Modellizzazione della dispersione in mare.

Introduzione ai modelli numerici ed esempi di applicazioni nelle acque costiere liguri

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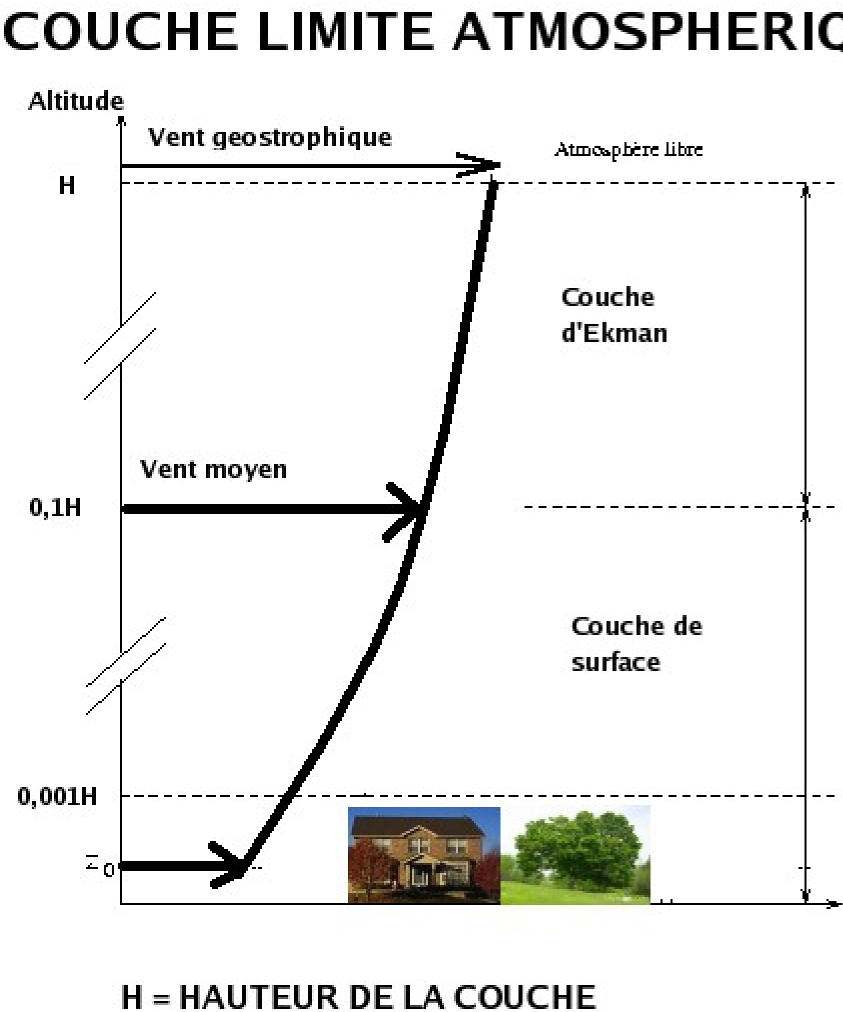
In atmosfera... (ripasso)



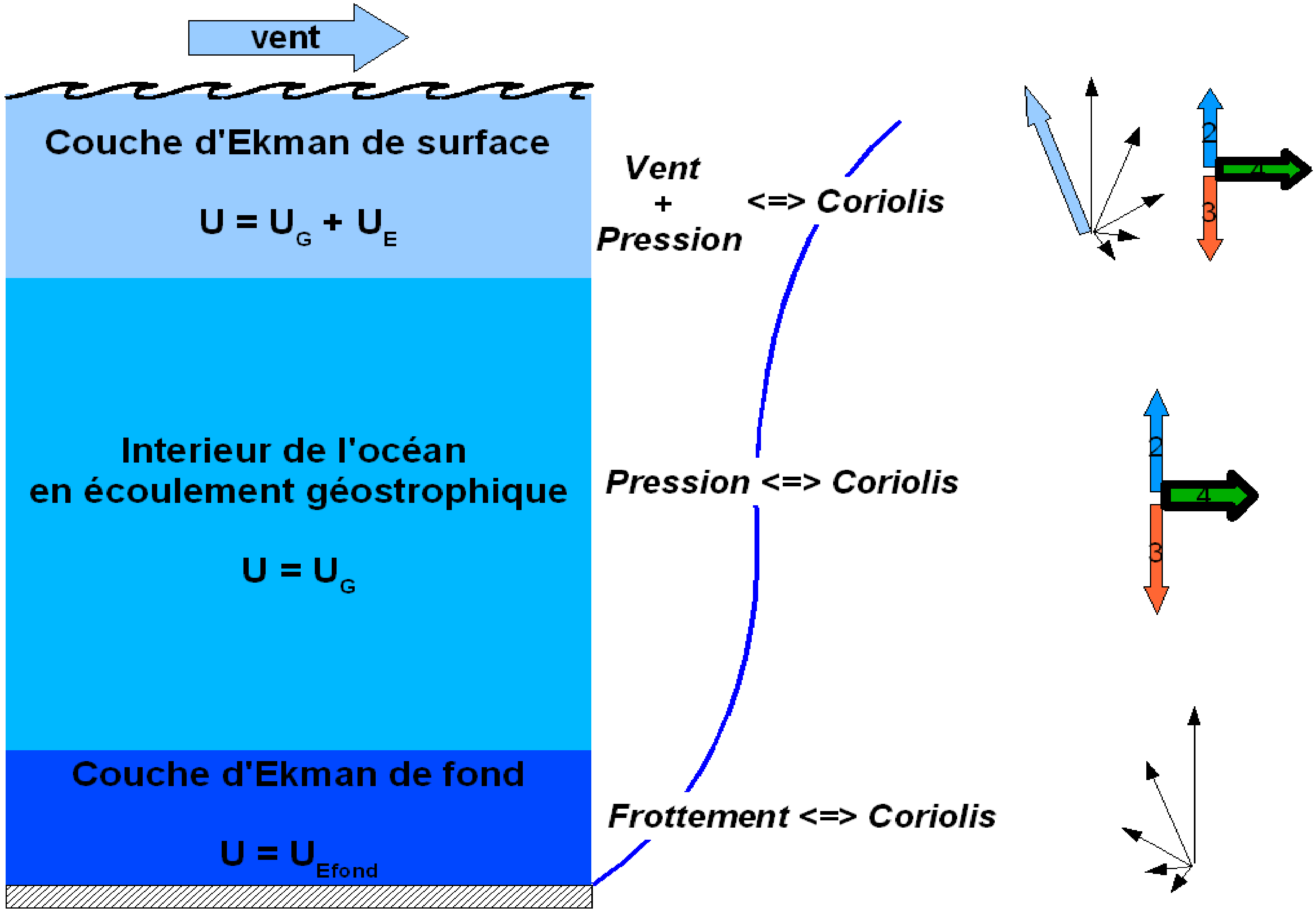
http://fr.wikipedia.org/wiki/Couche_limite

En météorologie, on appelle couche limite planétaire la zone de l'atmosphère entre la surface (terre ou mer), où la friction ralentit le déplacement de l'air, et l'atmosphère libre où cette dernière devient négligeable. Elle varie entre 0,5 et 3 km d'épaisseur selon la stabilité de l'air et la rugosité de la surface. Elle est en moyenne de 1 500 mètres. L'étude théorique de cette tranche d'atmosphère divise en fait la couche limite planétaire comme la superposition de deux couches dont les épaisseurs sont très inégales:

La **couche d'Ekman** dans laquelle le vent est causé par un équilibre entre le gradient de pression, la force de Coriolis, due à la rotation quotidienne de la Terre, et une portion de la friction diminuant graduellement jusqu'à l'atmosphère libre. La vitesse et la direction au sommet de cette couche est approximativement celle du vent géostrophique alors qu'elle diminue graduellement et tourne vers la plus basse pression à mesure qu'on descend vers le sol

La **couche de surface** ou **couche limite de turbulence atmosphérique** immédiatement au contact du sol et dont l'épaisseur ne dépasse pas le dixième de celle de l'ensemble de la couche limite. La vitesse de l'air y est causée par la convection due aux différences de températures et par les effets dynamiques du reliefs. Le flux y est turbulent. On parle également d'une sous-couche rugueuse tout près de la surface, qui varie de quelques centimètres à quelques dizaines de mètres selon les aspérités du relief. La vitesse y tend vers zéro.

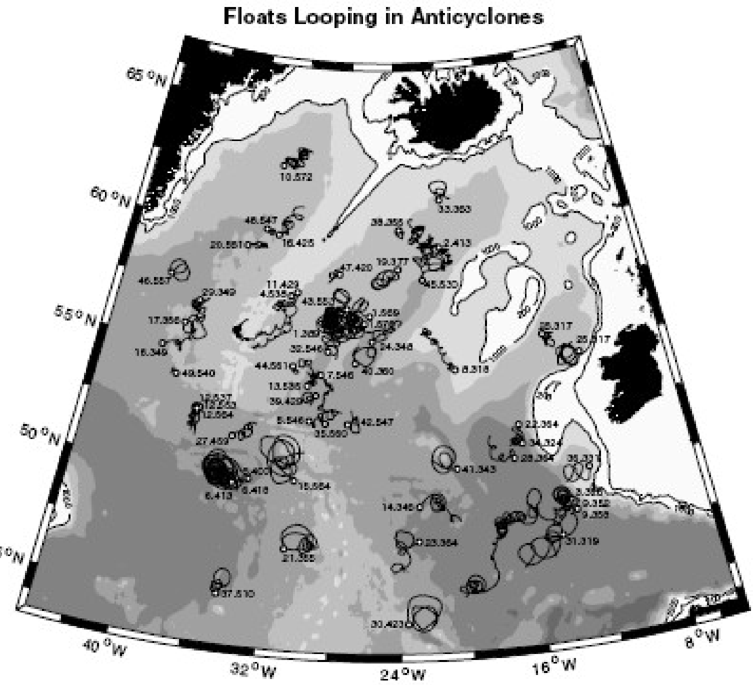
In mare

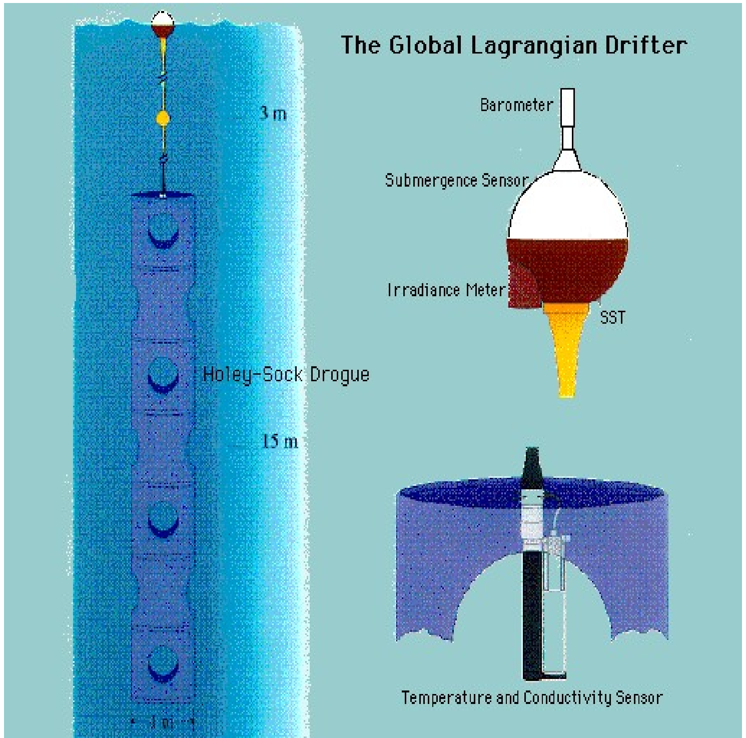


vent
Couche d'Ekman de surface
U = U_G + U_E
Interieur de l'océan
en écoulement géostrophique
U = U_G
Couche d'Ekman de fond
U = U_Efond
Vent
+
Pression
<=> Coriolis
Pression <=> Coriolis
Frottement <=> Coriolis
2
3
4
2
3
4

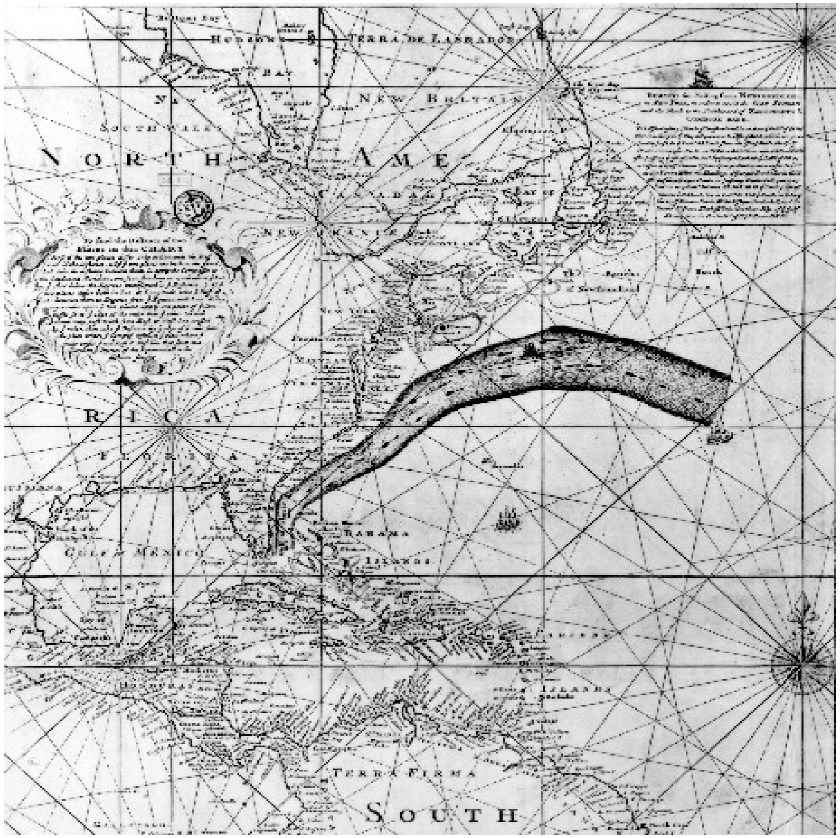
A Semtner (1995), **Modeling Ocean Circulation**, Science, 269,5229,1379-1385
http://www.mbari.org/staff/braccio/Science/semtner.html

Even though systematic observations began in the 1880s with pioneering observations by Nansen and others, the seagoing and theoretical efforts were mainly oriented toward describing large-scale circulation, which was often regarded as steady for lack of more detailed information. It was not until the 1960s, when long-distance tracking of drifting buoys at mid-depth showed currents to be highly variable on quite small spatial scales (5), that oceanographers became aware of the immensity of their task.





http://www.meteo.shom.fr/buoyinfo/svpfig.html

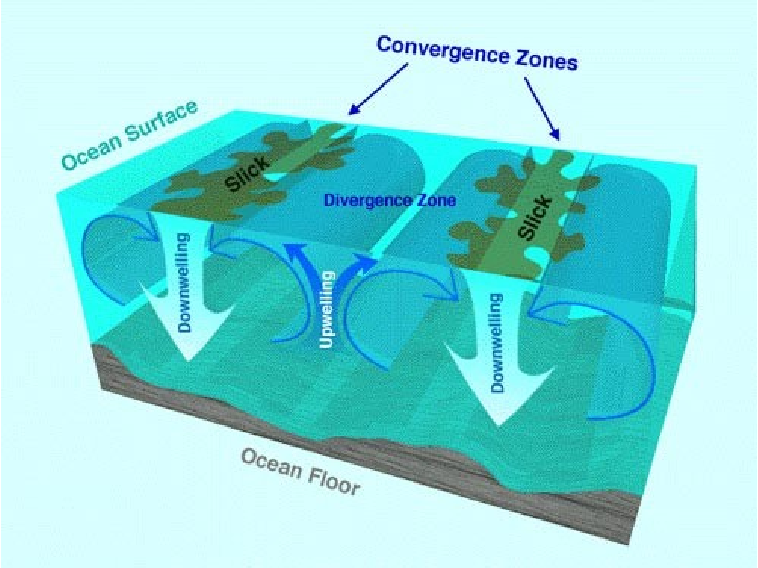


The Franklin-Folger map of the Gulf Stream, printed in 1769-1770.
This early map of the Gulf Stream location was produced by B. Franklin for the mail service from England, based on information from whaling captain Timothy Folger. This map was rediscovered by P. Richardson (1980), and is remarkably accurate. This image is from R. Peterson et al. (1996), article in Progress in Oceanography.

