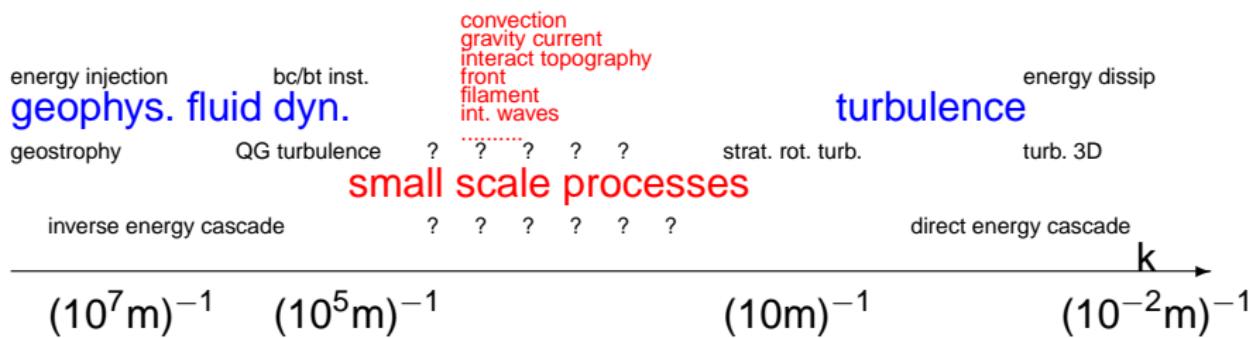
Ocean Dynamics by Scale



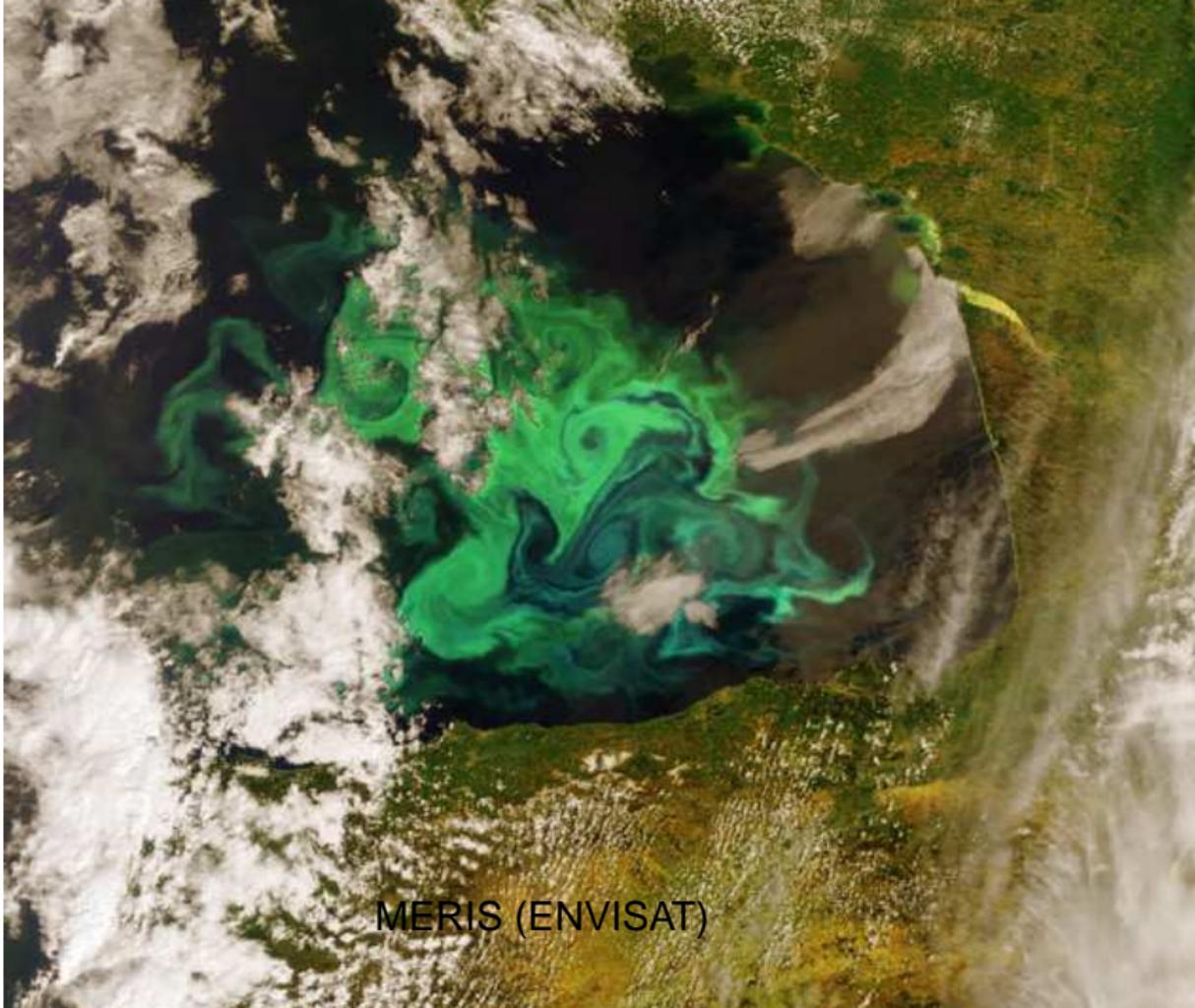
Ocean Dynamics by Scale



Ocean Dynamics by Scale

