Workshop SYNBIOS *Paris, July 6, 2015*

Coastal mesoscale processes and submesoscale horizontal diffusivity during LATEX.

Anne Petrenko, A. Doglioli, M. Kersale, F. Nencioli, F. d'Ovidio, F. Diaz and the LATEX group

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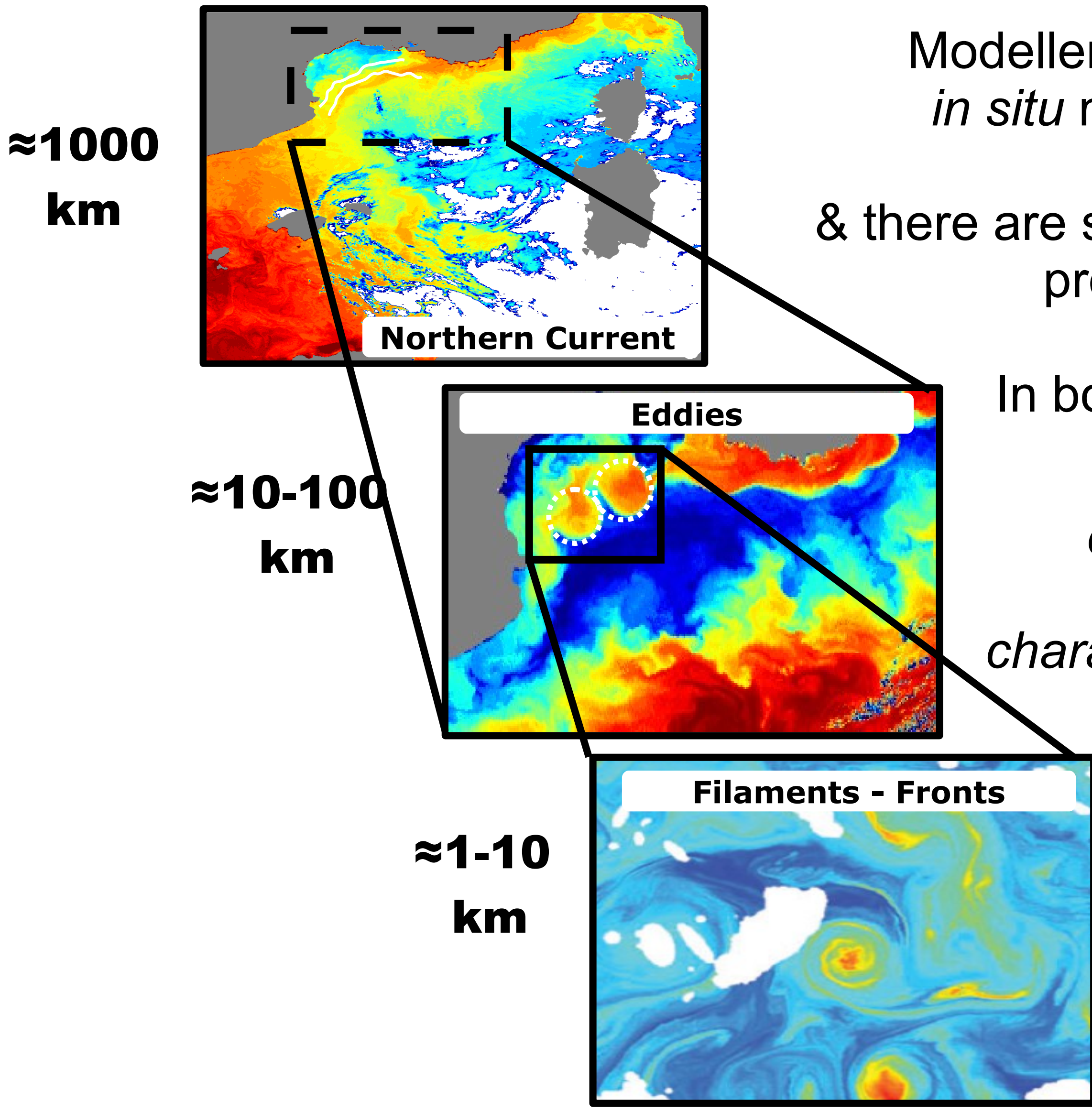
cnrs

IRD Institut de recherche pour le développement

UNIVERSITÉ DU SUD TOULON VAR

Approaches - Challenges

In the last decade, submesoscale dynamics has been predominantly investigated through the analysis of numerical models. (e.g. Capet et al.08)



Modellers generally highlight the need of *in situ* measurements at submesoscale

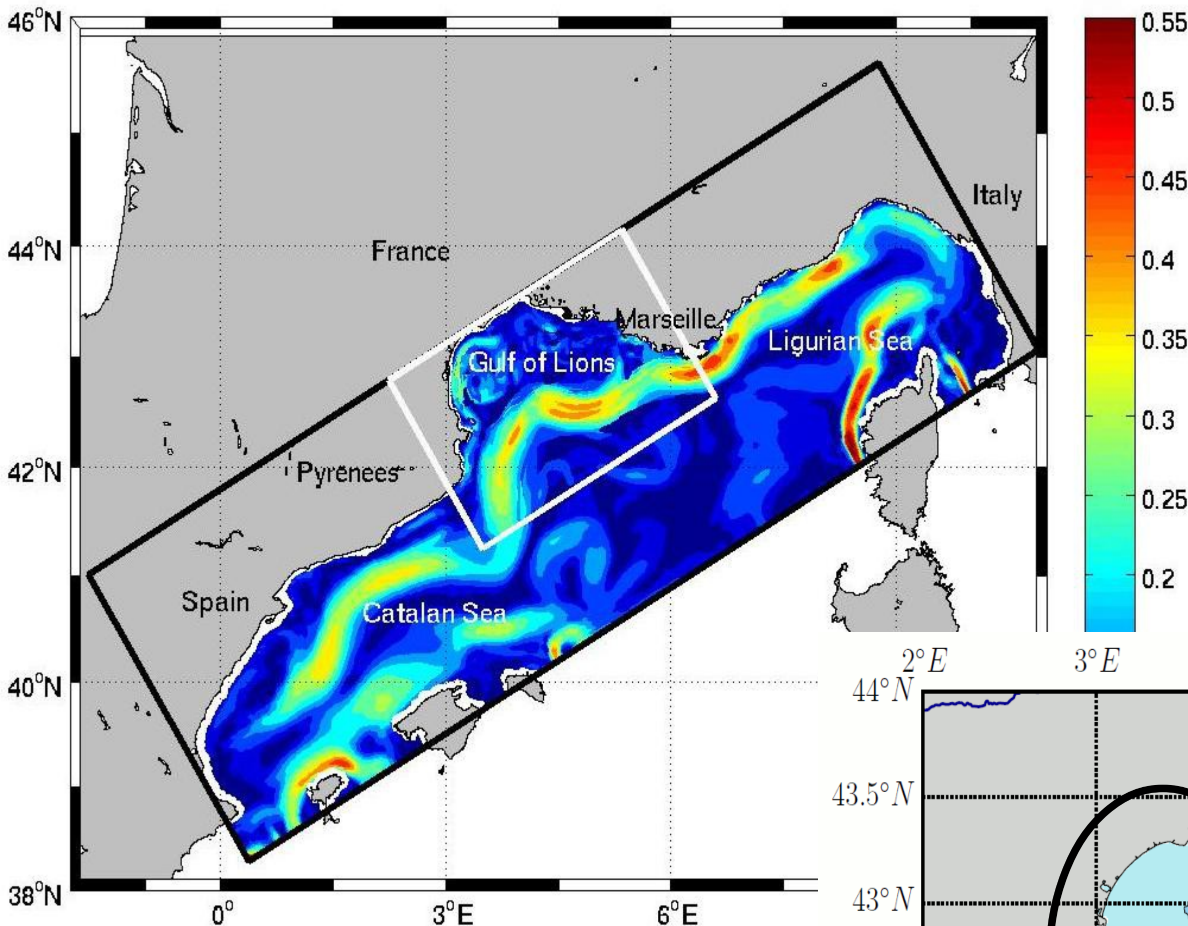
& there are still open questions about mesoscale processes in coastal regions.

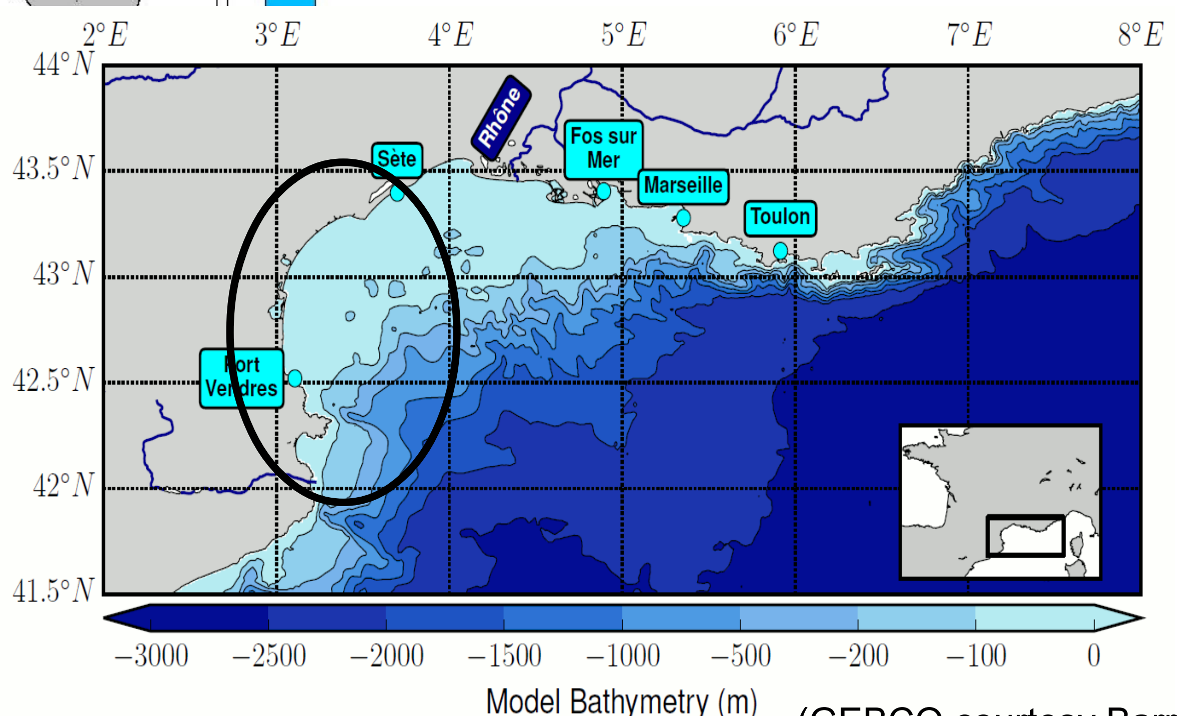
In both cases these measurements are :

a big challenge
due to the non predictive
and/or ephemeral
characteristics of these structures.

Lagrangian approach
& adaptive strategy
& innovative instrumentation

Study site



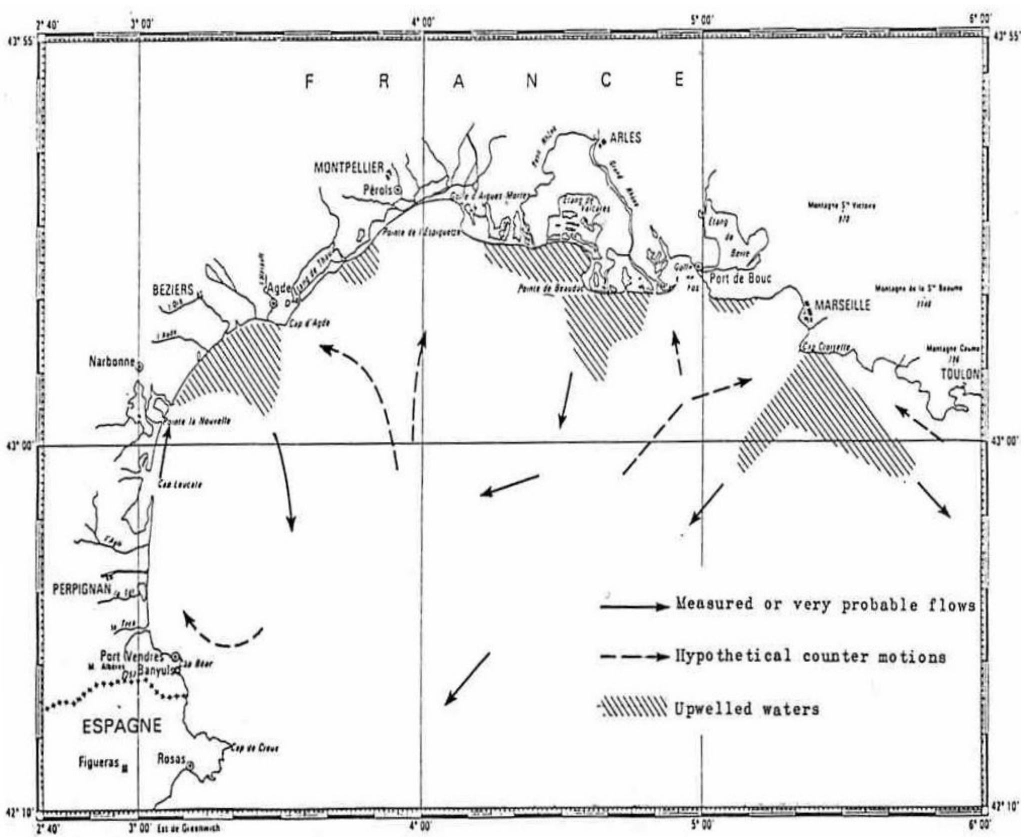


(GEBCO,courtesy Barrier)

Study zone: Gulf of Lion (GoL)

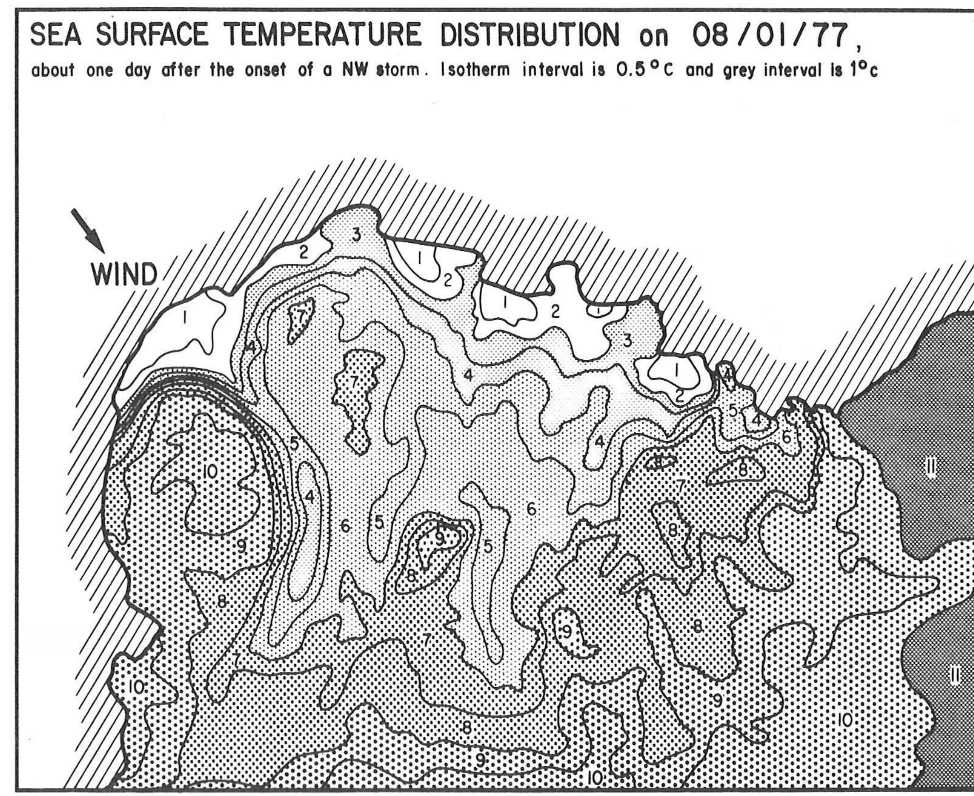
Hypothesis of Millot:
anticyclonic circulation following northwesterly wind (Tramontane)

[Millot 1979]



Current measurements with moorings

[Millot 1982]

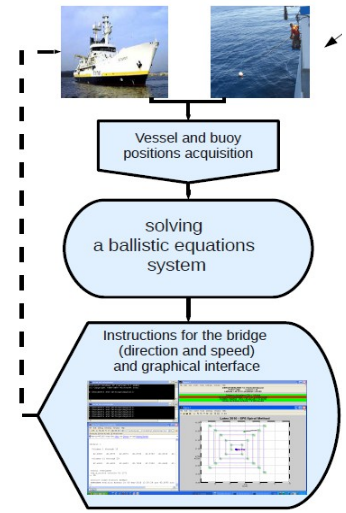


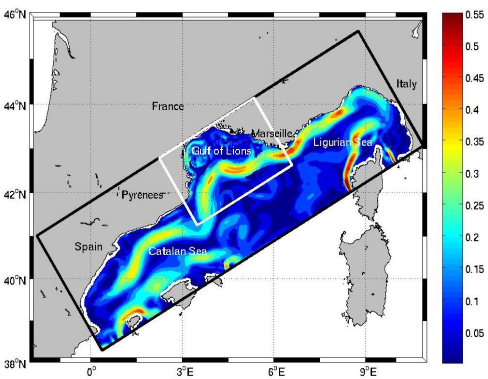
SST, August 1, 1977, 09 00 TU

LATEX - LAgrangian Transport Experiment

Objective

understand the influence of mesoscale
coupled physics – biogeochemistry
on cross-shelf (coast-offshore) exchanges





Methodology

Multi-disciplinary project

Numerical modelling & *in situ* measurements

multi-«tools»: Lagrangian floats, SF6 tracer, hull-mounted ADCPs, Eulerian moorings, satellite images, gliders.

PIs: Anne Petrenko and Frédéric Diaz

founded by LEFE/IDAO & CYBER – Région PACA

Pilot project 2007 – Main project 2008-11

LATEX - LAgrangian Transport Experiment

MODELLING

3D Circulation Model (Symphonie)
(realistic run, 2001 to 2011)

Coupled Physical (Symphonie)
Biogeochemical (Eco-3M)
Modeling (2001-...)

