Energy diffusion and dissipation processes in ocean surface

Philippe Fraunié

Mediterranean Institute of Oceanography

UNIVERSITÉ DE TOULON

cnrs dépasser les frontières

Dedicated in Memmory to Prof JM Redondo UPC Barcelona

Small Scale Turbulence (J.M. Redondo)

For the small scale, as basic indicator of the potential energy to kinetic energy ratio, we use the **Richardson's Number**, either its flux (Rf) or gradient form (Rg). This is a parameter able to distinguish between different stratification types.

Rf is defined as the ratio of buoyancy and the production term in the turbulent kinetic energy:

$$\frac{\partial K}{\partial t} = \overline{u'_j \frac{\partial}{\partial t}\left(\frac{p'}{\rho} + \frac{1}{2} u'_i u'_i\right)} + \overline{u'u}\frac{\partial \bar{u}}{\partial Z} - \frac{g}{\rho}\overline{\rho' w'} - \nu \overline{\nabla u'_j \nabla u'_j} \longrightarrow Rf = \frac{g}{\rho}\frac{\overline{\rho' w'}}{\overline{u'w'}\frac{\partial u}{\partial Z}}$$

(Mixing Efficiency)

Considering the Boussinesq relationships between turbulent fluxes and average gradients as well as other expression:

$$K_m \overline{\rho' w'} = -\frac{\partial \rho}{\partial Z}$$

$$K_h \overline{u'w'} = \frac{\partial u}{\partial Z}$$

$$\frac{1}{\theta_0}\frac{\partial \theta}{\partial Z} = -\frac{1}{\rho}\frac{\partial \rho}{\partial Z}$$

$$Ri = \frac{K_m}{K_h} Rf$$

Obtaining the gradient Richardson number:

$$Ri = \frac{\dfrac{g}{\theta_0}\dfrac{\partial \theta}{\partial Z}}{\left[\left(\dfrac{\partial U}{\partial Z}\right)^2 + U^2\left(\dfrac{\partial \alpha}{\partial Z}\right)^2\right]}$$

INSTABILITY

WEAK STABILITY

STABILITY

Where: u,α-speed and direction wind; θ-potential temperature; g-gravity acceleration and Z-height.

Dynamic Model

Tamay Özgökmen 2011

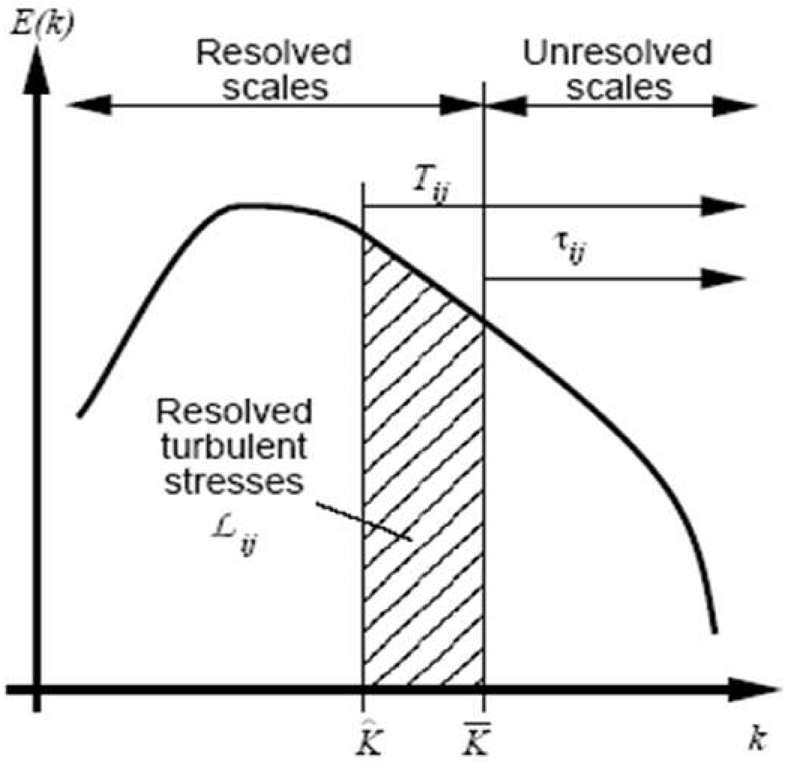
- Filter again resolved scales

- Assume same form of model can be applied to both subgrid and resolved stresses

$$T_{ij} = \widetilde{\overline{u_i u_j}} - \tilde{\bar{u}}_i \tilde{\bar{u}}_j$$
$$L_{ij} = \widetilde{\bar{u}_i \bar{u}_j} - \tilde{\bar{u}}_i \tilde{\bar{u}}_j$$

$$L_{ij} = T_{ij} - \tilde{\tau}_{ij}$$

- Compute Smagorinsky constant



GERMANO, M. 1992 Turbulence: the filtering approach. *J. Fluid Mech.* **238**, 325.

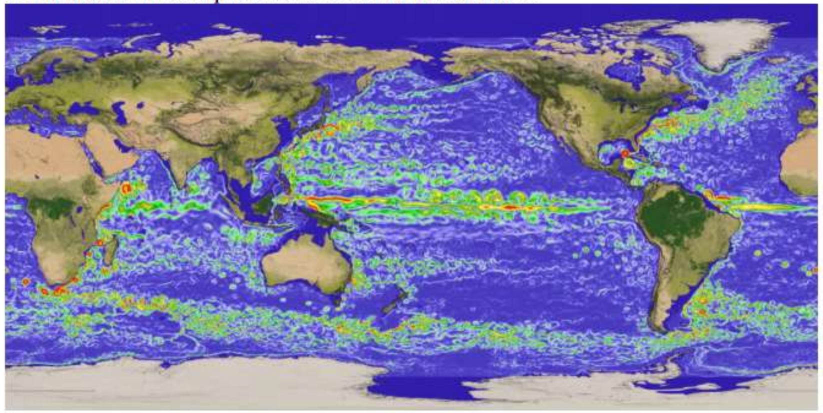
PIOMELLI, U. AND LIU, J. 1995 Large eddy simulation of rotating channel flows using a localized dynamic model. *Phys. Fluids A* **7**, 839.

Large scales (climate)

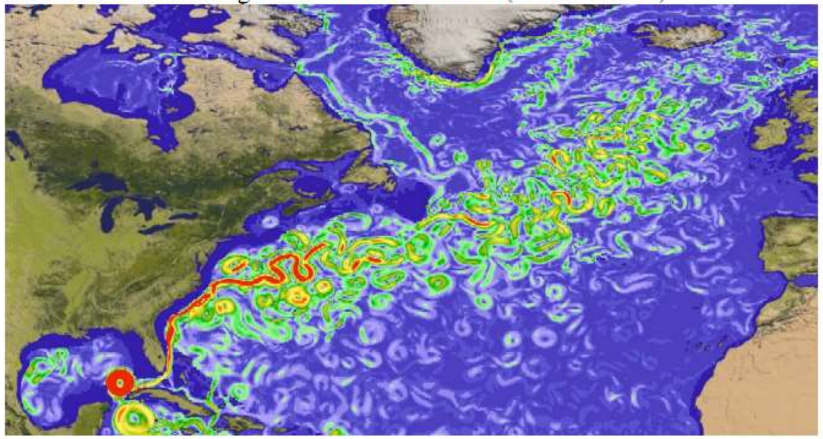
(El Niño – la Niña)

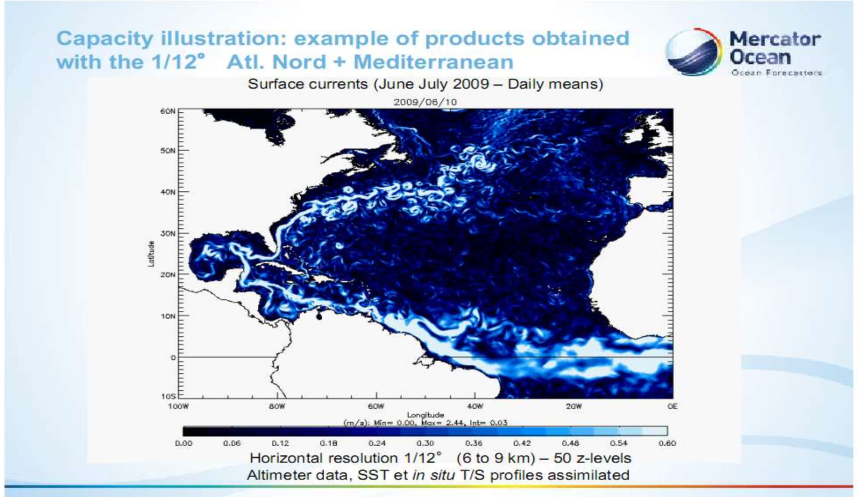
Time scale of horizontal diffusion

Simulations numériques sur le « *Earth-Simulator* »



Modèle de circulation générale haute résolution (~10kmx10km)