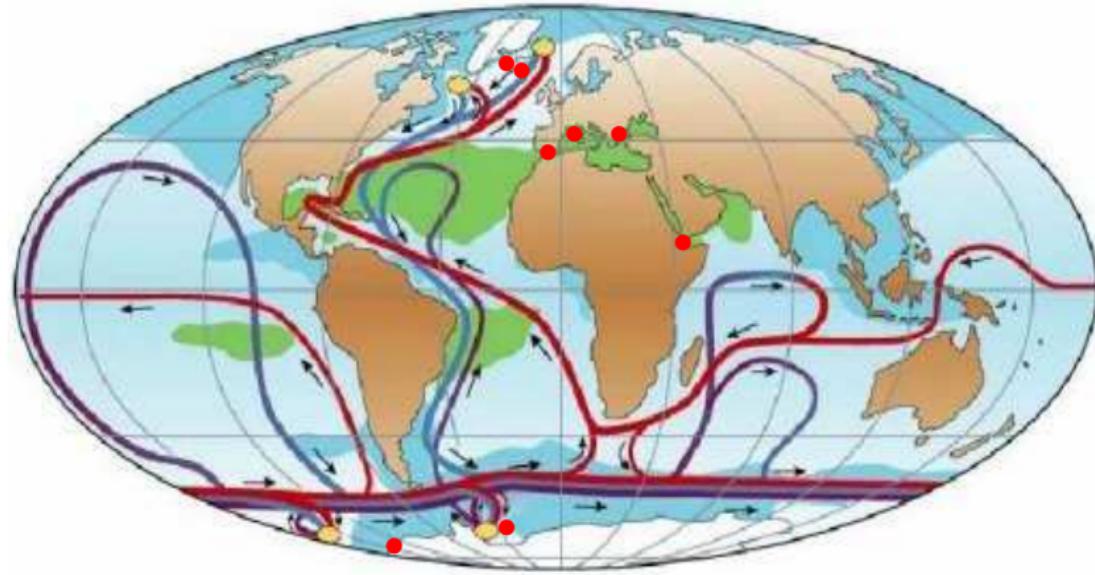






MERIS (ENVISAT)

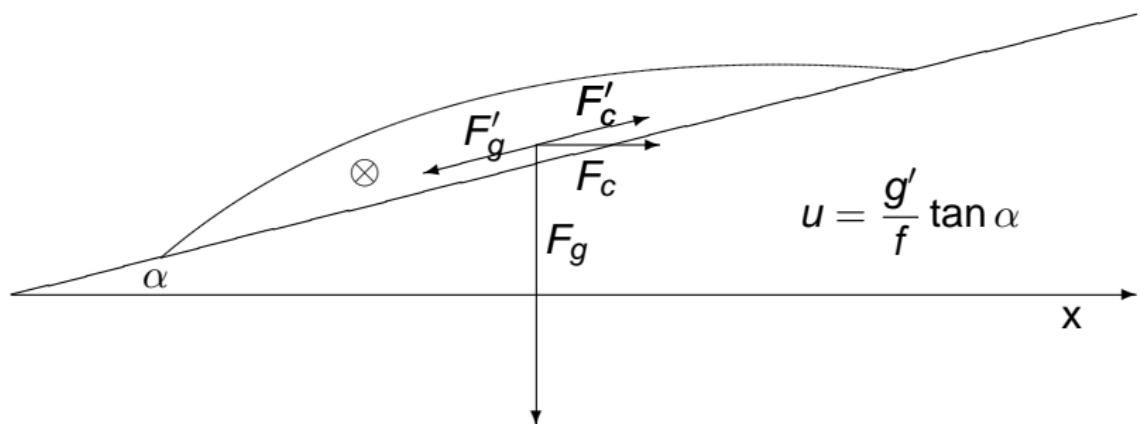
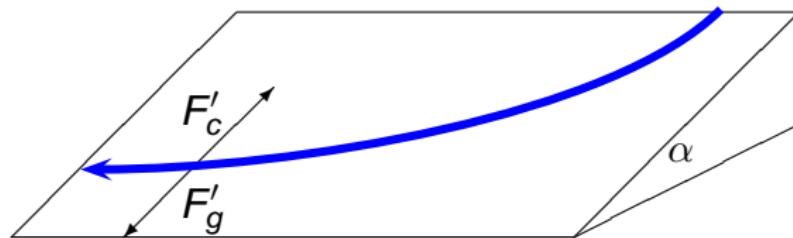
Gravity Current