Lyapunov exponents (FSLE) analysis
in collaboration with F. d'Ovidio [LOCEAN]

High resolution altimetry data
in collaboration with IMEDEA group (Spain)
and J. Bouffard (ESA Int., Rome)

EXPERIMENTAL

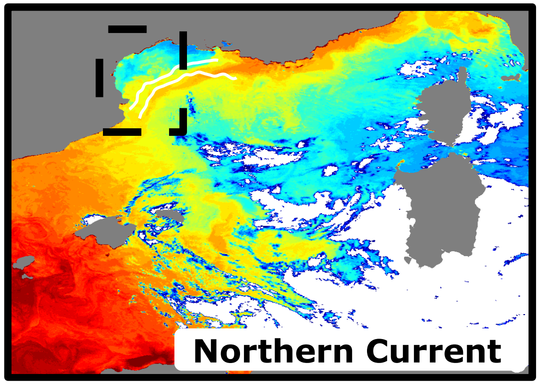
Sept. 2007 – Latex00 cruise
RV Téthys II
Tests of Lagrangian navigation & background concentraiton of SF6

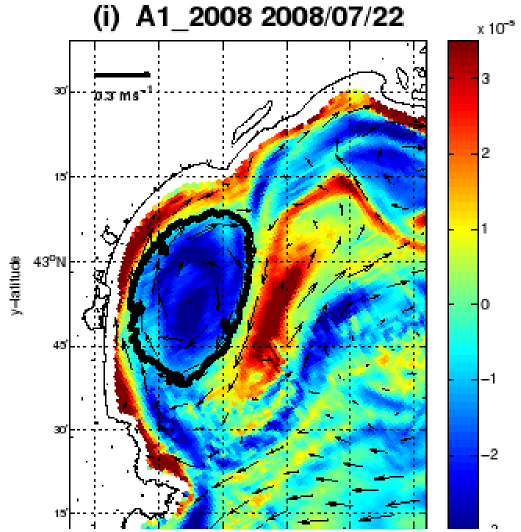
Sept. 2008 – Latex08 cruise
RV Téthys II
Eddy mapping (ADCP, XBT)

Aug. 2009 – Latex09 cruise
RV Téthys II
Eddy mapping (ADCP, CTD) and moorings deployment

Sept. 2010 – Latex10 cruise (Sept 1- 24)
RVs Suroît and Téthys II
In-situ and satellite FSLE experiment
SF6 release
Gliders, ADCP, CTD mapping

2 main questions for today



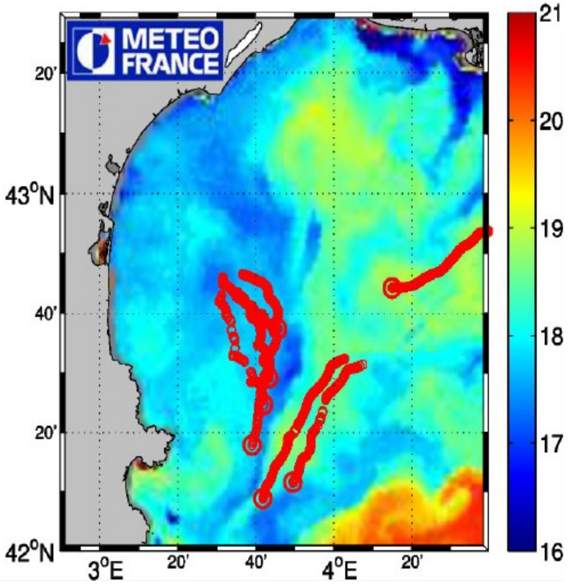


Coastal eddies :
how are they generated ?

what are their characteristics ?
do they influence coastal-offshore transfer ?
interregional exchanges ?...

Can we estimate horizontal diffusivity ?

1st method using Lagrangian floats/FSLE and thermosalinograph data
2nd method using a passive tracer release and its successive mappings



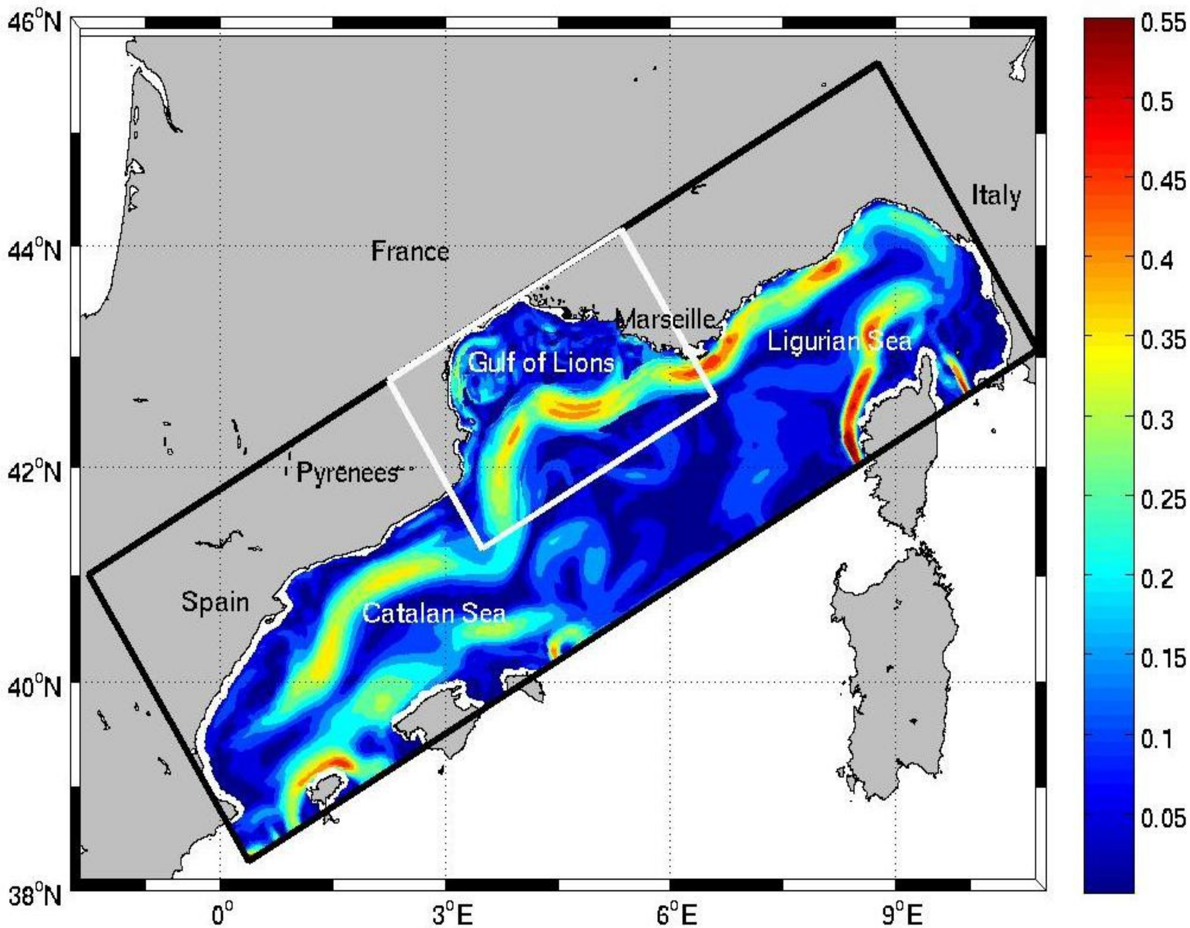
Part I - Coastal mesoscale processes

Part II – (Sub)mesoscale horizontal diffusivity

Part III – Perspectives towards submesoscale

3D Circulation Model (Symphonie)

In collaboration with P.Marsaleix and C.Estournel
[Pôle d'Océanographie et Couplage, Toulouse]



[Hu et al., Ocean Model., 2009]

3D; Primitive Equations
Horizontal grid : Arakawa C
Vertical: 40 sigma-z hybrid
Closure Scheme: [Gaspar et al., 1990]

Atmos. Forcing: Météo-France Aladin
Boundaries: OPA outputs (MFSTEP)
Initialization: [Estournel et al., 2003]

Domain: NW Med + Gulf of Lion

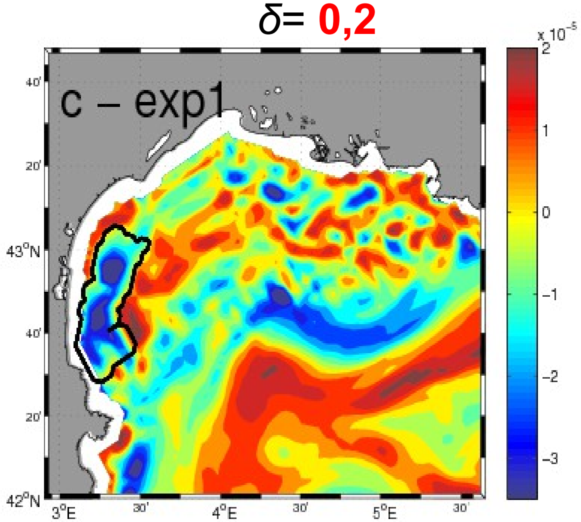
One – Way nesting [Spall et Holland, 1991]

Resolution: 3km → 1km

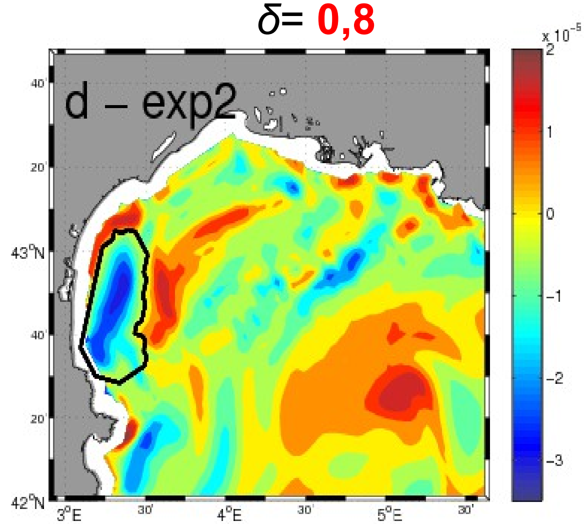
3D Circulation Model (Symphonie)

Sensitivity study on resolution & horizontal diffusion (upwind scheme)

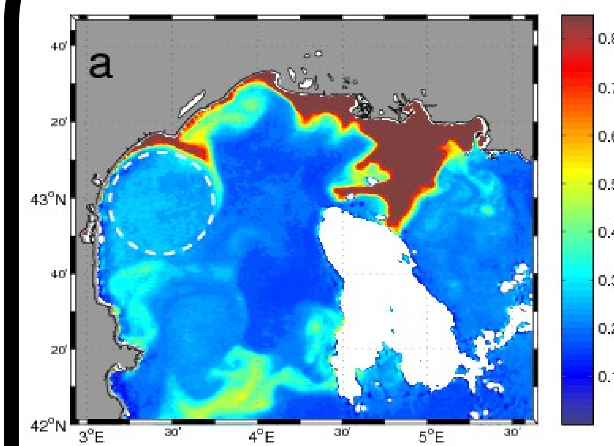
Résolution: **3km**
δ= **0,2**



Résolution: **3km**
δ= **0,8**

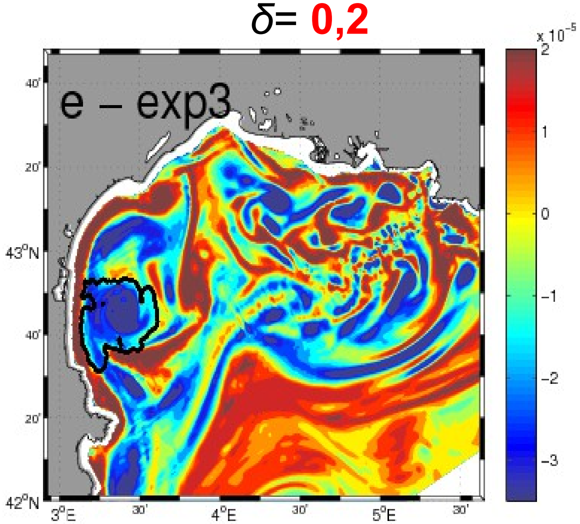


SeaWiFs
2001, 07/25



Chlorophyll a concentration
July 25, 2001
(E. Bosc)

Résolution: **1km**
δ= **0,2**



Résolution: **1km**
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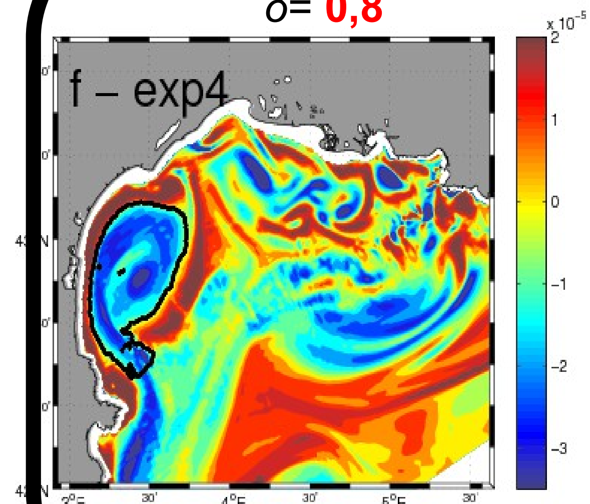


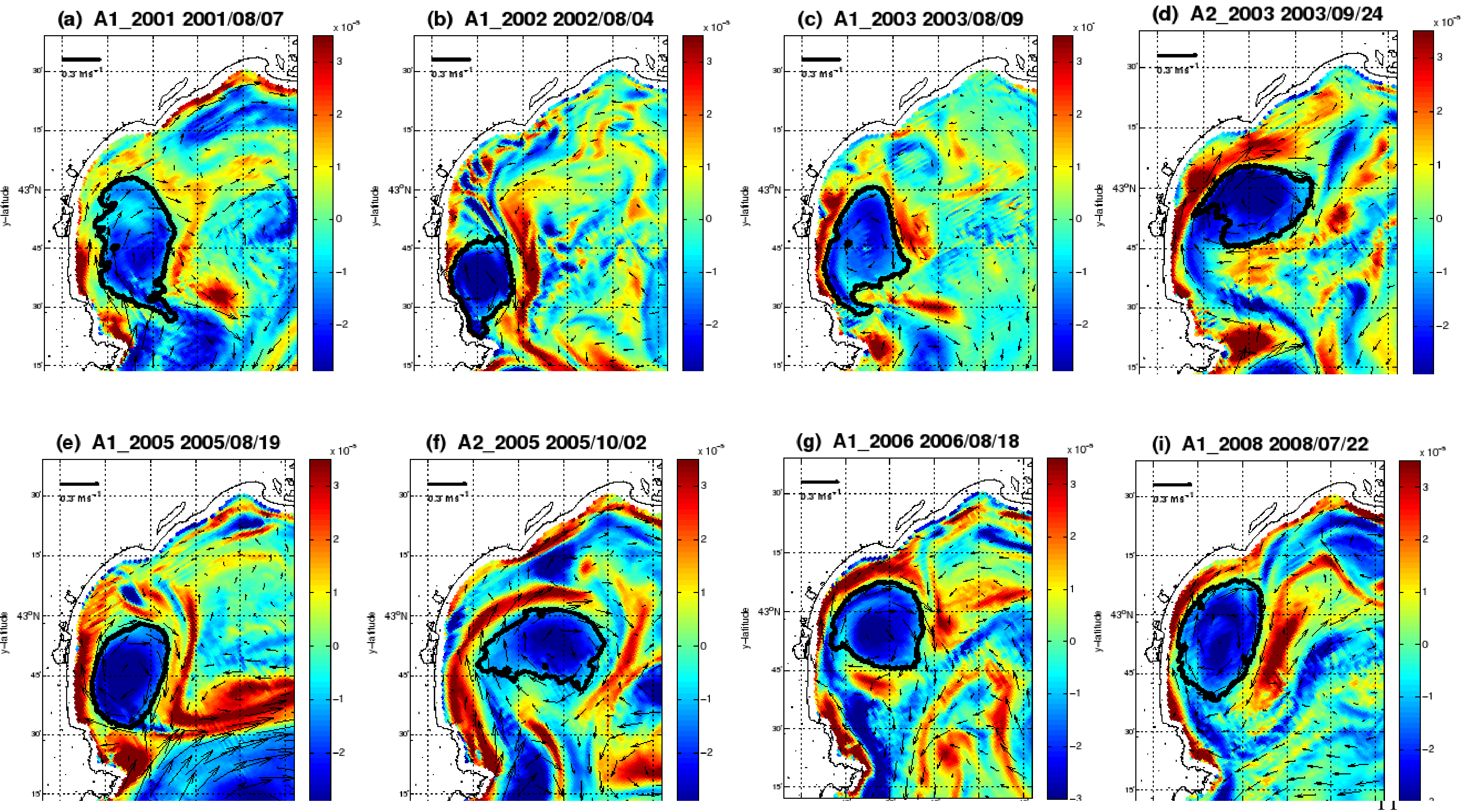
Rel.vort. 20-m depth 25/07/2001

[Hu et al., Ocean Model., 2009]

using WATERS [Doglioli et al.,2007]

3D Circulation Model (Symphonie)

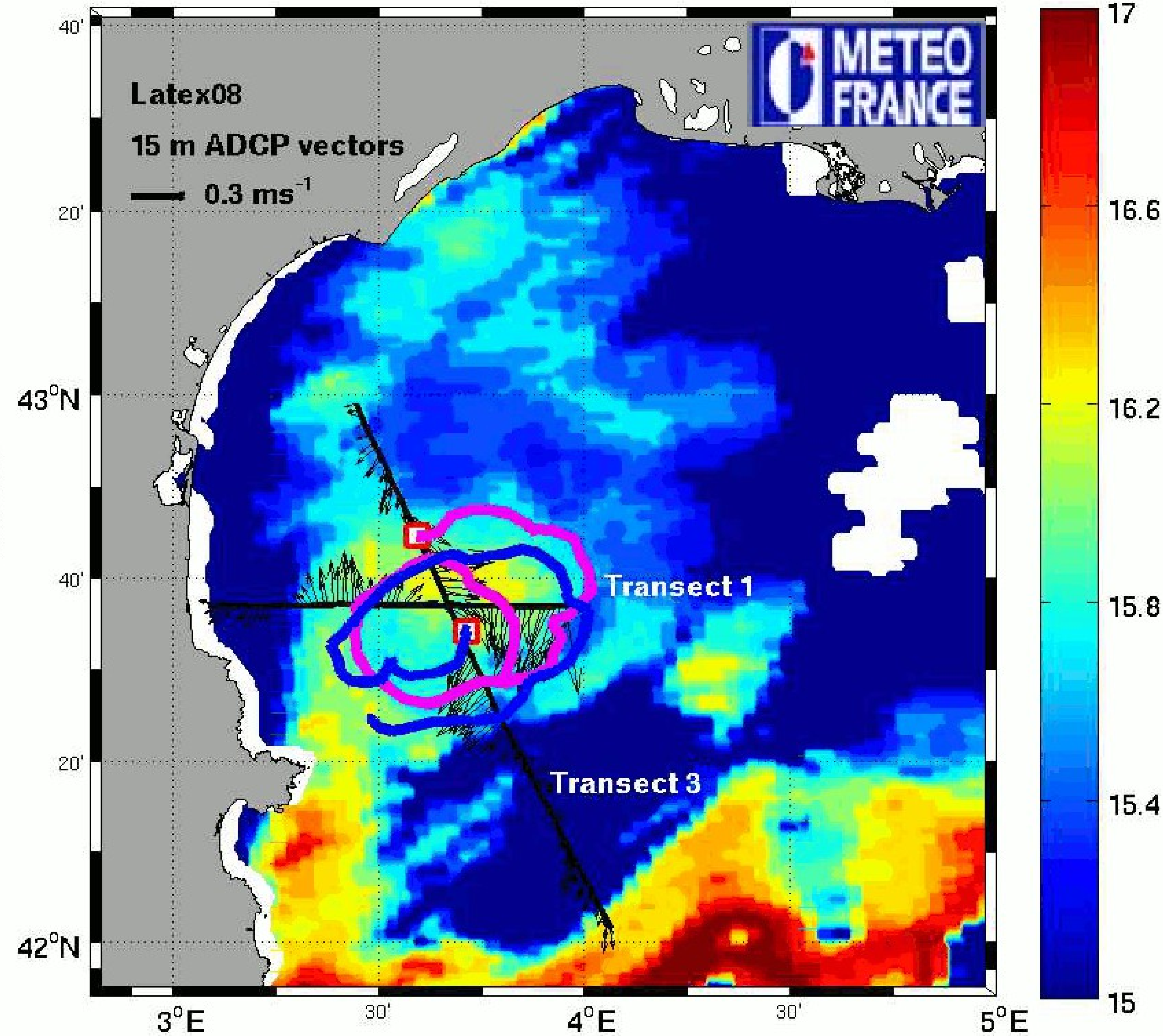
«Bestiary» of GoL eddies from 2001 to 2008



[Hu et al., JGR, 2011]

Latex08 cruise (1 – 6 september 2008)

Latex08 Eddy

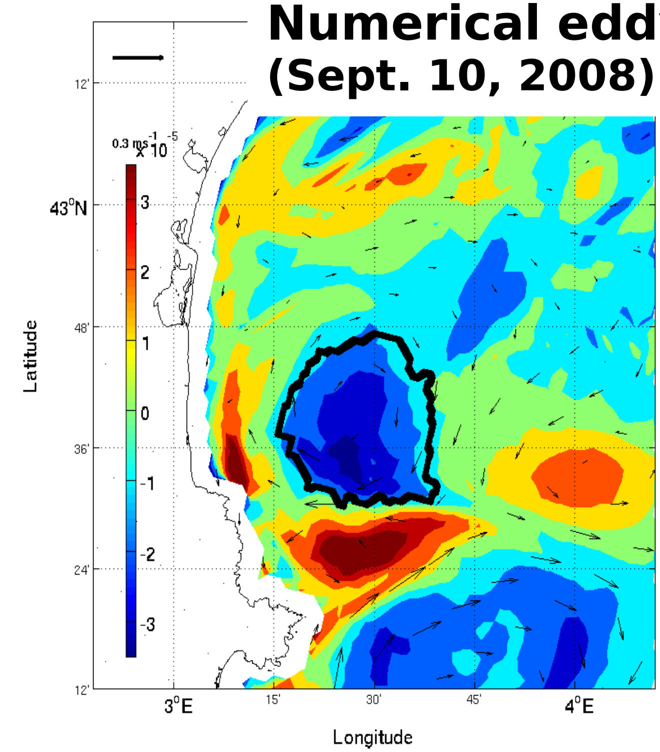


[Hu et al., JMS, 2011]

