EGU

Session NP 2.2

Interaction and energy transfer between an atmospheric and an oceanic layer at the synoptic and the meso-scale

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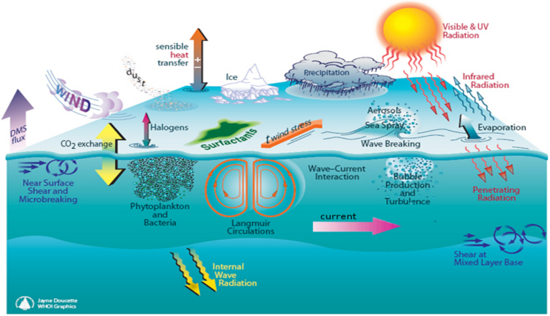
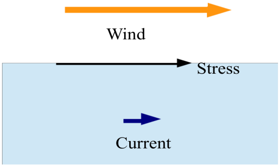
Context



- non linear processes over a large range of scale
- difference of air/water density leads to high stiffness

We focus on the exchange of momentum (parameterized by a quadratic drag law).



Todays numerical models :

atmosphere :	Dirichlet boundary condition	$\Leftrightarrow$	wind is supposed to vanish at the surface	$\Leftrightarrow$	direct effect of ocean currents neglected
ocean :	Neumann boundary condition	$\Leftrightarrow$	the shear of the atmosphere on the ocean is applied to the ocean		

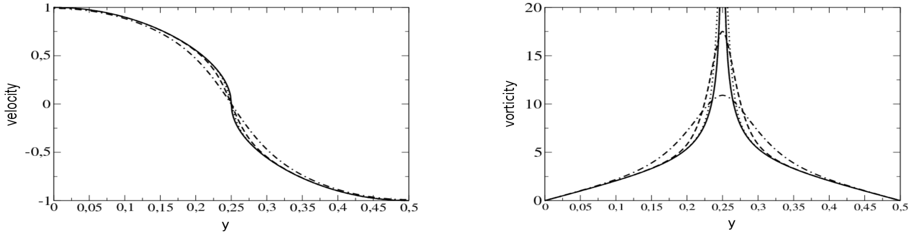
- Is it well adapted when the resolution, in both, the atmosphere and the ocean become even finer ?

Contents

1D Model : source of instability

Atmosphere :

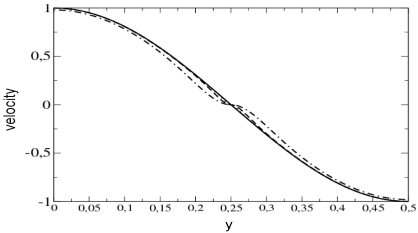
$$\frac{c_D}{H^a}|u^a(y)|u^a(y) - \nu^a \partial_{yy} u^a(y) = F_0 \cos(2\pi y/L)$$

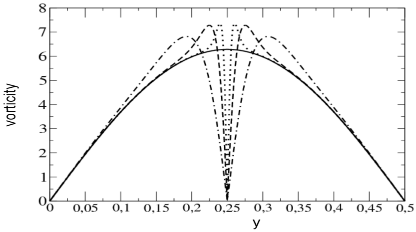


Legend : —$\nu^a = 0$ ... $\nu^a = 10^{-5}$ - - -$\nu^a = 10^{-4}$ -.-. $\nu^a = 10^{-3}$

- ν^a control the width and the height of the atmospheric vorticity peak.

Ocean : $F^{ao} = \nu^a \partial_{yy} u^a + \tilde{F}^a$ and a linear damping at its lower boundary

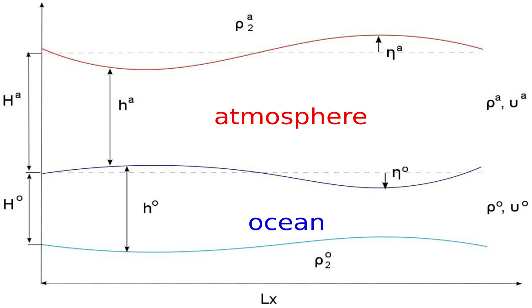




Legend : —$\nu^a = 0$ ... $\nu^a = 10^{-5}$ - - -$\nu^a = 10^{-4}$ -.-. $\nu^a = 10^{-3}$

- Vorticity maxima are key to barotropic instability (*Vallis(2006), Paldor and Ghil (1997)*)
- The distance between the maxima, which is the important length scale for instability is governed by ν^a.