Gula et al, J.Phys.Oceanogr., 2015

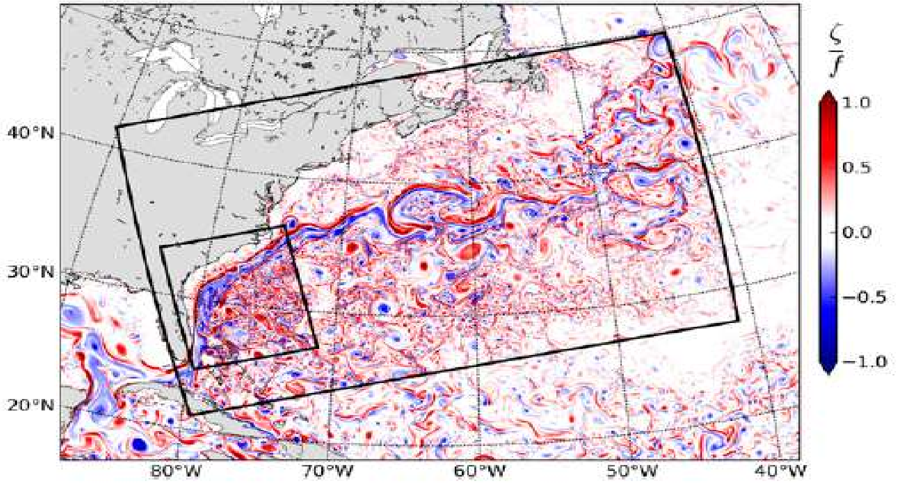
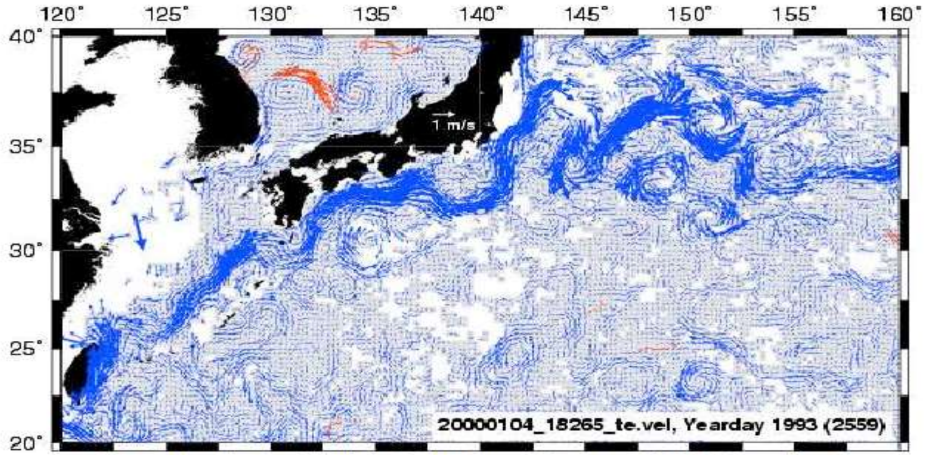
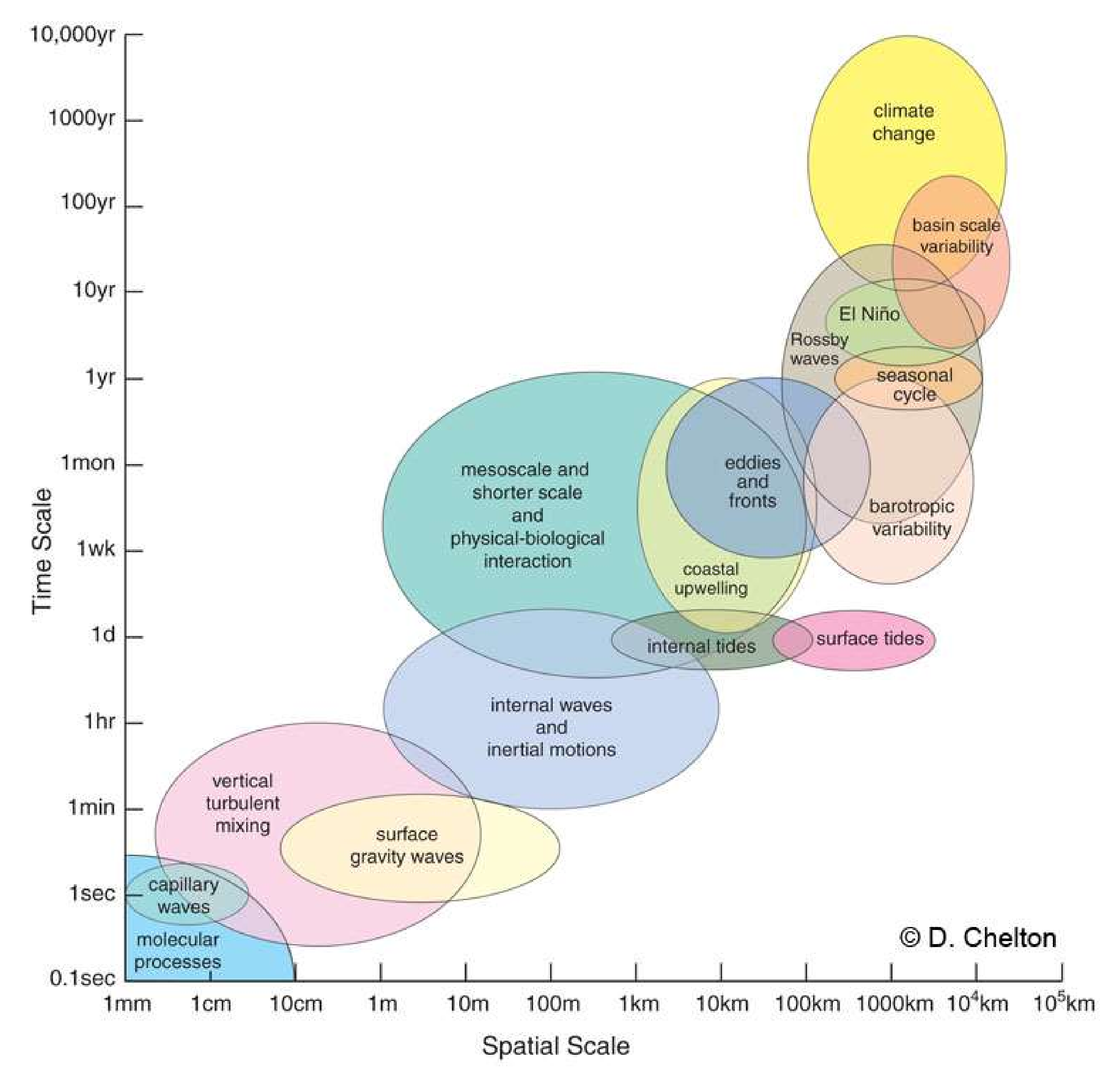


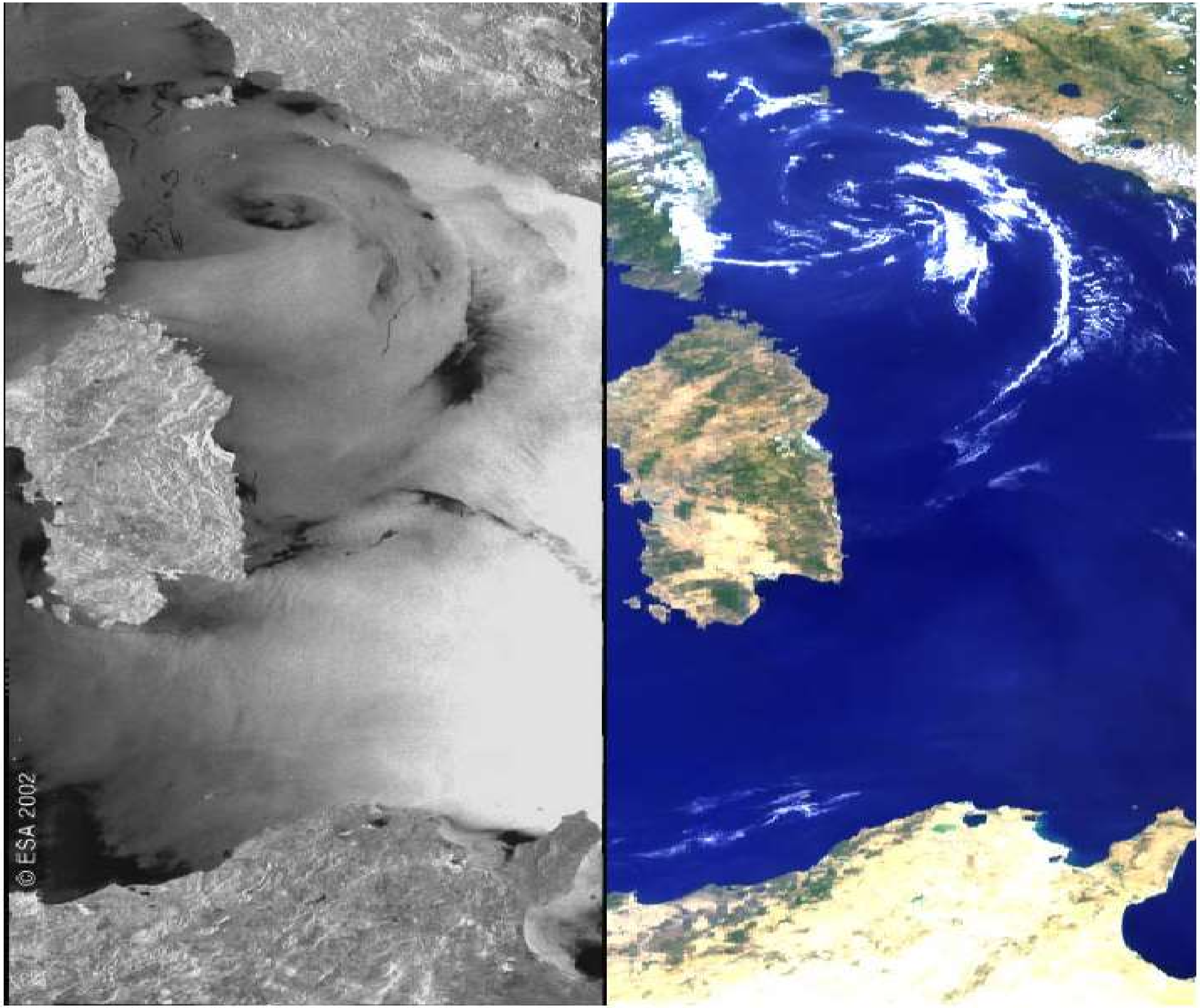
FIG. 3. Instantaneous surface relative vorticity $\zeta = v_x - u_y$ in the region of the Gulf Stream at the end of winter as simulated by ROMS. The parent domain ROMS0 ($\Delta x \approx 6$ km) covers most of the Atlantic Ocean (not shown). The boundaries of the successive nested domains ROMS1 ($\Delta x = 2.5$ km) and ROMS2 ($\Delta x = 750$ m) are delineated by thick black lines. The relative vorticity plotted