ADCP @15 m, SST, drifters

V_{tg} ~ 0.3 ms^{-1}
R ~ 15 - 20 km

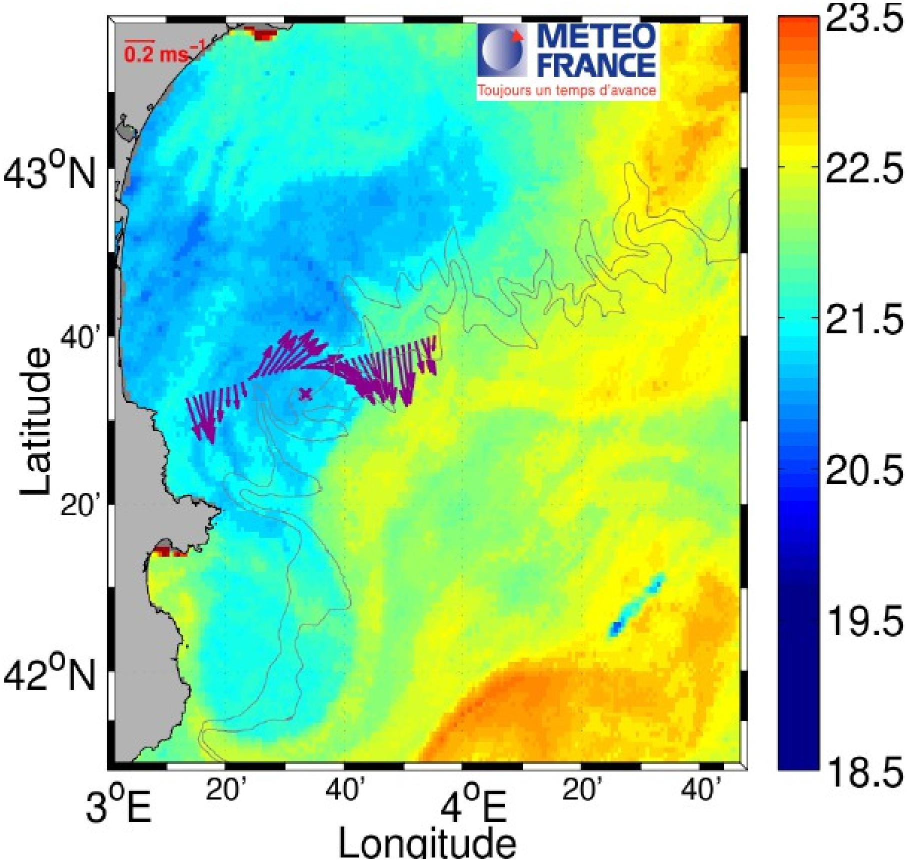
Numerical eddy (Sept. 10, 2008)



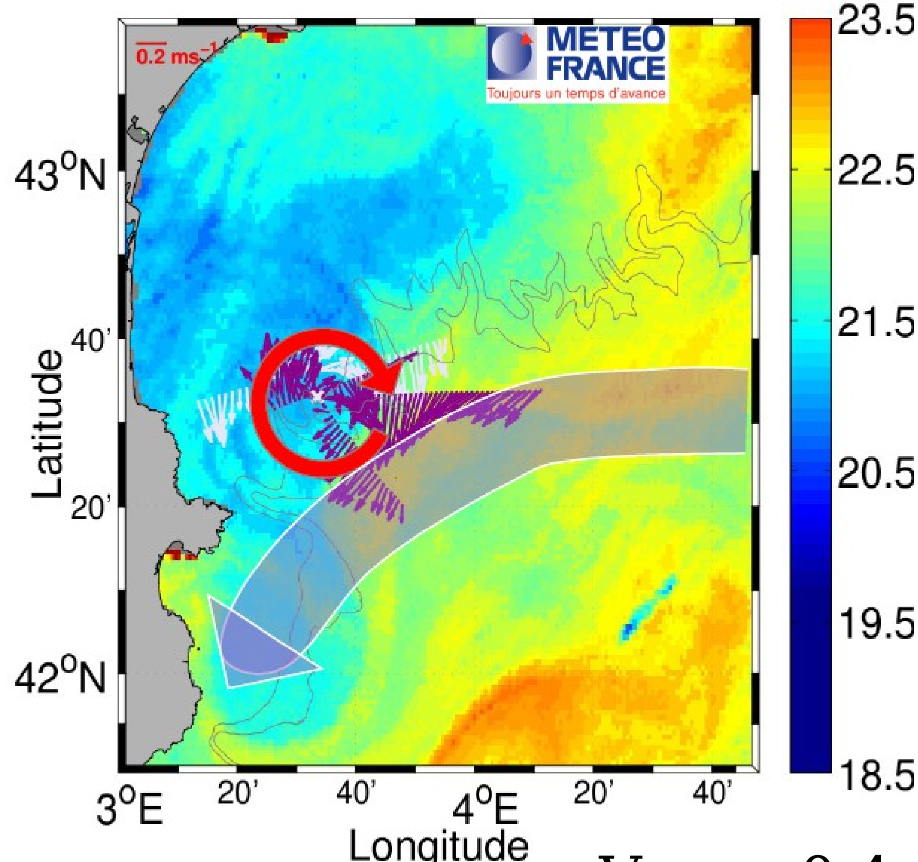
Latex09 cruise (24-28 august 2009)

Satellite data to localize Latex09 eddy, then...

First transect through
satellite estimated center



ADCP 15m depth - SST (°C) August 28

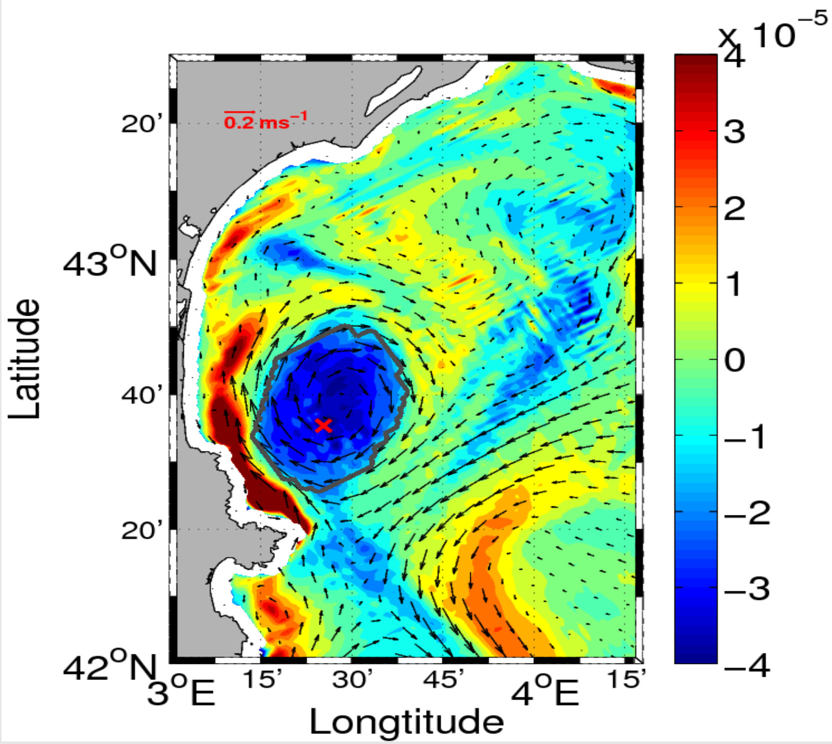


$V_{max} \sim 0.4\ m.s^{-1}$

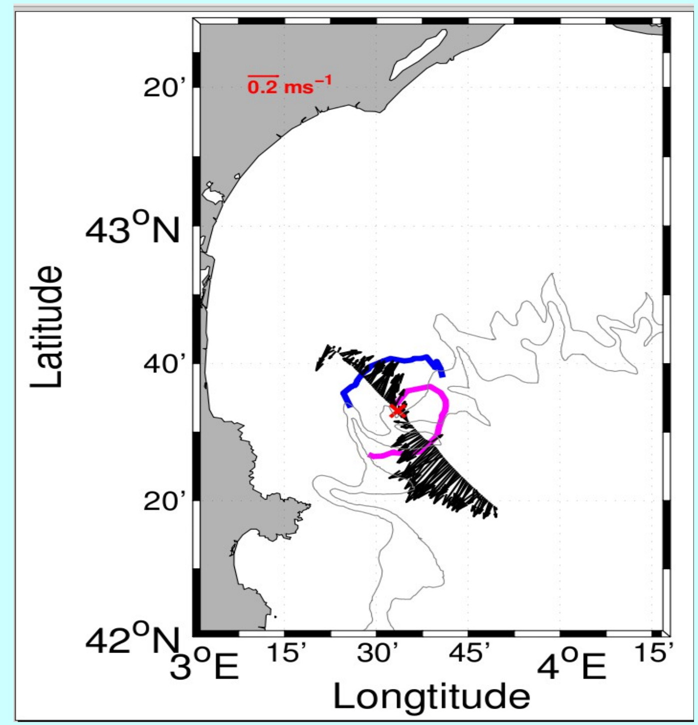
$T \sim 3$ days

Eddy center detection [Nencioli et al., 2008]
Study of Latex09 [Kersalé et al., 2013]

Latex09 eddy : model – data comparaison



Eddy detected by wavelet analysis
Relative vorticity [s^{-1}] 15m depth August 27



ADCP data August 27 +
Buoys from August 26-29

Center: 3°26'E – 42°36'N

D_{eddy} = 28,6 ± 1,4 km

$Depth_{max}$ = 37 m

Center: 3°34'E – 42°33'N

D_{eddy} = 22,7 ± 1,2 km

$Depth_{max}$ = 35 m

[Kersale et al., JGR, 2013]

Part I - Coastal mesoscale processes :

eddy generation process ?

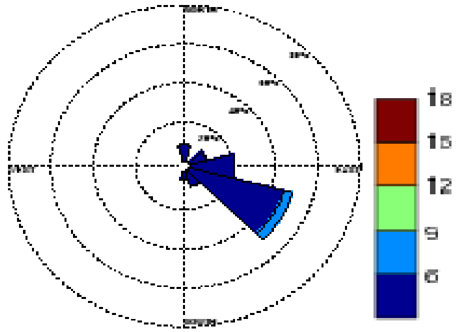
Part II – (Sub)mesoscale horizontal diffusivity

Part III – Perspectives towards submesoscale

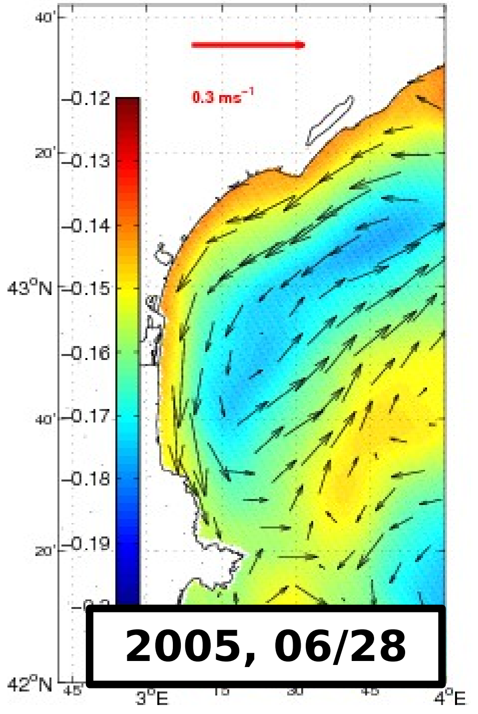
Eddy generation process

e.g. Eddy A1_2005: July 10 → Sept 04

Wind rose:



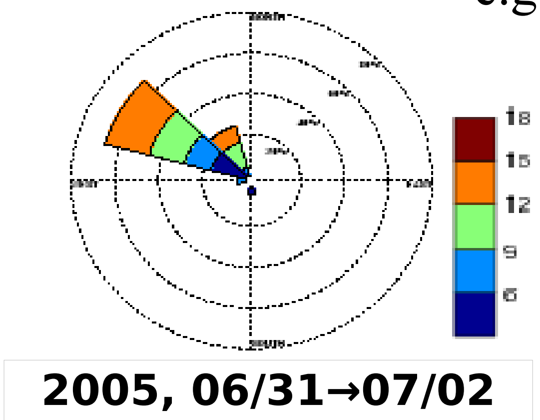
2005, 06/26→28

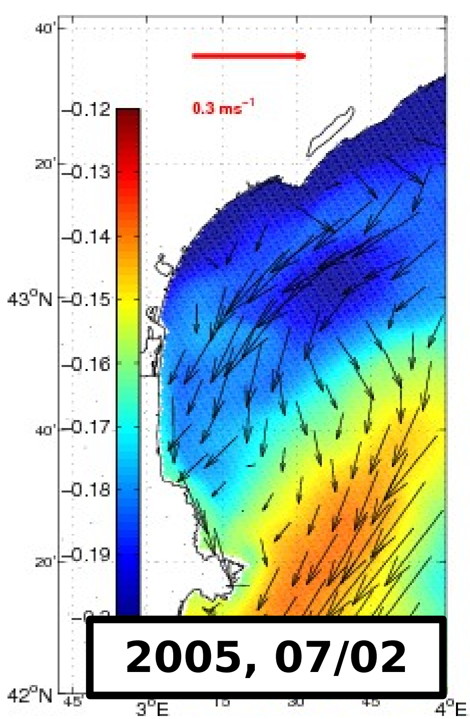


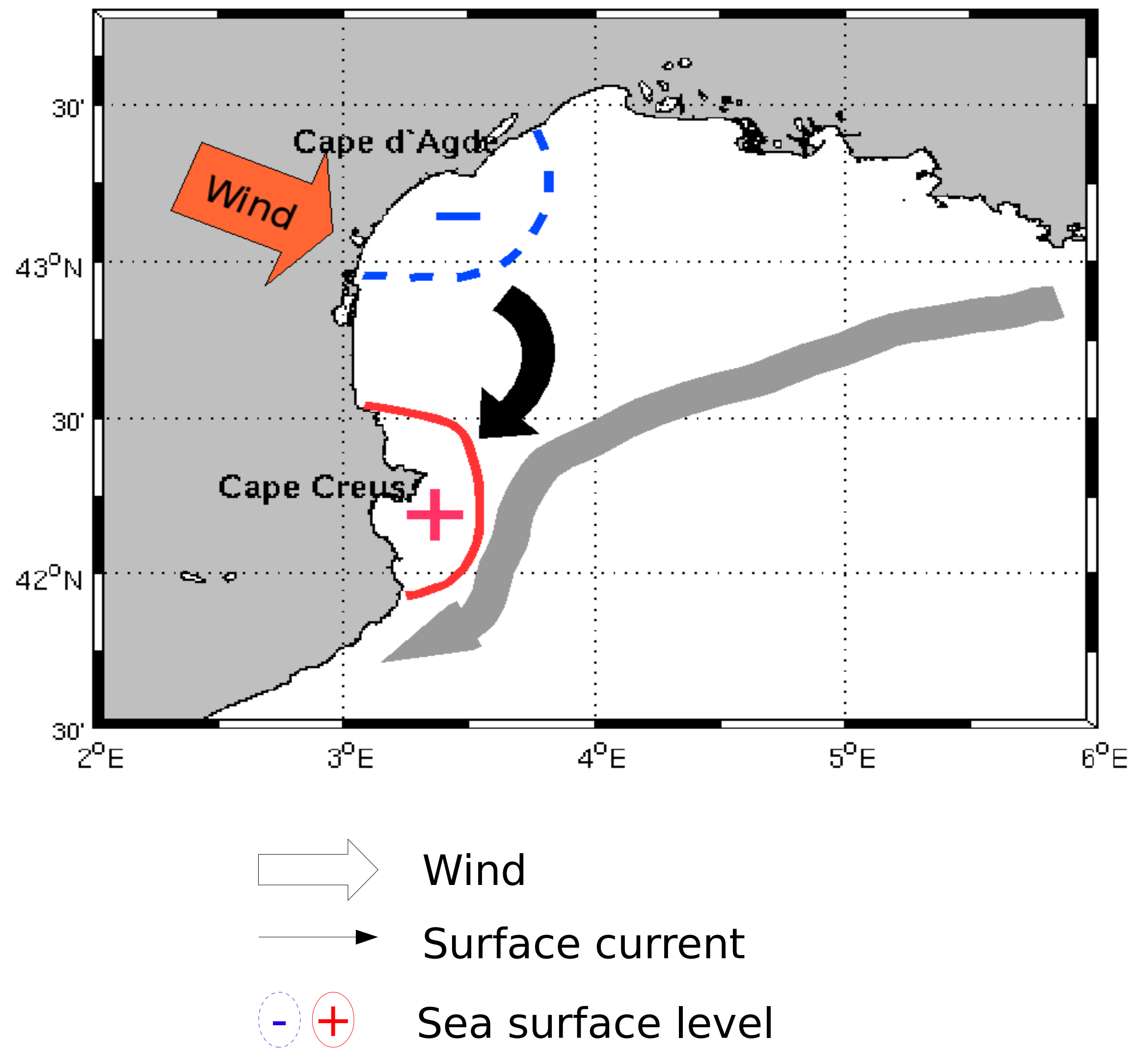
SSH
+
Surface currents

Eddy generation process

e.g. Eddy A1 2005: July 10 → Sept 04

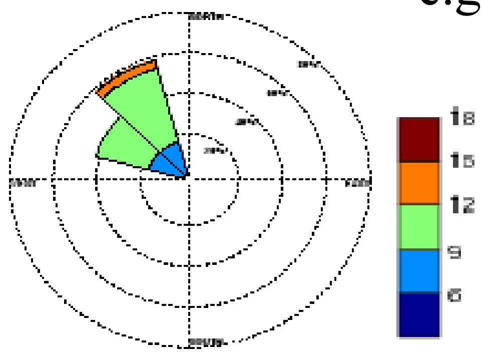




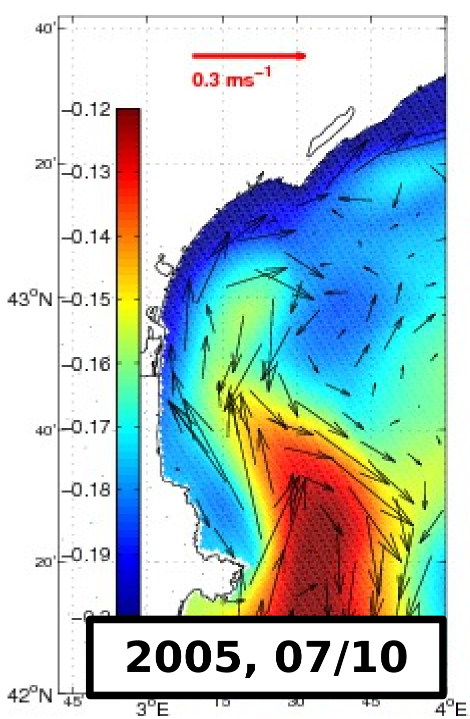


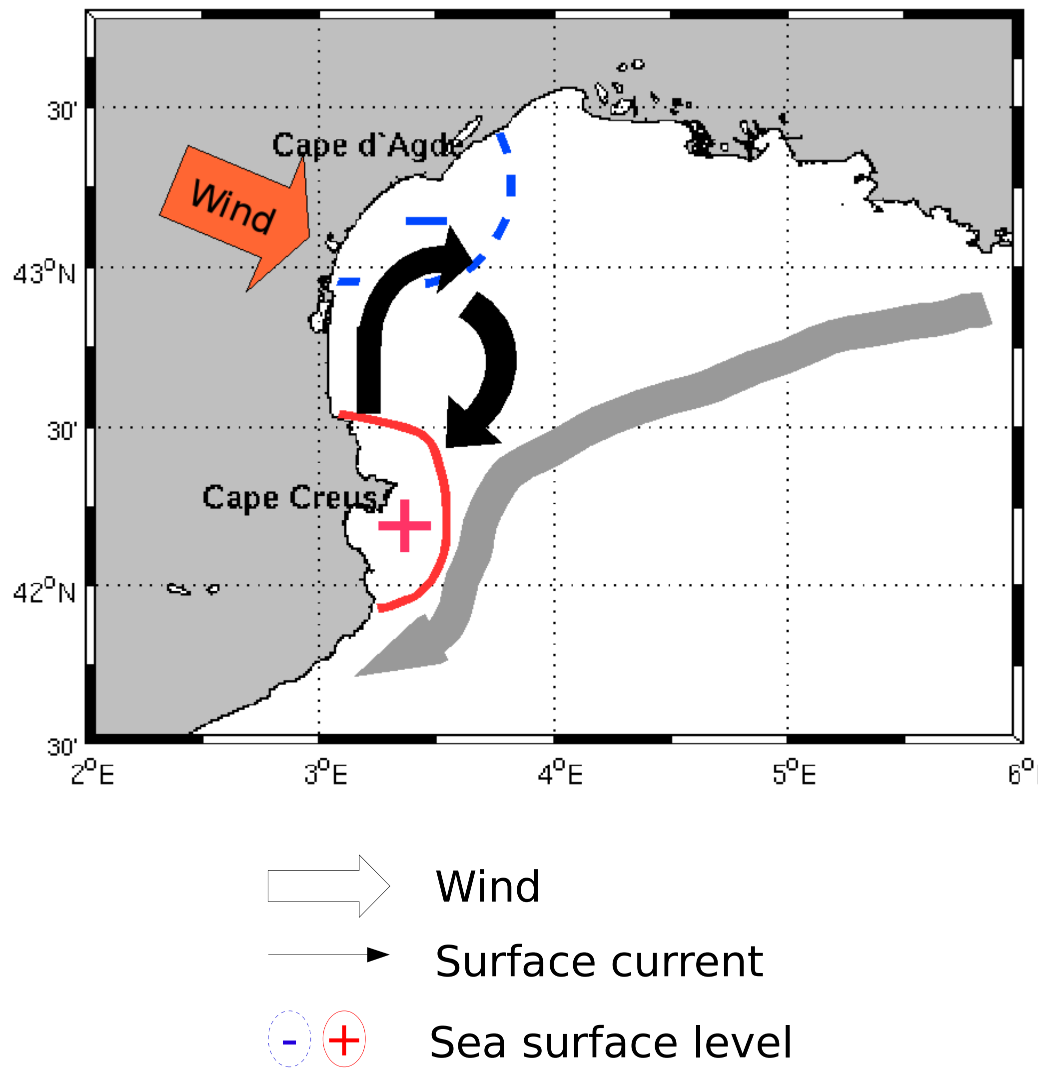
Eddy generation process

e.g. Eddy A1 2005: July 10 → Sept 04



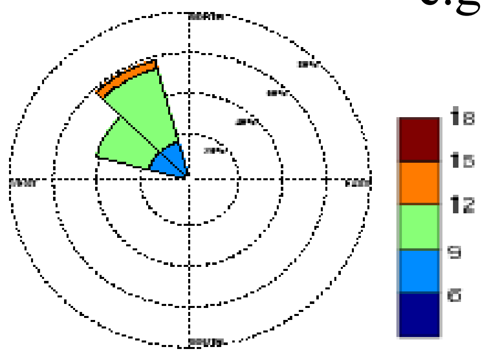
2005, 07/8→10



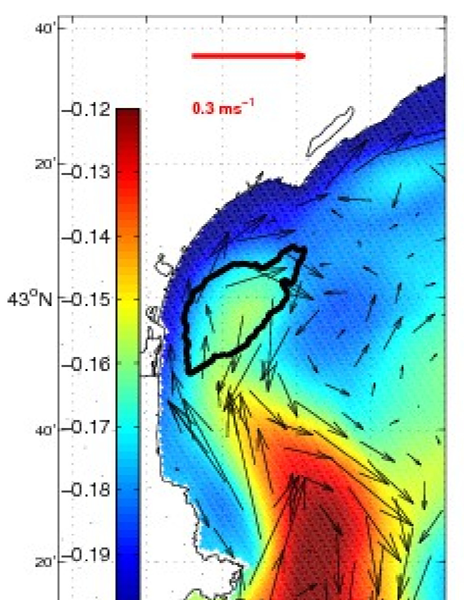


Eddy generation process

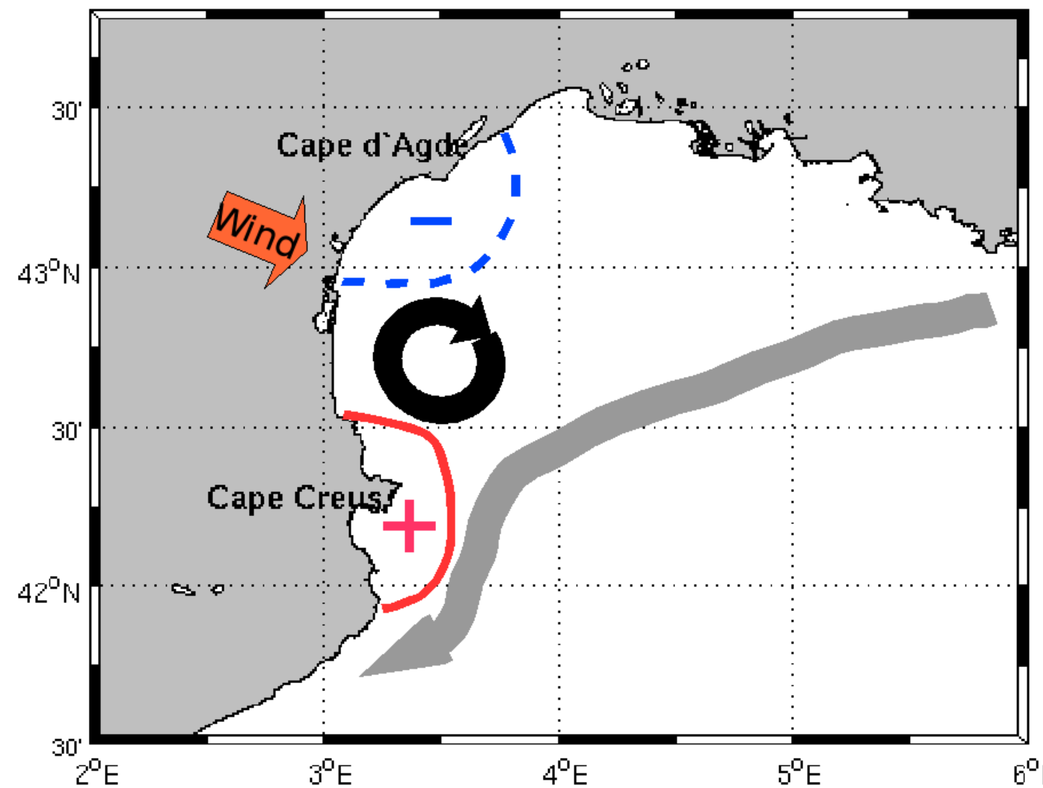
e.g. Eddy A1 2005: July 10 → Sept 04

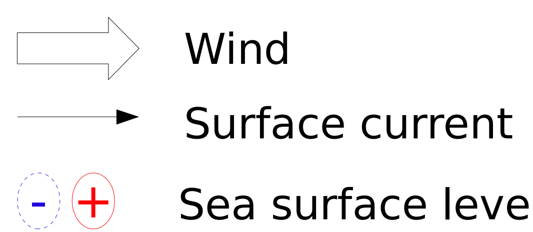


2005, 07/8→10



2005, 07/10





Eddy generation process

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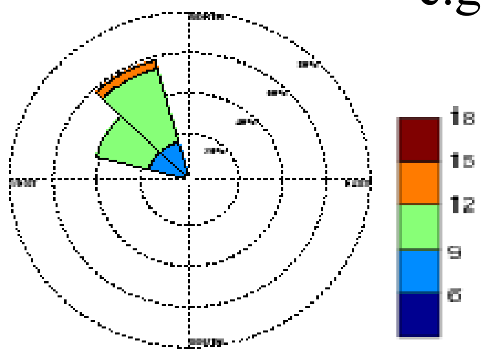
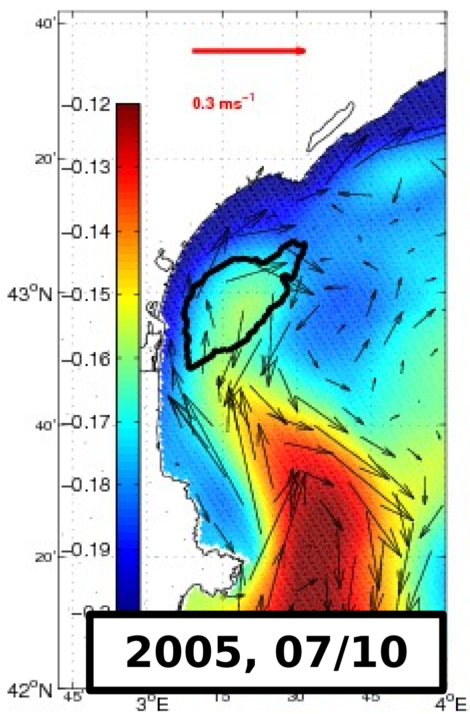
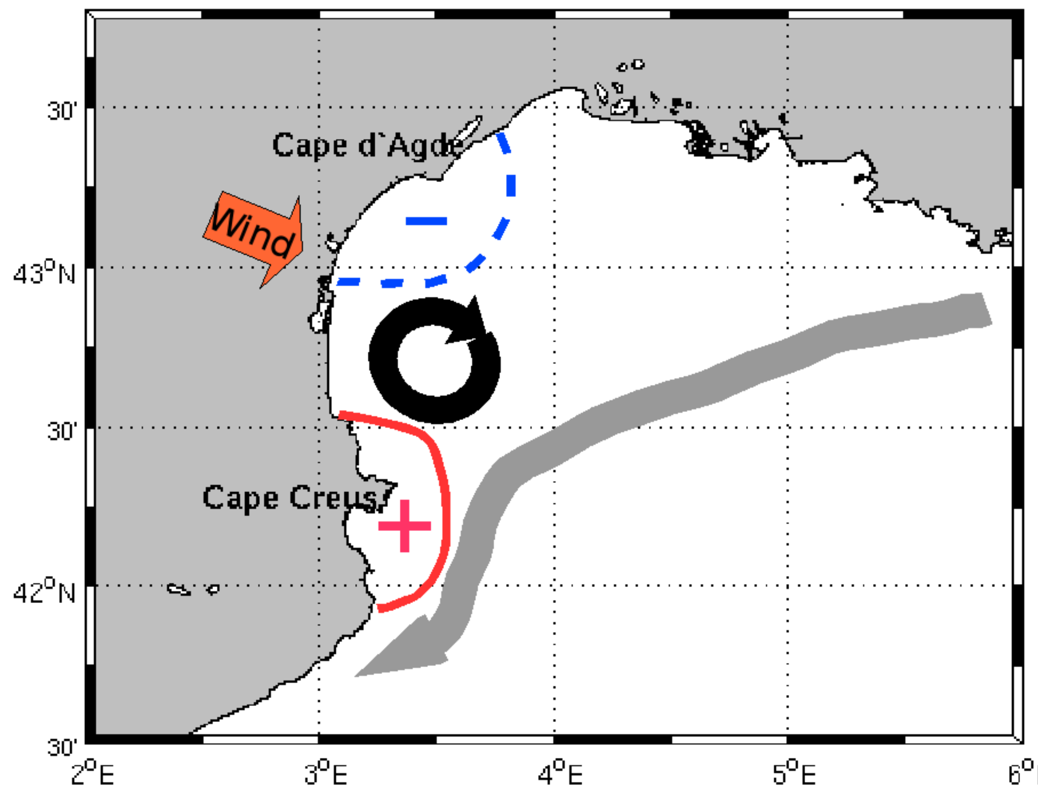


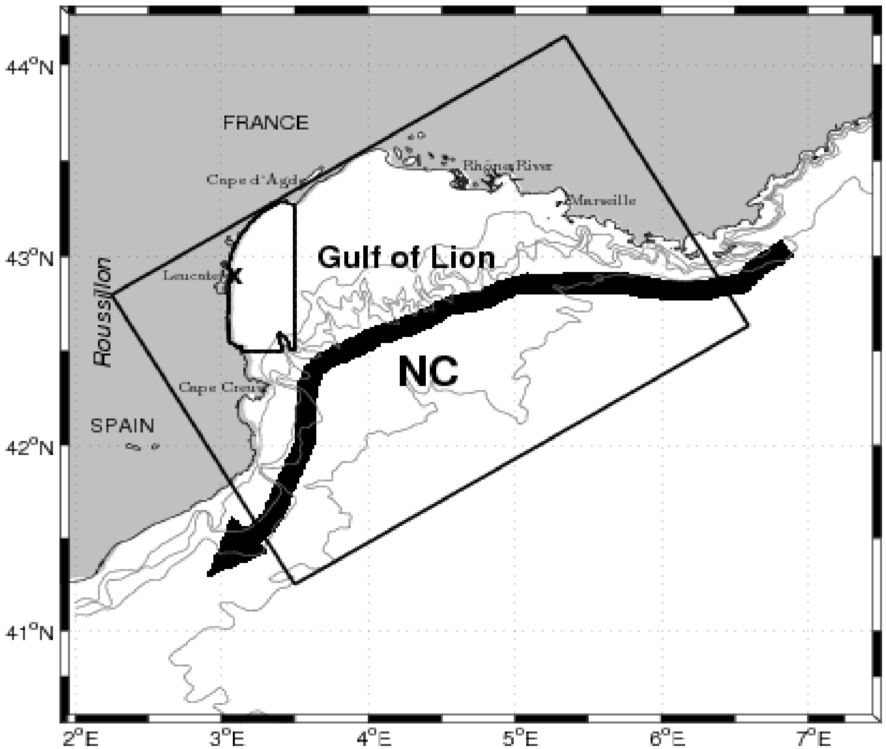
2005, 07/8→10





Millot's hypothesis confirmed! but...

3D Circulation Model (Symphonie)

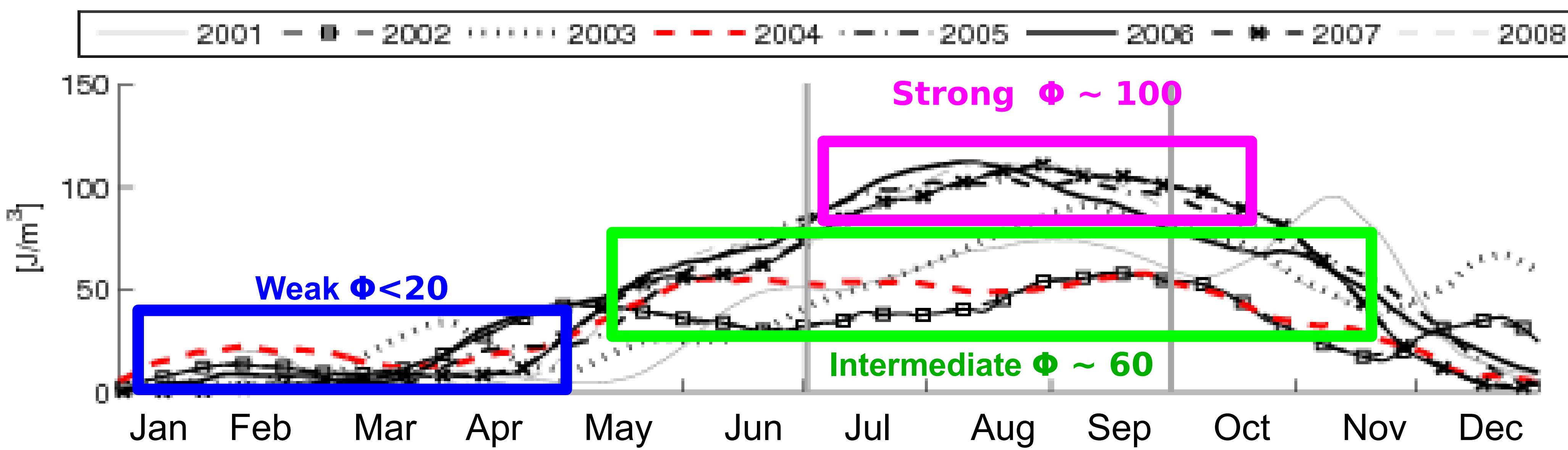


Influence of stratification on the eddy

$$\phi = \frac{1}{D}\int_{-H}^{\eta} gz(\bar{\rho}-\rho)dz$$

Potential energy anomaly
[Simpson, 1981; Schaeffer, 2010]

High |Φ| → Strong stratification



3D Circulation Model (Symphonie)

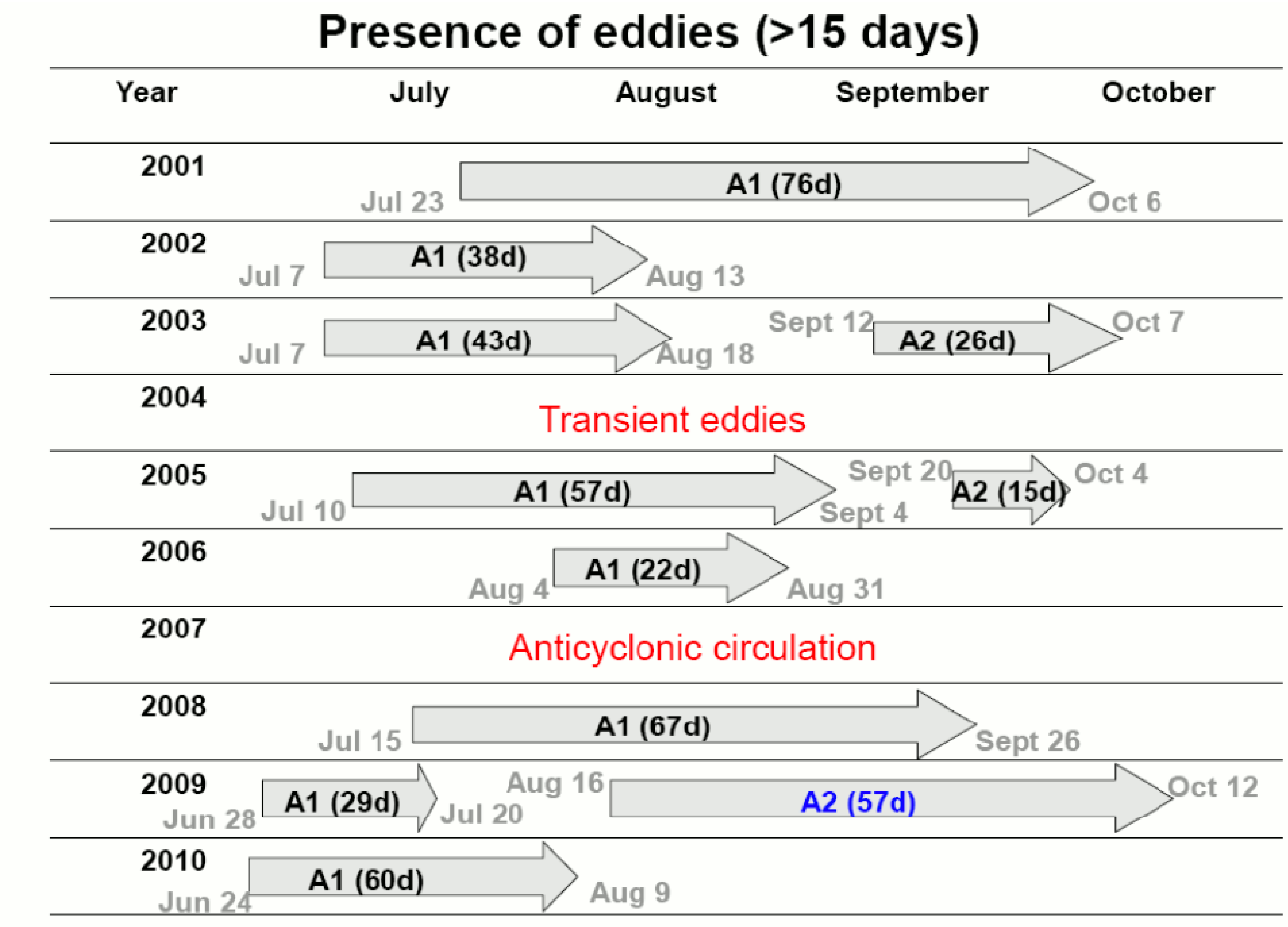
Generation process (« *the recipe for a nice GoL eddy!* »)