C:\ANDREA\ENSEIGNEMENT\GULFSTREAM\movie_vectors15fps.avi

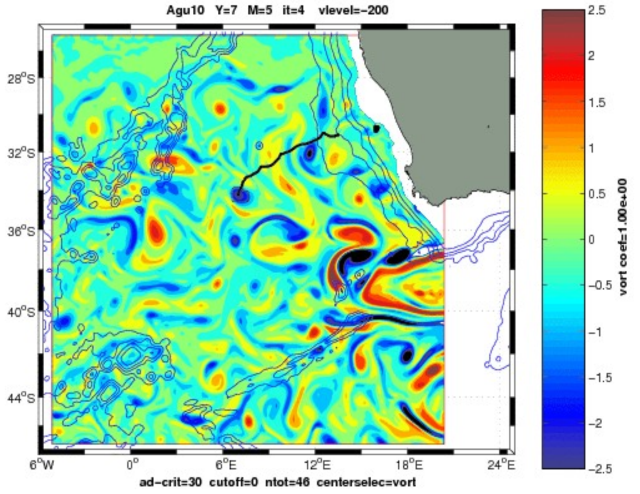
C:\ANDREA\ENSEIGNEMENT\GULFSTREAM\movie_ring04_10fps.avi

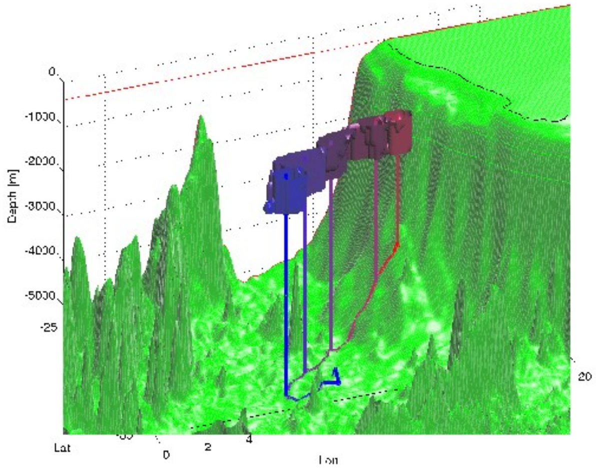
Strato limite oceanico di superfice: *Cellule di Langmuir*



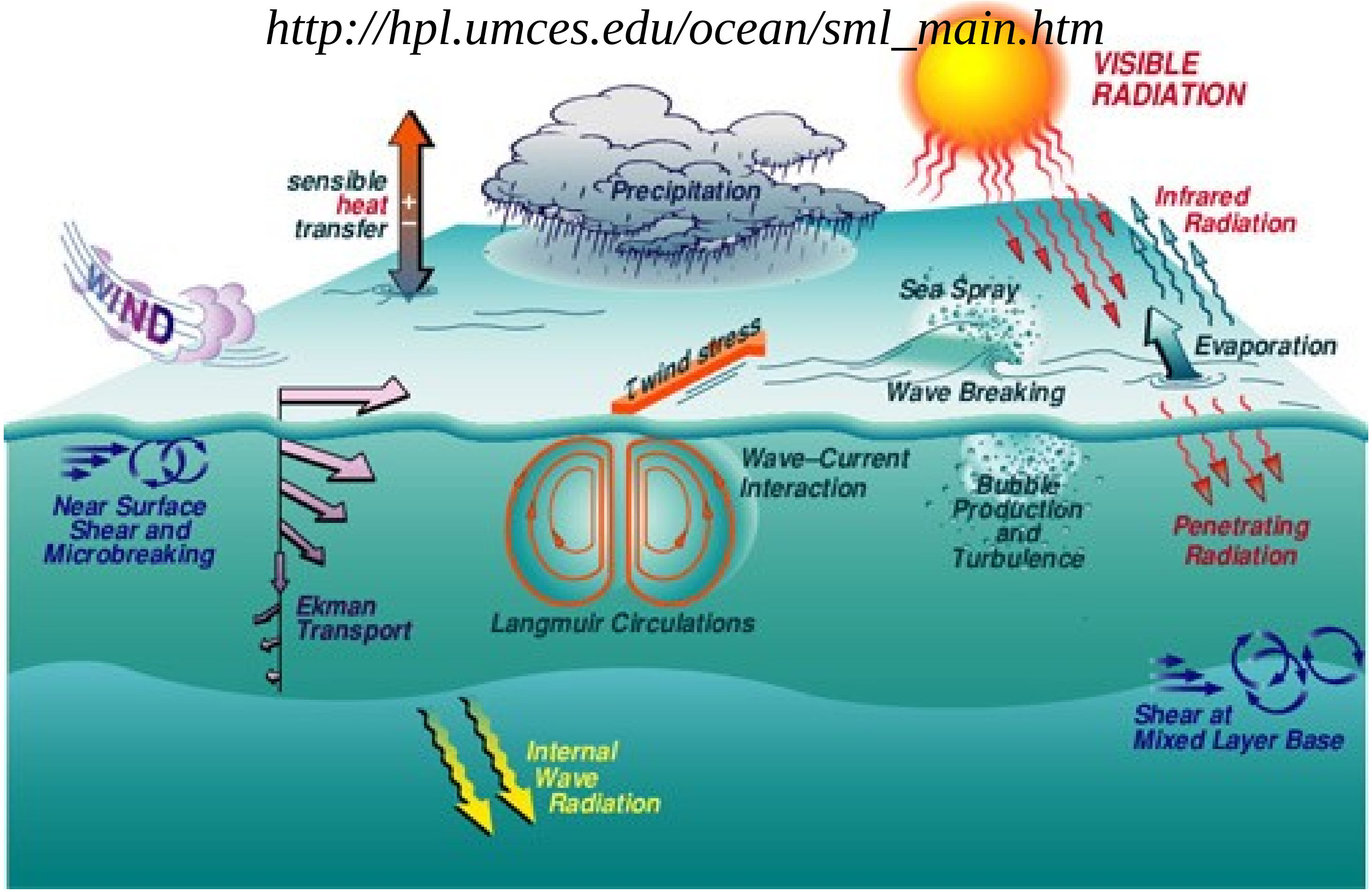
http://sealevel2.jpl.nasa.gov/jr_oceanographer/oceanographer-dgiacomo.html

Strutture di mesoscala: *Agulhas Rings*



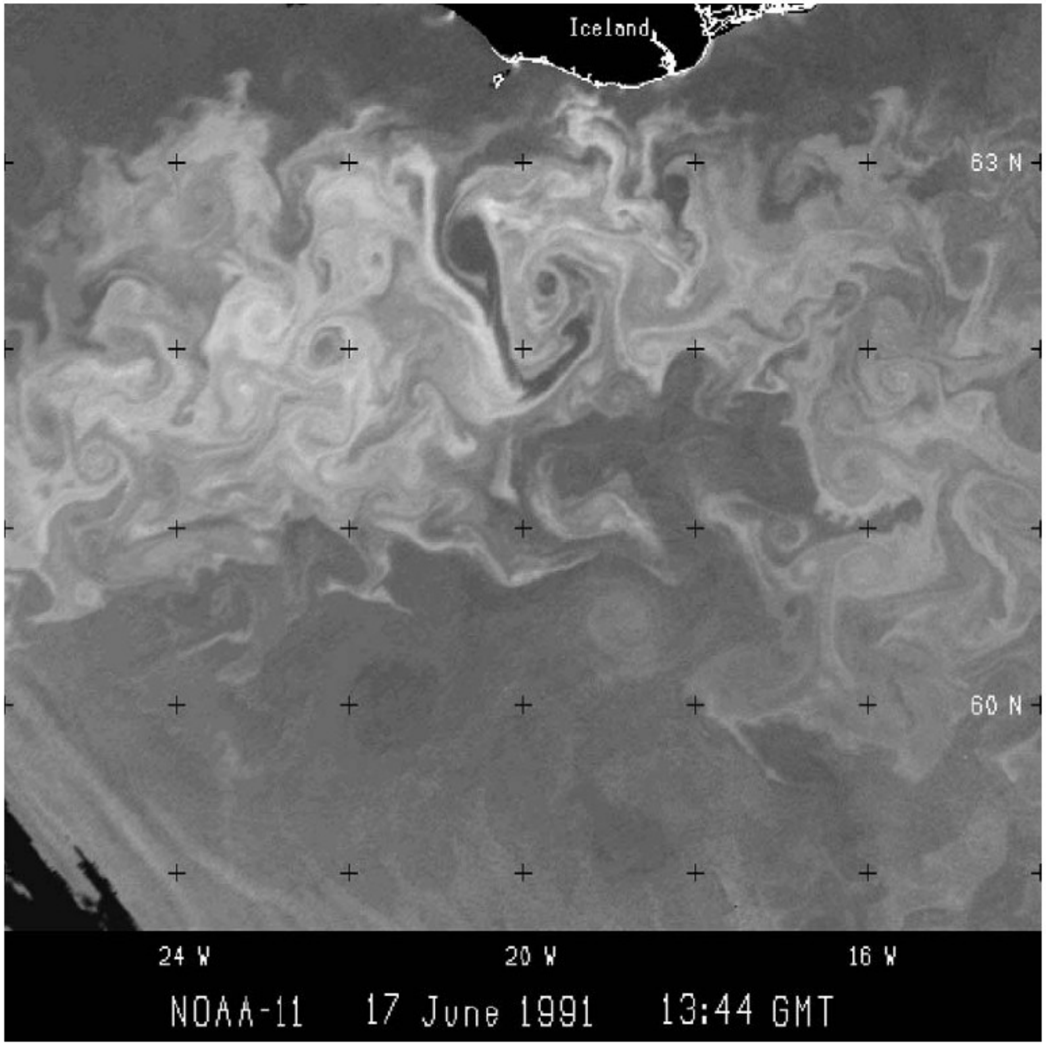


http://hpl.umces.edu/ocean/sml_main.htm



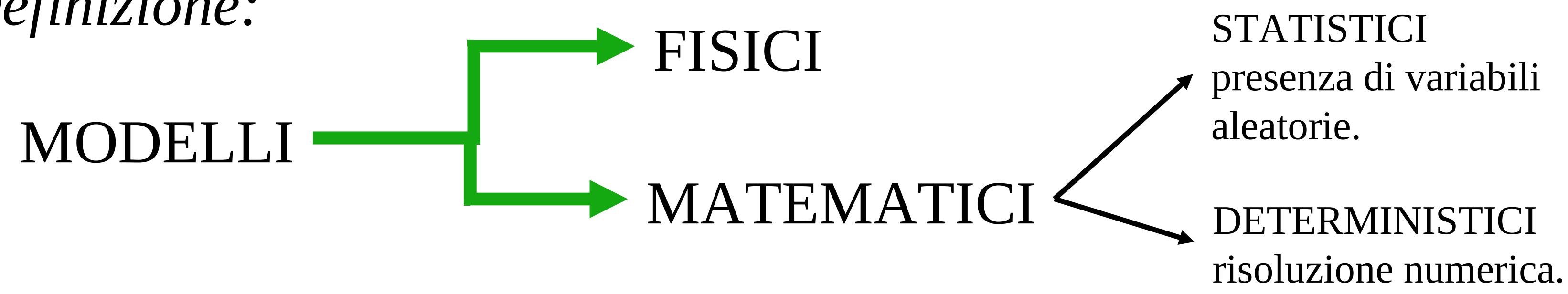
The upper region of the ocean typically exhibits of a surface mixed layer with a thickness of a few to several hundreds meters. This mixed layer is a key component in studies of climate, biological productivity and marine pollution. It is the link between the atmosphere and deep ocean and directly affects the air-sea exchange of heat, momentum and gases. Moreover, turbulent flows in the mixed layer affect biological productivity by controlling both the supply of nutrients to the upper sunlit layer and the light exposure of phytoplankton.

Several processes contribute to turbulent mixing in the mixed layer. Thermal convection can be generated by the ocean losing heat through longwave back radiation or evaporative cooling. The shear generated in wind-driven currents can produce Kelvin-Helmholtz billows. The interaction between surface waves and wind-driven shear current also produces Langmuir circulation, consisting of counter-rotating vortices with their axes aligned roughly in the wind direction.

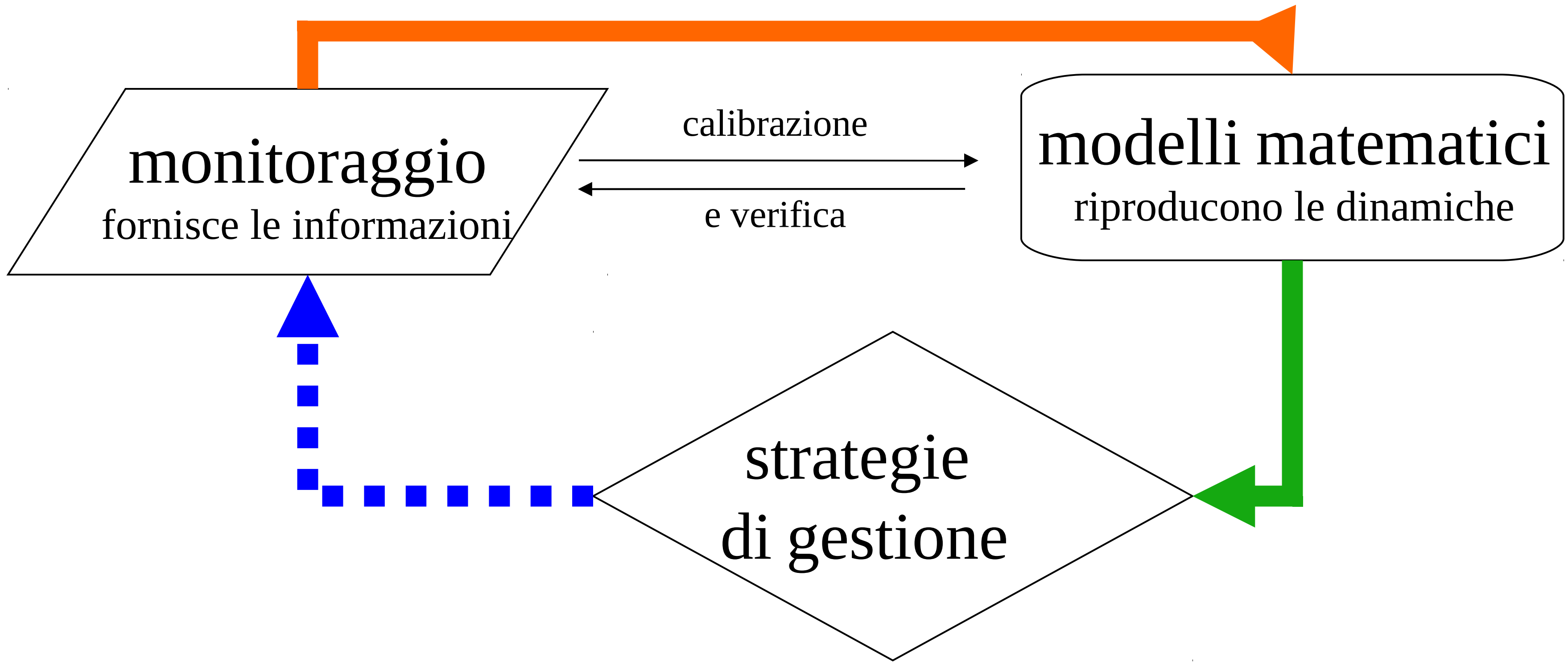


Advanced Very High Resolution Radiometer (AVHRR) image of a phytoplankton bloom south of Iceland in June 1991. For
:ach of the crosses is approximately 110 km apart. Crudely speaking the paler a region the higher the concentration of
ankton cells within it. The light is being reflected by microscopic plates grown as a covering by the phytoplankton (*Emiliania*
). Aside from the large scale population explosion or "bloom" between 61N and 63N there is a great deal of patchiness at
scales. In particular, note the strong signature of the local currents, especially eddy features and thin filaments. Movie 1, an
on of the AVHRR observations of this area from 15–23 June, can be found at http://dx.doi.org/10.1016/S0079-611(03)00085-
ı reveals the dynamic nature of the patchiness. The raw data was received by Dundee Satellite Receiving Station. Steve Groom
AS, Plymouth Marine Laboratory processed the images.

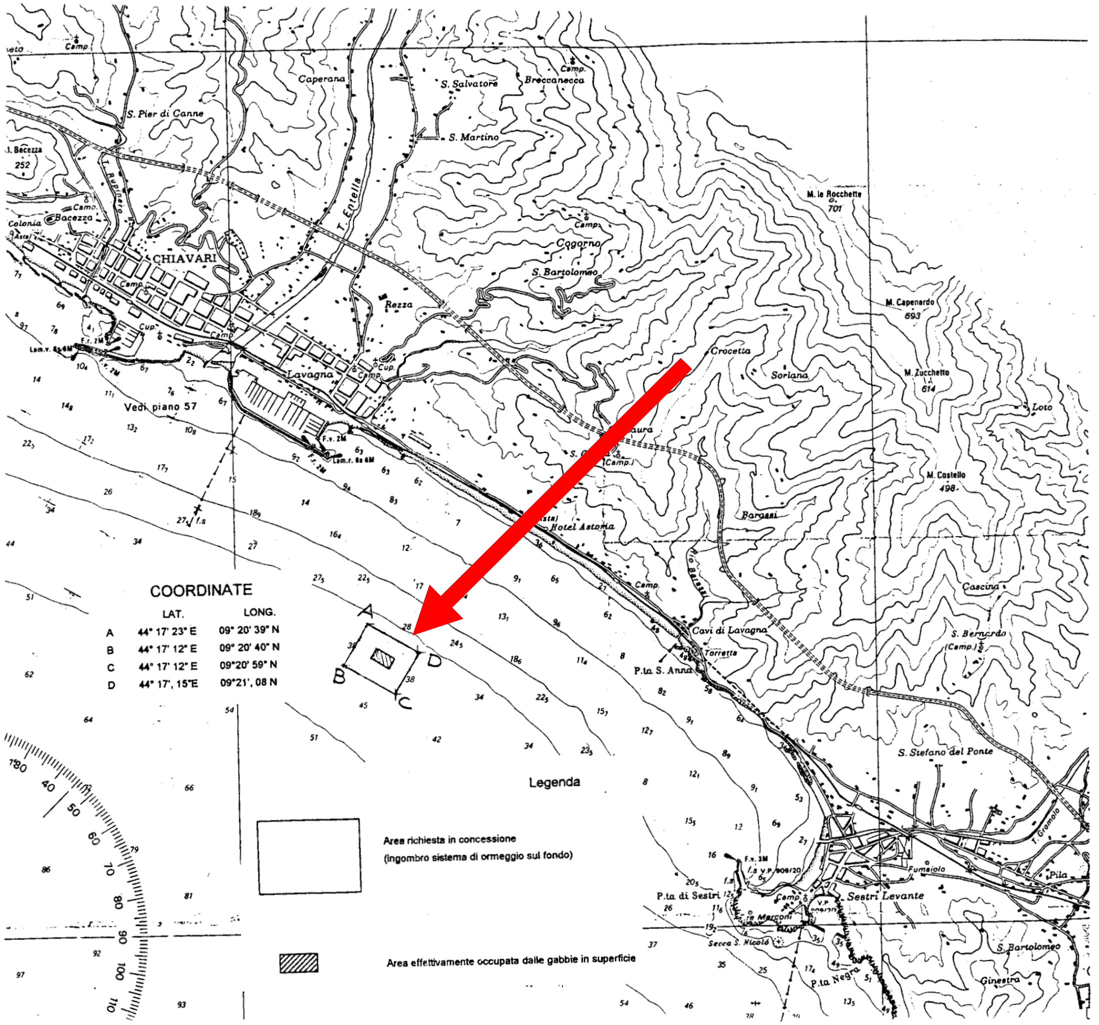
Definizione:



Utilizzo:



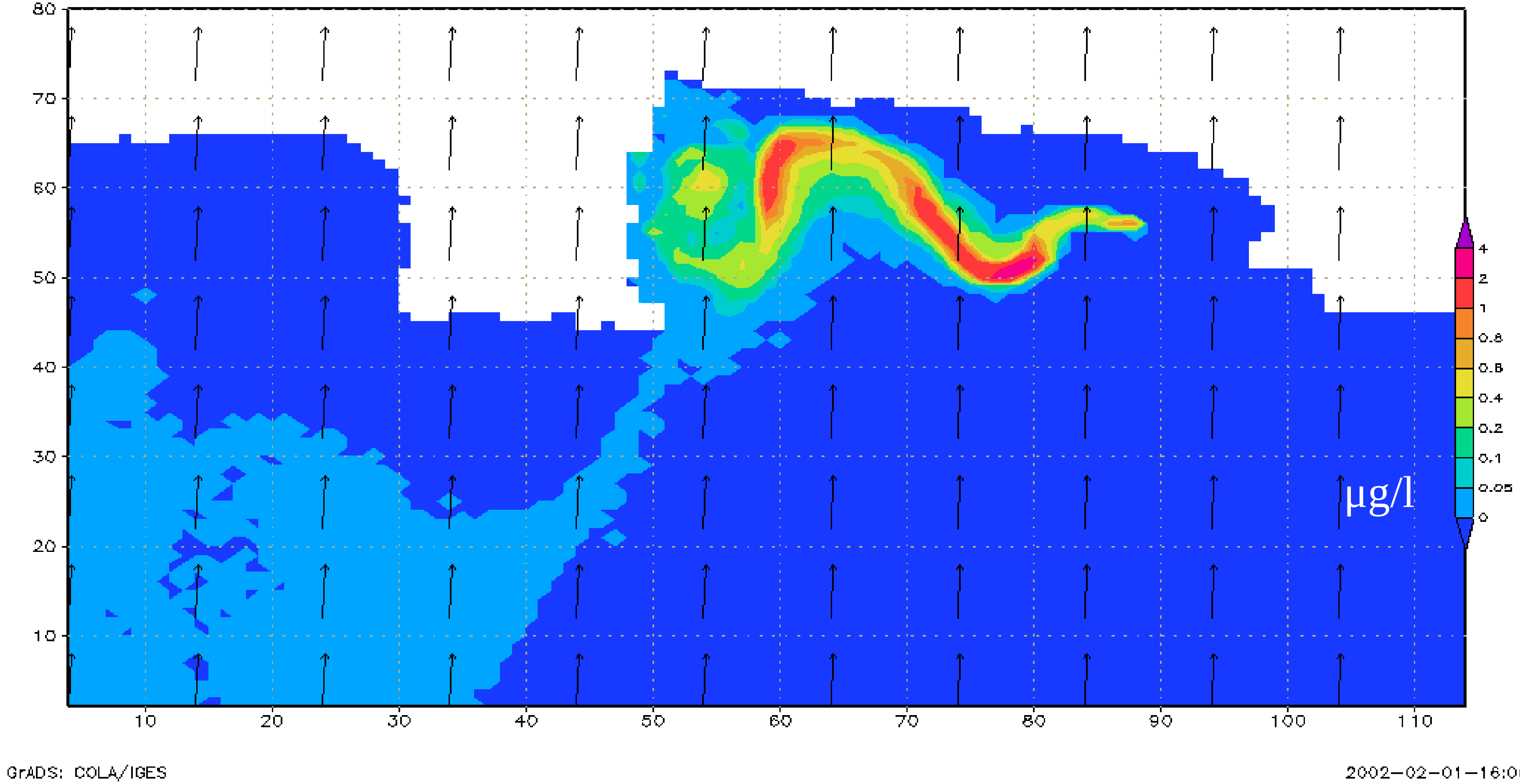
L’impianto di maricoltura



Caratteristiche:

- Impianto off-shore (35-40 m)
- Target produttivo pari a 200 tonnellate di pesce annue
- Orate e spigole all’inizio
- Successiva diversificazione delle specie ittiche
- Prodotto finito: pesci di taglia pari a 300-400 g o superiori

Simulazioni avvettivo dispersive per i nutrienti



Densità di massa

Velocità

Pressione

Sforzi molecolari

Coriolis

Sforzi turbolenti

$$
\begin{cases}
\dfrac{d\rho}{dt} + \rho\nabla\cdot\mathbf{v} = 0 & \text{(eq.continuità)} \\[2ex]
\dfrac{d\mathbf{v}}{dt} = -\dfrac{\nabla p}{\rho} + \dfrac{1}{\rho}\nabla\cdot\mathcal{T} + \dfrac{1}{\rho}\nabla\cdot\mathcal{R} - \nabla\Phi - \nabla\Phi_m + 2\mathbf{\Omega}\wedge\mathbf{v} & \text{(eq.momento)} \\[2ex]
\dfrac{dT}{dt} = \kappa_T\nabla^2 T + \dfrac{Q}{\rho c_\alpha} & \text{(eq.calore)} \\[2ex]
\dfrac{ds}{dt} = \kappa_s\nabla^2 s + \dfrac{\Sigma}{\rho} & \text{(eq.salinità)} \\[2ex]
\alpha = \alpha(T,\rho,s) & \text{(eq. di stato)}
\end{cases}
$$

Temperatura

Salinità

Volume specifico

Geopotenziale

Potenziale di marea

Processi di trasporto

AVVEZIONE → Movimento dell'inquinante dovuto a processi di flusso <u>risolti</u>

DISPERSIONE

↓

Distribuzione dell'inquinante nel fluido dovuta a processi di flusso <u>non risolti</u>

DIFFUSIONE → Moti molecolari e turbolenza

Fick (1855)

Coeff. di diffusione

$$\mathbf{M} \propto \nabla \mathbf{c}$$

Coeff. di dispersione

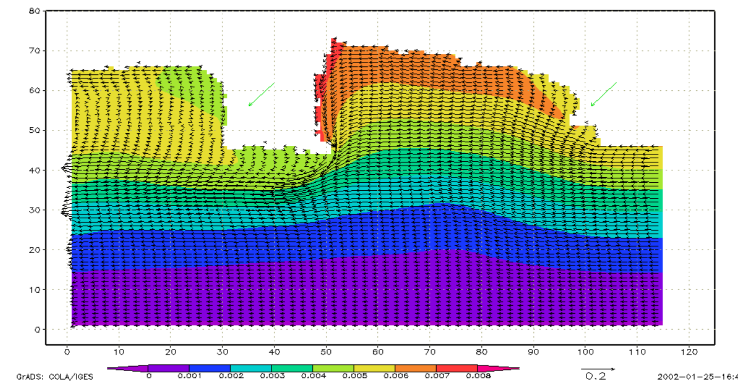
Taylor (1921)

SHEAR → Gradienti spaziali di velocità

Applicazione dei modelli

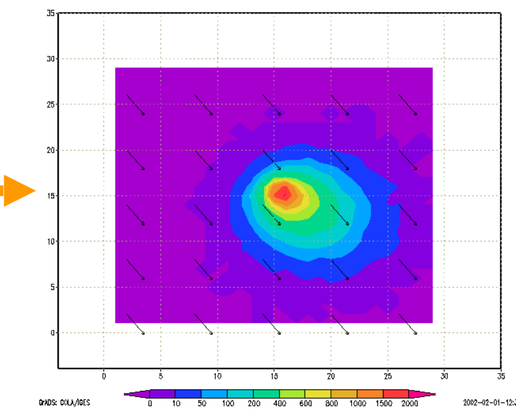
POM2D

Calcola le velocità mediate in verticale

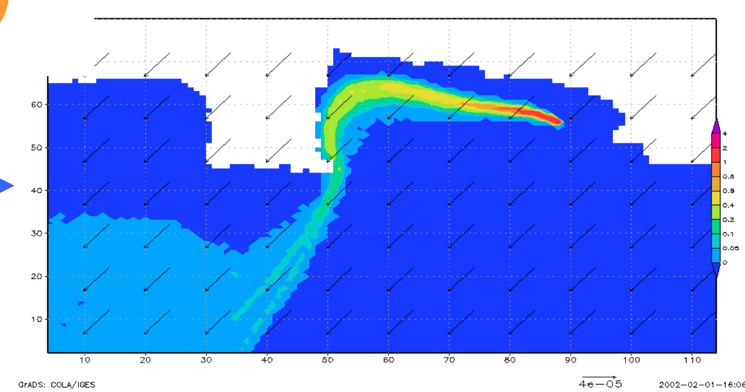


LAMP3D

Calcola gli spostamenti delle particelle



POM2D + *LAMP3D*



Processi di trasporto

AVVEZIONE → Movimento dell'inquinante dovuto a processi di flusso <u>risolti</u>

DISPERSIO

Distribuzione del l'inquinante nel fluido dovuta a processi di flusso <u>non risolti</u>

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Fick (1855)

Coeff. di diffusione

M∝∇c

Coeff. di dispersione

r (1921)

→ Gradienti spaziali di velocità

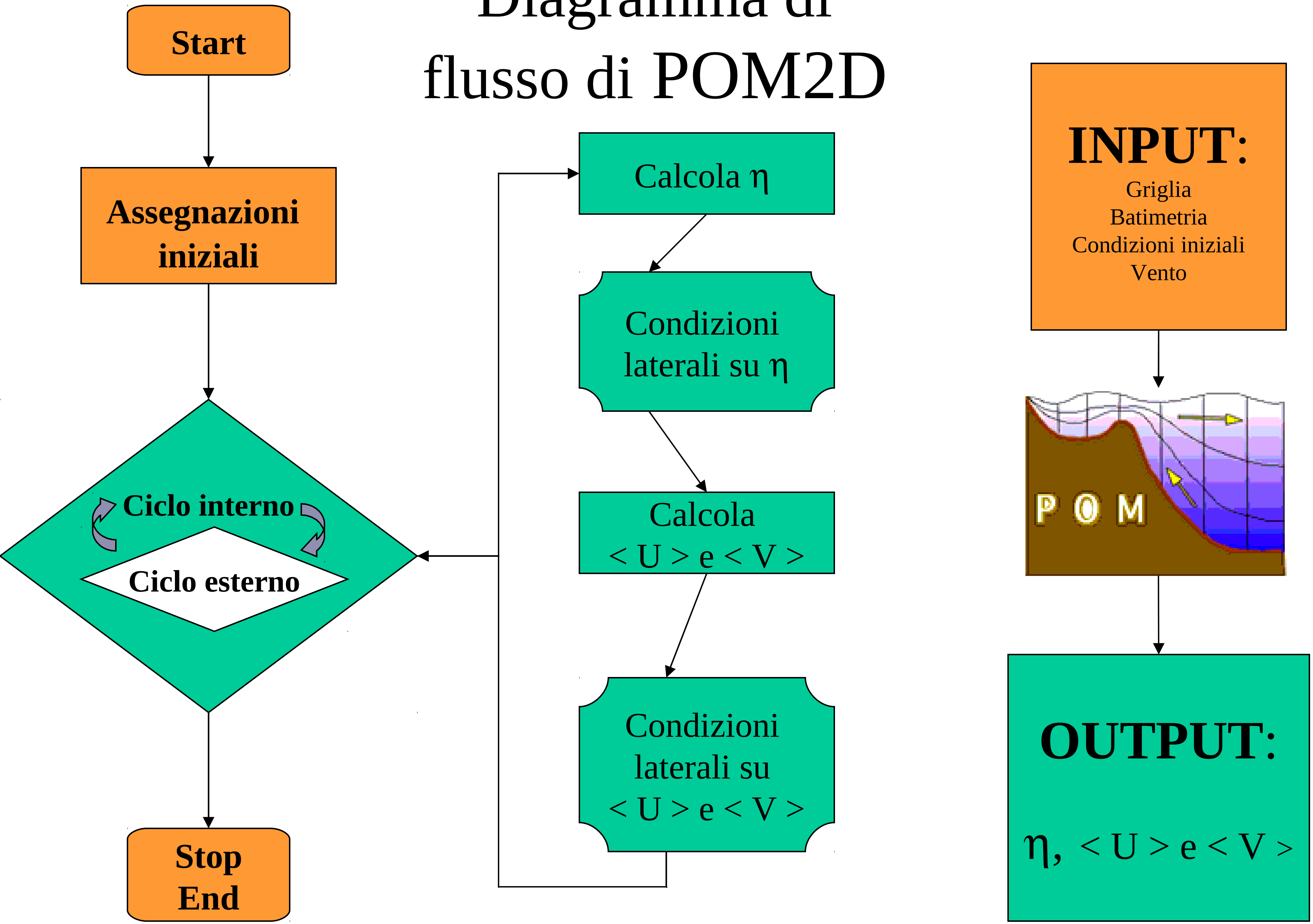
POM (Princeton Ocean Model)

www.aos.princeton.edu\WWWPUBLIC/htdocs.pom.

- Finite difference
- Free surface.
- Primitive equations (hydrostatic, Boussinesq).
- Horizonal grid: Curvilinear orthogonal coordinate.
- Mode split technique:
  external mode (2D depth averaged, barotropic) ⇒ *EL(i,j), UA(i,j), VA(i,j)*
  internal mode (3D, baroclinic) ⇒ *U(i,j,k), V(i,j,k), T(i,j,k), S(i,j,k)*

BAROTROPIC APPROXIMATION:
- Simplier to calibrate;
- More numerically stable;
- Faster as computing time.

Diagramma di flusso di POM2D

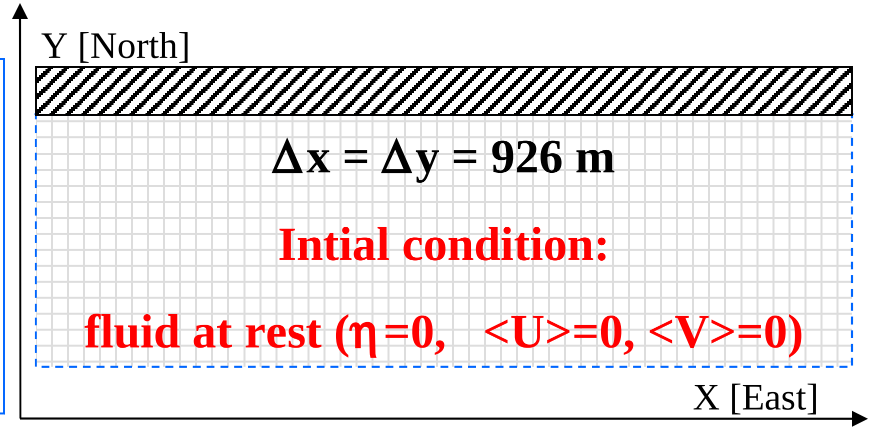


WIND TESTS with POM-2D mode

BCOND settings

Weastern Boundary:

- η: radiation (gravity wave velocity)
- <U>: zero gradient
- <V>: zero gradient



Eastern Boundary:

- η: radiation (gravity wave velocity)
- <U>: zero gradient
- <V>: zero gradient

Southern Boundary

- η: clamped η= 0
- <U>: zero gradient <V>: zero gradient

Vertically-integrated and linearized momentum equation for a homogeneous fluid with surface and bottom stresses

[Chapman 85]

$$\frac{\partial P}{\partial t} - fQ = -gH\frac{\partial \eta}{\partial x} + \frac{\tau_x^S}{\rho} - \frac{\tau_x^B}{\rho}$$

$$\frac{\partial Q}{\partial t} + fP = -gH\frac{\partial \eta}{\partial y} + \frac{\tau_y^S}{\rho} - \frac{\tau_y^B}{\rho}$$

where

$$P = \int_{-H}^{0} u\,dz$$

$$Q = \int_{-H}^{0} v\,dz$$

TEST 2

Linear Bathymetry: H=c*y, **Cross-shelf wind:** $-\tau^s_y/\rho = -10^{-4}\ m^2\,s^{-2}$

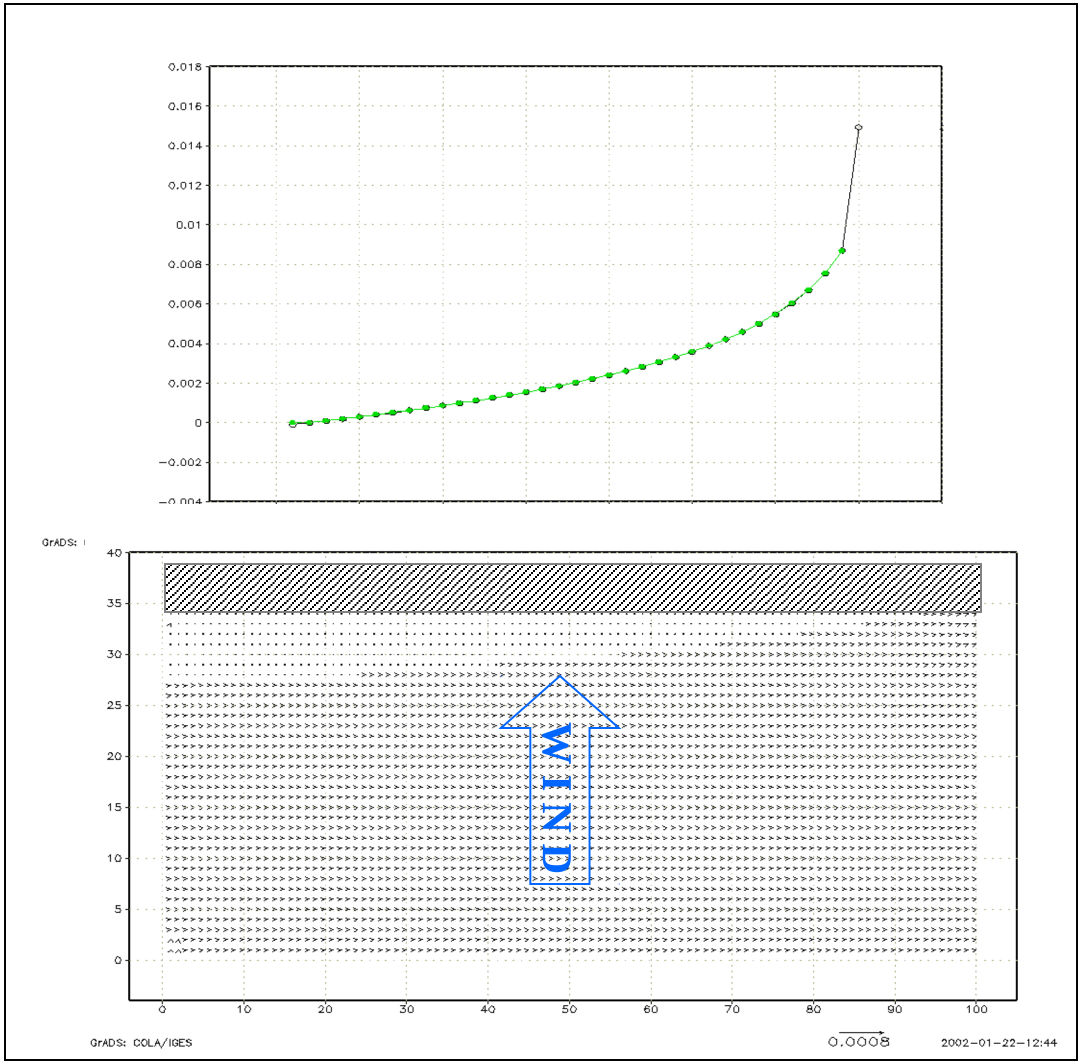
Hypothesis:

- Steady state
- P = Q = 0 everywhere (balance between wind stress and horizontal pressure gradient)
- Bottom stress negligible

Analytical solution

$$\eta(y) = -\frac{\tau_y^S}{\rho g m} ln\left[\frac{H(y)}{H(-L)}\right]$$

$$\frac{\partial \eta}{\partial x} = 0$$



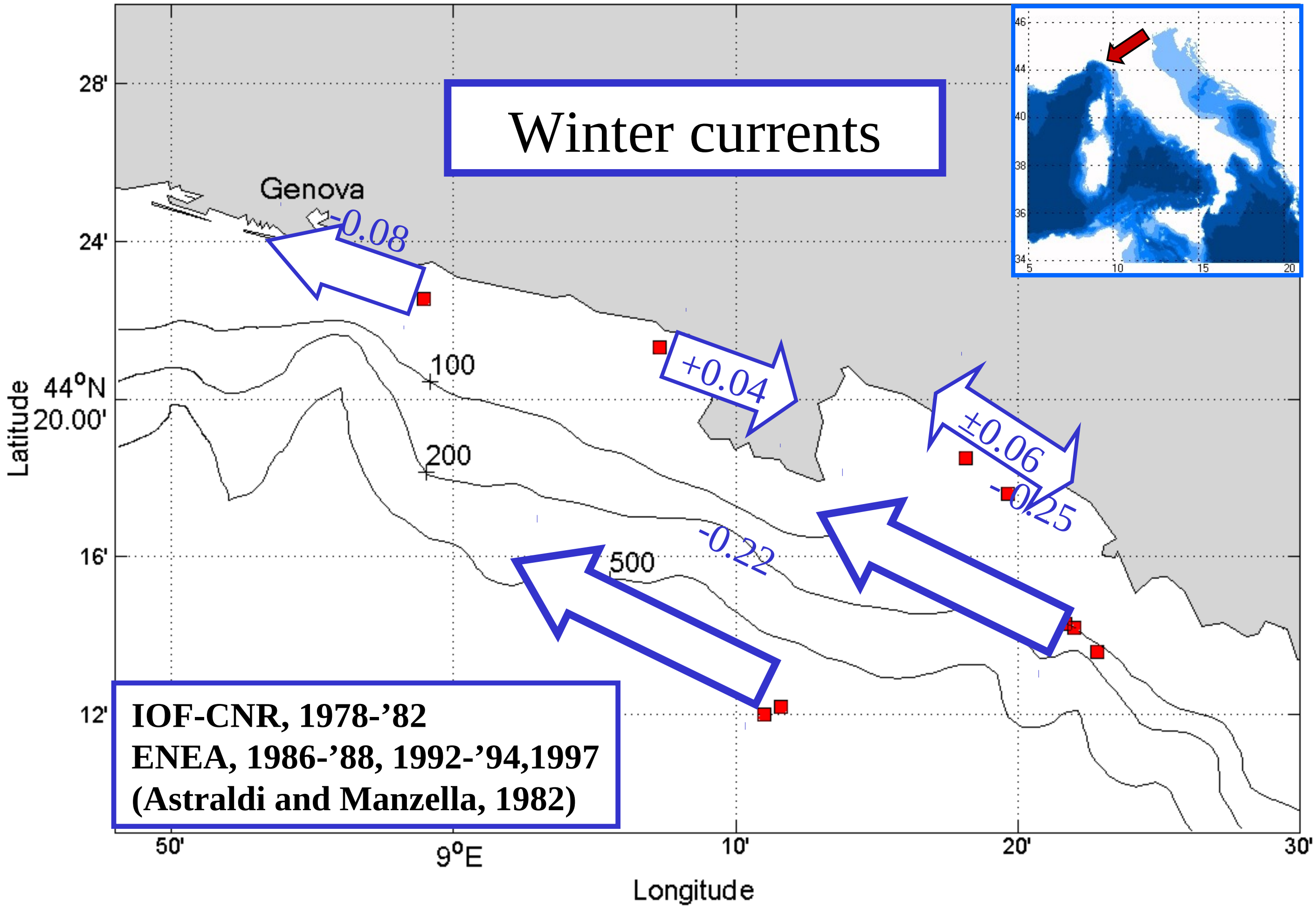
Study area

Bathymetry

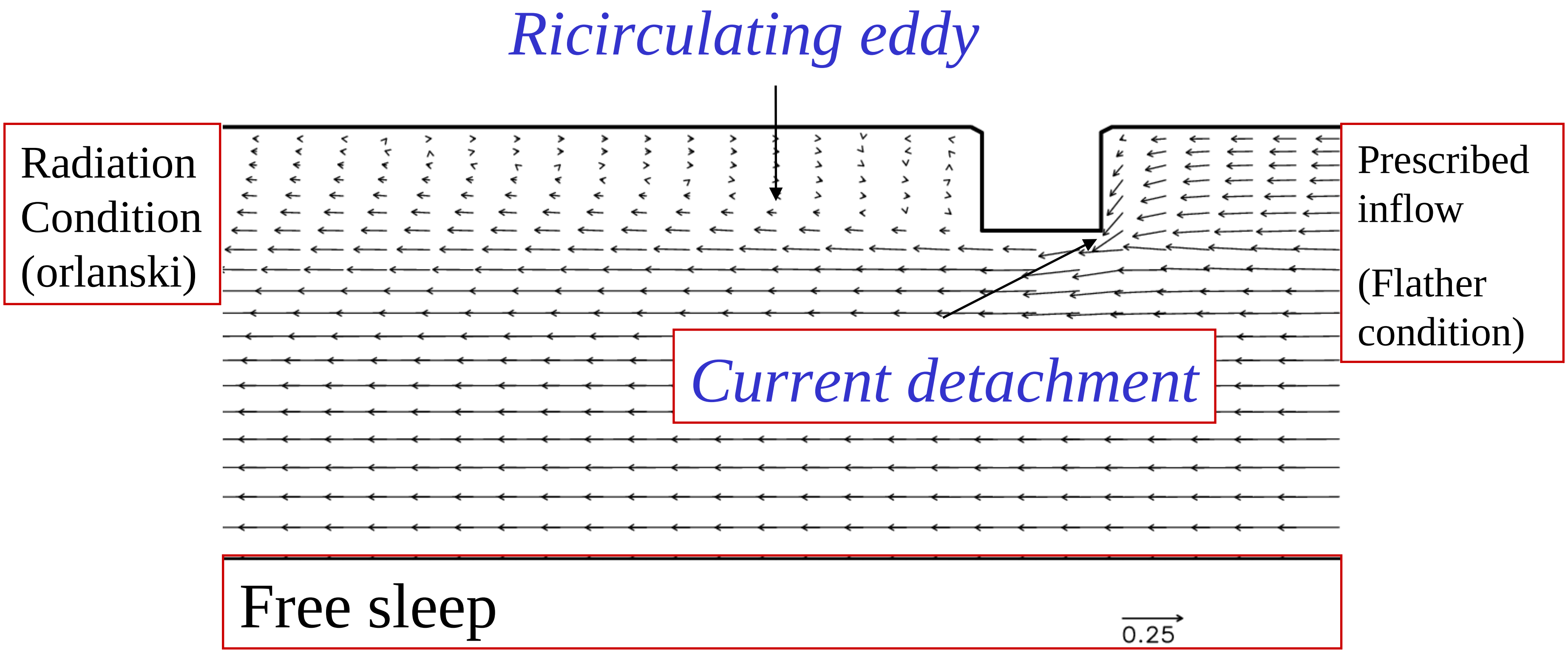
- headland Promontorio di Portofino;
- abrupt coast;
- narrow shelf and steep slope.

Current mesurements (winter time)

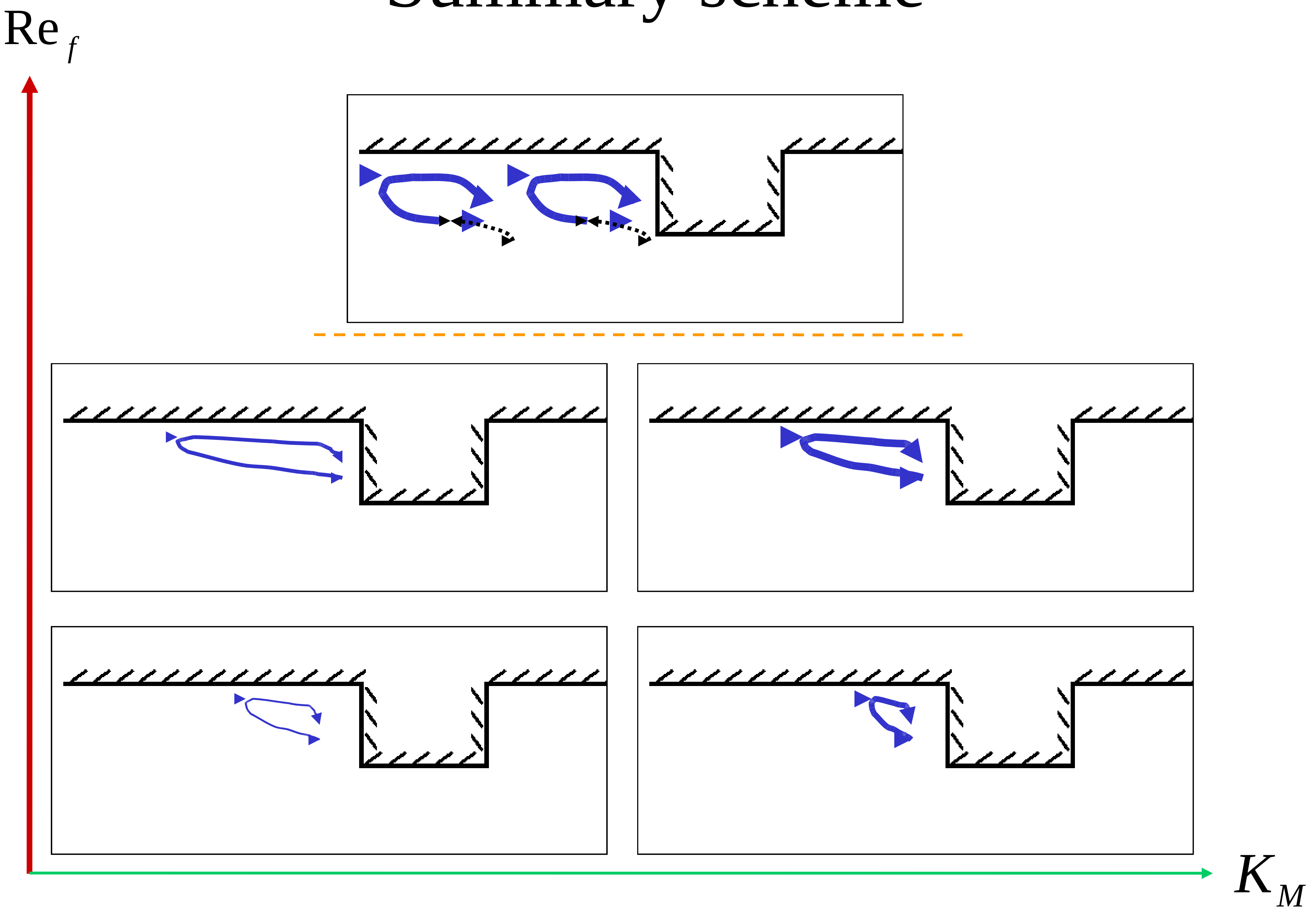
- persistent geostrophic inflow;
- persistent countercurrent in the Golfo Paradiso;
- oscillating direction in the Golfo del Tigullio;



Numerical setting and typical solution

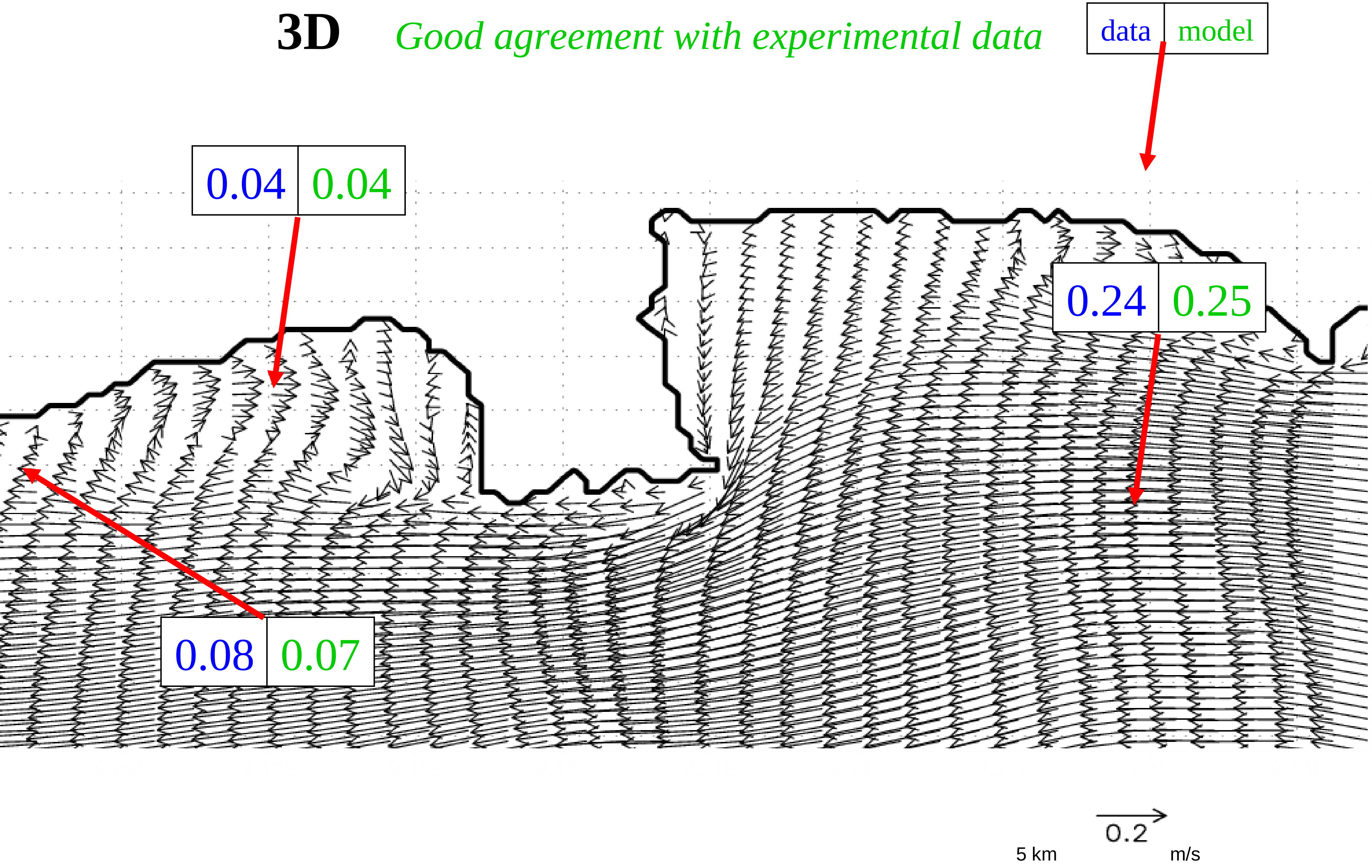


Summary scheme



Real bathymetry REf=40

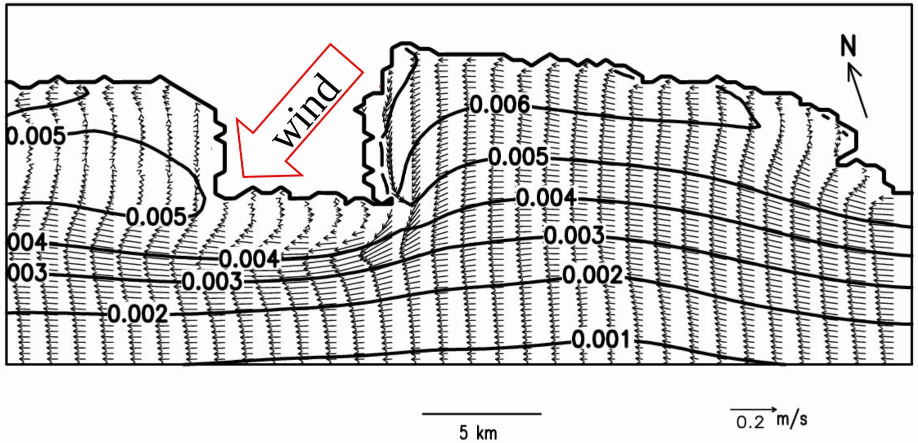
3D *Good agreement with experimental data*

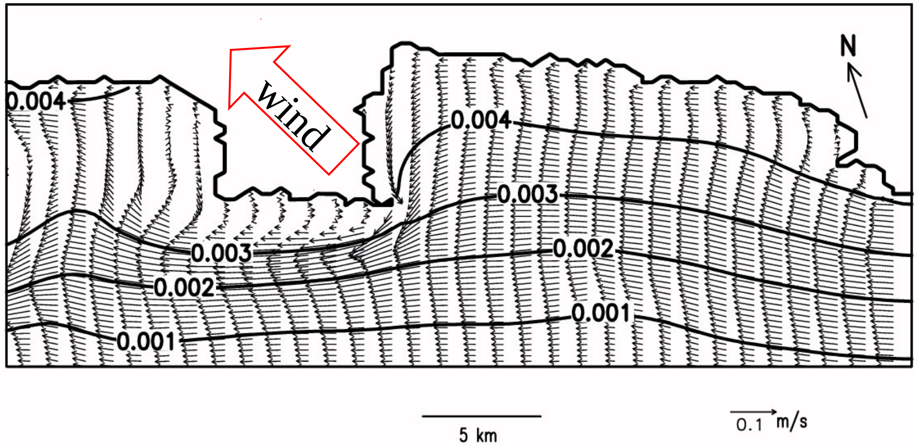


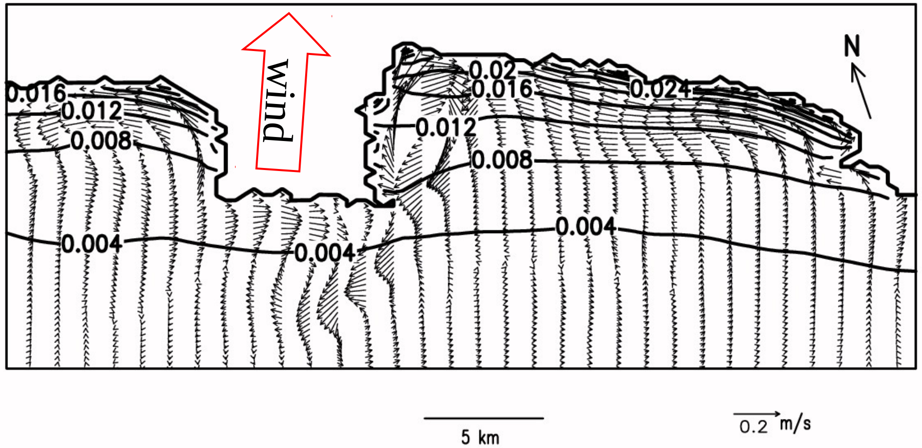
Water circulation

12 days simulation with
a typical local wind sequence

LEGEND:
Free surface elevation [m] and
current depth averaged velocity [m/s]