Champ de vitesse déduit de la hauteur de la mer (TOPEX-Poseidon)

Time / Space scaling

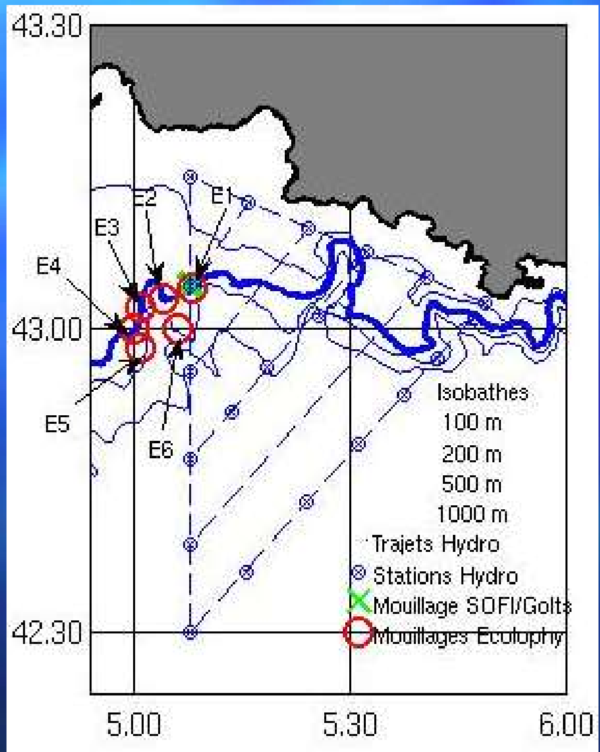




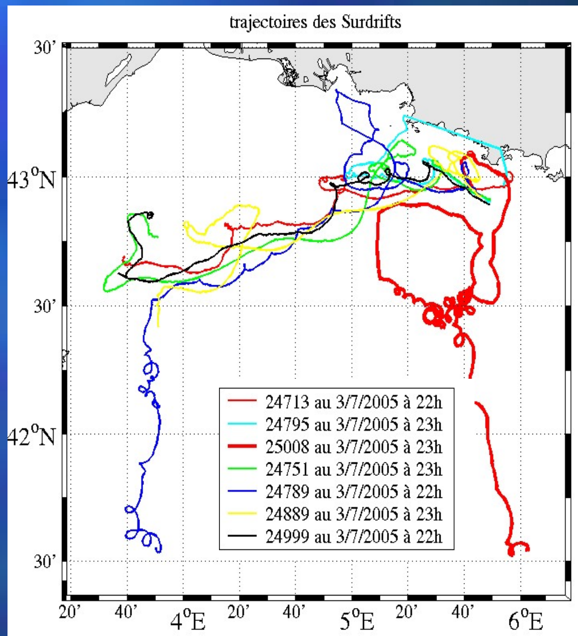
Comparación de imagen satélite de SAR y de MERIS (visible) de ENVISAT (ESA).

Field experiments 2005

ECOLOPHY cruise RV THETYS II INSU

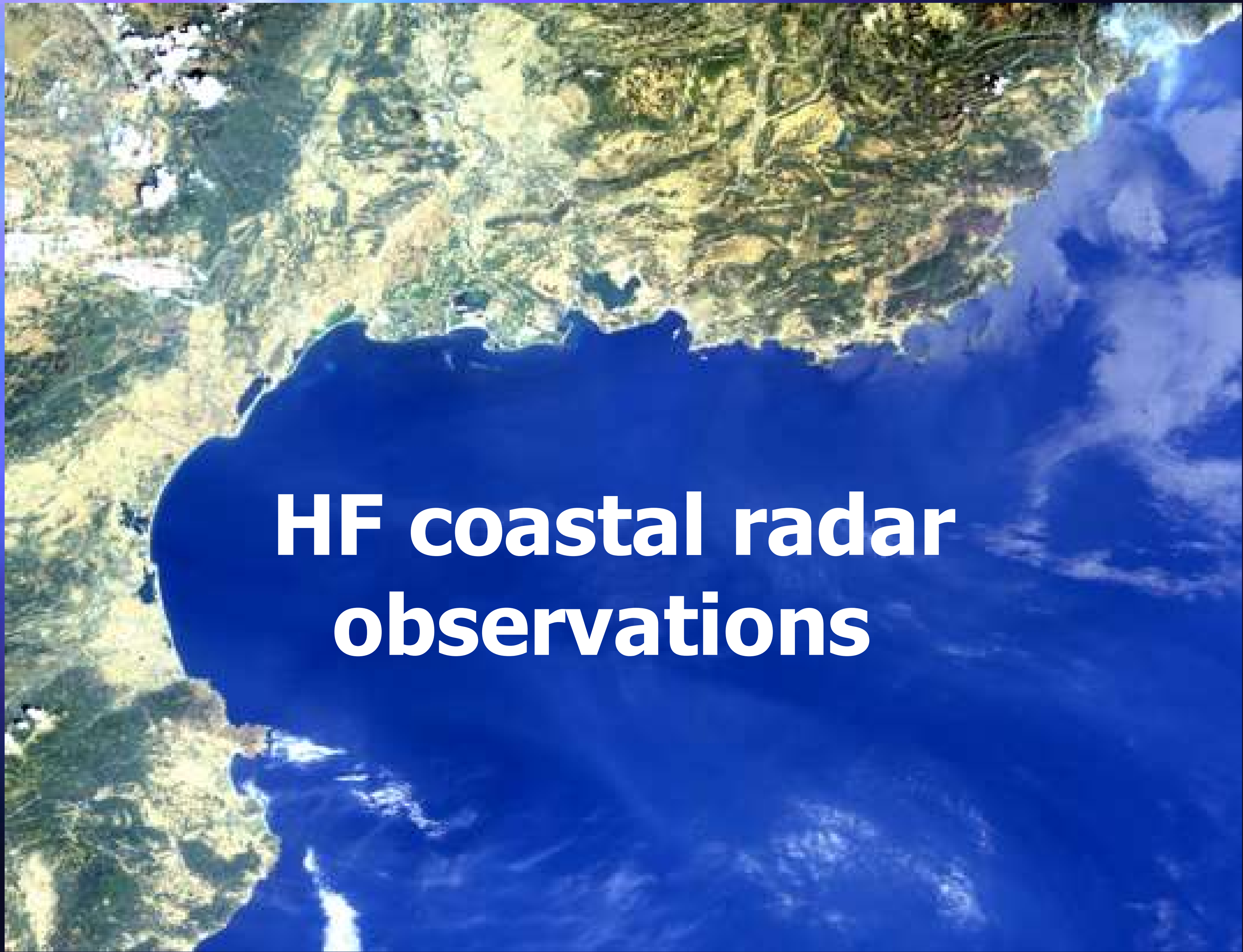


Mouillages couranto-hydrologiques

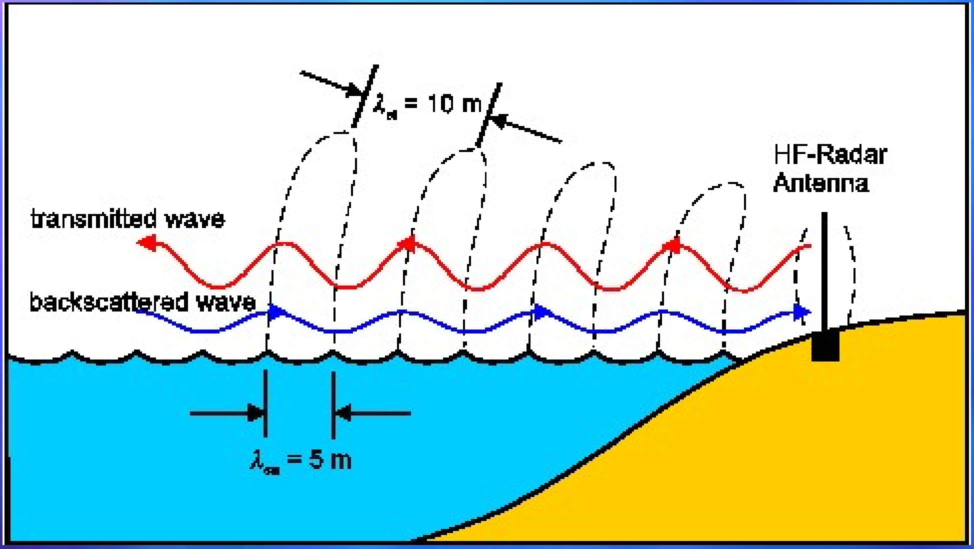


Trajectoires de flotteurs sub-surface largués fin juin 2005.