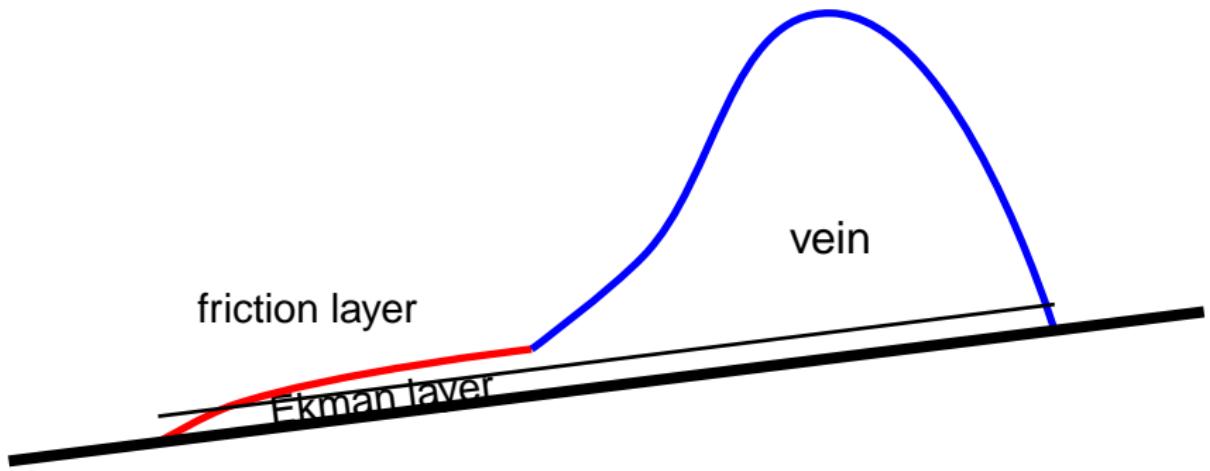
(Rahmstorf, Nature 2002)