Shallow-Water model



Typical horizontal scale :

$$Rd^o = \sqrt{g^o H^o}/f = 20km$$
$$Rd^a = \sqrt{g^a H^a}/f = 200km$$

Reduced gravity shallow water equations (k=a or o) :

$$\begin{aligned}
\partial_t u^k + u^k \partial_x u^k + v^k \partial_y u^k - f v^k + g^k \partial_x h^k &= \nu^k \nabla^2 u^k + F_x^k + \tilde{F}_x^k \\
\partial_t v^k + u^k \partial_x v^k + v^k \partial_y v^k + f u^k + g^k \partial_y h^k &= \nu^k \nabla^2 v^k + F_y^k + \tilde{F}_y^k \\
\partial_t h^k + \partial_x [h^k u^k] + \partial_y [h^k v^k] &= 0
\end{aligned}$$

Quadratic drag law (classical) :

$$\begin{pmatrix} f_x^k \\ f_y^k \end{pmatrix} = \pm \rho^a C_d \sqrt{(u^o - u^a)^2 + (v^o - v^a)^2} \begin{pmatrix} u^o - u^a \\ v^o - v^a \end{pmatrix}, \quad C_d = 8.10^{-4}$$

Initially : - narrow jet in geostrophic equilibrium in the y-direction in the atmosphere.
- narrow jet in geostrophic equilibrium in the x-direction in the ocean (in 2D).

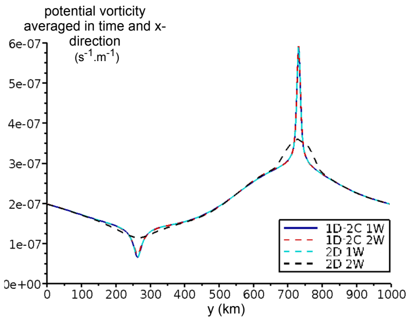
$\tilde{F}^a$: restoring acts to force the atmosphere at large scale to initial conditions.
$\tilde{F}^o$: damping in the ocean to dissipate mechanical energy.

Numerical model : - Fine spatial resolution ($dx = dy = 2km$)
- Short time step ($\Delta t = 15s$).

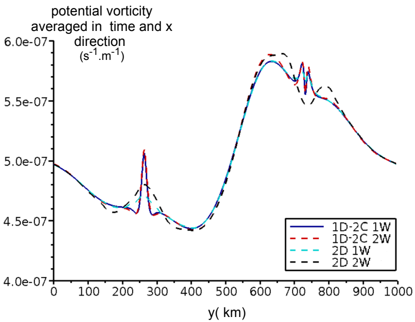
Result integration

- vanishing atmospheric velocities and strong velocity gradient at y=260 and 740km

Atmosphere



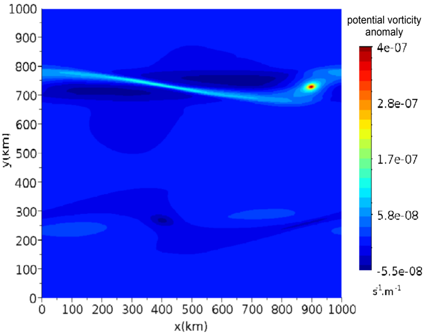
Ocean



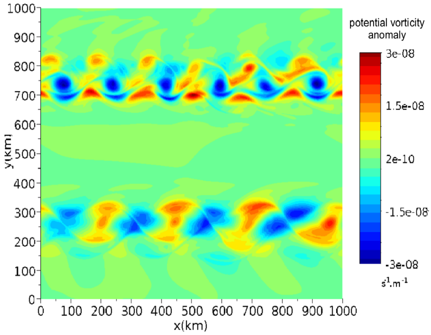
- analogue to the situation observed in the 1D model

2D integration :

Atmosphere, t=2000 days



Ocean, t=2000 days



- The unstable dynamics in the atmosphere is slaved to the ocean dynamics.