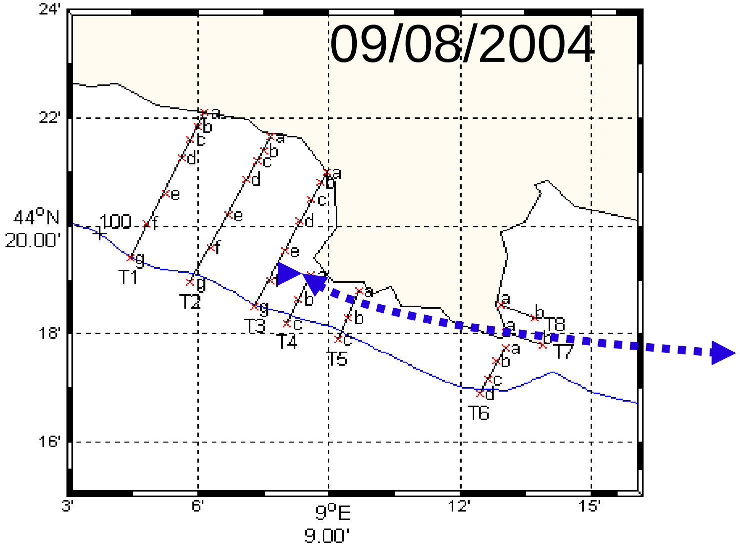


Along shelf currents calculated by the model are consistent with:

- *Measurements*
- *Other numerical experiments*

Sonde CTD

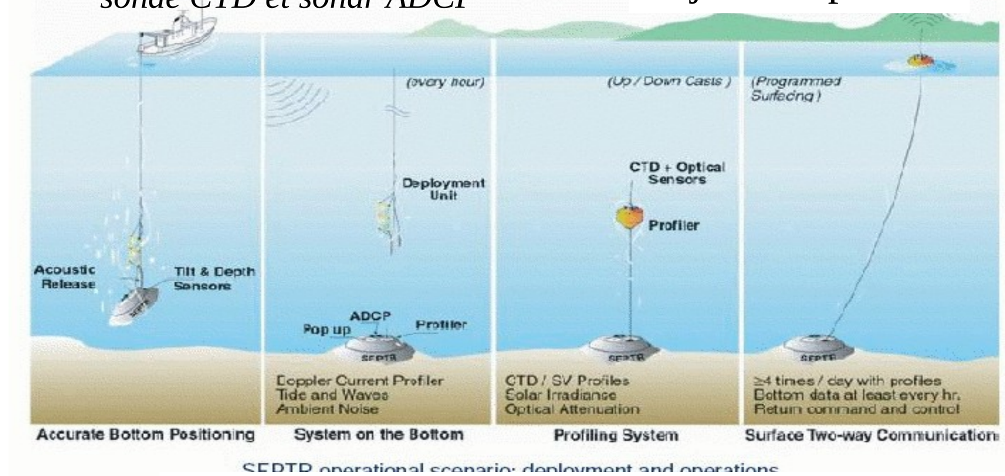
17/06/2004
09/08/2004



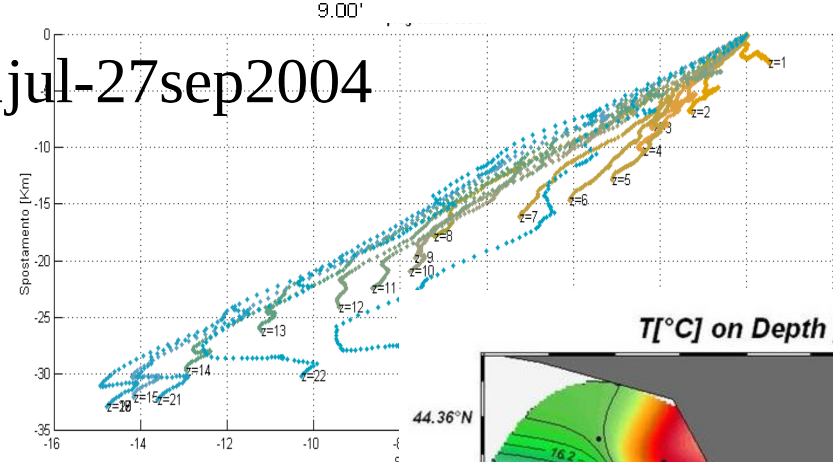
SEPTR du NURC-OTAN

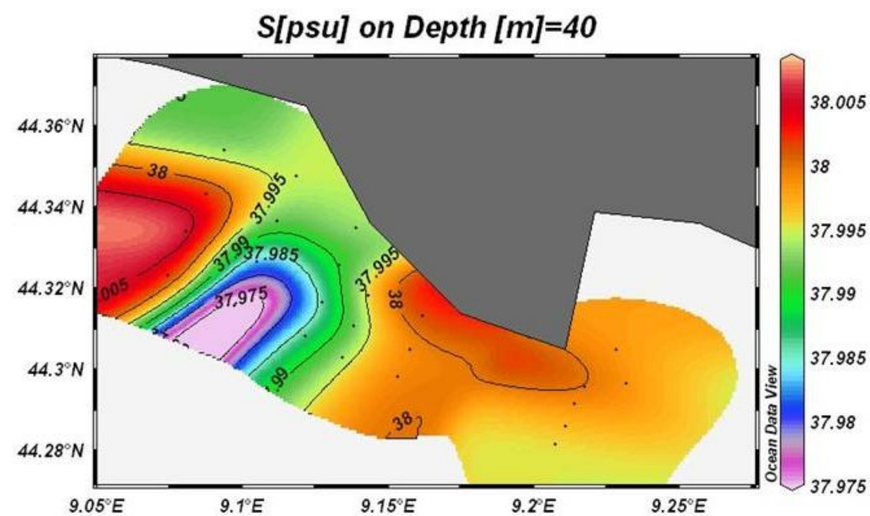
23jul-18aug2003
01jul-27sep2004

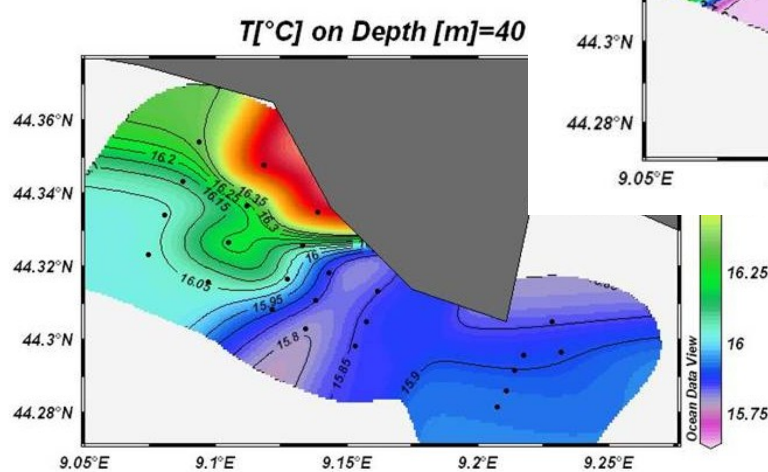
sonde CTD et sonar ADCP



01jul-27sep2004







09/08/2004

Processi di trasporto

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↓

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Approccio Euleriano (alla dispersione)

- descrizione delle caratteristiche del sospeso/soluto tramite campi di concentrazione media <c(**r**,t)> ;
- evoluzione del campo <c(**r**,t)> basata sull'equazione di avvezione-dispersione.

Equazione di avvezione-dispersione

- v = <v> + v' e c = <c> + c' ;
- ipotesi di ergodicità;
- teoria K .

$$\frac{\partial <c>}{\partial t} + \bar{\mathbf{v}} \cdot \nabla <c> = K_{SH} \nabla^2 <c> + K_{SV} \frac{\partial^2 <c>}{\partial z^2} + \frac{\xi}{\rho}$$

Approccio Lagrangiano (alla dispersione)

- descrizione delle caratteristiche del sospeso/soluto tramite particelle;
- dinamica probabilistica di ogni particella basata sulla "probabilità di transizione" $P(\mathbf{r},t \mid \mathbf{r}_0,t_0)$ per ogni specie di inquinante.

Probabilità di transizione:

Probabilità che una particella che si trova in $\mathbf{r}_0$ all'istante t_0 si trovi in $\mathbf{r}$ all'istante t.

$$<c(\mathbf{r},t)> = \int_{-\infty}^{t} \int_{\mathcal{V}} P(\mathbf{r},t \mid \mathbf{r}_0,t_0)\ \xi(\mathbf{r}_0,t_0)\ d\mathbf{r}_0\ dt_0$$

Modelli a particelle

$$\mathbf{v}_e = \overline{\mathbf{v}} + \mathbf{v}'$$

da misure euleriane di corrente
oppure
fornita da un modello idrodinamico

'velocità di diffusione'

Random walk

approssimazione AR(0)

$$\mathbf{v}'_n = \boldsymbol{\mu}$$

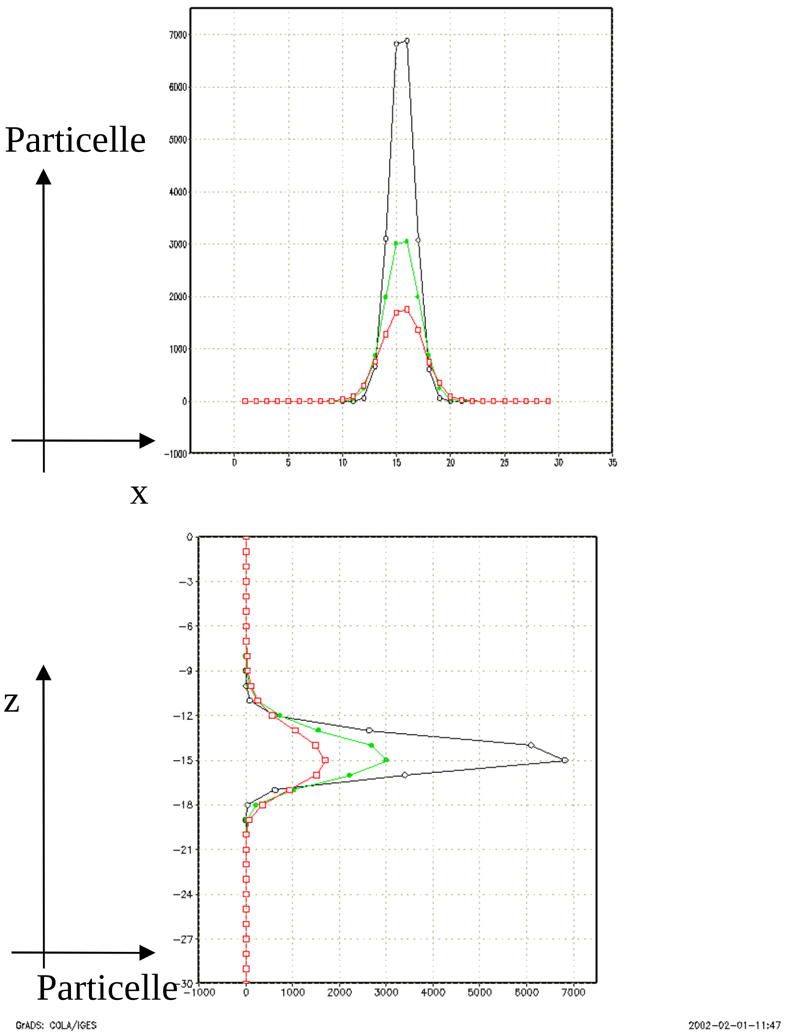
$$\boldsymbol{\varrho} = \boldsymbol{\mu}\Delta t$$

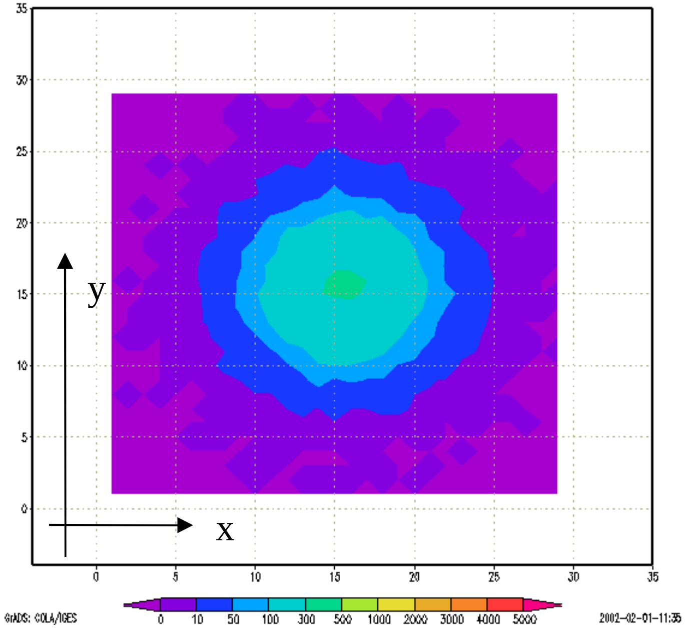
$$\mathbf{r}_{n+1} - \mathbf{r}_n = \overline{\mathbf{v}}\Delta t + \boldsymbol{\varrho}$$