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

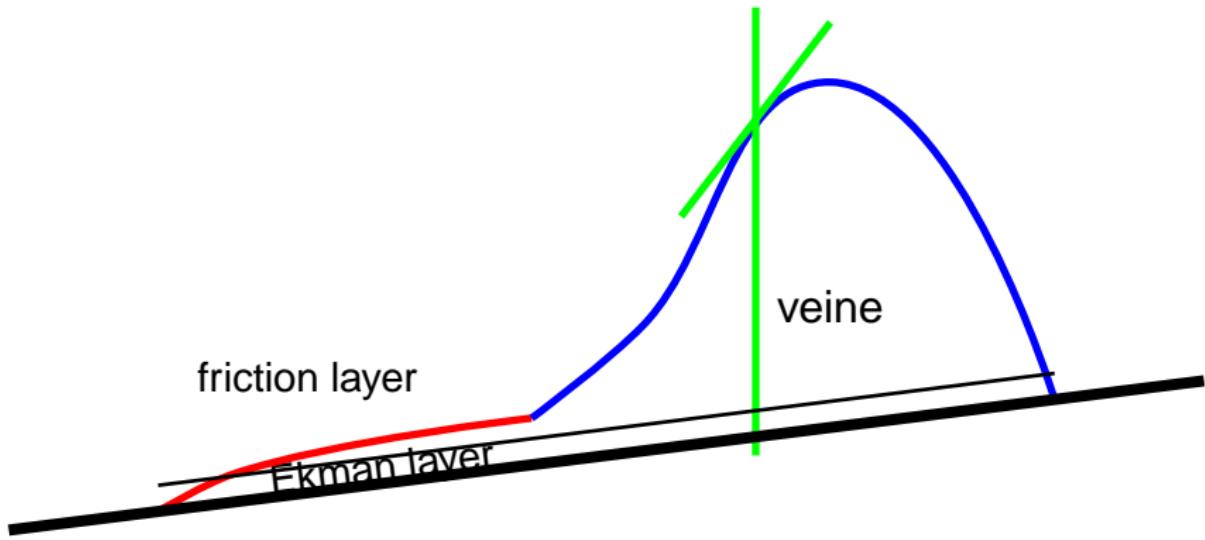
Geostrophy



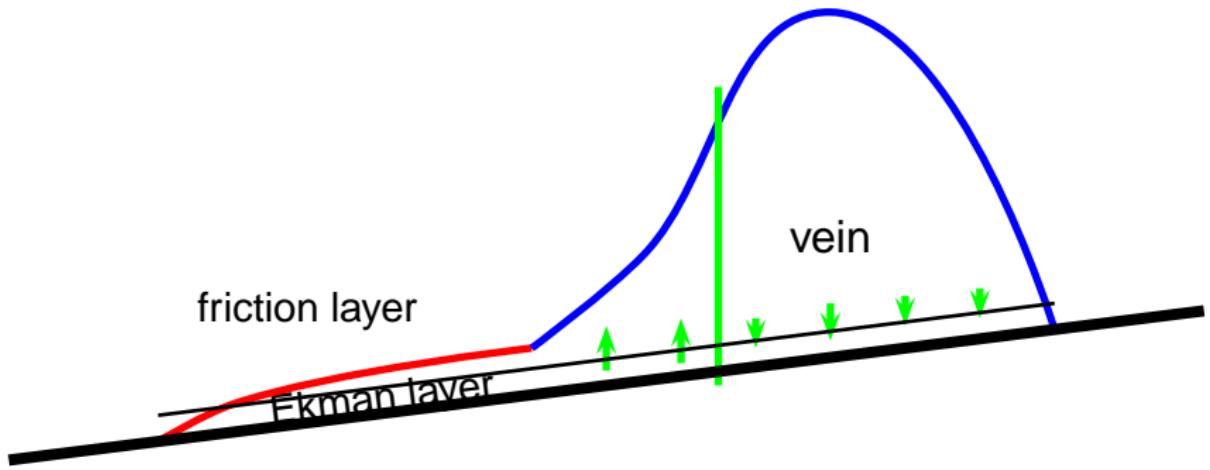
Forced Geostrophy



Forced Geostrophy



Forced Geostrophy



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 ?

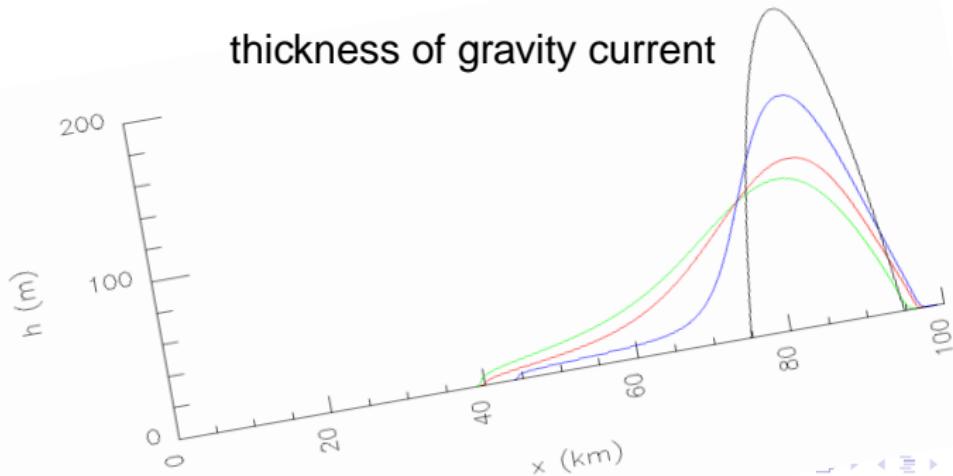
waves ?

retroaction of currents on roughness ?

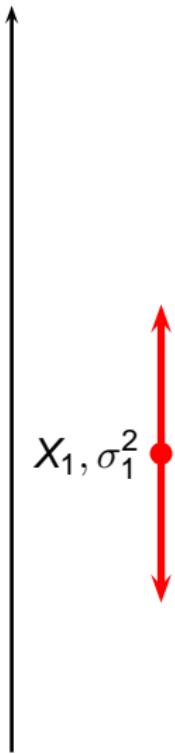
And : “The matter is far from being understood” Jiménez, Ann.
Rev. Fluid Mech. (2004).

Temporal Evolution SW

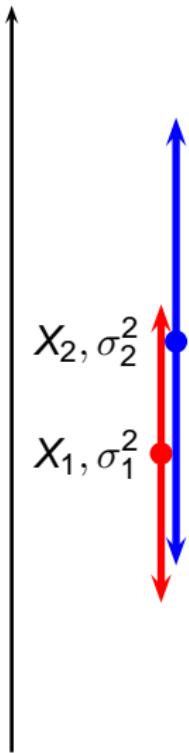
$$\begin{aligned}\partial_t u + u \partial_x u - fv + g'(\partial_x h + \tan \alpha) &= -Du + \nu \partial_x^2 u, \\ \partial_t v + u \partial_x v + fu &= -Dv + \nu \partial_x^2 v, \\ \partial_t h + u \partial_x h + h \partial_x u &= \nu \partial_x^2 h, \\ D = D(x, t) &= \frac{1}{h}(\tau + c_D |\mathbf{u}|).\end{aligned}$$