First part conclusions

- Instabilities are due to the physics of the quadratic drag law and the atmospheric turbulent viscosity.
- Instabilities are only apparent in fine resolution model which resolve the scale of the Rd^o in the atmosphere and the ocean.
- Instability can propagate from the ocean to the atmosphere in 2-way interaction.

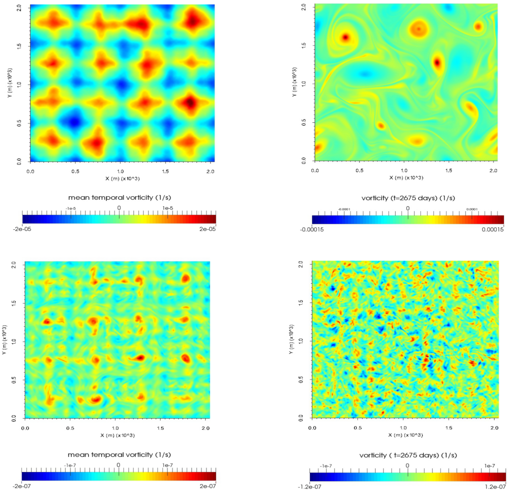
Qualitative description of turbulent simulations

$Cd = 1.10^{-4}$ (stable atmosphere)

temporal mean | instantaneous vorticity anomaly

atmo

ocean



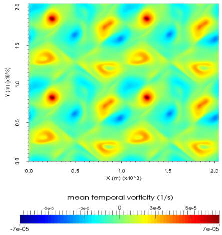
- forcing only visible in time averaged atmosphere but visible in the ocean
- co-organization of atmosphere-ocean only visible in averages due to large atmospheric perturbations
- ocean adapts only to a time averaged atmosphere
- only few coherent structures in the ocean because of perturbation by turbulent atmosphere

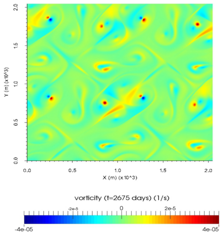
Qualitative description of turbulent simulations

$Cd = 8.10^{-4}$ (neutral atmosphere)

temporal mean | instantaneous vorticity anomaly

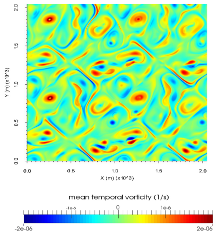
atmo

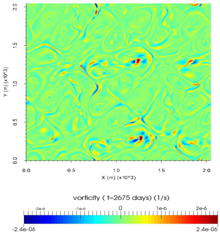




- coherent structures in the oceanic and atmospheric vorticities appear co-located

ocean



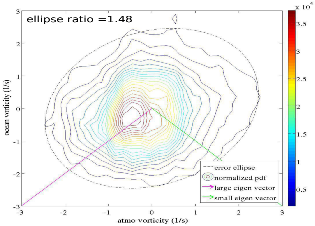


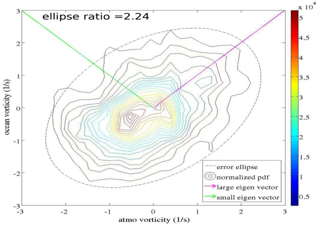
- spatial disorder with very slow evolution in time in both ocean and atmosphere