2 conditions are necessary to generate a long-life eddy:
1) strong North-West wind (Tramontane)
2) strong stratification

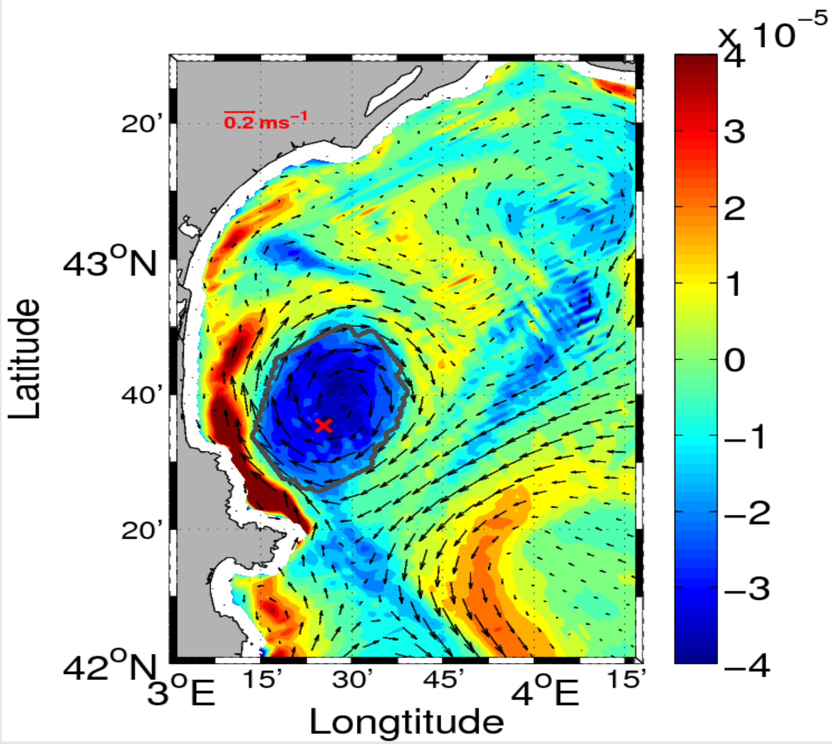
Wind	weak	strong	strong	strong	strong & persistent	strong & persistent
Stratif.	strong or weak	no	intermediate	strong	intermediate	strong
Eddy	*no*	*no*	*short-life*	*long-life*	*long-life*	*anticyclonic circulation*
		winter spring	early summer, end of fall, summer 2004	summers: 2001, 2003, 2005, 2006, 2008	summer 2002	summer 2007

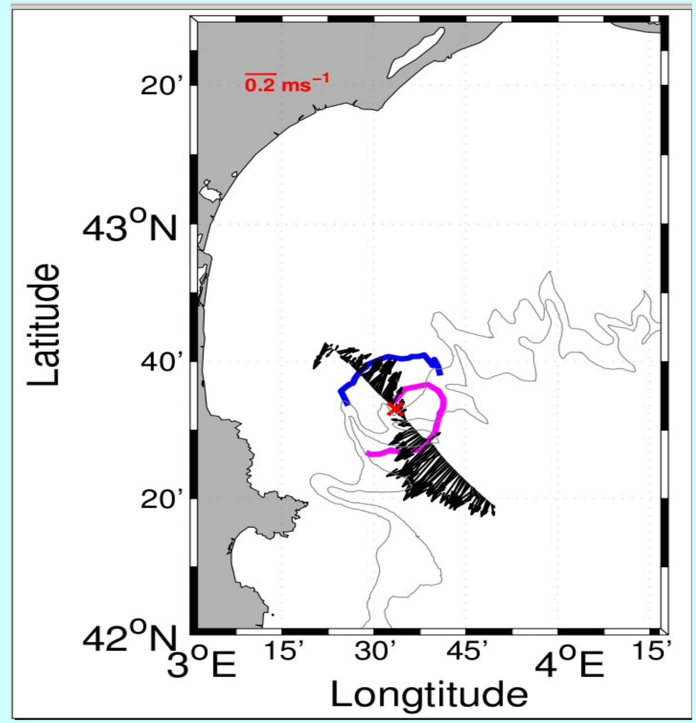
[**Hu et al., JGR, 2011**]

Latex eddies from 2001 to 2010



Latex09 eddy : model – data comparaison





Eddy detected by wavelet analysis
Relative vorticity [s^{-1}] 15m depth August 27

ADCP data August 27 +
Buoys from August 26-29

Center: 3°26'E – 42°36'N

D_{eddy} = **28,6 ± 1,4 km**

Depth $_{max}$ **= 37 m**

Center: 3°34'E – 42°33'N

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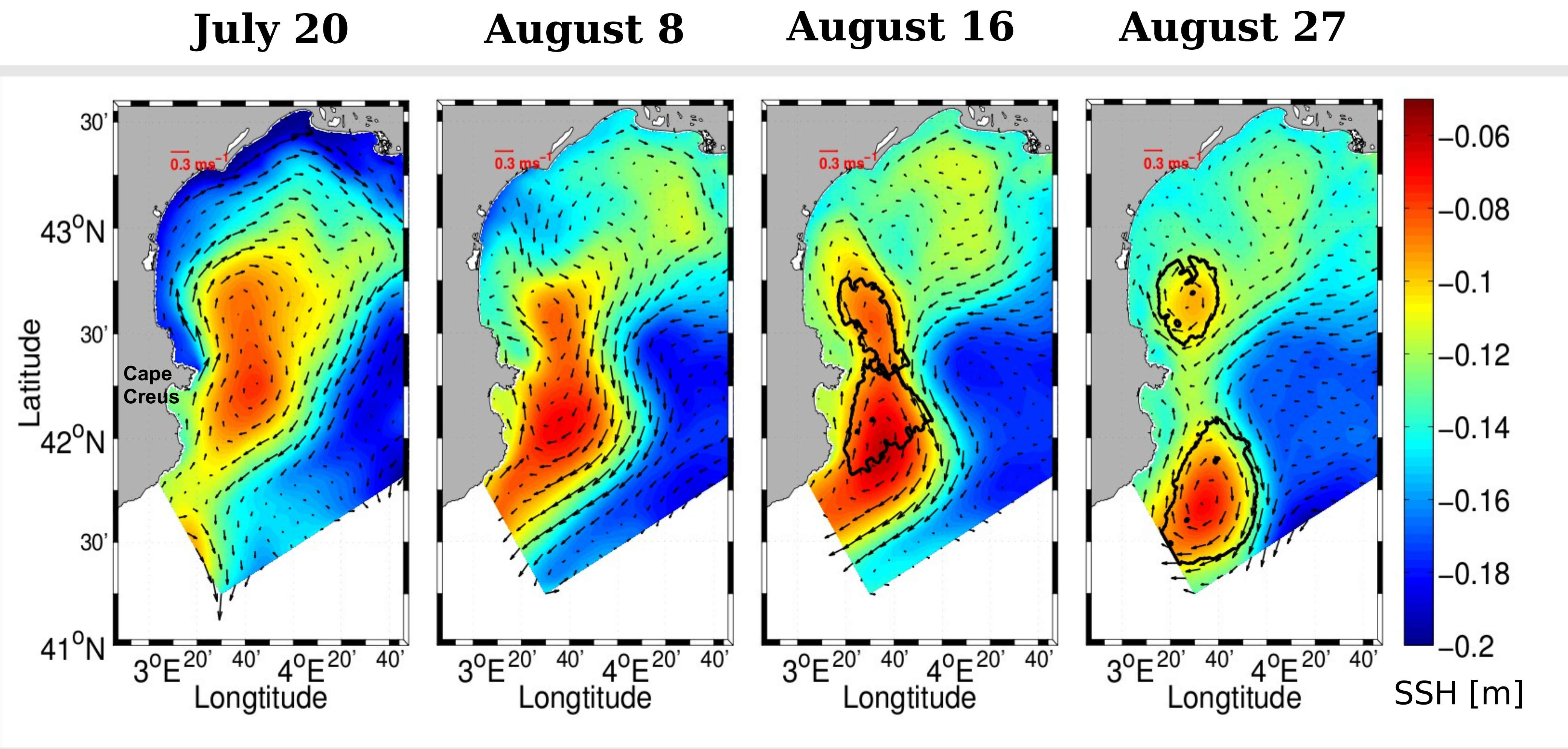
Depth $_{max}$ **= 35 m**

[Kersale et al., JGR, 2013]

Latex09 eddy generation



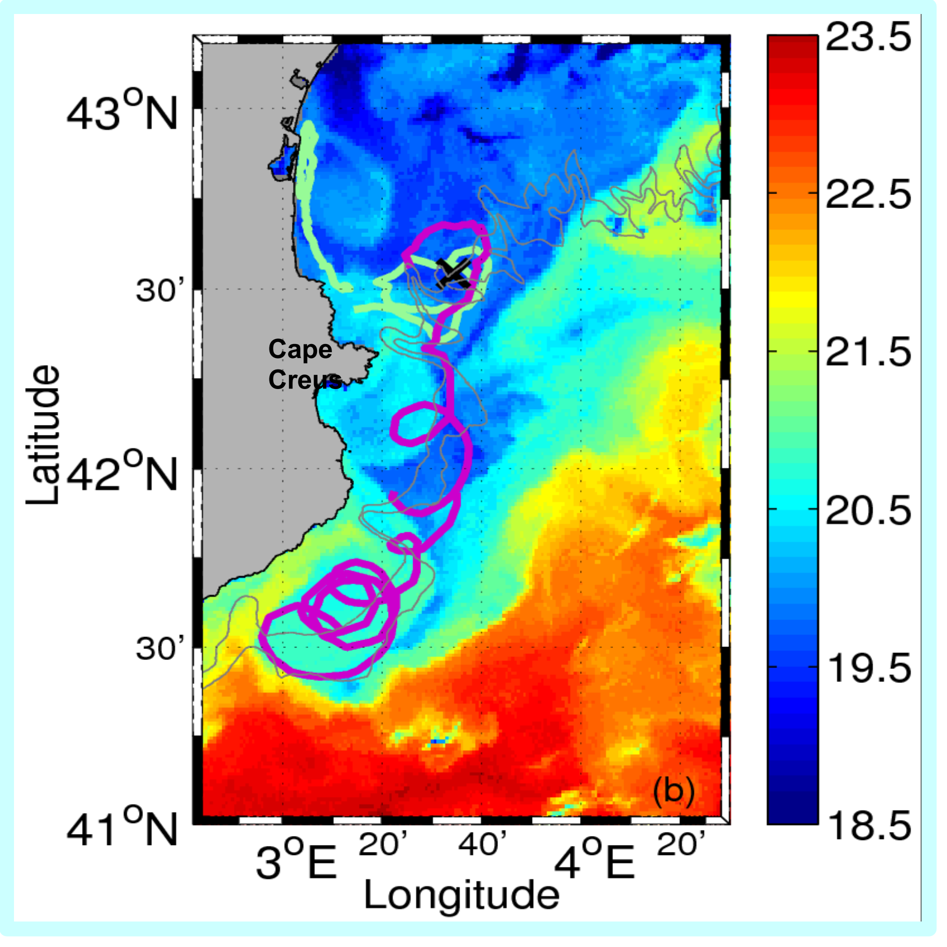
New Generation Process :

pushing and squeezing of an anticyclonic circulation between a meander of the NC and the coast

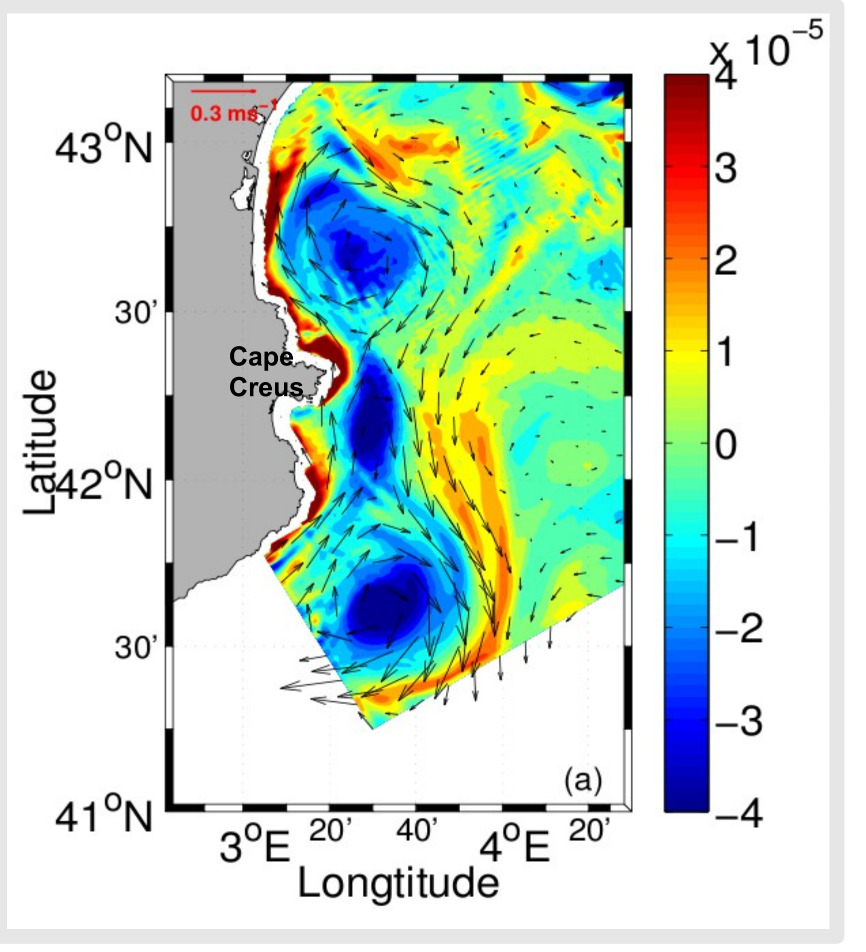
[**Kersale et al., JGR, 2013**]

Latex09 eddy : model – data comparaison

Latex09 feeds the Catalan eddy



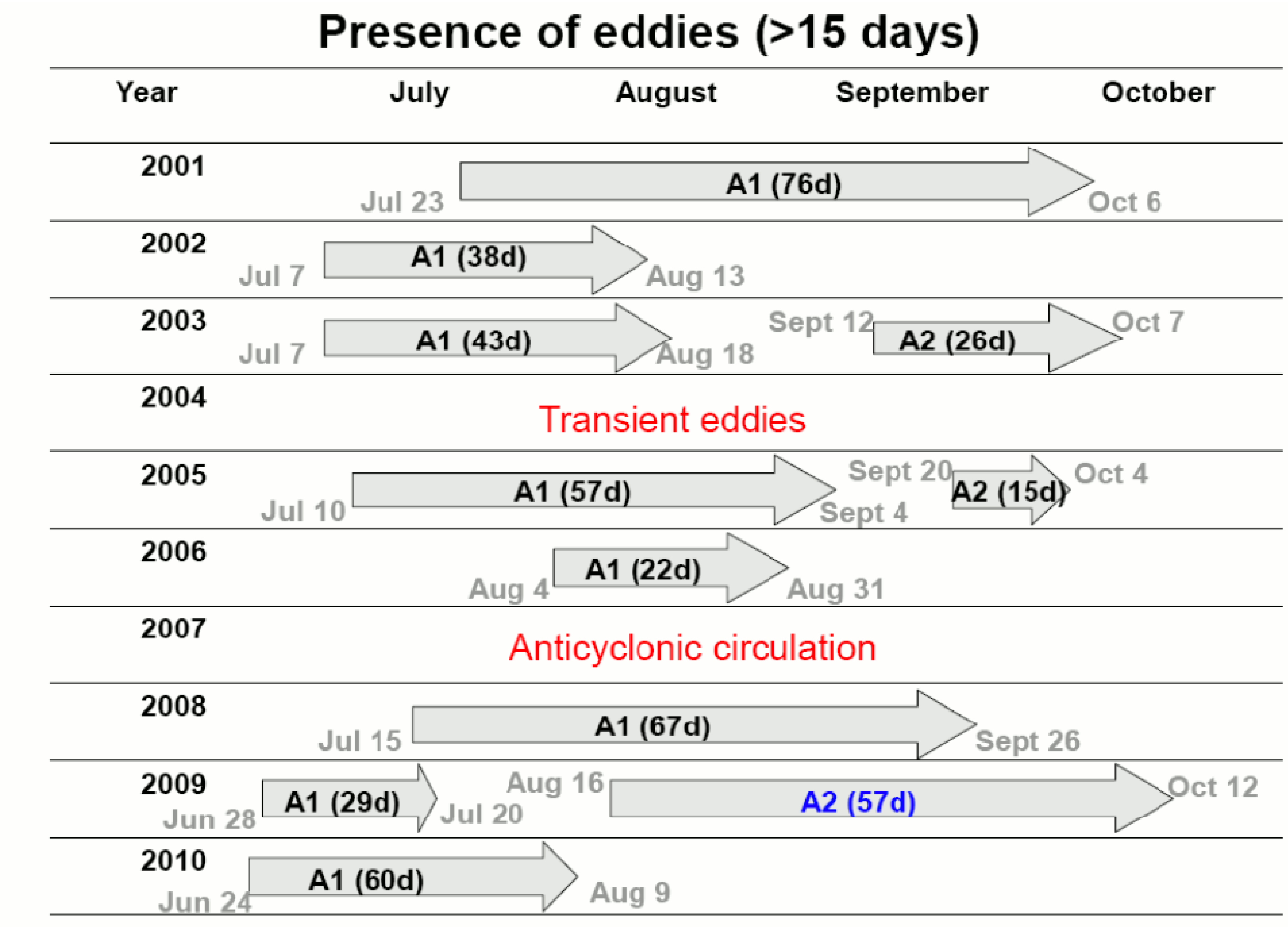
SST (°C) September 12
+Buoys from August 26- September 12



Relative vorticity [s^{-1}]
20m depth September 3

Drifter trajectories explained by the presence of a transient structure

Latex eddies from 2001 to 2010



Latex10 cruise (1-24 septembre 2010)

Tethys II

- 2 research vessels
- hull-mounted ADCPs
- inert tracer SF6
- 20 Lagrangian floats
- 3 ADCP moorings
- 3 gliders

Suroît

+ in real-time on the research vessels:
  - satellite imagery (SST, sea color, geostrophic currents < altimetry)
  - operationnal modelling (Previmer – Mars3D)
  - gliders' detection

No eddy in the French waters!!!