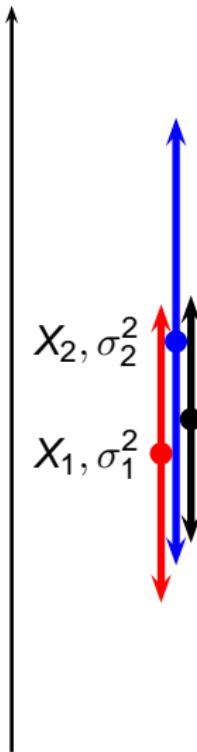
Data Assimilation



Data Assimilation



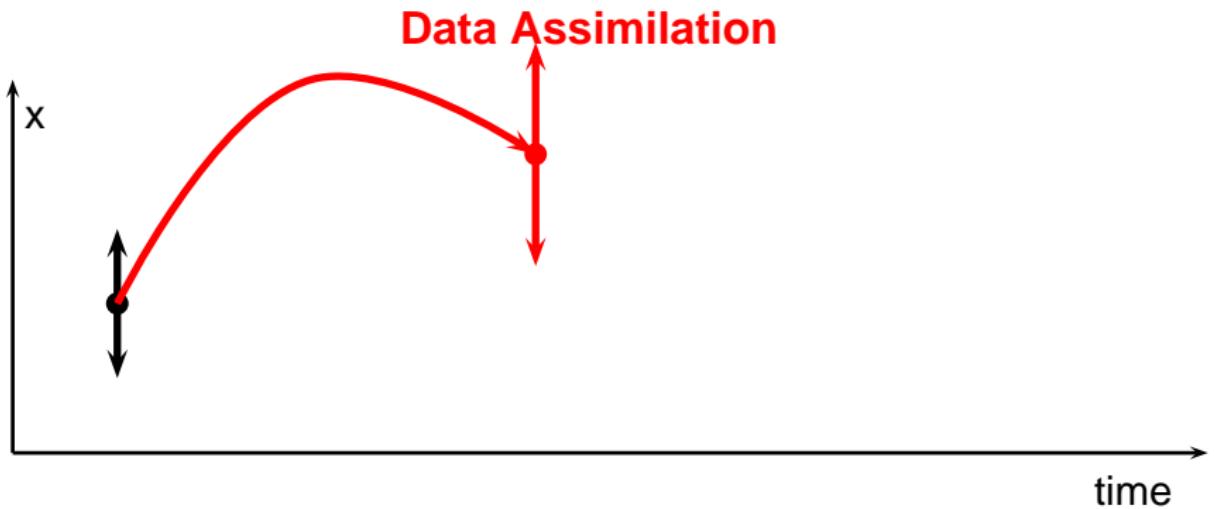
Data Assimilation

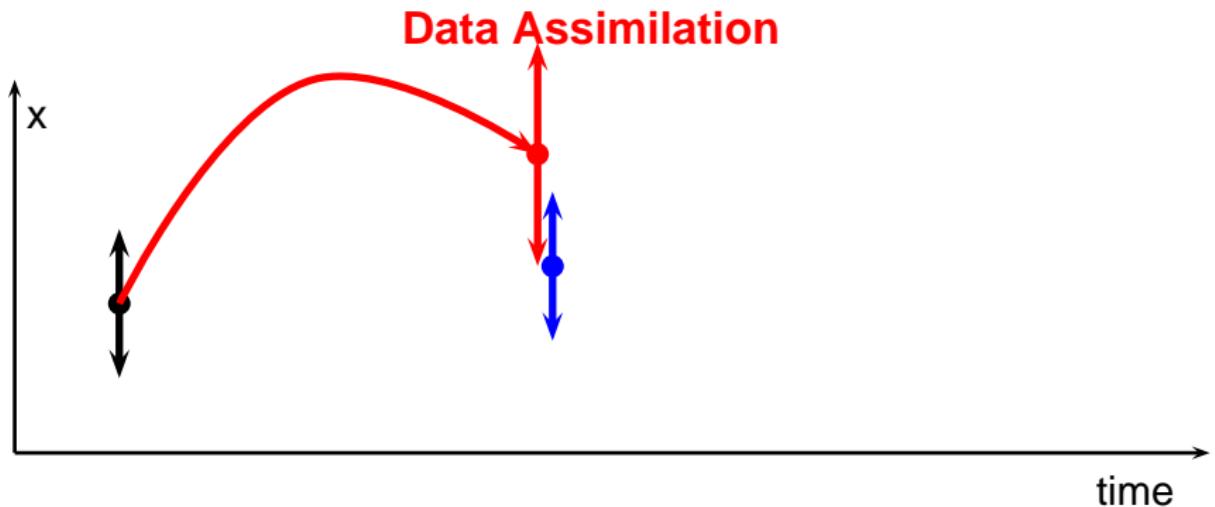


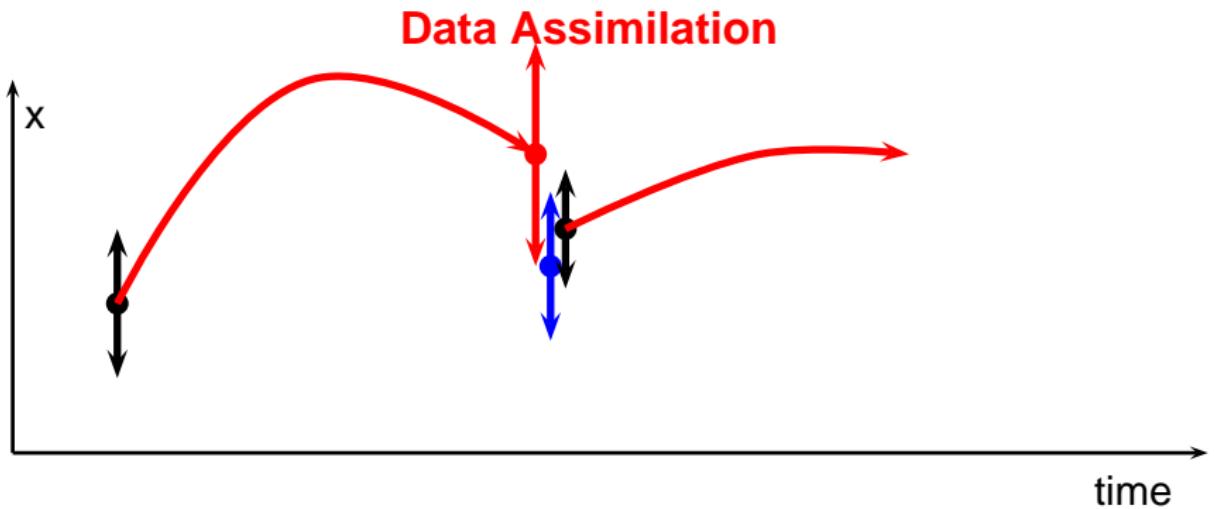