estrazione

$G\ (0,\sigma)$

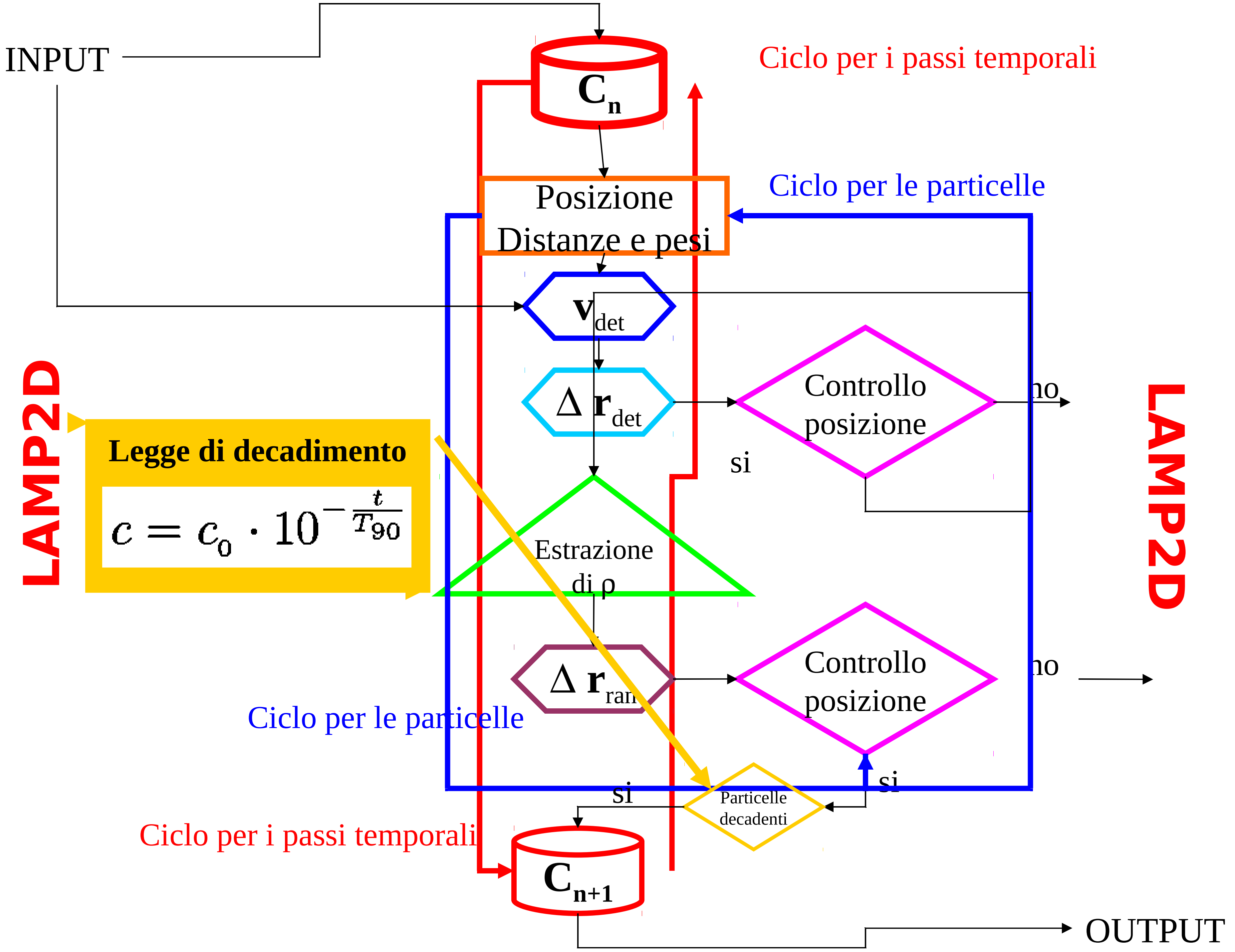
TEST di *LAMP3D*



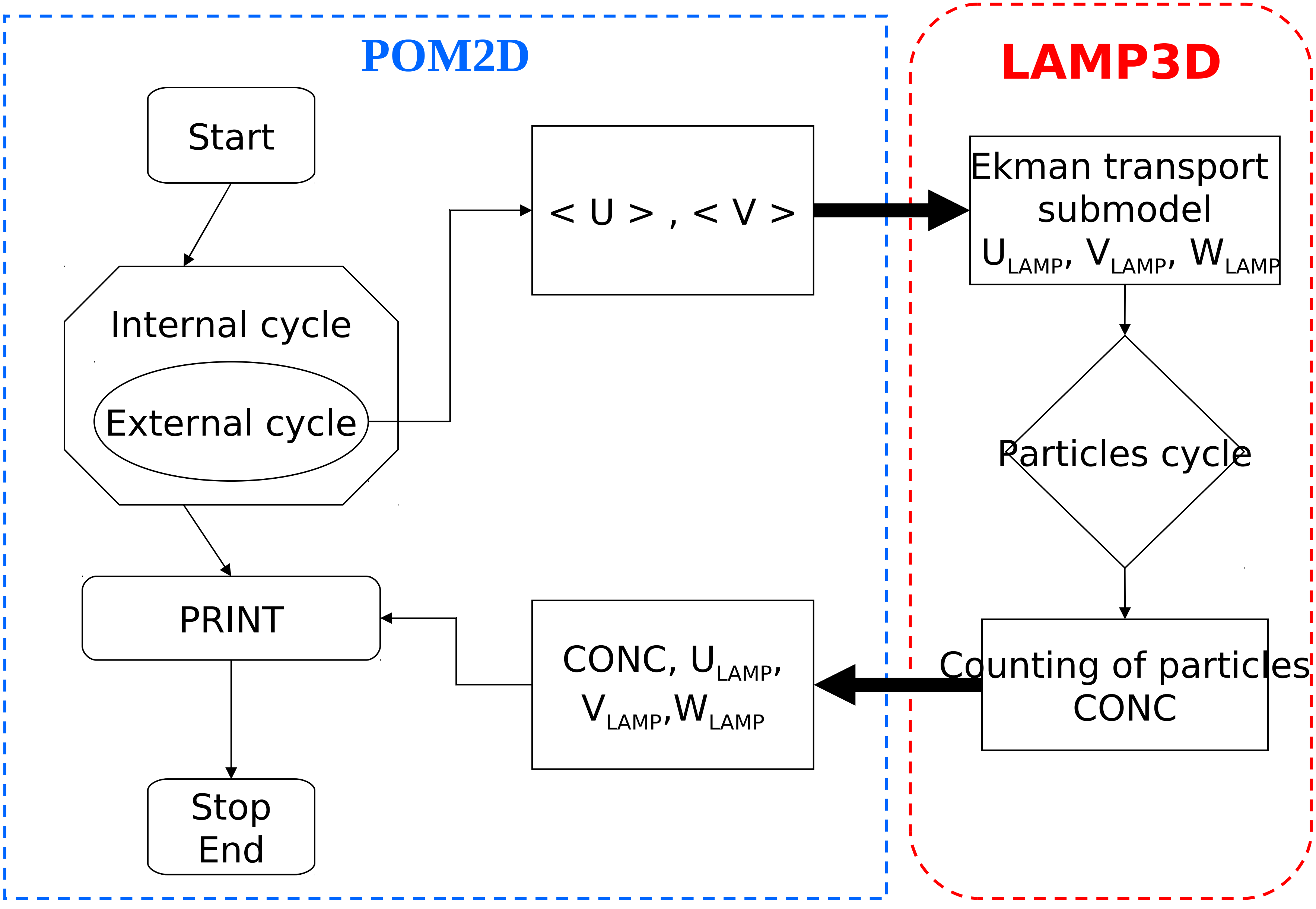


Velocità nulla

Test di diffusione


INPUT
Ciclo per i passi temporali
C_n
Ciclo per le particelle
Posizione
Distanze e pesi
$\mathbf{v}_{det}$
$\Delta\, \mathbf{r}_{det}$
Controllo posizione
no
si
LAMP2D
Legge di decadimento
$c = c_0 \cdot 10^{-\frac{t}{T_{90}}}$
Estrazione di ρ
$\Delta\, \mathbf{r}_{ran}$
Controllo posizione
no
Ciclo per le particelle
si
Particelle decadenti
si
Ciclo per i passi temporali
C_{n+1}
OUTPUT

POM2D-LAMP3D coupled model



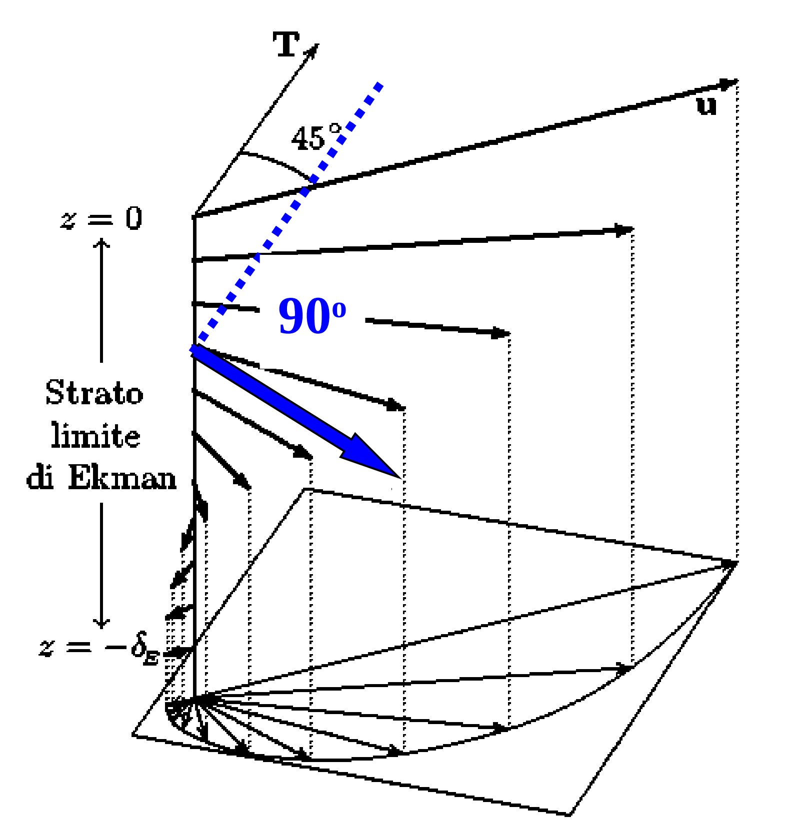
La spirale di Ekman

Profilo velocità

- fluido omogeneo ed *infinito*
- gradiente *p* orizzontale nullo
- moto stazionario
- vento costante

$$u + iv = V\, e^{\frac{\pi}{\delta_E} z}\, e^{i\left(\frac{\pi}{4} + \frac{\pi}{\delta_E} z\right)} \qquad (z \leq 0)$$

$$\delta_E = \pi \sqrt{\frac{2A_V}{f}}$$

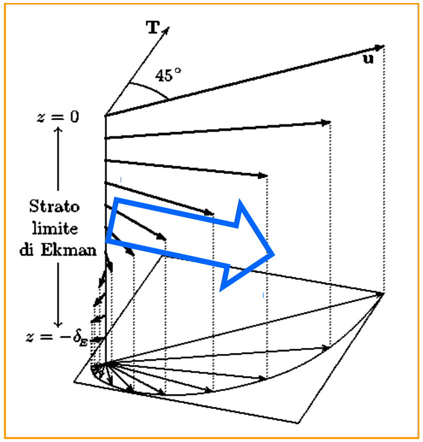


Trasporto

- integro tra $z = 0$ e $z = \delta_E$
- trascuro sforzo del vento a $z = \delta_E$

$$\mathbf{M} = -\frac{1}{f}\,\mathbf{k} \wedge \mathbf{T}$$

$$\mathbf{M} = \int_{-\delta_E}^{0} \mathbf{v}_H\, dz \qquad \mathbf{T} = \left(A_V \frac{\partial \mathbf{v}_H}{\partial z}\right)_{z=0}$$



$$u + iv = V\, e^{\frac{\pi}{\delta_E} z}\, e^{i\left(\frac{\pi}{4} + \frac{\pi}{\delta_E} z\right)} \qquad (z \le 0)$$

Ekman transport submodel

Spiral profile in a limited layer

$$(u + iv) = \langle u + iv \rangle\ \kappa H\, \mathcal{F}(z)$$

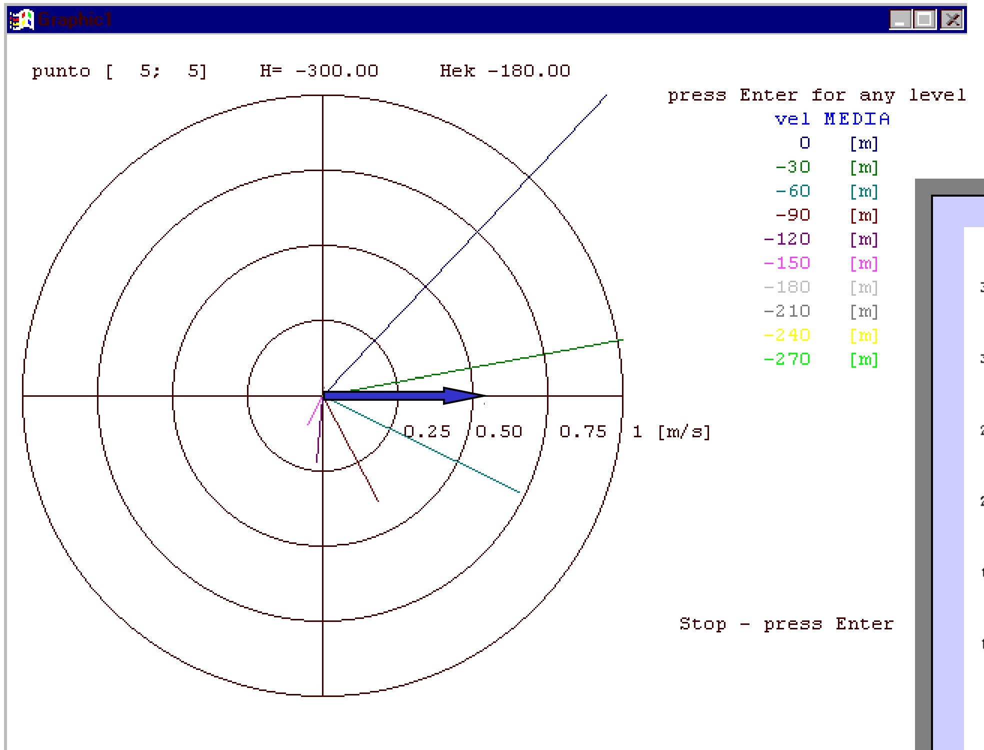
u(x,y,z)
v(x,y,z)

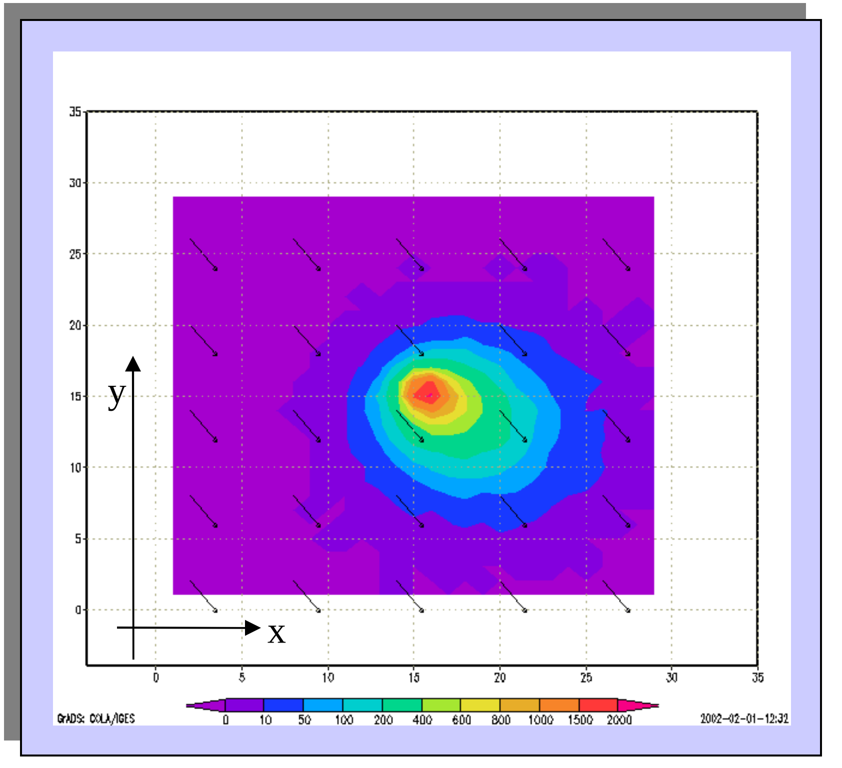
Mass conservation

$$\frac{\partial w}{\partial z} = -\mathcal{R}e\left\{\frac{\partial \mathbf{v}}{\partial x}\right\} - \mathcal{I}m\left\{\frac{\partial \mathbf{v}}{\partial y}\right\}$$

w(x,y,z)

TEST di *LAMP3D*

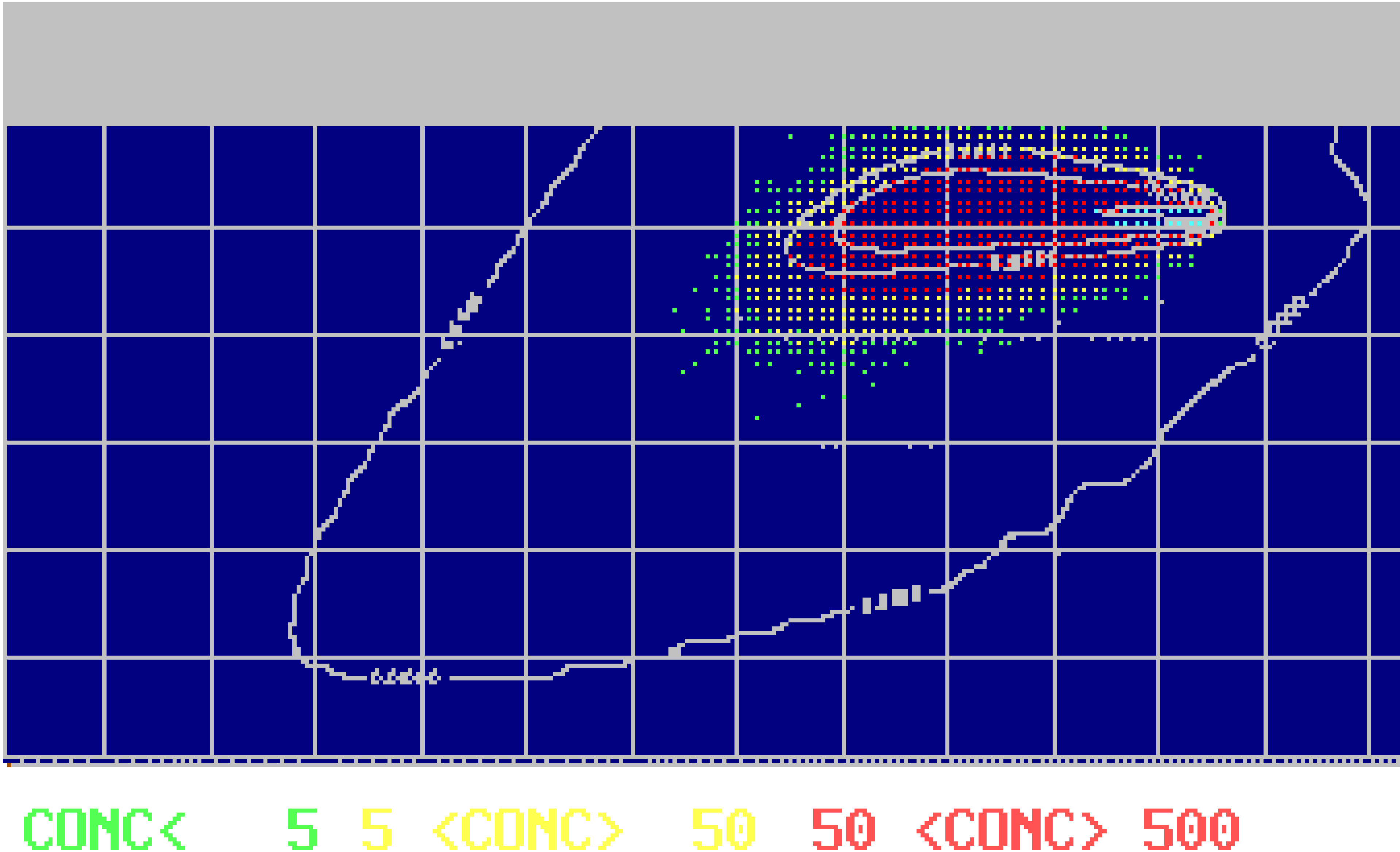




Corrente “orientale”
(Ovest-Est)
di 0.5 m/s

Tipica forma a goccia per un rilascio continuo

Comparison between LAMP (dots) and MIKE21 (contour lines)



Wastes Indicators

CONCENTRATION of:

- Nitrogen *(dissolved and particulated);*
- Phosforous *(dissolved and particulated);*
- Organic Carbon *(particulated).*

in

- Excretion products
- Uneaten feed
- Faecal matter

to assign a weight to particles

From literature:

- % of uneaten feed on the feed supplied;
- Velocities of sedimentation for particulated matter;
- % of each nutrient in feed (if not provided by feed productor);
- the soluble and sedimentable fractions of metabolic N and P;
- faecal production of fishes;

Assumptions:

- fish production

P = 200 ton/year

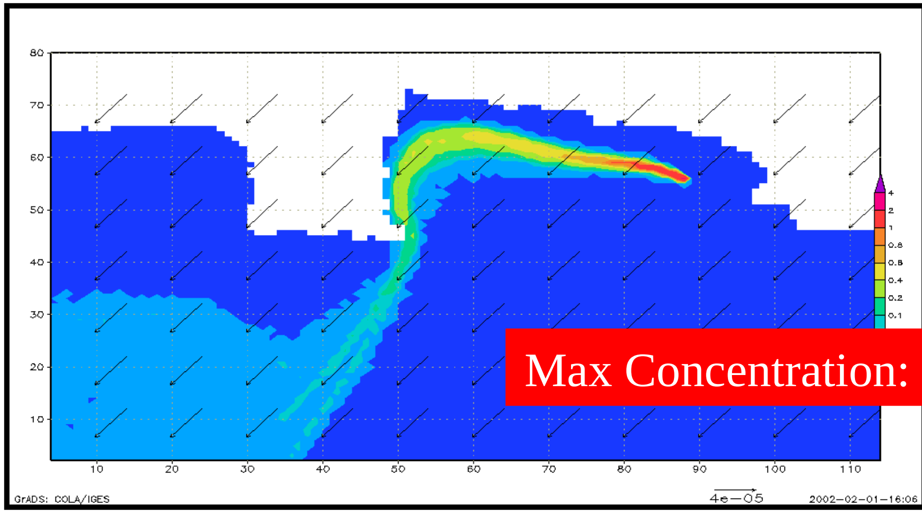
- feed conversion factor

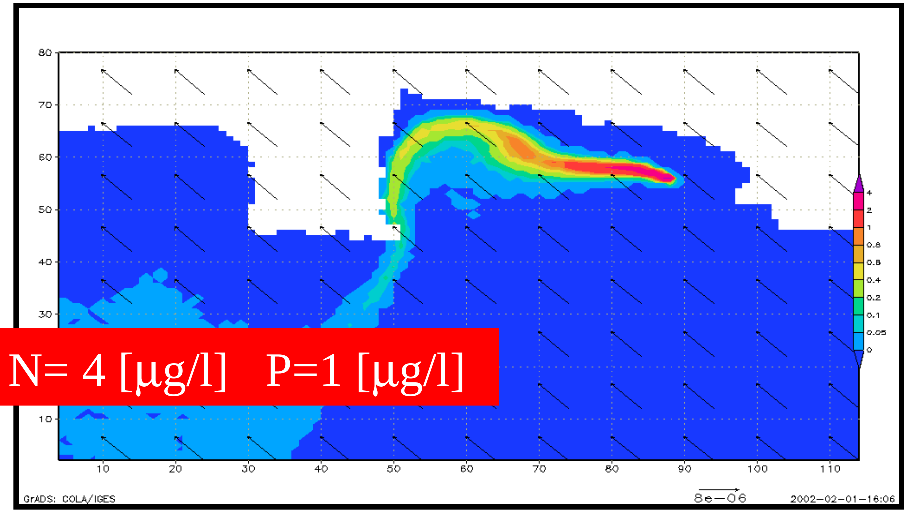
F_c =1.3 kg pellet/kg fish

Weigths of particles

	Uneated feed	Faecal pellet	Dissolved matter
	% of feed supplied = 5% Periodical release Vs=0.12 m/s	Balance of mass F_c =1.3 kg pellet/kg fish Continuous release Vs=0.04 m/s	Balance of mass F_c =1.3 kg pellet/kg fish Continuous release Vs=0. m/s
N	% in feed = 6.6% ***1 particle = 2.35 g***	% particulated = 22% ***1 particle = 0.932 g***	% dissolved = 78% ***1 particle = 3.32 g***
P	% in feed = 1.35% ***1 particle = 0.48 g***	% particulated = 79% ***1 particle = 0.814 g***	% dissolved = 21% ***1 particle = 0.22 g***
C	% in feed = 45% ***1 particle = 16 g***	Faecal production = 1.9 g/kg fish % organic carbon= 28% ***1 particle = 0.04 g***	----

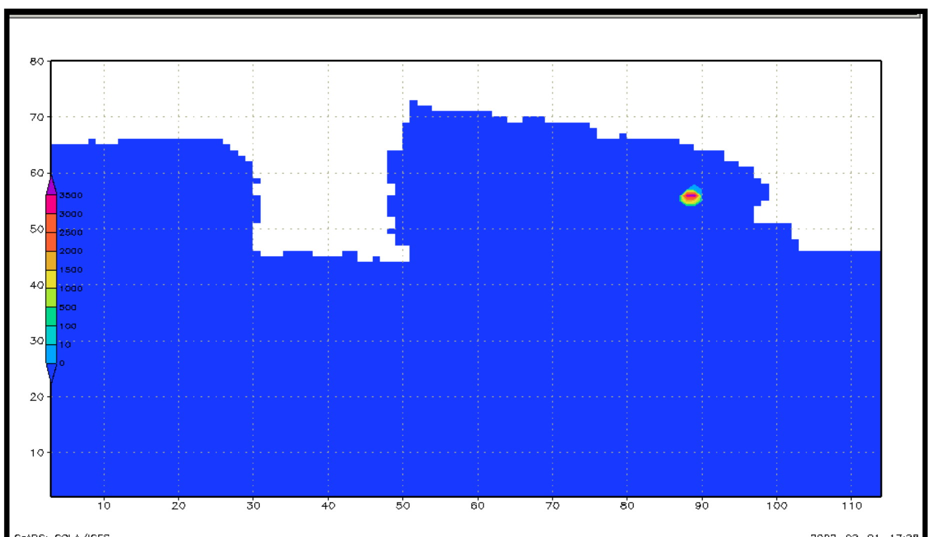
Dissolved nutrients

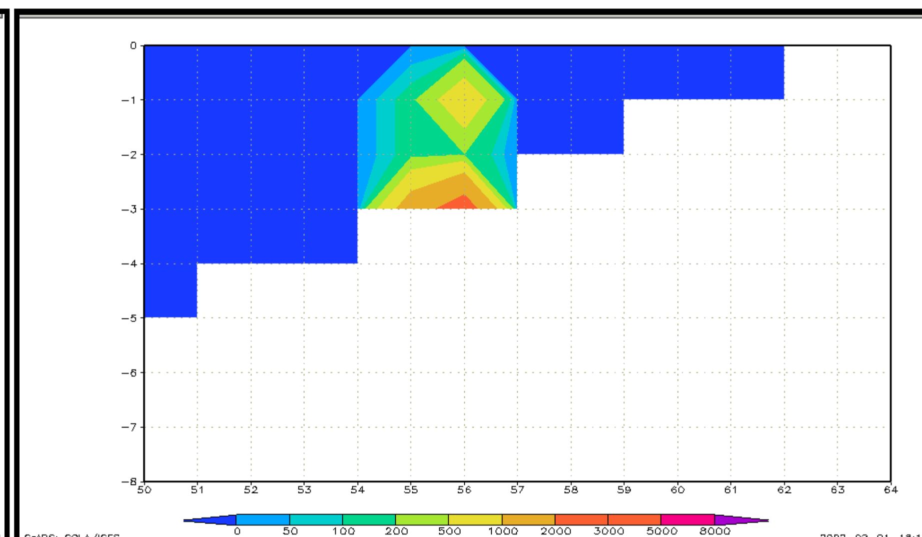




Max Concentration: N= 4 [μg/l] P=1 [μg/l]

Particulated matter

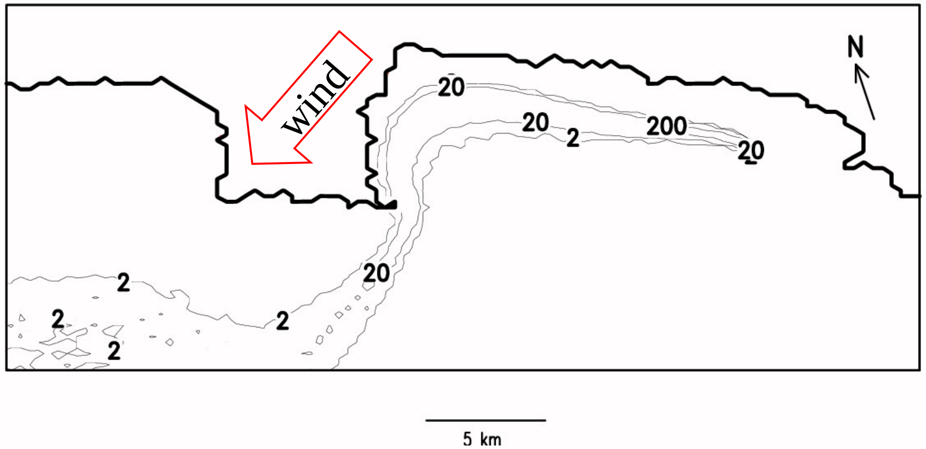


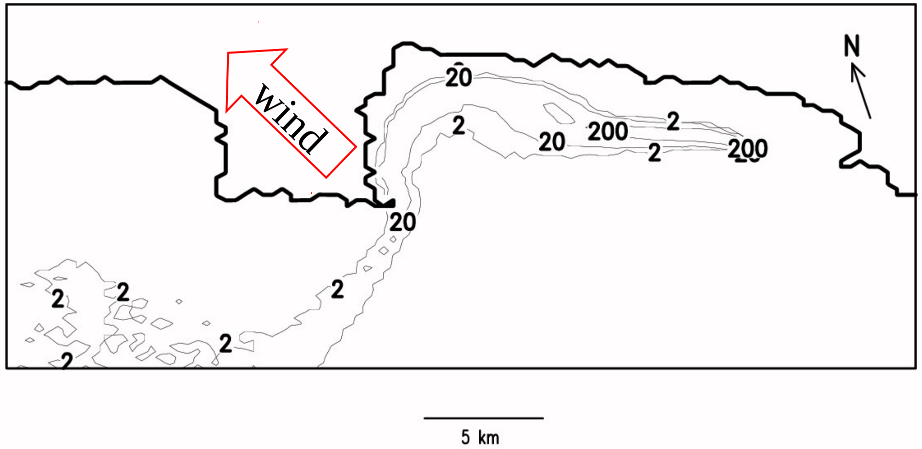


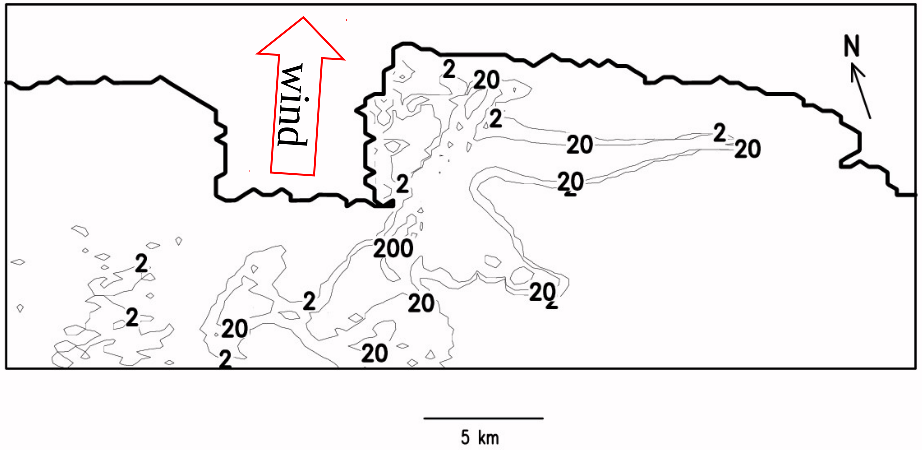
Dissolved nutrients

LEGEND:
Number of particles / grid cell

200 = { 0.83 μgN/l ; 0.05 μgP/l }



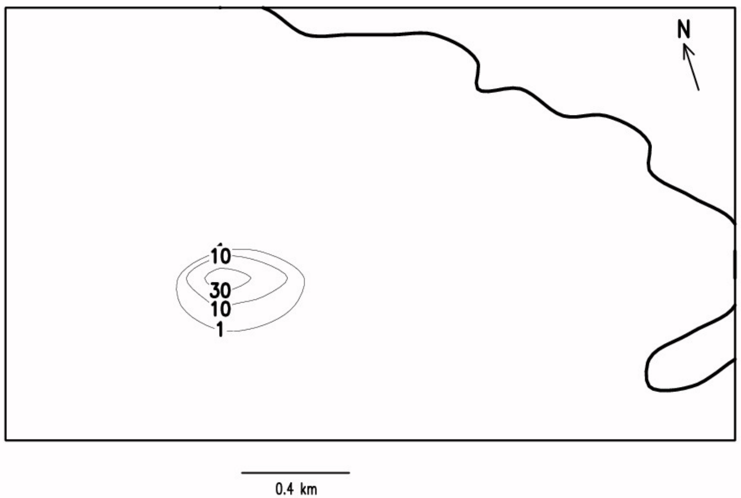


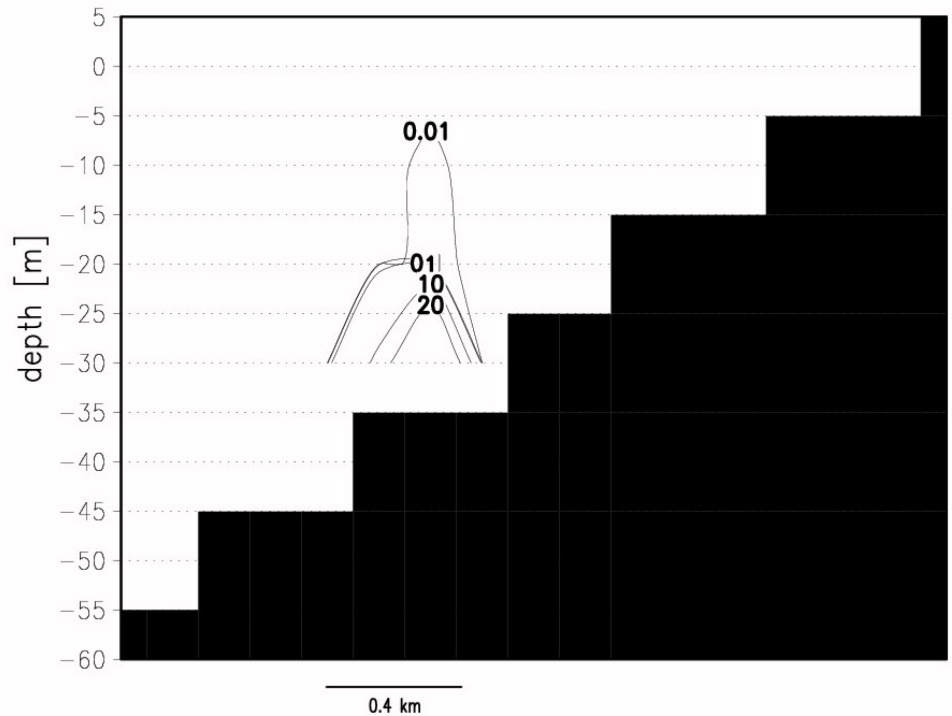


- *Important role of headland;*
- *Best dilution with NE wind;*
- *Nutrients trapped in eddies with SSW wind.*

Particulated matter

LEGEND:
Number of particle /grid cell x 10^3
30 = 0.6 gC/m^2

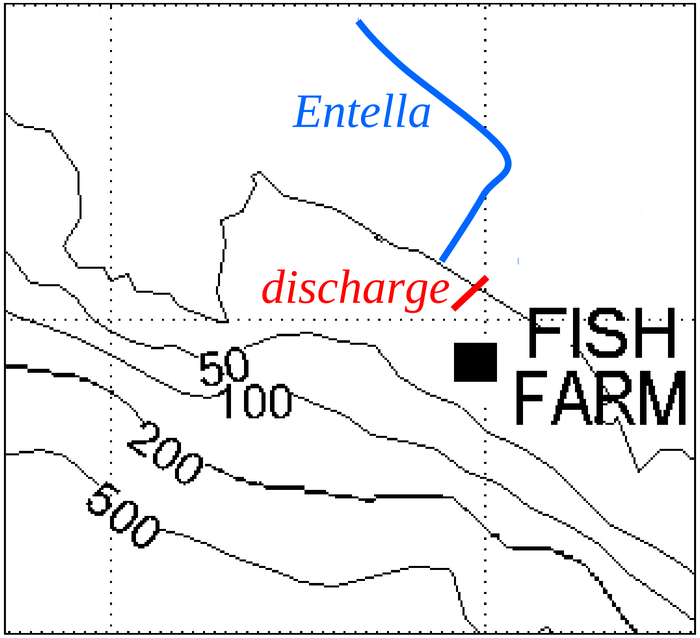




- *Sinking velocity comparable to local current velocity;*
- *The sedimentable matter of any origin remains in the zone of sea cages;*
- *Bell-shaped sedimentation.*
- *Maximum loading rate calculated for organic carbon by the model:* ***0.085 gC/m²/day***

Comparison with data

DISSOLVED MATTER:
data values >> model output
Actual setup do not take into account the pre-existng environmental concentration (role of the river Entella and the sewage discharge from the treatment plant of Lavagna)

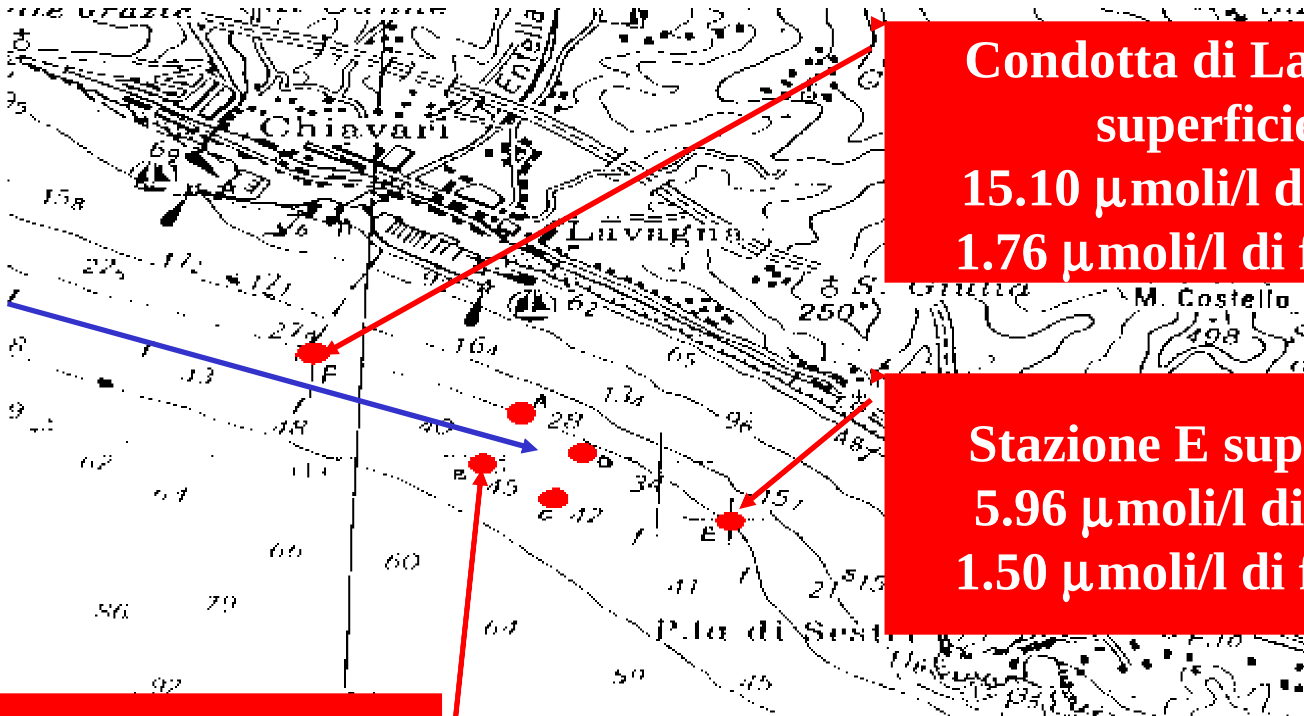


PARTICULATED MATTER:
redox potential values indicate an impact restricted to fish farm area
Agreement with the model

Simulazioni avvettivo-dispersive

Le concentrazioni non superano i 4 μg/l per l'azoto   cioè i 0.065 μmoli/l

Le concentrazioni non superano i 1 μg/l per il fosforo   cioè i 0.032 μmoli/l



Condotta di Lavagna superficie
15.10 μmoli/l di azoto
1.76 μmoli/l di fosforo

Gabbie

Stazione E superficie
5.96 μmoli/l di azoto
1.50 μmoli/l di fosforo

Stazione B fondo
0.72 μmoli/l di azoto
1.62 μmoli/l di fosforo

Predominanti gli apporti terrestri

Conclusions

Concentration predicted by the model:

- are not in contrast with the experimental data;
- result low in investigated area in both water column and sediment compartments;
- never exceed the predicted amounts warned in environmental risk assesment.