Bivariate probability density function

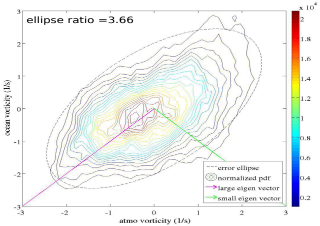
$Cd = 1.10^{-4}$ | $Cd = 8.10^{-4}$

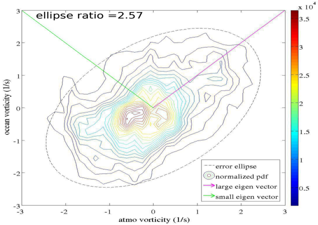
instantaneous





average

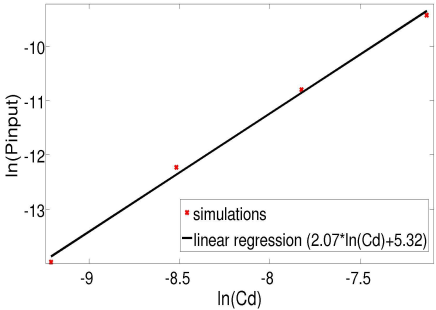




- when the fast variation of the atmosphere are filtered out the correlation increases (2 times higher).

- low time variability in instantaneous and mean and high correlation

Power input to the ocean

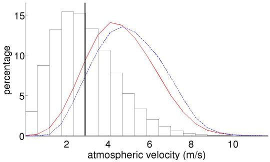


$$P = \rho_a C_d |U_a - u_o|(U_a - u_o)u_o$$

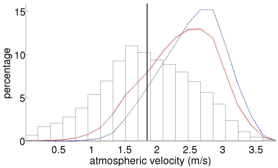
- Drag coefficient has a quadratic influence on the power input to the ocean.

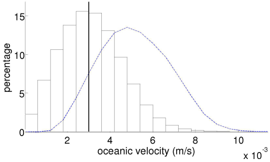
Power input to the ocean

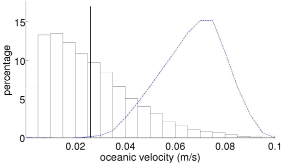
$Cd = 1.10^{-4}$



$Cd = 8.10^{-4}$







——— (red) percentage of energy loss by the atmosphere.

——— (blue) energy gain by ocean.

——— mean velocity.

14percent of the fastest oceanic speed contribute to half of the Pinput

3 percent of the fastest oceanic speed contribute to half of the Pinput
→ increase on correlation

approximation of *Pinput*= $\rho_a Cd|\overline{u_o}|\overline{u_a}^2$

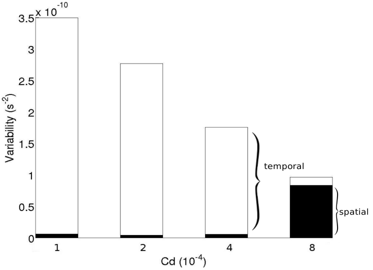
3 times higher → neglect the correlation of the magnitude

16 percent lower → neglect the angle between wind and current

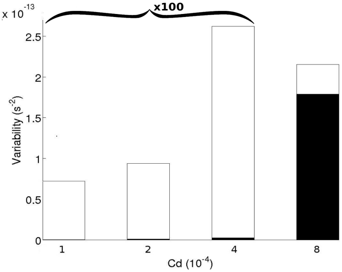
→ estimation neglects correlation between current and wind but also the angle between the corresponding velocity vector.

Spatial and temporal variability

atmosphere



ocean



lower Cd : decreasing of temporal variability with drag and very low spatial variability («3percents)

$Cd = 8 \times 10^{-4}$: spatial variability about 86percent of total variability.

variability 100 times larger than for other Cd with more than 3/4 due to spatial variability

→ quenched disorder state

Conclusions

- Time-scale dependence of the air-sea interaction.
- Estimation of the power input with the average speeds of the atmosphere and ocean neglects the variance of the wind and the correlation between current and wind speeds but also the angle between the corresponding velocity vectors.
- Phase change in the dynamics of the atmosphere-ocean system for $Cd = 8 \times 10^{-4} \rightarrow$ quenched disorder state
- No significant generation of gravity waves in the ocean.

Perspectives

- Study phase change with simpler model (point vortices).
- Air-sea interaction around an island $\rightarrow$ strong vorticity in the atmosphere (atmospheric wake) governs ocean dynamics.
  (poster presentation in AS2.2)
- Research of a postdoctoral position.