→ Use of real-time Lyapunov exponents' analysis (on altimetry AVISO data) to check the existence of FSLE manifolds - TETHYS II

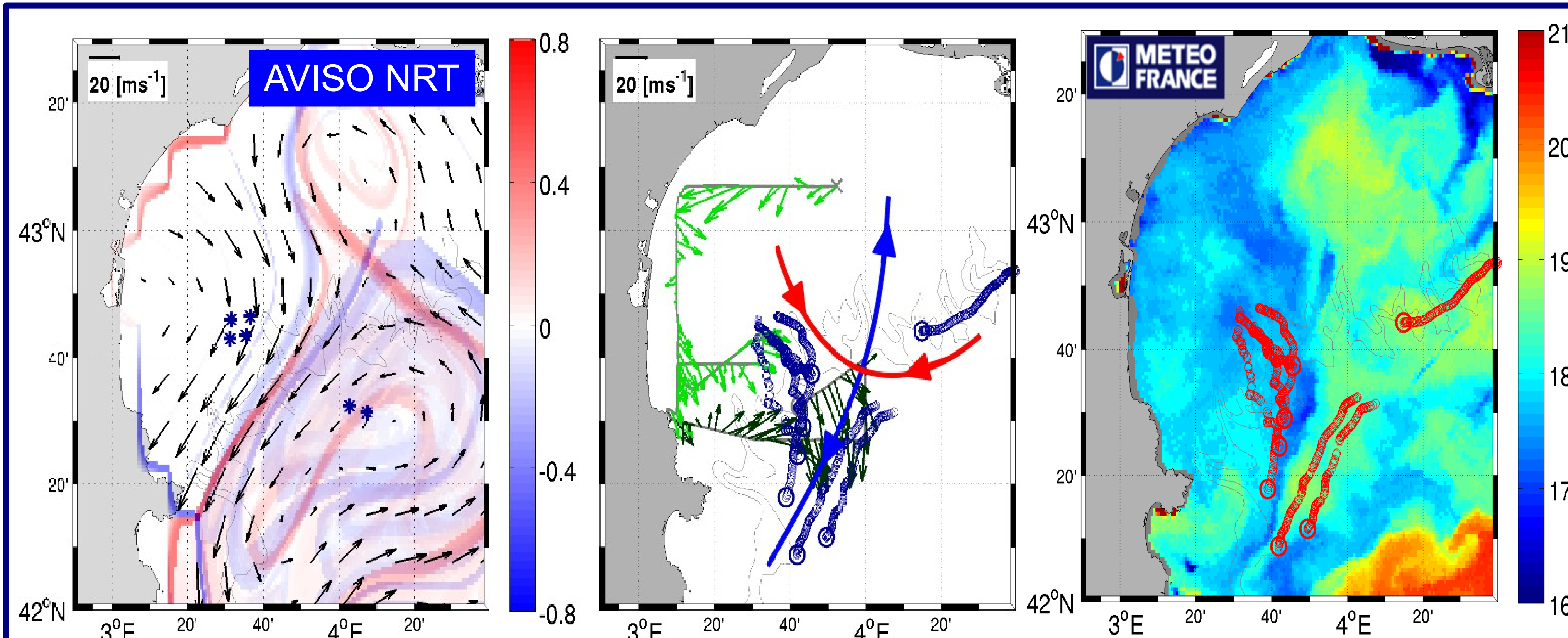
→ Tracer release and mappings - SUROIT

Latex10 cruise (1-24 septembre 2010)

In-situ quasi real-time (with F. d'Ovidio) detection of Lagrangian Coherent Structures

LYAP(UNOV) 1

Altimetry LCS **In situ LCS** **AVHRR SST**



+ 2 other ones : LYAP 2 and LYAP 3

[Nencioli et al, GRL, 2011]

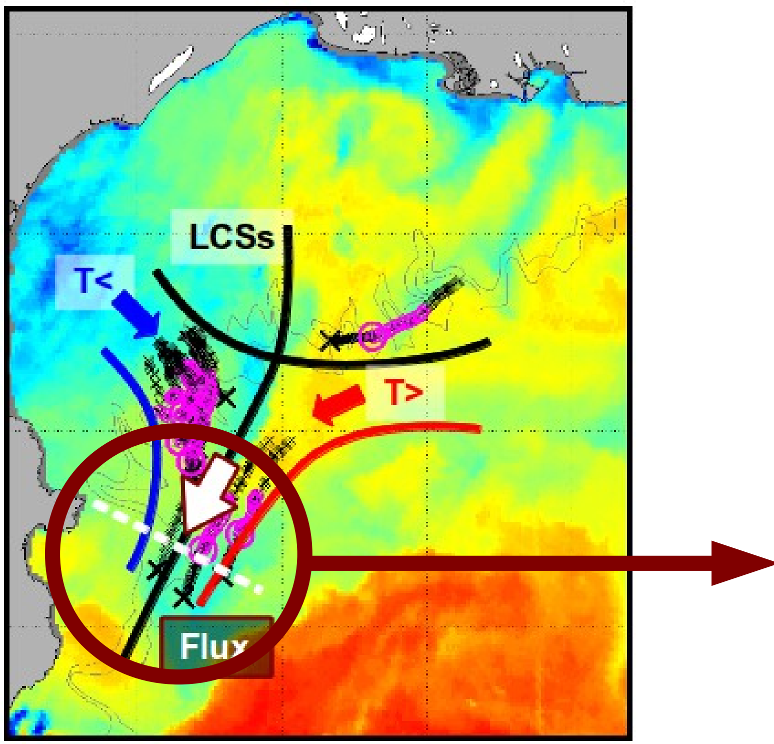
Part I - Coastal mesoscale processes

Part II – Submesoscale horizontal diffusivity
1st method using Lagrangian floats/FLSE and thermosalinograph data

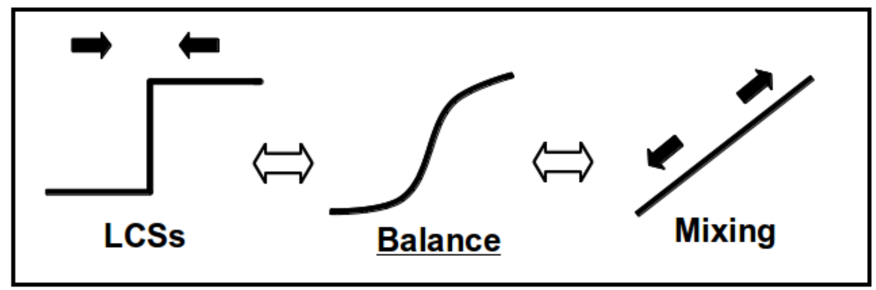
Part III – Perspectives towards submesoscale

Latex10 cruise (1-24 septembre 2010)

Combining Lagrangian and ship-based measurements
to estimate front-related parameters



TSG data to compute Kh coefficients



Shape of T and S fronts across the attractive LCS results from balance between convergence and horizontal mixing

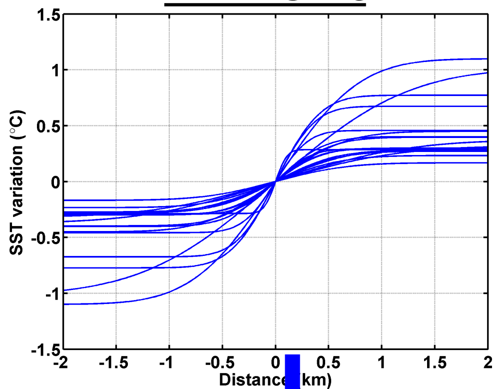
Submesoscale Kh coefficients important for high-resolution numerical models (physics + biogeochemistry)

Few in-situ estimates (i.e. Flament et al. 1985, Ledwell et al. 1998)

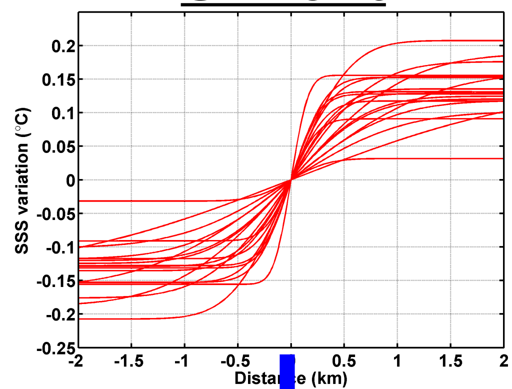
Latex10 cruise (1-24 septembre 2010)

Total of 30 cross-front transects identified

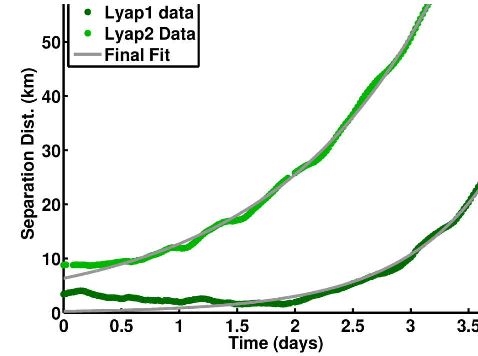
T Front



S Front



Strain rate



C_3 estimated from the fits of the curves

$$T(x) = C_1 + C_2\, erf\left(C_3 (x - C_4)\right)$$

$$with\ C_1 = \frac{T_1 + T_2}{2},\ C_2 = \frac{T_2 - T_1}{2},\ C_4 = x_0.$$

$$K_H = \frac{\gamma}{(2\,\mathrm{C3}^2)}$$

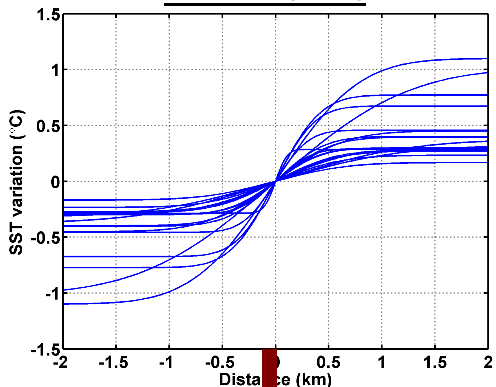
(Thorpe, 1983 ;
Ledwell et al. 1998;
Abraham, 2000)

[Nencioli et al, JGR, 2013]

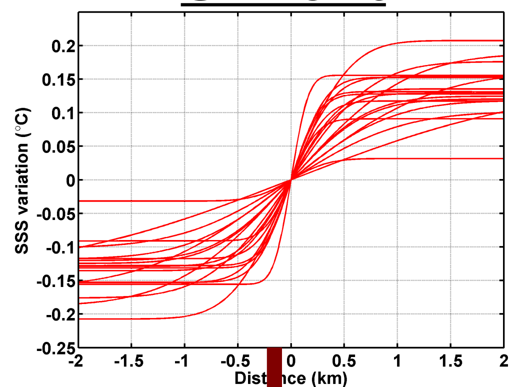
Latex10 cruise (1-24 septembre 2010)

Total of 30 cross-front transects identified

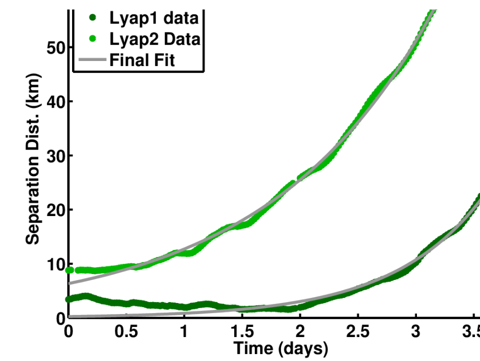
T Front



S Front

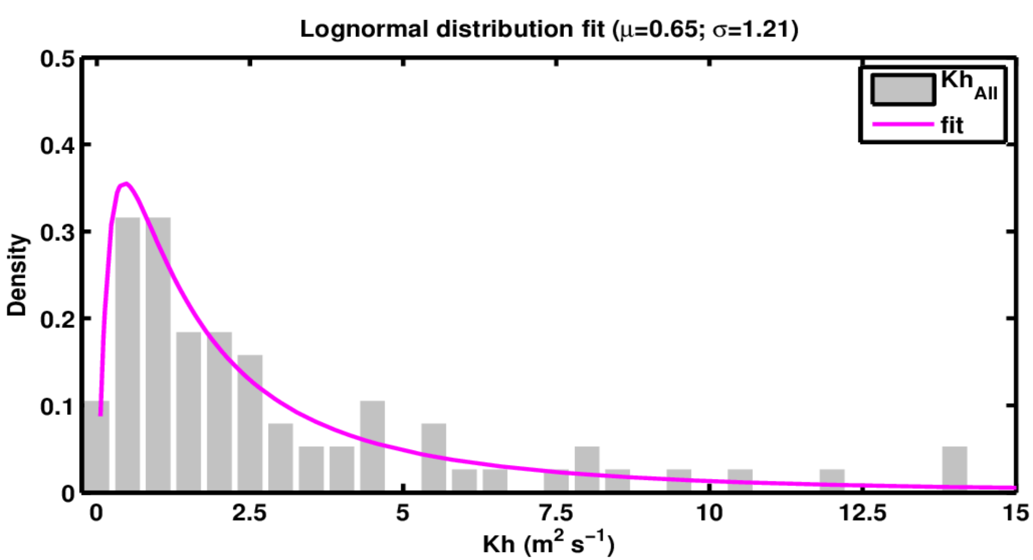


Strain rate



$$K_H = \frac{\gamma}{\left(2\,\mathrm{C}3^2\right)}$$

Eddy diffusivity coefficients



[Nencioli et al, JGR, 2013]

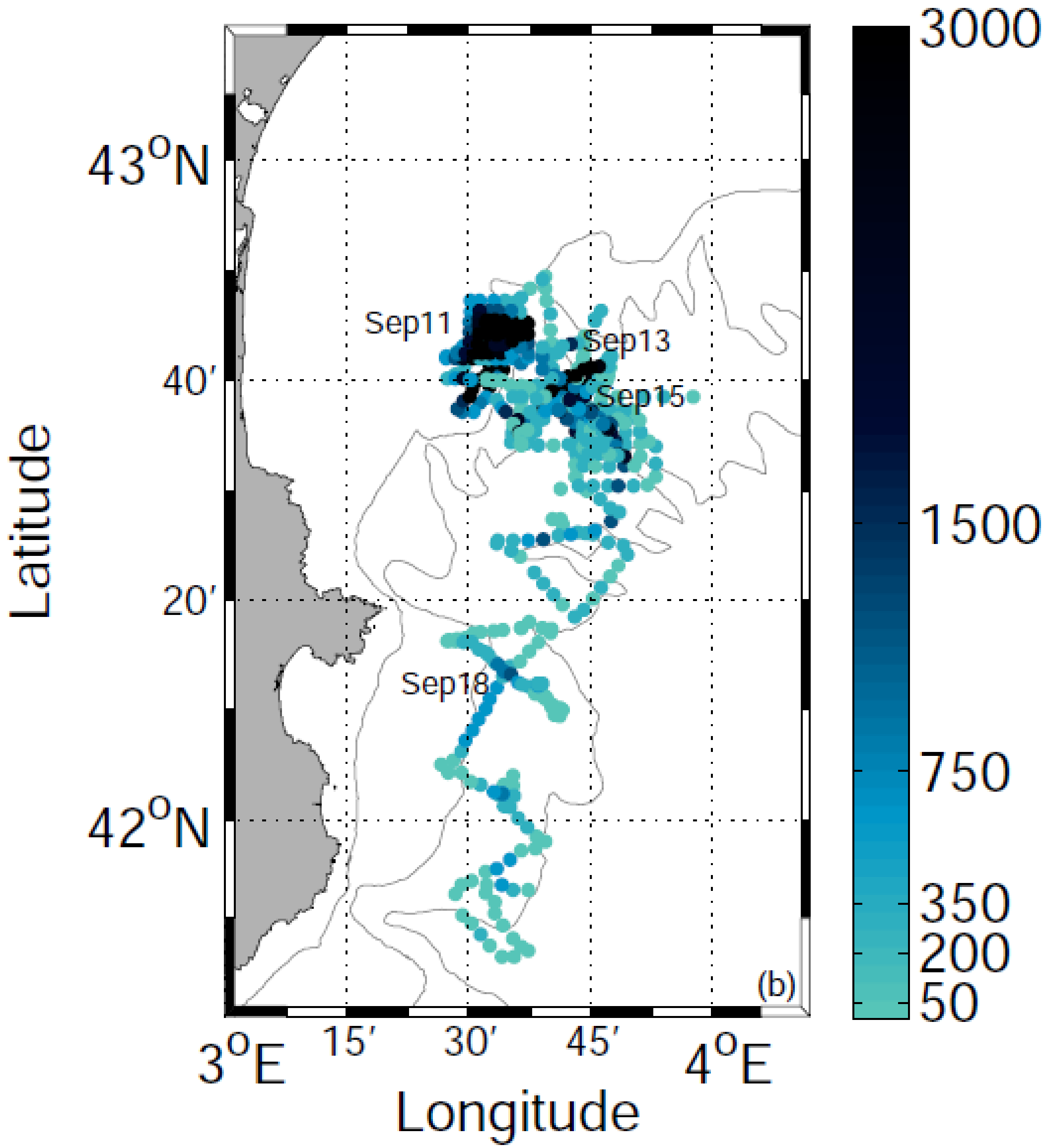
- 70% of estimates between 0.4 - 5 $m^2\ s^{-1}$
- Front widths range from 1 to 4 km
- Kh_{SST} similar to Kh_{SSS}
- Log-normal distribution

Part I - Coastal mesoscale processes

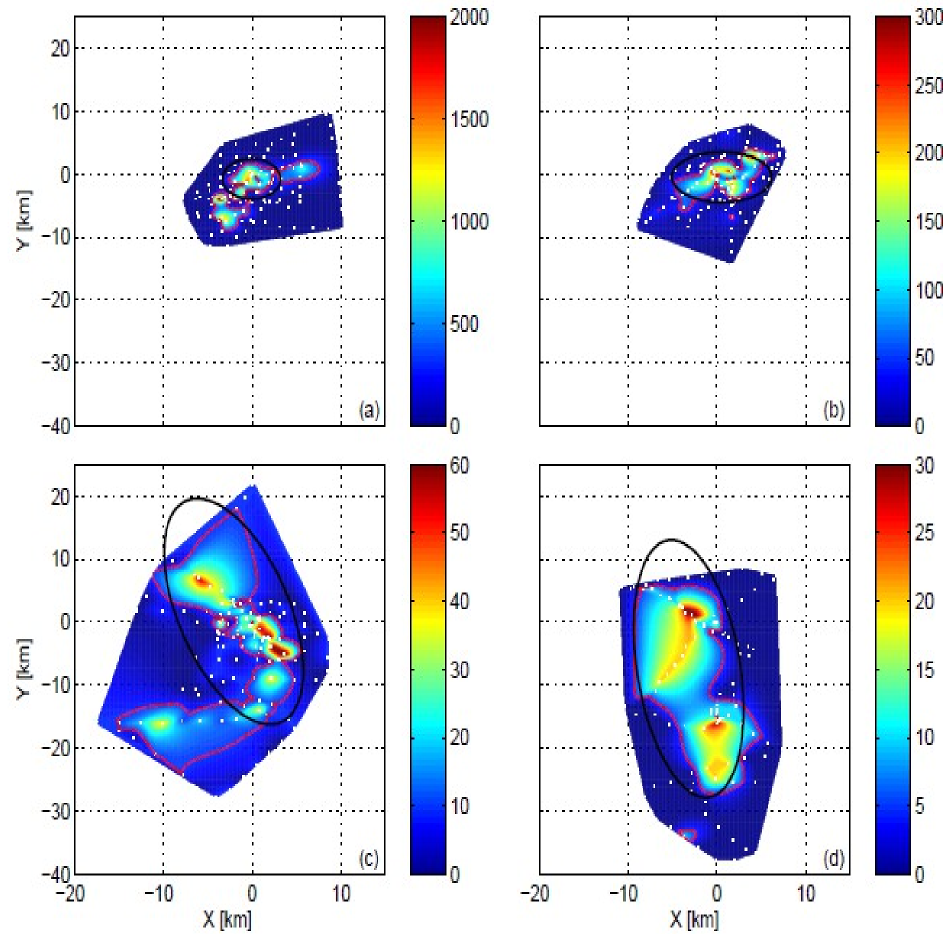
Part II – Mesoscale horizontal diffusivity
2nd method using a tracer release

Part III – Perspectives towards submesoscale

Latex10 cruise : 4 mappings after the tracer release



Map of the SF6 patch, color-coded by SF6 concentrations [fmol L−1]