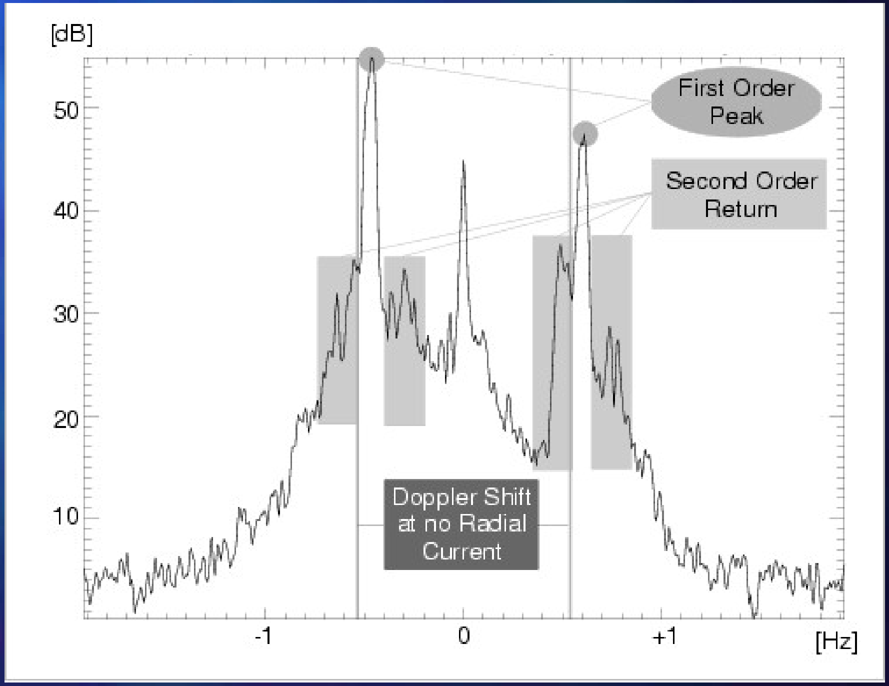
HF coastal radar observations



ICoastal radar WERA : how does it work, what do we measure?



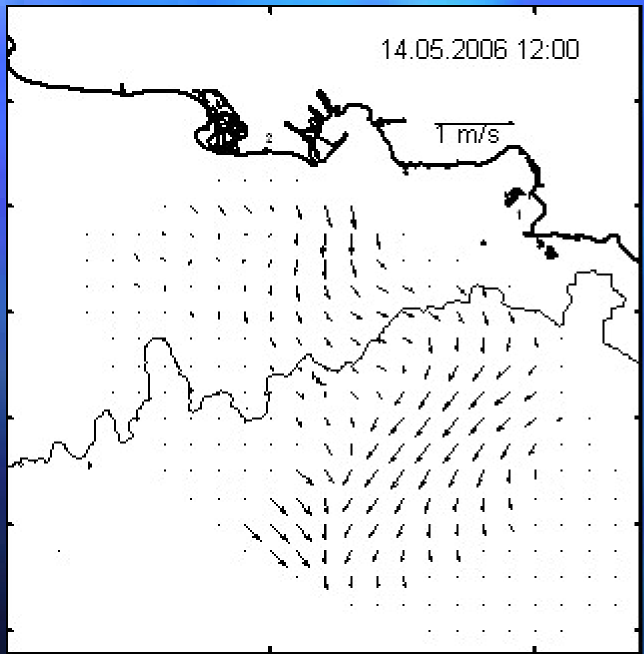
http://ifmaxp1.ifm.uni-hamburg.de/WERA.shtml

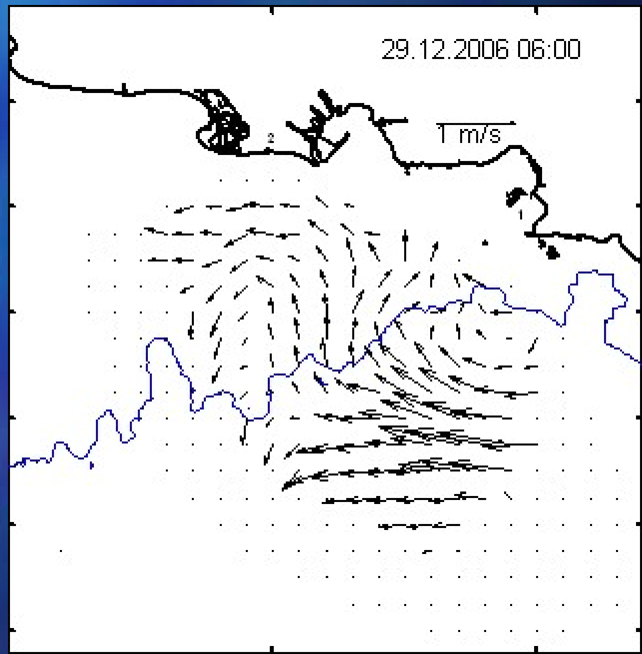


Radar observations

Inertial circulation

Anticyclonic circulation

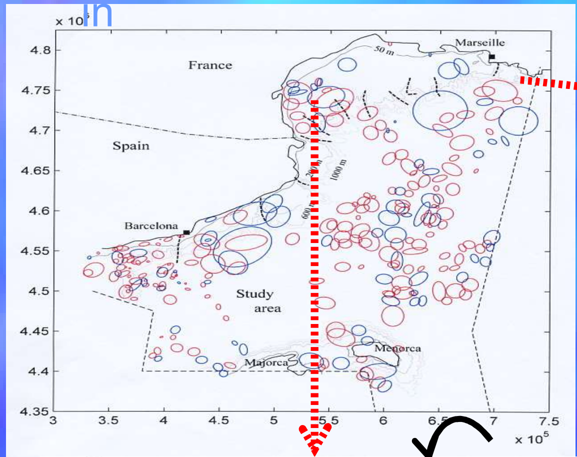


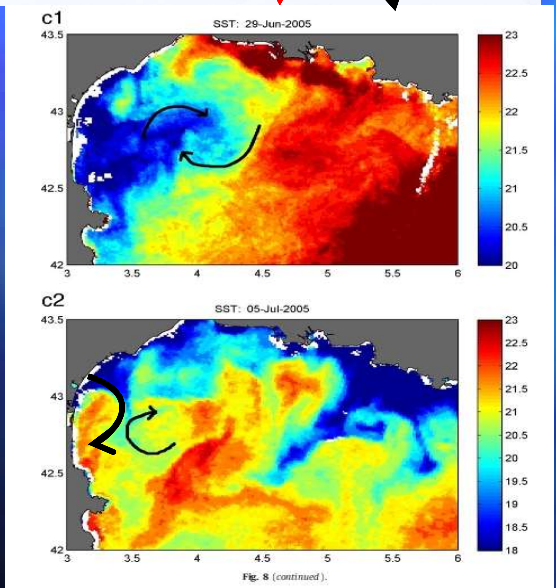


By courtesy of P. Forget, Y. Barbin (LSEET)

Observational evidences...

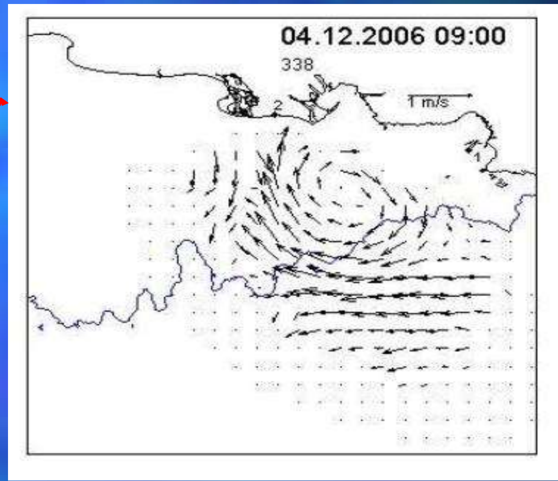
From SAR images...
(Platonov et al., 2007, in





From SST images...
(Rubio et al., 2009)