$$X = (\sigma_2^2 X_1 + \sigma_1^2 X_2) / (\sigma_2^2 + \sigma_1^2)$$
$$\sigma^2 = (\sigma_2^2 \sigma_1^2) / (\sigma_2^2 + \sigma_1^2)$$

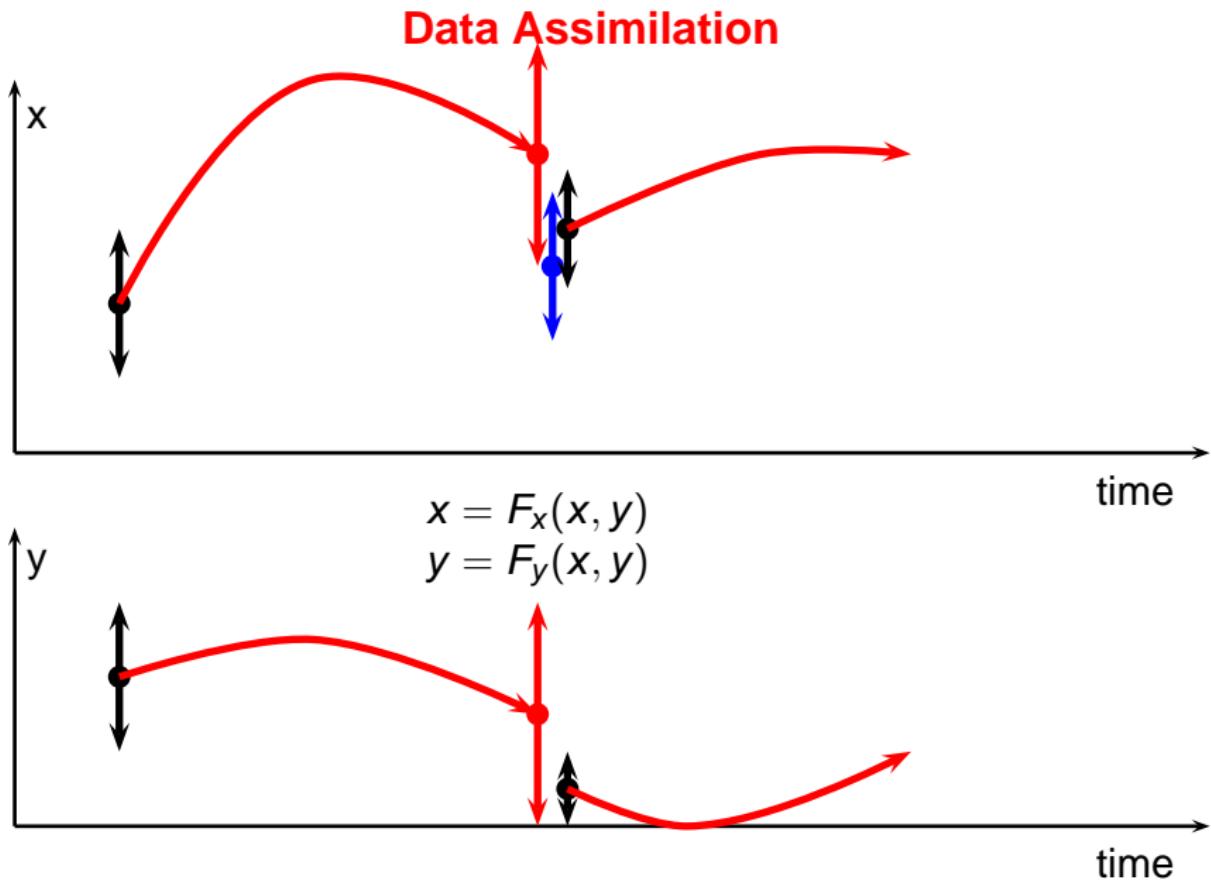
Data Assimilation











Estimation Procedure

Augmented State Vector (containing parameters) :