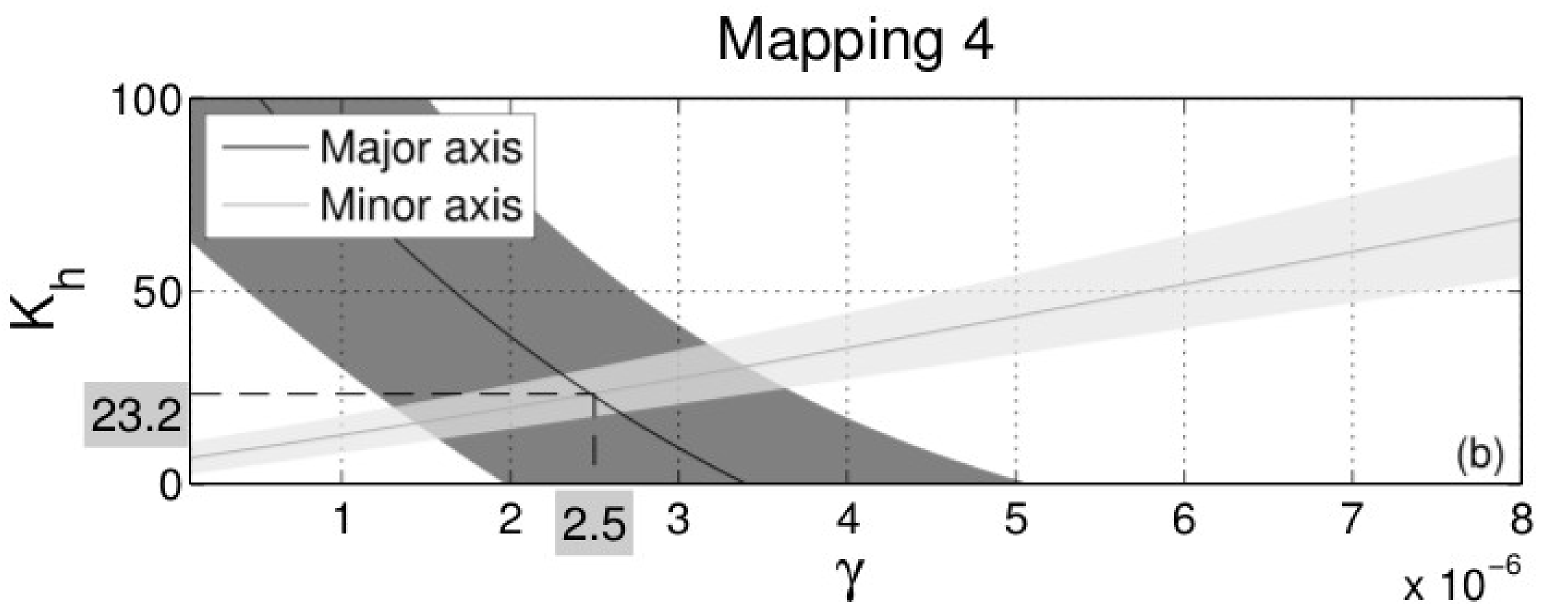
Mapping – Contour line (CL) and Gaussian ellipsoids (GE)

Calculation of the horizontal diffusion coefficient (method 2a):

Diffusion-Strain model (Sundermeyer and Ledwell, 2001)

$$\begin{cases} \sigma_l^2 = \left(\sigma_{l_0}^2 + \frac{K_h}{\gamma}\right) e^{2\gamma t} - \frac{K_h}{\gamma} \\ \sigma_w^2 = \left(\sigma_{w_0}^2 - \frac{K_h}{\gamma}\right) e^{-2\gamma t} + \frac{K_h}{\gamma} \end{cases}$$

σ_{l0} and σ_{w0} from Mapping 2



$$\gamma = 2.5\, 10^{-6}\, s^{-1}$$
$$K_h = 23.2\, m^2\, s^{-1}$$

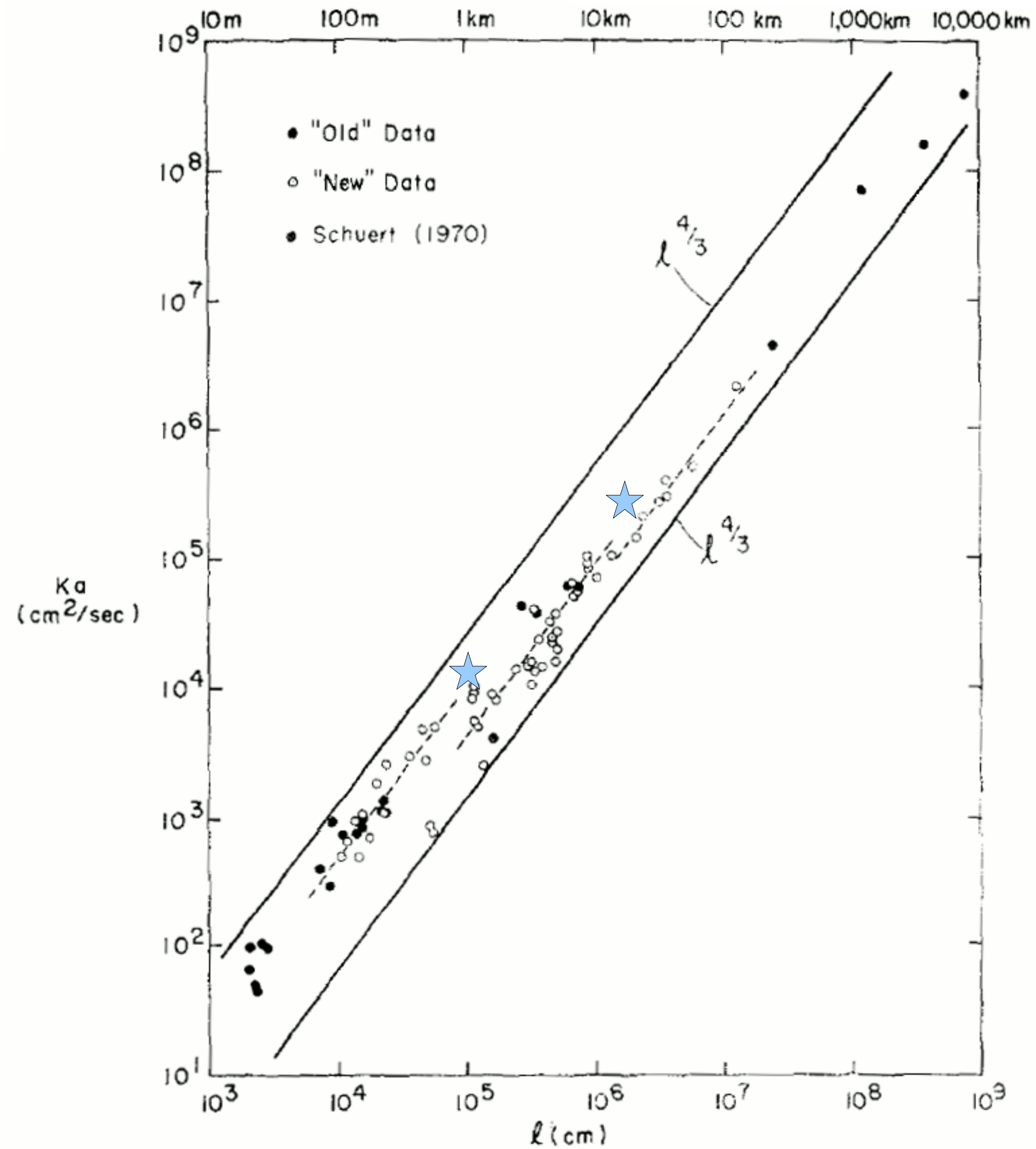
Latex10 cruise : Kh calculation

$$K_h = 0{,}4 - 5\, m^2 s^{-1}$$

dist. 1-4 km

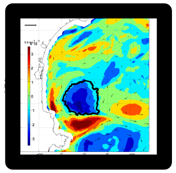
$$K_h = 20 - 30\, m^2 s^{-1}$$

dist. 10-100 km

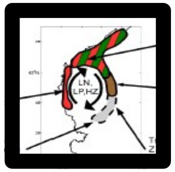


Okubo, Deep Sea Res.,1971

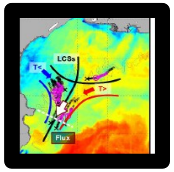
Latex - some of the results



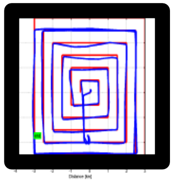
knowledge improvement of (sub)mesoscale circulation in the GoL: eddy generation, dimensions, behavior; presence of LCS and hyperbolic points.



interesting impact of eddies on biogeochemical tracer distribution suggested by the coupled model.



calculation of Kh.



development of Lagrangian navigation software & hardware; and multi-tool strategy for real-time tracking coastal eddies, LCS and/or submesoscale at sea.

estimation of cross-shelf exchanges based on altimetry derived LCS and in situ measurements (ADCP, TSG).

On-going projects

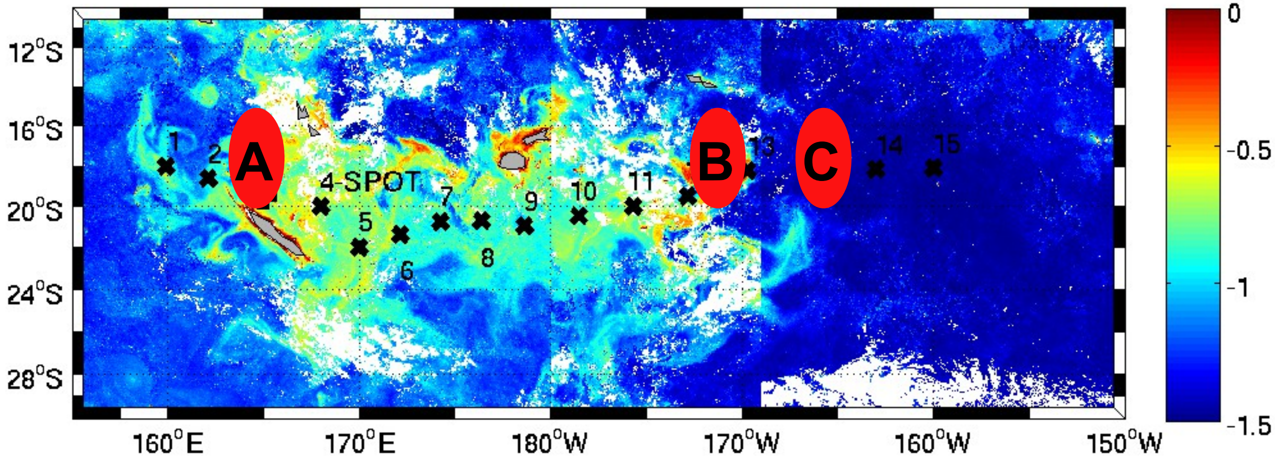
& Perspectives towards submesocales

OUTPACE (Oligotrophy to UlTra-oligotrophy PACific Experiment)

PIs : T. Moutin, S. Bonnet

Main objective : to estimation production and fate of the organic matter (especially production sustained by di-nitrogen fixation) in 3 contrasting oligotrophic environments.

Pacific Ocean

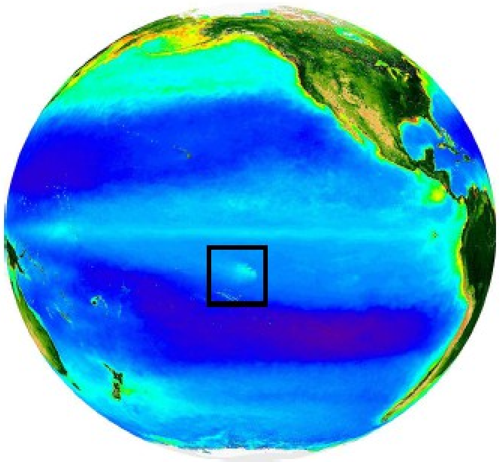


March – mid April 2015

Lagrangian adaptative strategy, floats and MVP

L. Bellomo, A. Doglioli, F. d'Ovidio, C. Maes, F. Nencioli, A. Petrenko, G. Rougier and the OUTPACE team

Island effect

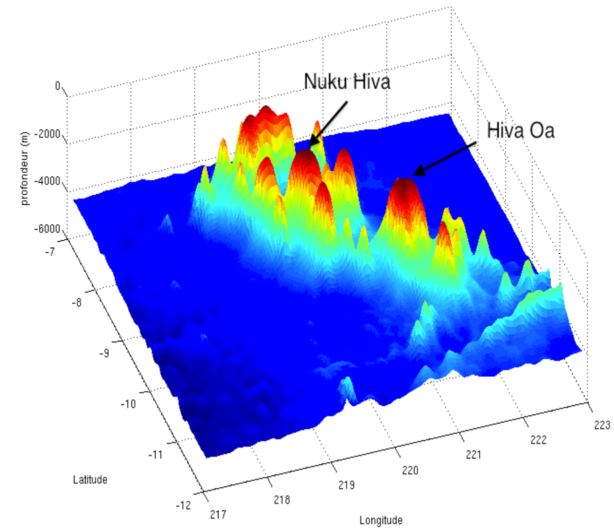


Objectives :

Dynamics of island wakes

Impacts on biogeochemistry

Wake eddies



Scales :

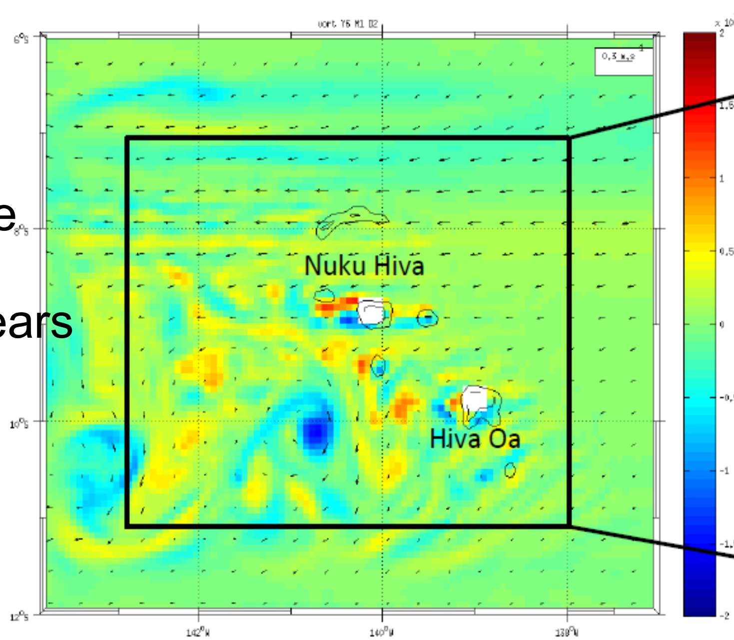
Regional

to (sub) mesoscale

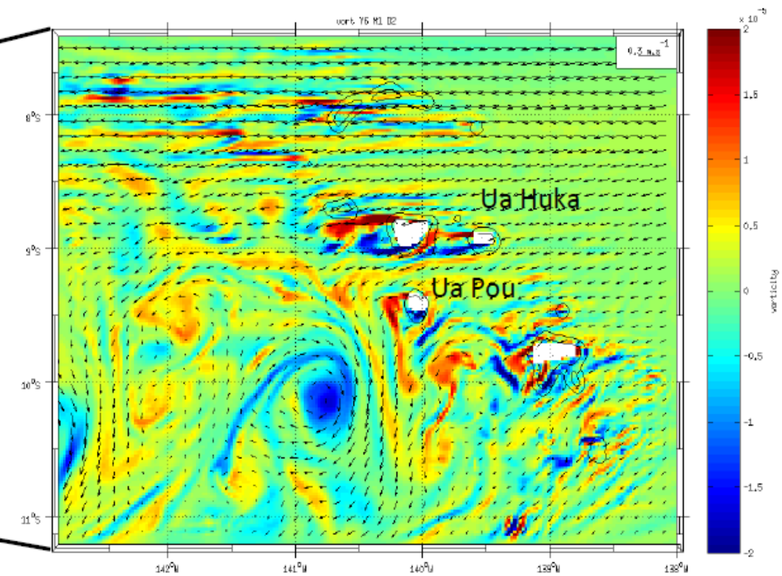
Climatological

with contrasting years

ROMS-AGRIF (users)



Champs de vorticité de la grille mère à 1/15°
(D02M01Y06)

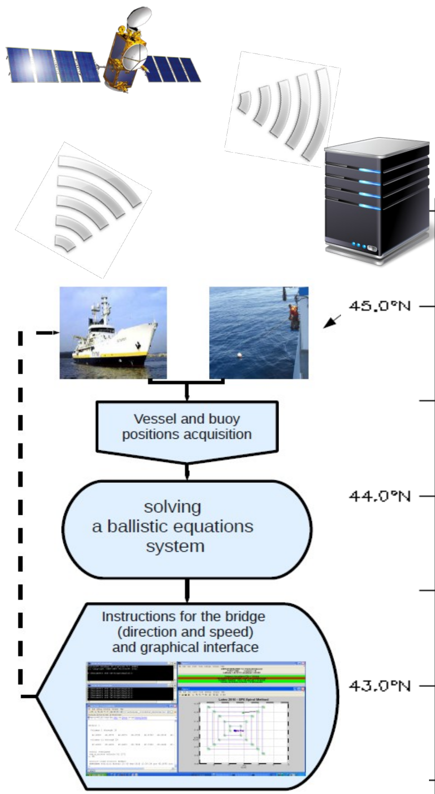


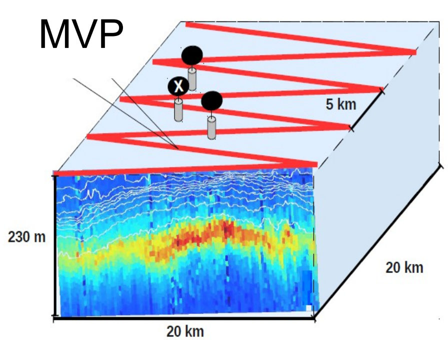
Champs de vorticité de la grille fille à 1/45°
(D02M01Y06)

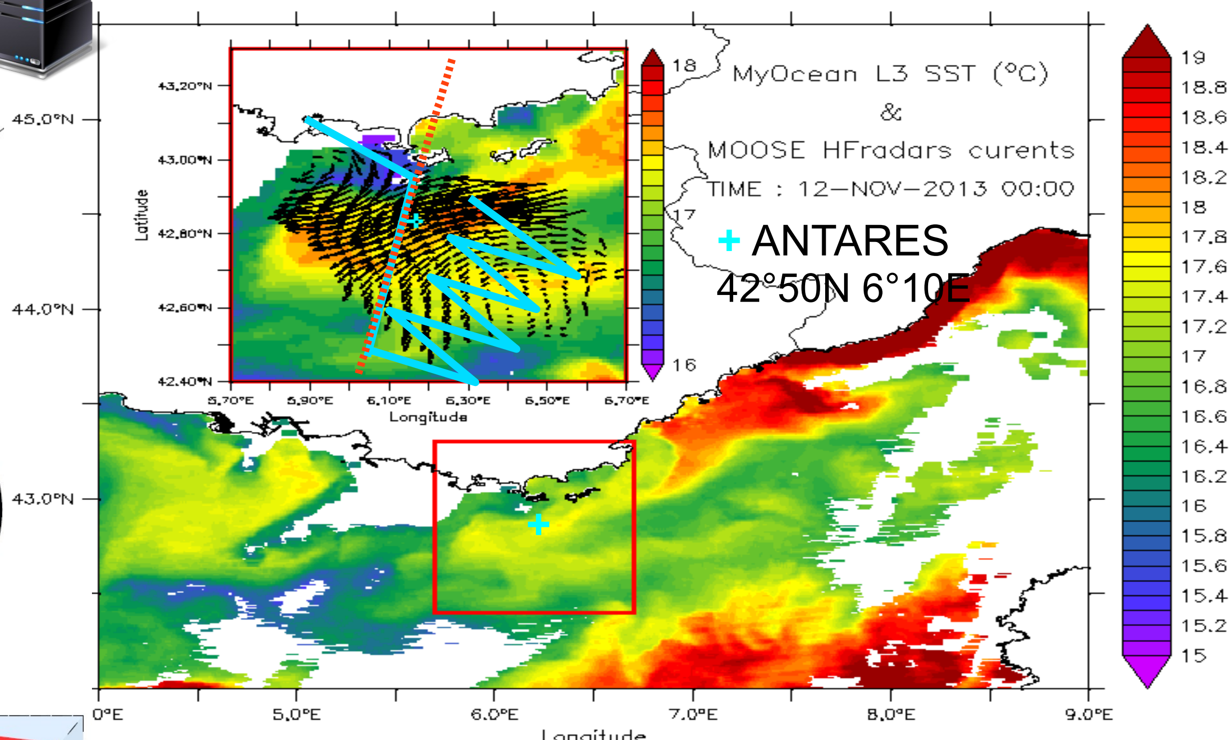
PhD thesis of Hirohiti Raapoto
(co-direction UPF – AMU ; J.C Gaertner, A. Petrenko, A. Doglioli, E. Martinez)

OSCAHR (PIs A.M. Doglioli & G.Grégori)

Observing **S**ubmesoscale **C**oupling **A**t **H**igh **R**esolution







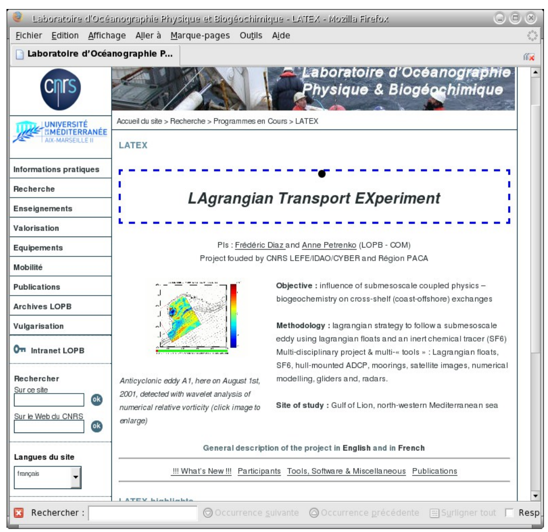
OSCAHR cruise 1-8 november 2015

Thank you for your attention!