From HF radar experiment,
the ECOLO campaign...
(Forget et al.,

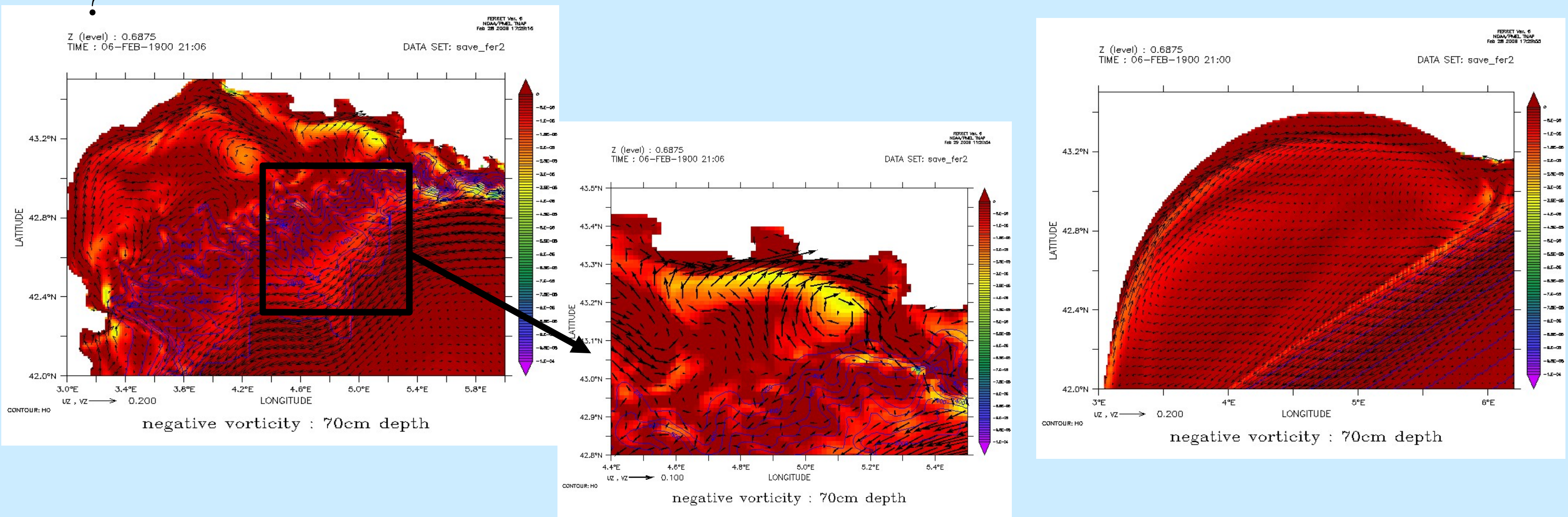


... main problematics

- eddies and vortex activity in the coastal zone
- interactions with the basin-scale circulation (the NC)
- toward better estimate of inshore/offshore exchanges

Driving mechanisms of eddy formation

Respective effects of wind (inertia) / bathymetry
?



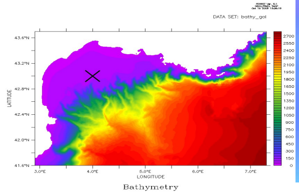
Similar length-scale and position
-> **northern winds pulses** (Mistral, Tramontane)
-> realistic **bathymetry and coast line**

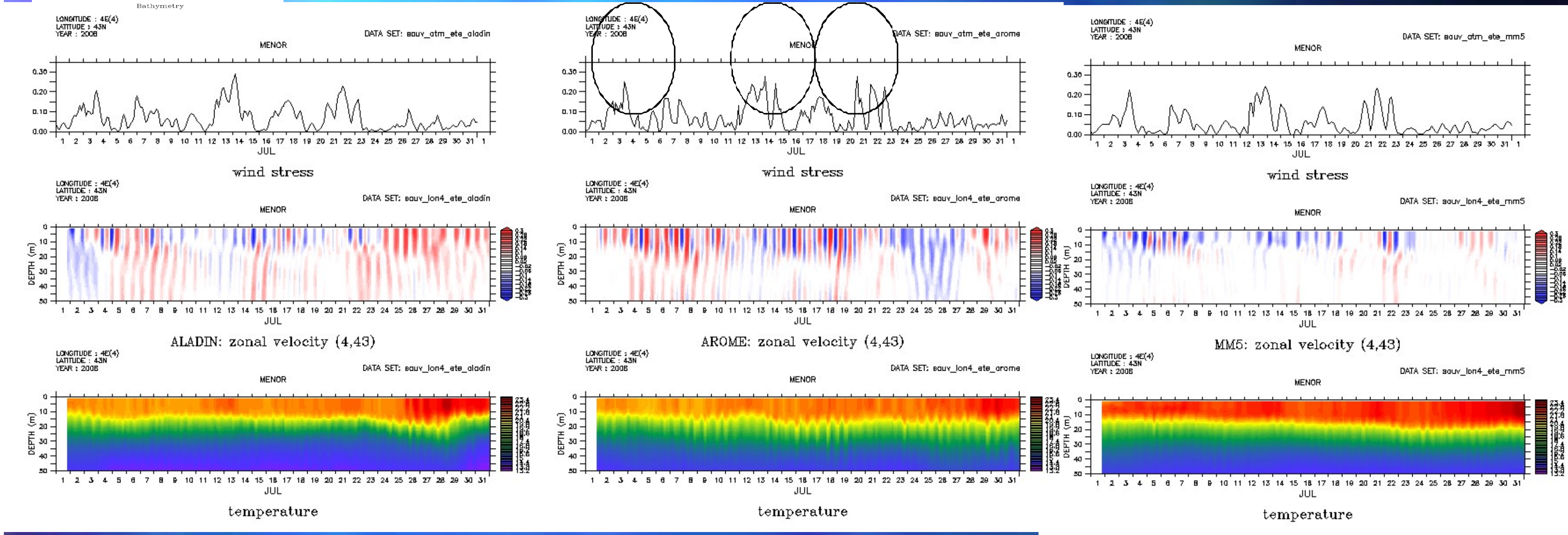
Other possible forcings :

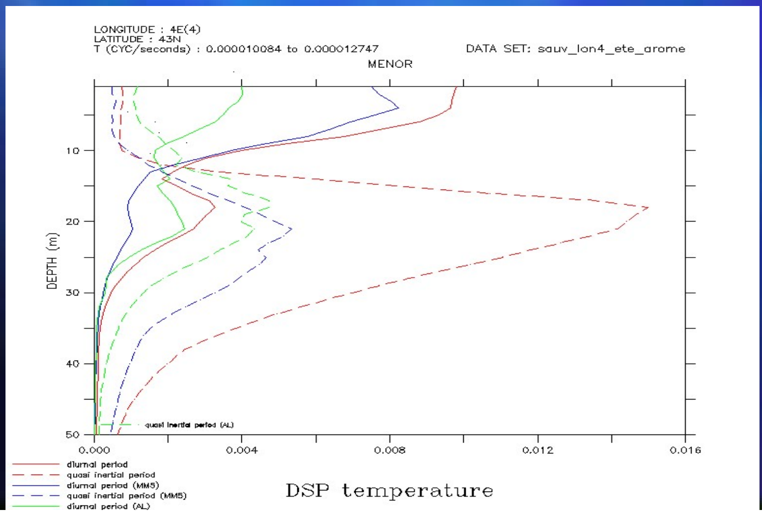
- **Liguro-Provencal current** intrusions on the shelf
- **Rhône river** plume
- Thermohaline

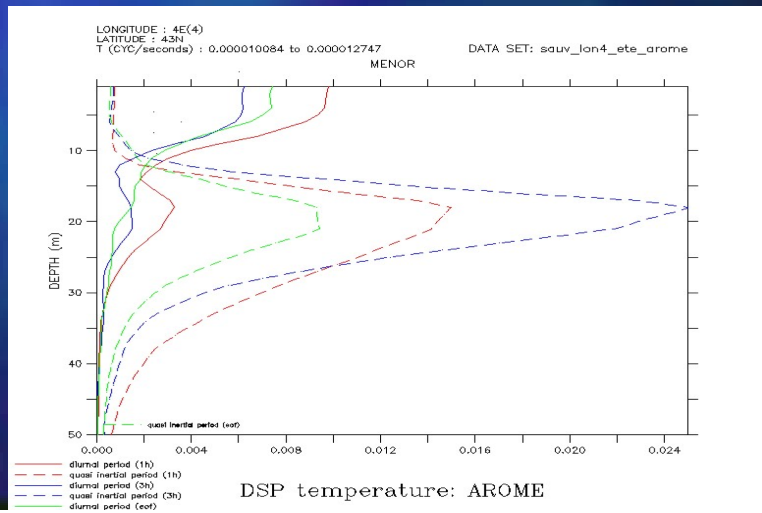
-> **interactions**

Internal waves: summer 2008



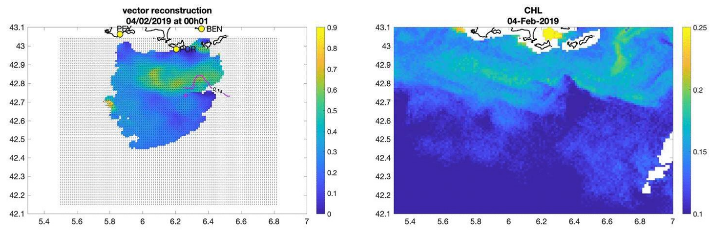




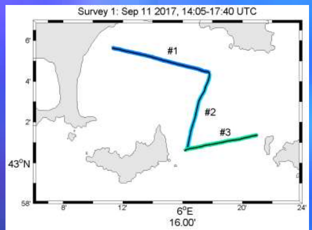


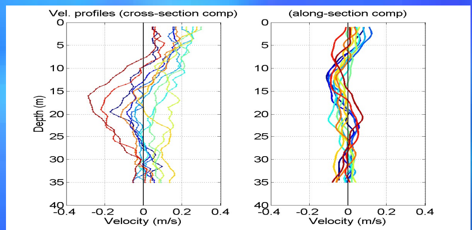
OCARINA (D. Bourras)