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

Tool : EnKF (Ensemble Kalman Filter) :

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

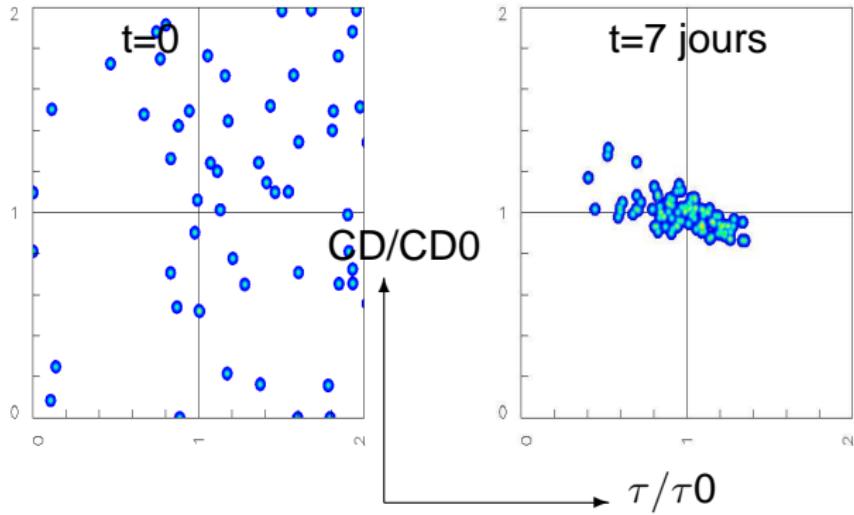
$$\mathbf{K} = \mathbf{P} \mathbf{H}^T (\mathbf{H} \mathbf{P} \mathbf{H}^T + \mathbf{W})^{-1} \quad (3)$$

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

Initial choice of parameters ?

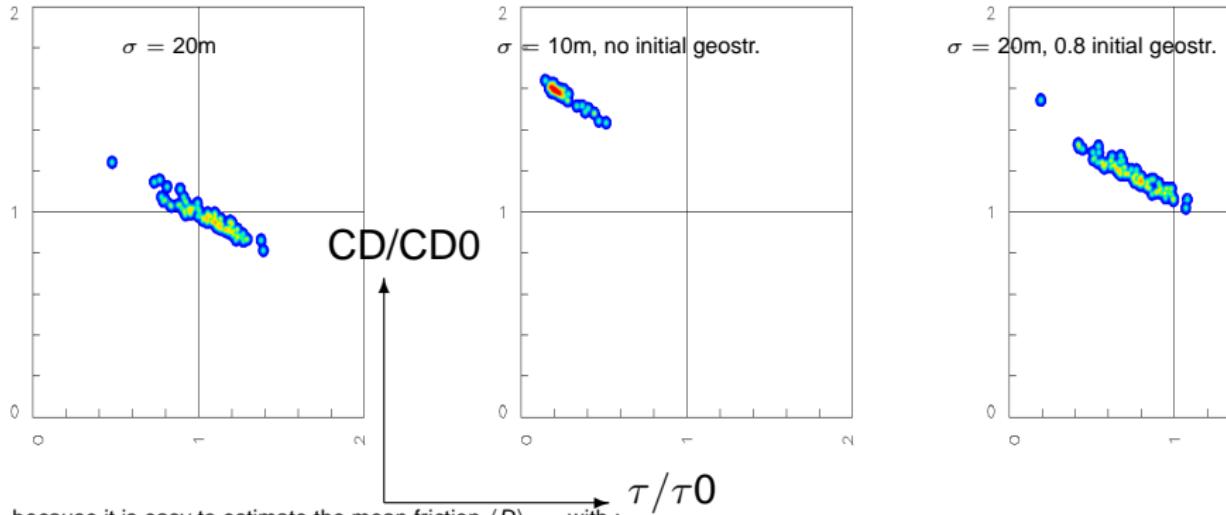
Is it possible to estimate r and c_D by observing only $h(x)$?

Assimilation every hour with an observation error of $10m$,
 $\tau_0 = 5.10^{-4} \text{ ms}^{-1}$, $c_{D0} = 5.10^{-3}$



Yes !

Why is the ensemble aligned ?