Contributors :
A.M. Doglioli, F.Nencioli, M. Kersalé, Z.Hu, F.Diaz, R.Campbell, I.Dekeyser, N. Barrier, J.Bouffard, G.Rougier, J-L Fuda, B.Queguiner, L.Bellomo, T.Moutin, S.Bonnet, C.Yohia, L.Rousselet (MIO)
and d'Ovidio (LOCEAN), T. Labasque (Univ. Rennes1), S.Blain (LOB), C.Maes (LPO), E.Martinez & H. Raapoto (EIO).

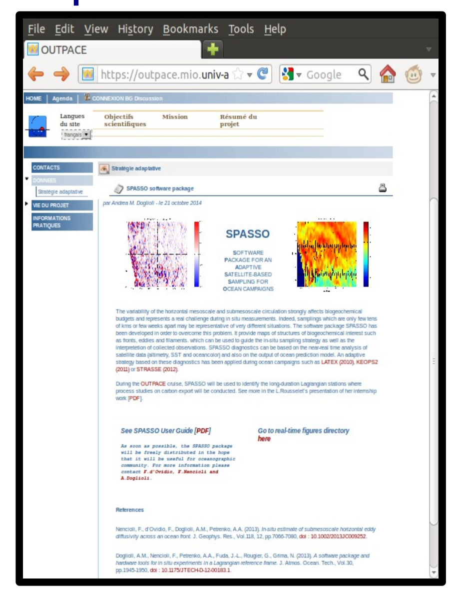
LATEX

http://www.com.univ-mrs.fr/LOPB/LATEX



OUTPACE

https://outpace.mio.univ-amu.fr

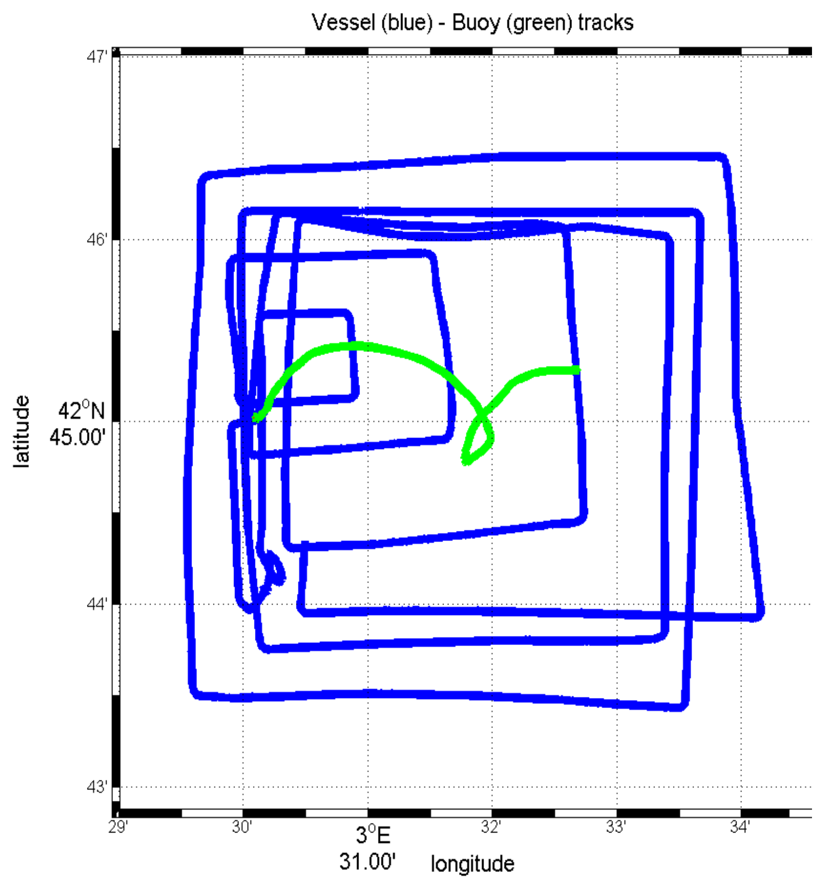


OSCAHR

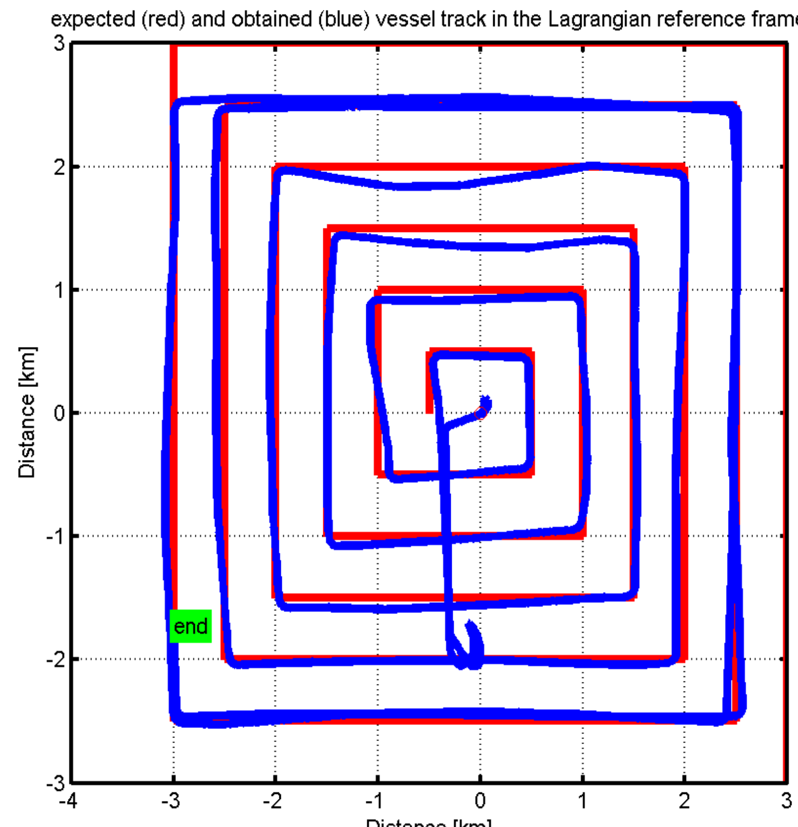
http://www.mio.univ-amu.fr/?-COUPLAGE-P2B2M-&lang=fr

Latex10 cruise : Lagrangian tracer release

Real time communication with an Iridium buoy to follow the water mass and disperse the tracer following a square-spiral pattern



Vessel and buoy tracks in geographical coordinates



Expected and obtained vessel track in the Lagrangian reference frame

[Doglioli et al, JAOT, 2013]

Multi-nutrient, multi-plankton functional types model, non-Redfieldian stœchiometry [Baklouti *et al.*, 2006a,b; Hermann, 2007; Eisenhauer et al., 2009, Fontana et al., 2009, Auger et al, Biogeosciences, 2011...]

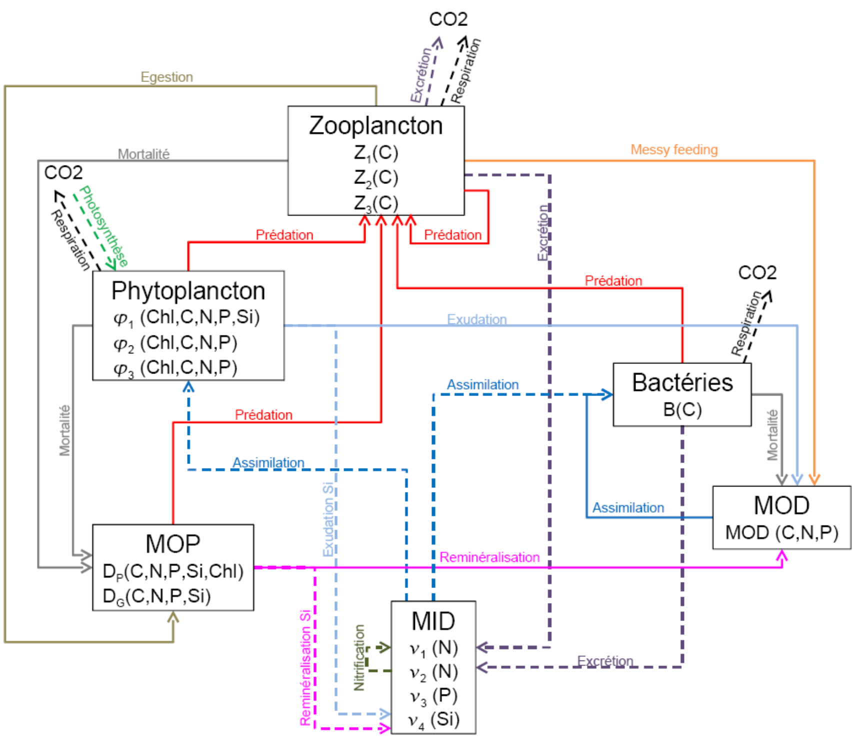
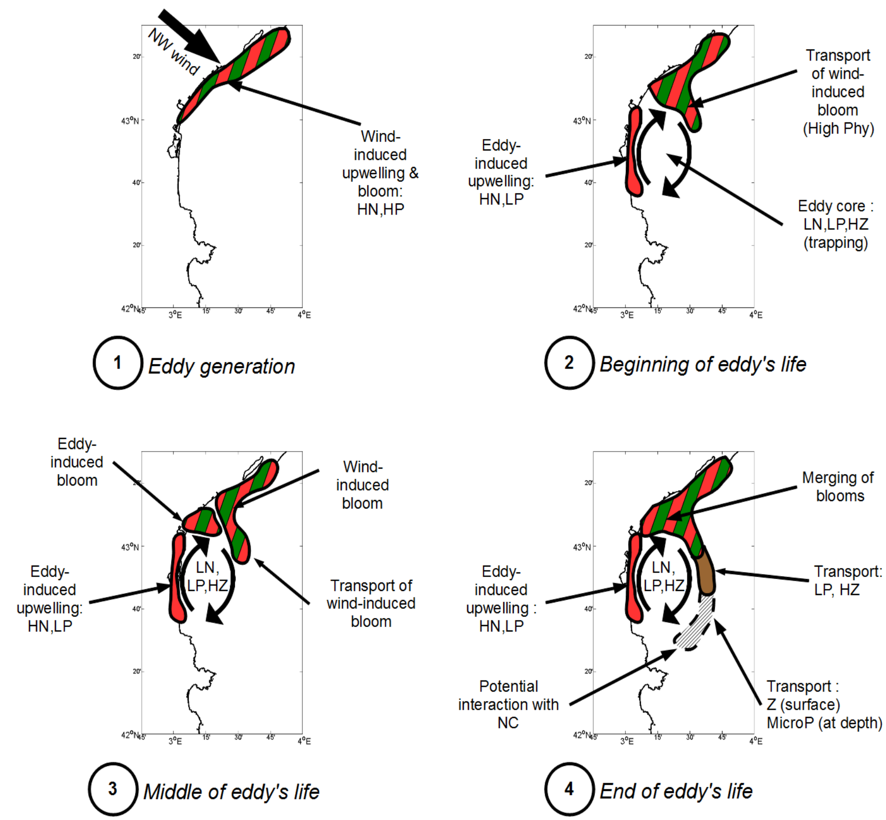


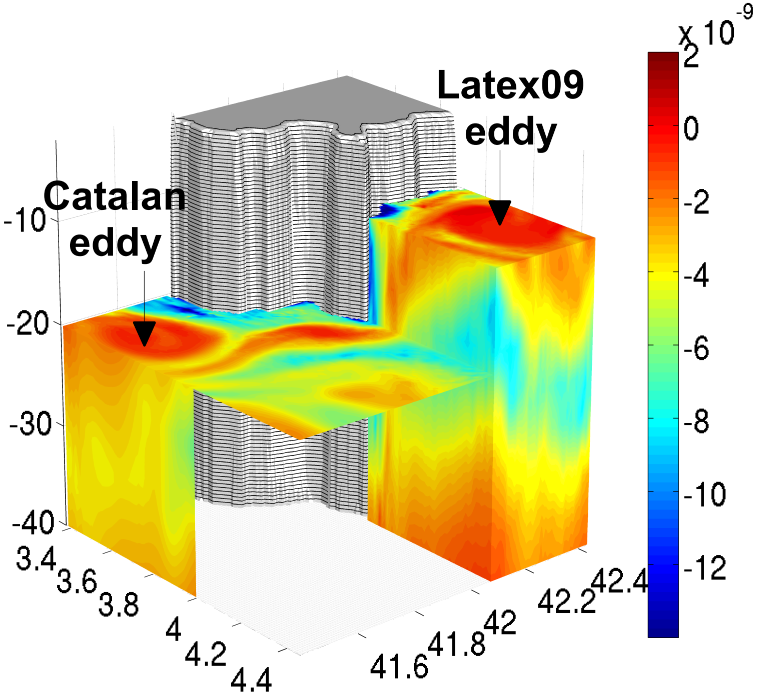
FIG. 5.1 – Interactions entre les différents groupes fonctionnels dans le modèle Eco3M-MED



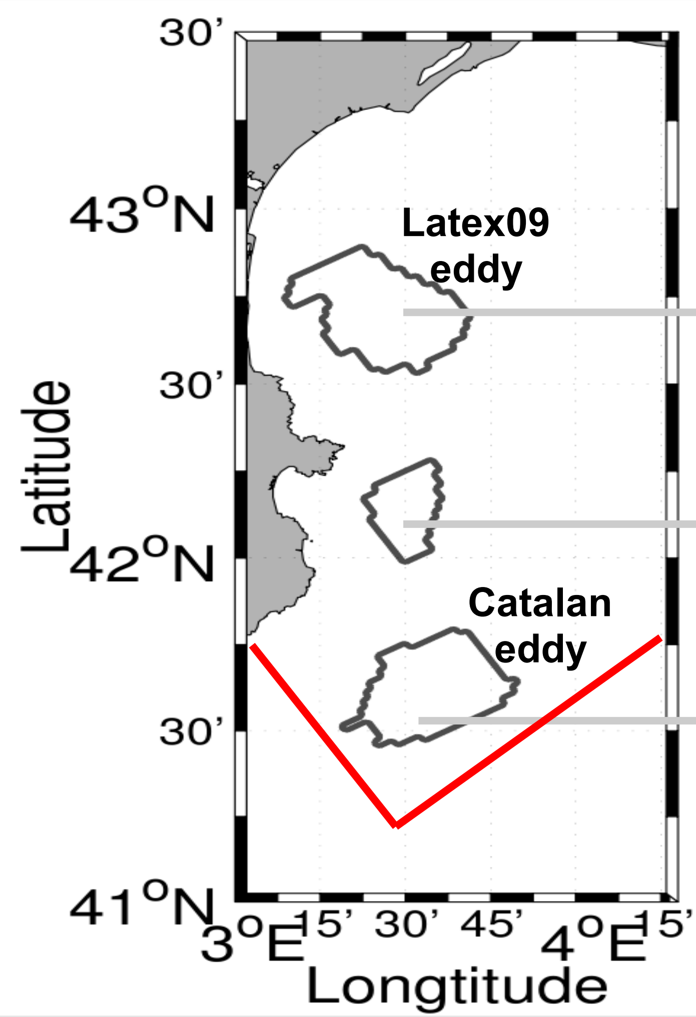
[Campbell et al., Progr.Oceanogr., 2013]

Latex09 eddy : mass loss estimation

Potential vorticity [kg.m^{-4}.s^{-1}] on September 3



Eddies as detected by wavelet analysis



Loss of mass 41%

33% of the Latex09 eddy's mass

Gain of mass?

Interactions between the two eddies lead to a transfer of mass and vorticity from the GoL to the Catalan shelf

[Kersalé et al, JGR, 2013]

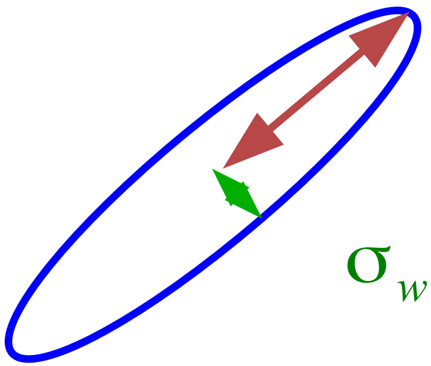
Latex10 cruise : Kh calculation

Calculation of the horizontal diffusion coefficient (method 2b)

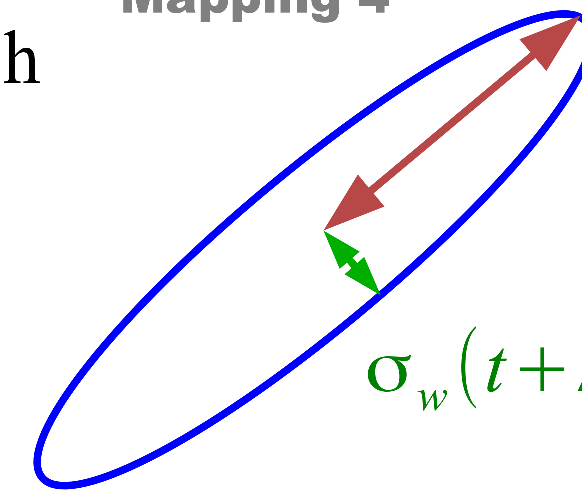
Steady State model (Abraham et al., 2000)

Mapping 2 → **Mapping 4**

$$\Delta t = 108\text{h}$$



$$\sigma_w(t) = 4\text{km}$$



$$\sigma_w(t+\Delta t) = 5.9\text{km}$$

$$\sigma_l(t) = 5.6\text{km} \xrightarrow{\gamma} \sigma_l(t+\Delta t) = 20.5\text{km}$$

$$\gamma = \frac{\ln \dfrac{\sigma_l(t+\Delta t)}{\sigma_l(t)}}{\Delta t}$$

$$K_h = \left(\frac{\sigma_w}{2}\right)^2 \gamma$$

$$\gamma = 3.4\,10^{-6}\,s^{-1}$$

$$K_h = 29\,m^2\,s^{-1}$$

Latex10 cruise : Kh calculation

Diffusion-Strain model	Steady State model
$\gamma = 2.5\,10^{-6}\,s^{-1}$	$\gamma = 3.4\,10^{-6}\,s^{-1}$
$K_h = 23.2\,m^2\,s^{-1}$	$K_h = 29\,m^2\,s^{-1}$

- An equilibrium is reached after a period of adjustment between 2 and 4.5 days

- The two models converge to similar estimates.

After such time scale, in this environment, Kh was not particularly sensitive to the further stretching of the patch.

Field campaign Latex10

Dispersion of a patch of SF6 in coastal waters

Quantification & validation of SF6 gas exchange

Estimation of Kh