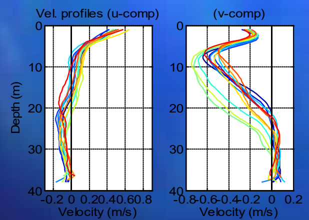
TURBIDENT campaign 2018

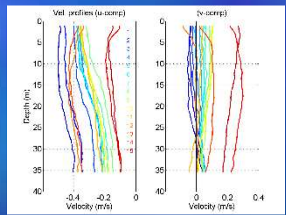


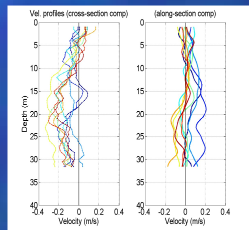
Dumas, Granoullé & Guérin

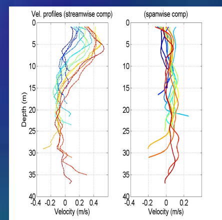


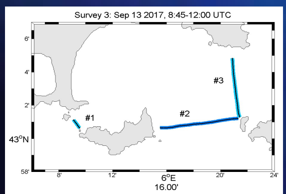




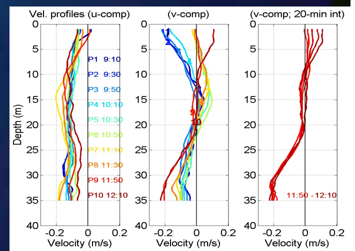




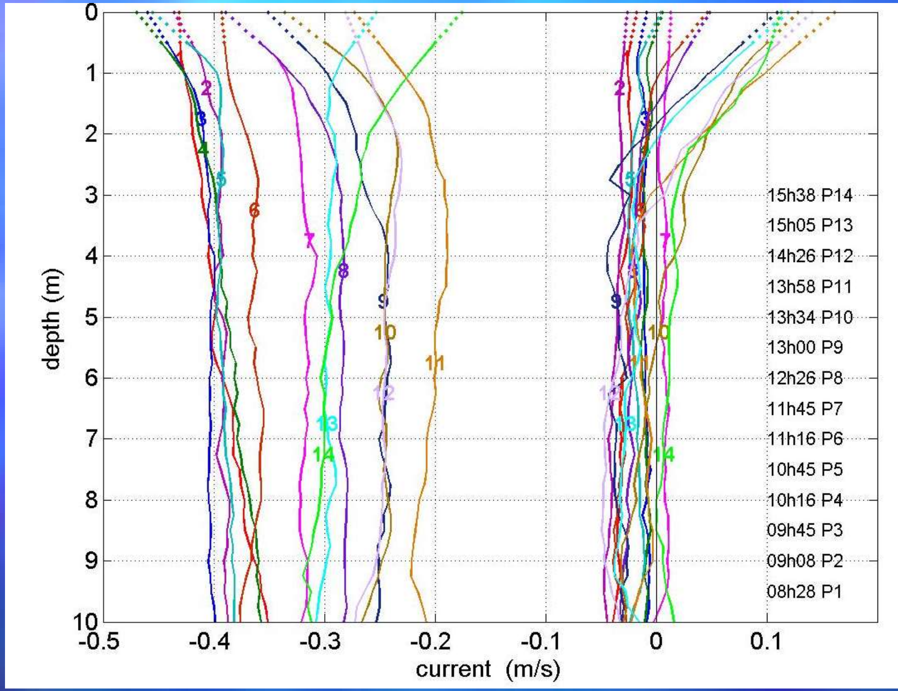




D. Bourras, H. Branger,
A. Sentchev



SUBCORAD campaign 2013



Posters EGU2018-5188, EGU2018-14417

Turbulent diffusion (J.M. Redondo)

Figura 3-5. **Imágenes de la rotura del oleoducto de BP en el Golfo de México**

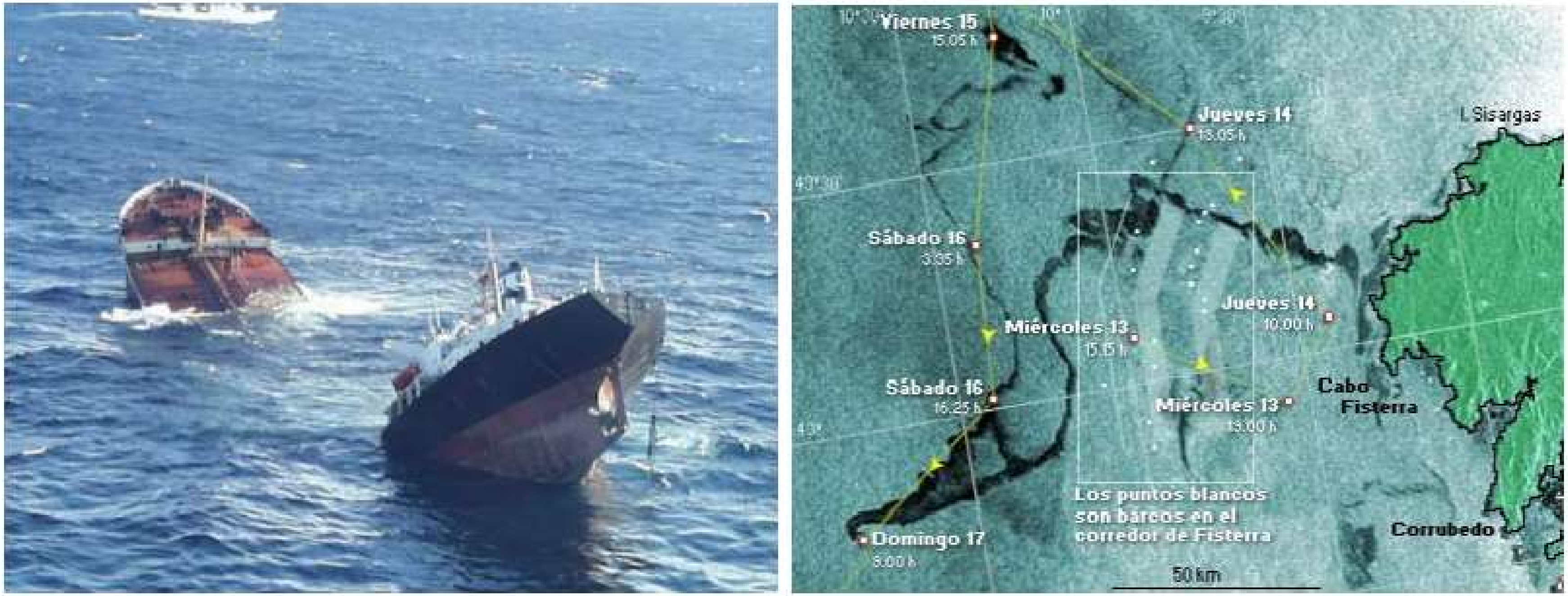


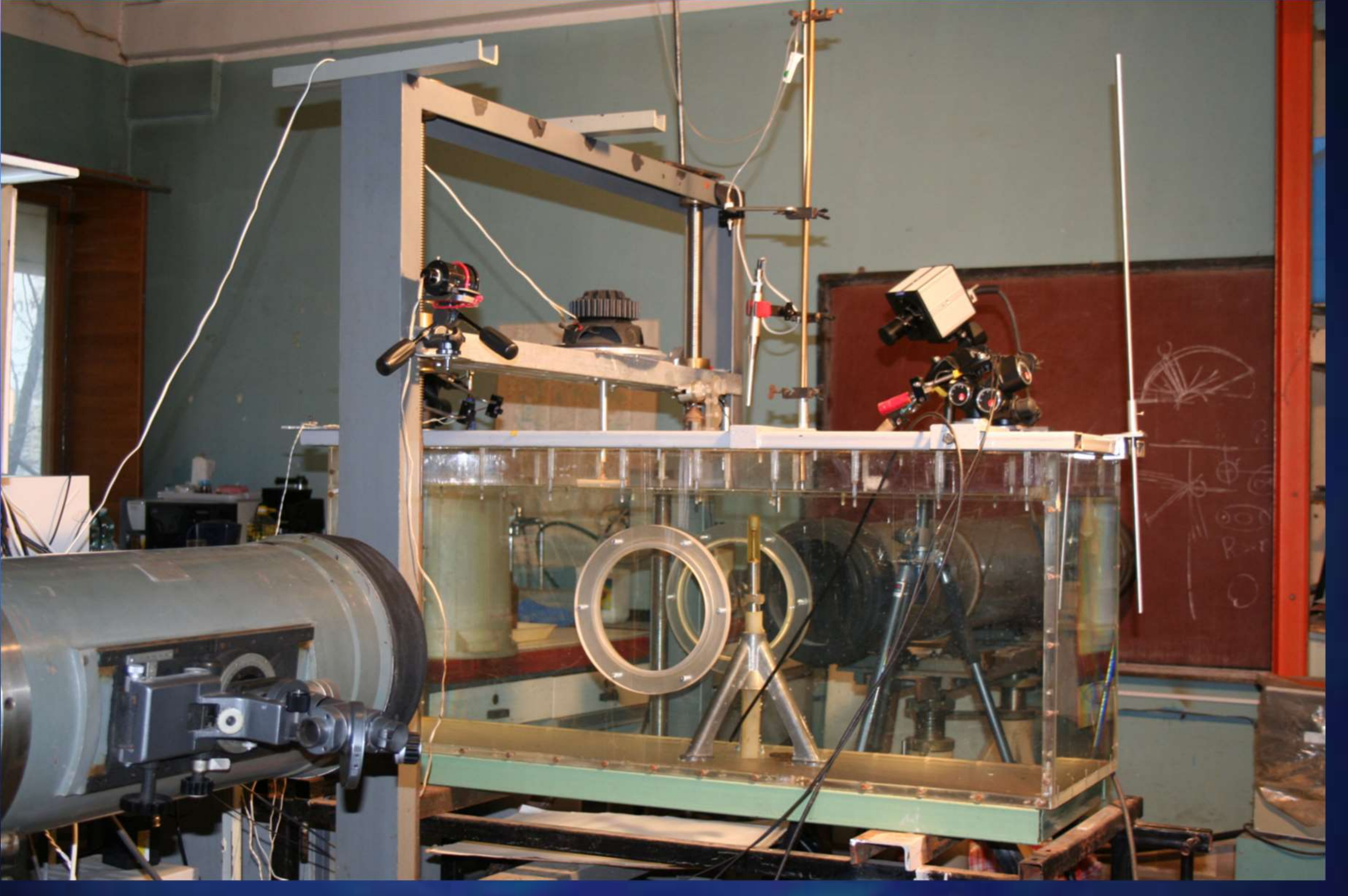
Figura 3-3. Accidente del Prestige

El buque frigorífico 'Sierra Nava' quedó varado en la bahía de Cádiz el 28 de enero de 2007 al intentar entrar en el puerto de Algeciras en medio de una tormenta, con 350 tn, afectando 10 km de costa del Estrecho.