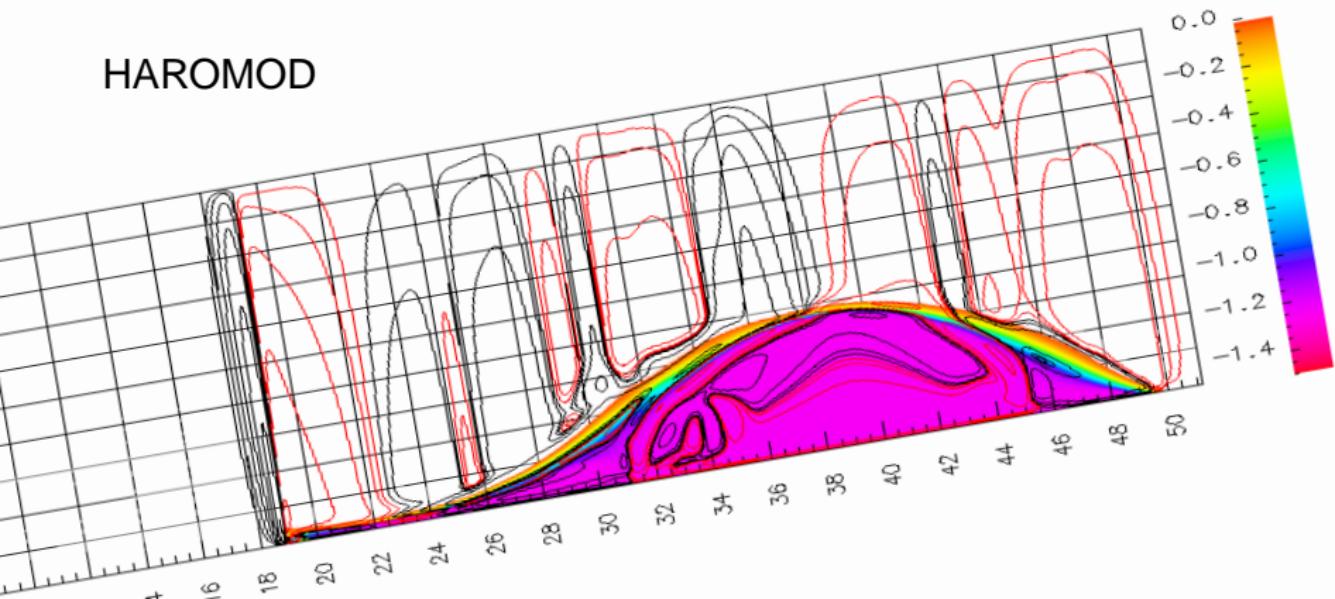


$$D = (\tau + c_D |\mathbf{u}|)$$

but it is more difficult to discriminate between linear Rayleigh friction and a quadratic drag law. We have a fast convergence on a slow manifold corresponding to $\langle D \rangle_{x,t} = \text{const.}$ followed by a slow convergence within the slow manifold.

Non-hydrostatic simulation :

HAROMOD



modified SW

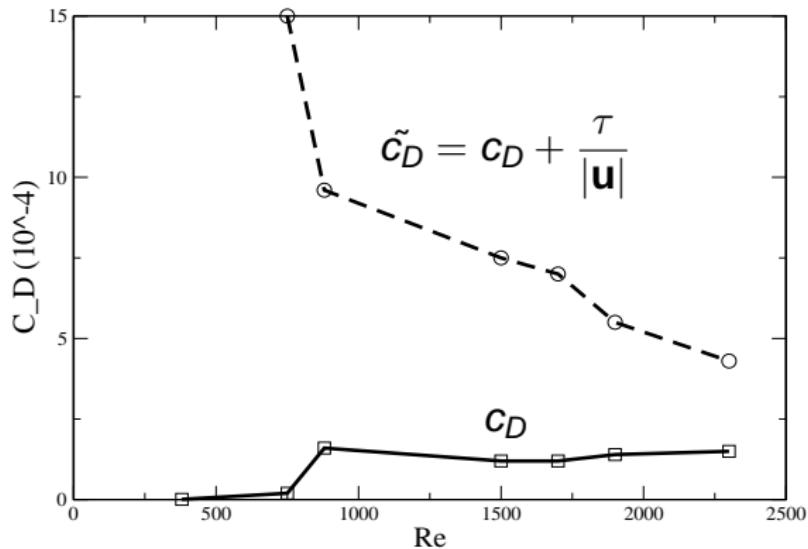
$$\begin{aligned}\partial_t u + \beta u \partial_x u - fv + g'(\partial_x h + \tan \alpha) &= -Du, \\ \partial_t v + \gamma u \partial_x v + fu &= -Dv,\end{aligned}$$

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

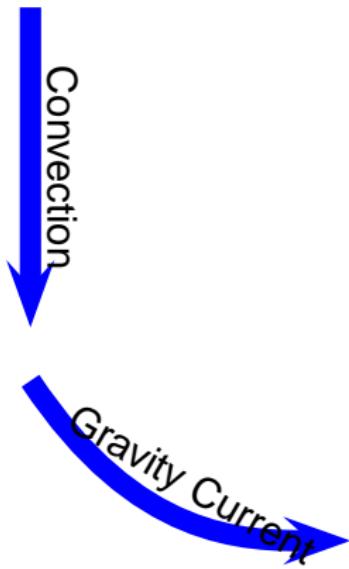
$$\gamma = \frac{h \int_0^h uv dz}{\int_0^h u dz \int_0^h v dz} \approx 1/8$$

Assimilation :

Estimation de paramètres et des lois de frottement :
détection de la transition d'écoulement laminaire vers turbulent.



Conclusions



Conclusions & Perspectives