Figura 3-4 El Sierra Nava varado en la playa.

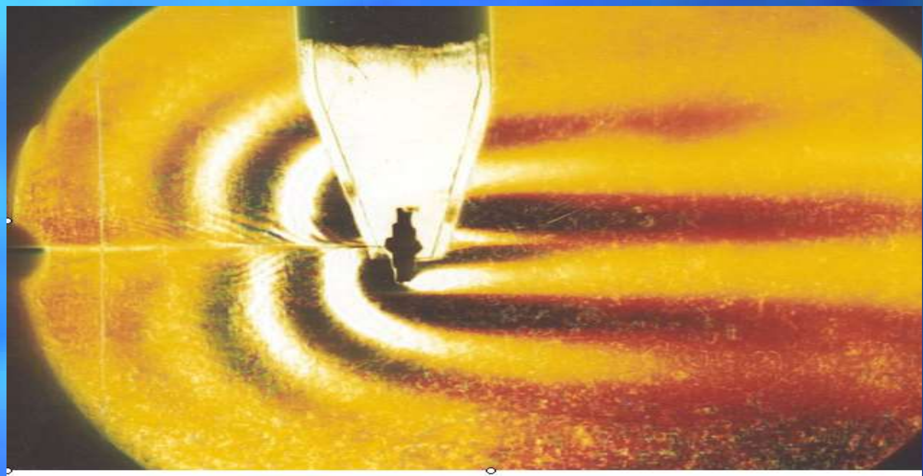
Turbulence scales

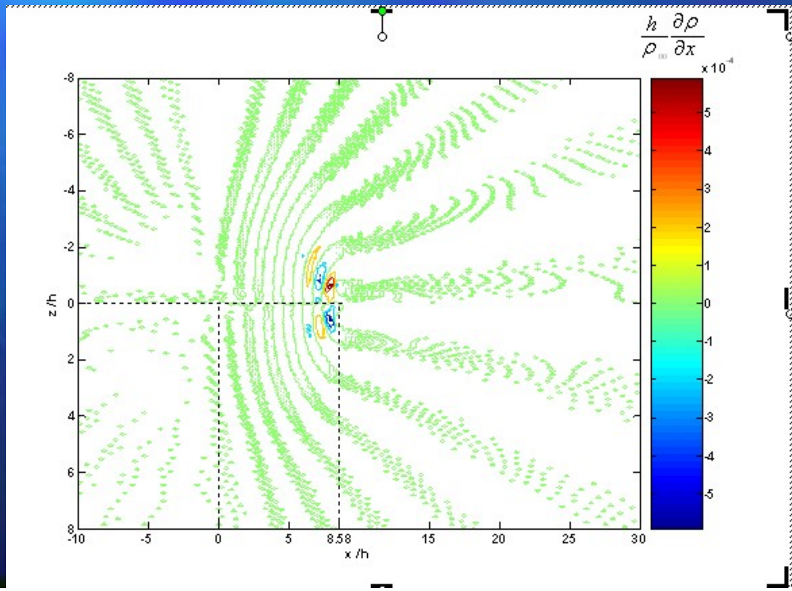
	Atmosphère	Laboratoire: Souflerie	Laboratoire: Canal	Océan
$\nu = \mu/\rho$ $(m^2 s^{-1})$	10^{-5} en tropo. /1 en méso.	10^{-5}	10^{-6}	10^{-6}
$Re = U \cdot L/\nu$	$10^8 - 10^9$ Tropo. Strato. / 10^4 méso.	$(410^3 - 2510^3)$ [2]	(10^3) [1]	$10^4 - 10^7$
$N_{BV} = \frac{g}{\rho}\frac{\partial \rho}{\partial z}$ (s^{-1})	10^{-2} - 210^{-2}	(2.5) [2]	$(0.24 - 0.98)$ [1]	$(0.1 - 1.74)$ [4]
ϵ $(\mathrm{m}^2 \cdot \mathrm{s}^{-3})$	$(10^{-7} - 10^{-4})$ [7] $(10^{-5} - 10^{-2})$ [5] $(3 - 710^{-2})$ [8]	$(10^{-4} - 1)$ [1]	$(10^{-6} - 10^{-3})$ [2]	$(10^{-10} - 10^{-8})$ [3] thermo. $(10^{-7} - 10^{-4})$ [3] fjord $(10^{-8} - 10^{-6})$ [4]
$\eta = \left(\frac{\nu^3}{\epsilon}\right)^{1/4}$ (m)	$(10^{-2} - 10^{-3})$ [6]	$(310^{-4} - 1710^{-4})$ [2]	$(210^{-4} - 710^{-4})$ [1]	$(310^{-3} - 10^{-2})$ [3] thermo. $(310^{-4} - 210^{-3})$ [3] fjord (10^{-3}) [4]
$l_o = \sqrt{\left(\frac{\epsilon}{N_{BV}^3}\right)}$ (m)	10-100	$(210^{-3} - 0.2)$ [2]	$(510^{-3} - 0.6)$ [1]	$(1 - 4)$ [4]
$l_T = \sqrt{\langle d^2(z) \rangle}$ (m)	$(25 - 120)$ [7]	(10^{-2}) [2]	(10^{-2}) [1]	$1 - 4)$ [4]

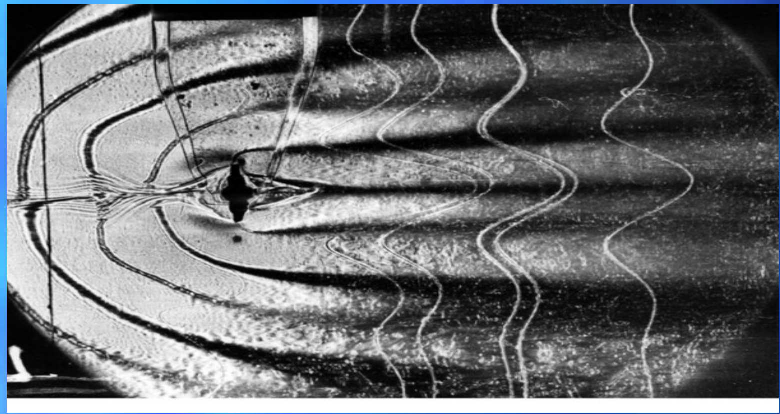


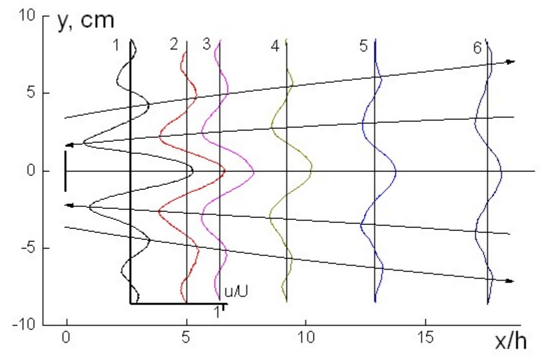
Mo

Lab Exp / Numerics

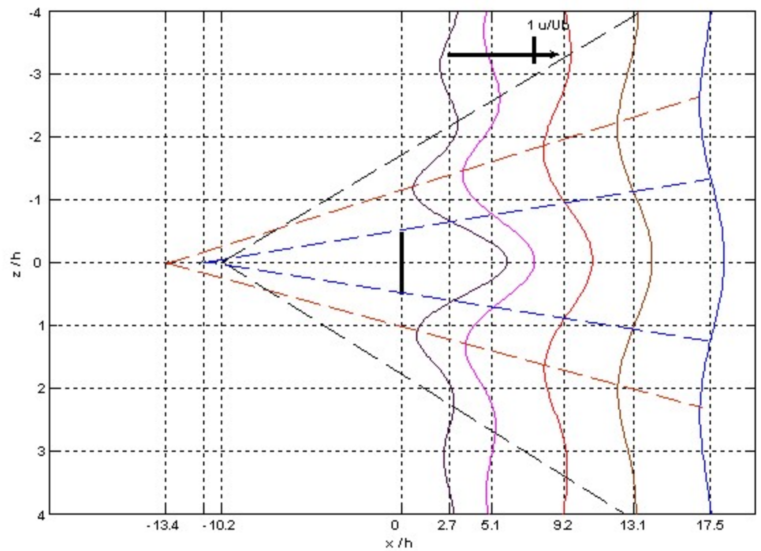







y, cm
10
5
0
-5
-10
1
2
3
4
5
6
u/U
1
0
5
10
15
x/h

b)


1 u/Ub
-4
-3
-2
-1
0
1
2
3
4
z / h
-13.4
-10.2
0
2.7
5.1
9.2
13.1
17.5
x / h

European Geosciences Union, General Assembly 2015, 12 - 17 April 2015

NUMERICAL SIMULATION OF NEAR WAKE STRATIFIED FLOW AT LOW REYNOLDS NUMBER

Philippe Fraunié [(1)], Hatem Houcine [(2)], Adel Gharbi [(2)], Yuli D. Chashechkin [(3)], Jose Manuel Redondo [(4)]

(1) Mediterranean Institute of Oceanography-MIO UM 110 UTLN - AMU - CNRS/INSU 7294 - IRD 235 BP 20132 F-83957 La Garde cedex, France.
(2) Laboratoire de Mécanique des Fluides, Faculté des Sciences de Tunis, Université El Manar, Le Belvédère 2092, Tunis, Tunisie.
(3) Institute for Problems in Mechanics of the Russian Academy of Sciences, Moscow, Russia.
(4) Department of Applied Physics - U.P.C. Campus Nord, Barcelona 08034 Spain.

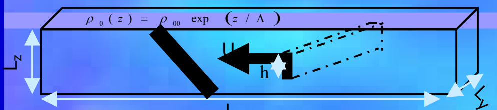
Abstract

Numeric modeling of a flow past vertical and horizontal strips towed in a linearly stratified tank are preformed by comparison to laboratory experiments using Schlieren visualization, density marker and probe measurements of internal wave fields. Both parts of the wave fields including upstream transient and downstream stationary waves were resolved. Analysis is here focusing on observed near wake singular components.

Key Words

- Stratified flows, wakes, internal waves, Large eddy simulation, thin strip

Geometric configuration



$u = 0,\ \frac{\partial w}{\partial x} = 0,\ \frac{\partial S}{\partial x} = \frac{\partial \rho}{\partial x} = 0 \quad at \quad x = 0, L_x \qquad \frac{\partial u}{\partial z} = 0,\ w = 0,\ \frac{\partial s}{\partial x} = \frac{\partial \rho}{\partial x} = 0 \quad at \quad z = 0, L_z$

Dimensionless parameters

$$Re = h/\delta_\nu = U_b h/\nu$$
$$Fr = \lambda/2\pi h = U_b/Nh$$
$$C_\Lambda = \Lambda/h$$

Mathematical formulations

Governing equations to the Boussinesq approximation

$$\frac{\partial \overline{u}_j}{\partial x_j} = 0$$

$$\frac{\partial \overline{u}_i}{\partial t} = -\overline{u}_j \frac{\partial \overline{u}_i}{\partial x_j} - \frac{1}{\rho_0}\frac{\partial \overline{p}}{\partial x_i} + \frac{\rho}{\rho_0} g\,\delta_{i3} + 2\frac{\partial}{\partial x_j}\left[(\nu + \nu_t)\overline{\tau}_{ij}\right] \qquad \overline{\tau}_{ij} = \frac{1}{2}\left(\frac{\partial \overline{u}_i}{\partial x_j} + \frac{\partial \overline{u}_j}{\partial x_i}\right)$$

$$\frac{\partial \overline{S}}{\partial t} = -\overline{u}_j \frac{\partial \overline{S}}{\partial x_j} + \frac{\partial}{\partial x_j}\left[(\kappa + \kappa_t)\frac{\partial \overline{S}}{\partial x_j}\right] \qquad \rho = \rho_0\left[1 + \beta_s(\overline{S} - \overline{S}_0)\right]$$

Smagorinsky model : $\nu_t = (C_s\delta)^2\,|\overline{\tau}| \qquad |\overline{\tau}| = \left|2(\tau_{ij}\tau_{ij})\right|^{1/2}$

Thin vertical strip

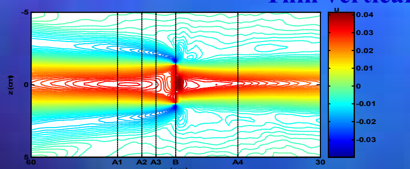


Fig.1. Isotachs of horizontal velocity; Tb = 17.4 s, N = 0.36 s−1, U = 0.033 cm/s, Fr = 0.036, Re = 8.25.

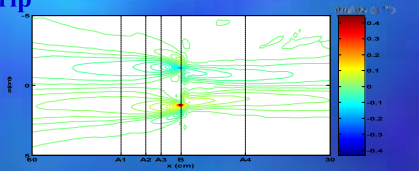


Fig.2. Iso-gradient lines of horizontal velocity; Tb = 17.4 s, N = 0.36s−1, U = 0.033 cm/s, Fr = 0.036, Re = 8.25.

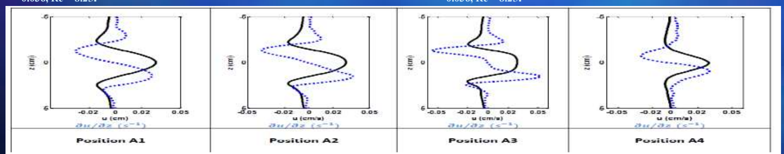


Fig.3. Profiles of the velocity u and its shear du/dz ; Tb = 17.4 s, N = 0.36 s−1, U = 0.033 cm/s, Fr = 0.036, Re = 8.25.

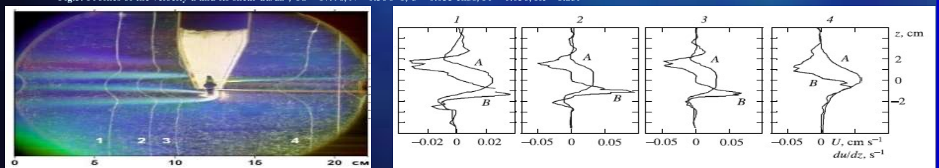


Fig.4. Shadowgraph of the leading disturbance and the plate wake with density markers (1–4) and the corresponding profiles of the velocity u (A) and its shear du/dz (B); Tb = 17.4 s, N = 0.36 s−1, U = 0.033 cm/s, Fr = 0.036, Re = 8.25.

Thin horizontal strip

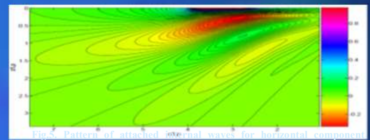


Fig.5. Pattern of attached internal waves for horizontal component of velocity, Tb=6.28s, h=5.5cm, U=1cm/s, λ=6.28cm, Fr=0.18, Re=550. (Numerical Result).

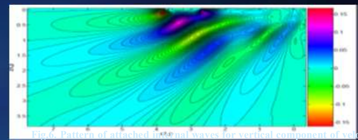


Fig.6. Pattern of attached internal waves for vertical component of velocity, Tb=6.28s, h=5.5cm, U=1cm/s, λ=6.28cm, Fr=0.18, Re=550. (Numerical Result).

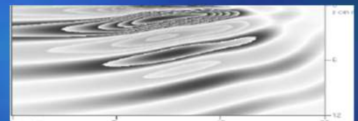


Fig.7. Pattern of attached internal waves for horizontal component of velocity, Tb=6.28s, h=5.5cm, U=1cm/s, λ=6.28cm, Fr=0.18, Re=550. (Analytical Result).

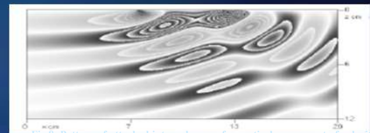


Fig.8. Pattern of attached internal waves for vertical component of velocity, Tb=6.28s, h=5.5cm, U=1cm/s, λ=6.28cm, Fr=0.18, Re=550. (Analytical Result).

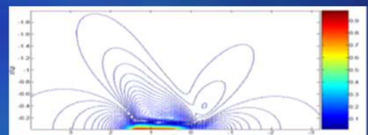


Fig.9. Modulus of horizontal component of velocity near a short strip moving from right to left, Tb=14s, h=2cm, U=1cm/s λ=14cm, Fr = 1.12, Re = 200. (Numerical Result).

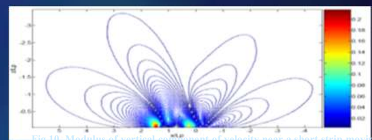


Fig.10. Modulus of vertical component of velocity near a short strip moving from right to left, Tb=14s, h=2cm, U=1cm/s λ=14cm, Fr = 1.12, Re = 200. (Numerical Result).

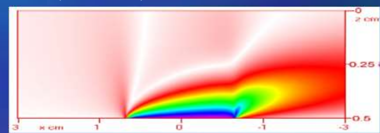


Fig.11. Modulus of horizontal component of velocity near a short strip moving from right to left, Tb=14s, h=2cm, U=1cm/s λ=14cm, Fr = 1.12, Re = 200. (Analytical Result).

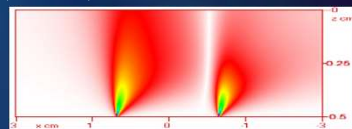


Fig.12. Modulus of vertical component of velocity near a short strip moving from right to left, Tb=14s, h=2cm, U=1cm/s λ=14cm, Fr = 1.12, Re = 200. (Analytical Result).

Conclusions

- The present work provided useful physical insights on internal wave generation in a towed body system.
- The pattern of flow near moving horizontal strip fully agrees with analytical results, attached internal waves near the body and details of the fine structure of the boundary layer are distinguished, one peak band for the horizontal component and two bands for the vertical component of velocity are visualized in the flow around the horizontal strip.

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Conclusions

- New interest in sub-mesoscale and stratified flow for climate and safety purposes
- Need of lab experiments and HR observations
- Large (even limited) computing facilities allow to value previous theoretical and experimental works