Outlooks

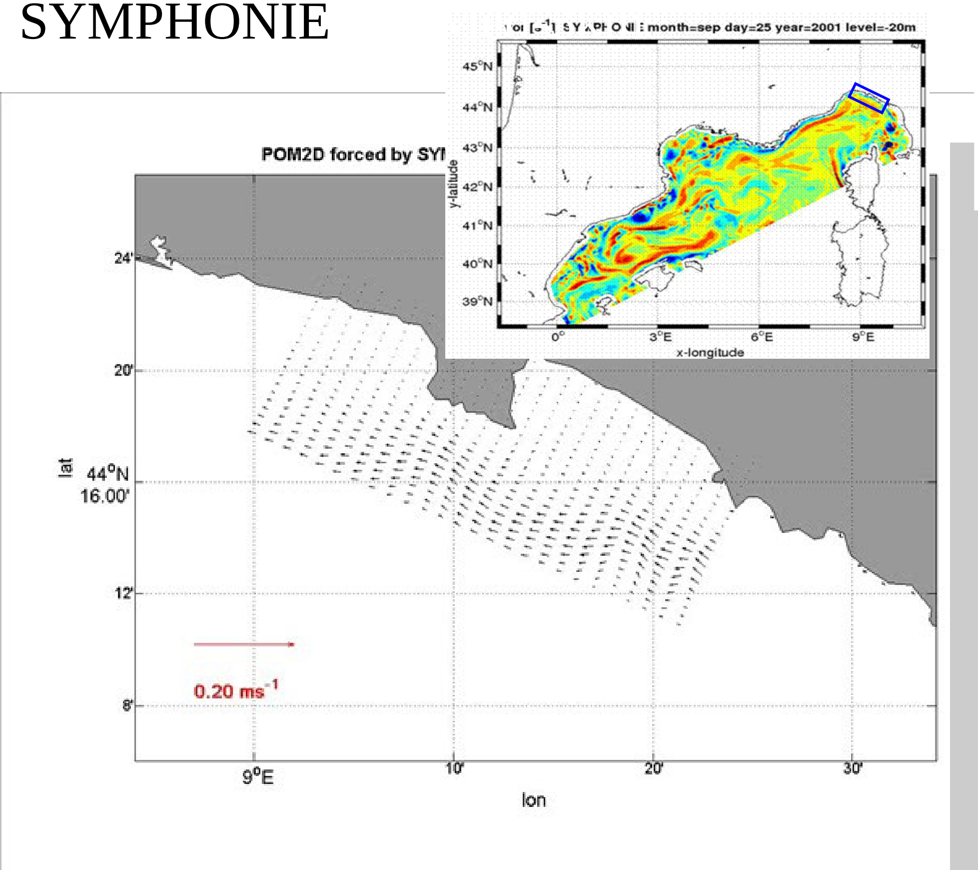
- Model validation with data on a regional scale.
- New experimental monitoring strategy both in water and sediment compartment.
- Implementation of resuspension dynamics.

Travail en cours

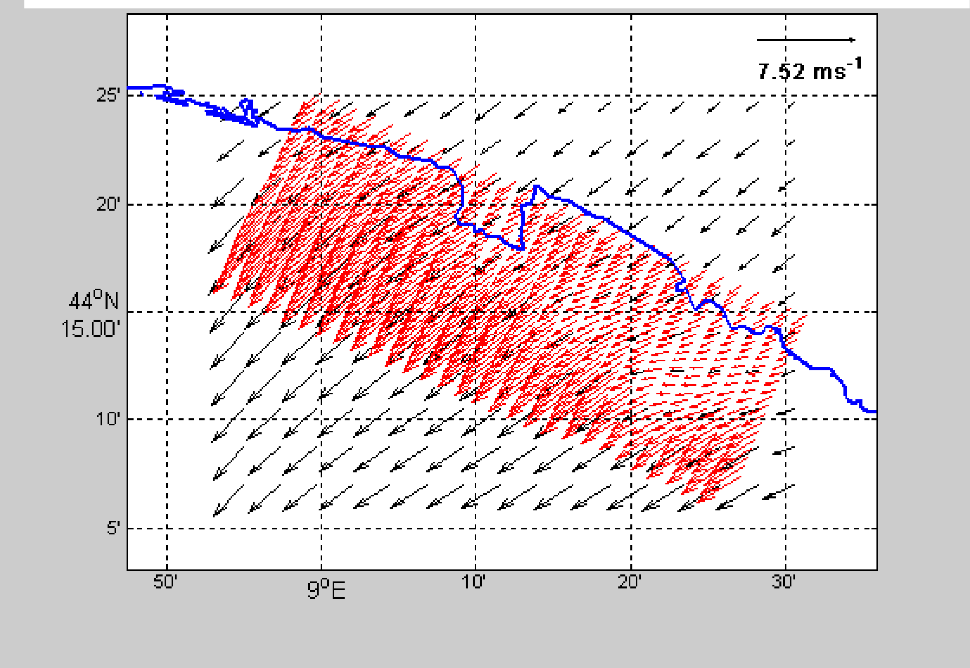
en collaboration avec Departement de Physique-Université de Gênes

Afin d'une simulation réaliste de la circulation, est-il important forcer le model côtier avec un vent à très haute résolution en région à topographie complexe?

coastal model (code POM) forced by SYMPHONIE



WINDS (Wind-field Interpolation by Non-Divergent Schemes) is a diagnostic mass-consistent model for simulation of the three-dimensional wind field in complex terrain at mesoscale



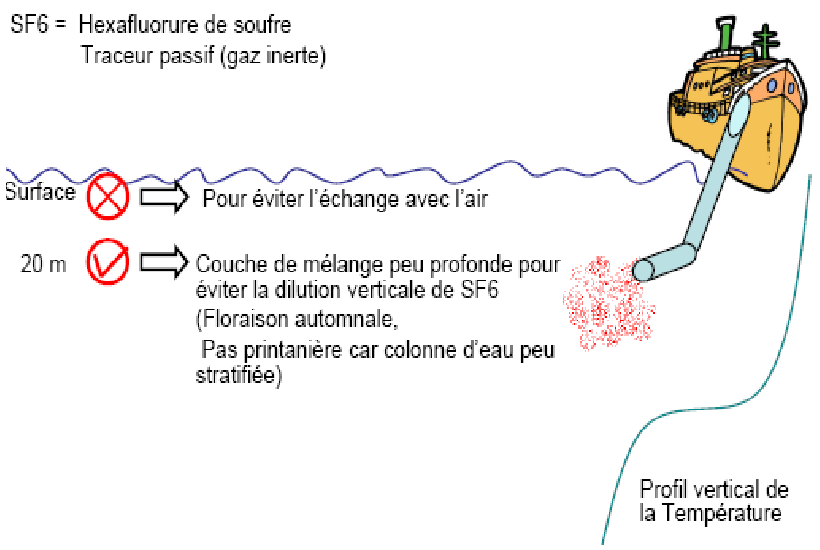
PROJET LATEX (LAgrangian Transport EXperiment)

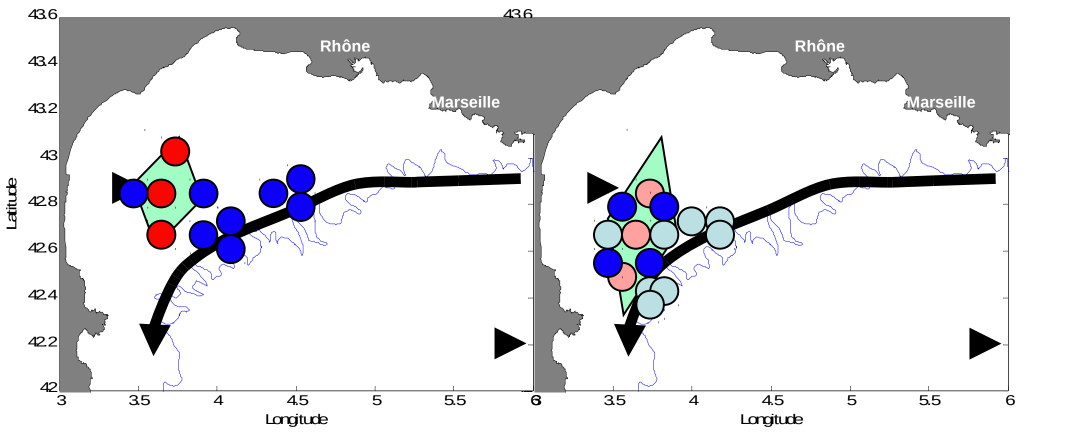
Objectif: rôle de la dynamique couplée physique - biogéochimie à (sub) méso-échelle dans les échanges côte-large

Méthodologie : utiliser une démarche lagrangienne pour le suivi d'une structure tourbillonnaire de (sub)méso-échelle marquée avec un traceur chimique inerte (SF_6)

LATEX = LATEX00 (projet pilote) + LATEX

2007 → **2008-2010**





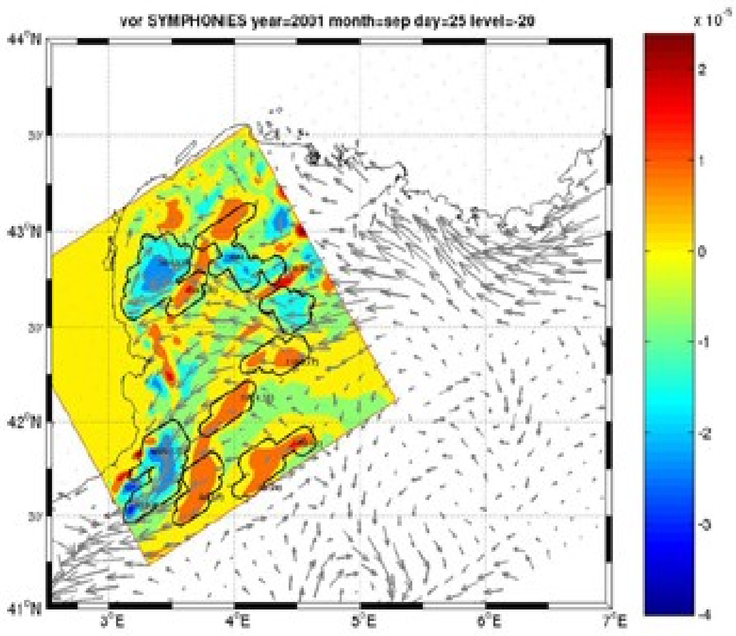
LATEX = projet pilote LATEX00 + projet LATEX

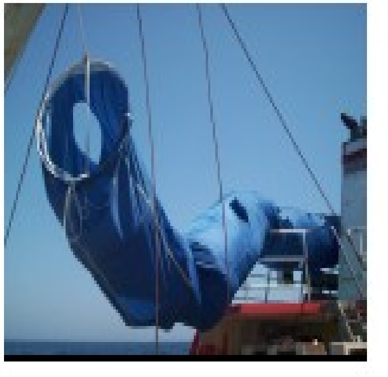
LATEX00 (2007)

Approfondissement des connaissances sur les processus (sub)méso-échelle et mise à point de la stratégie de mesure

modèle SYMPHONIE +
Analyse en ondelettes +
Flotteurs lagrangiens

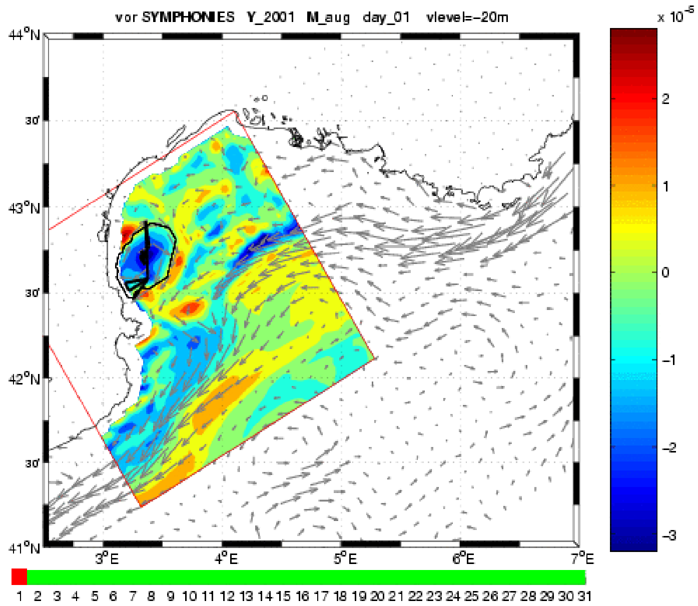
Campagne en mer
tests de navigation lagrangienne +
mesures de C_{amb} du SF_6



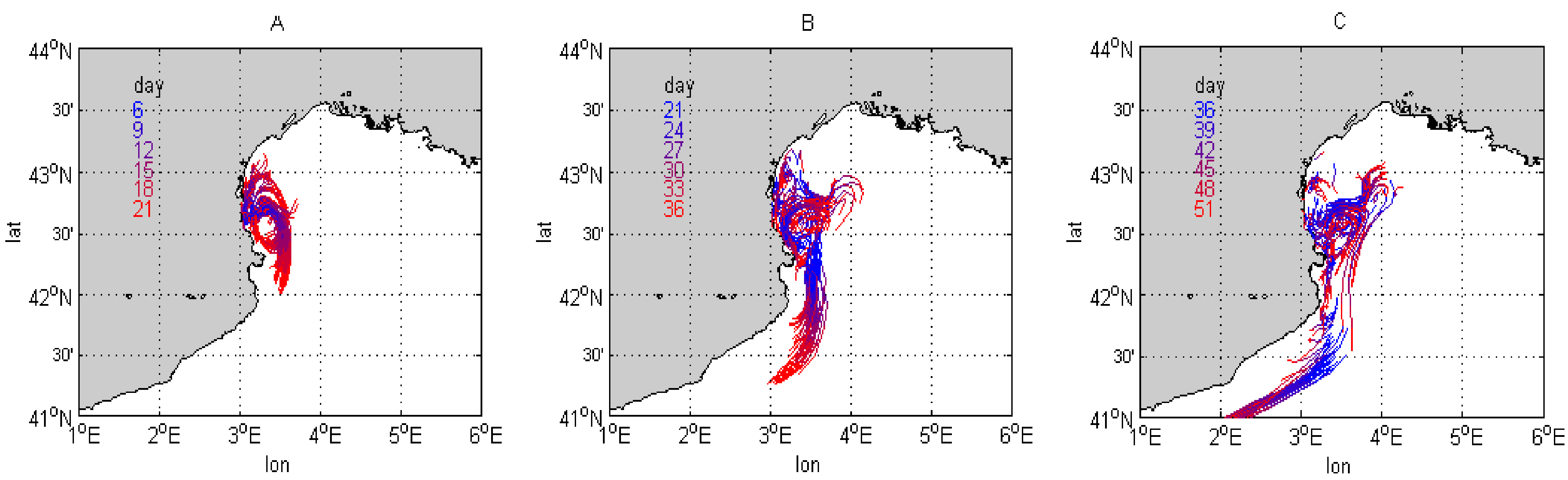


Tourbillon anticyclonique **A1(01)**

durée: 32 jours animation montrée sur la dernière partie (1er – 18



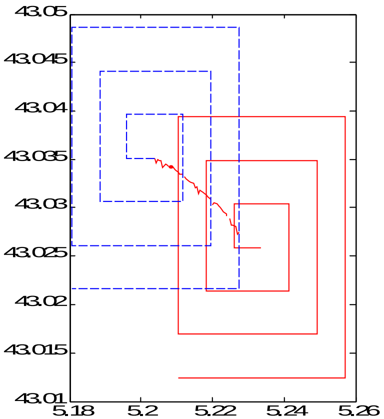
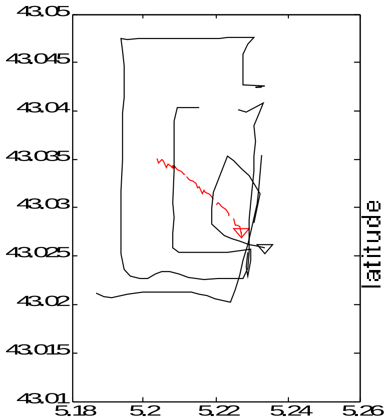
Site web ZiYuan Hu, master 2007
http://www.com.univ-mrs.fr/~h307258/

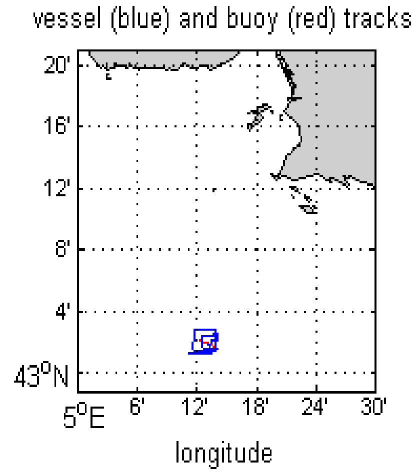


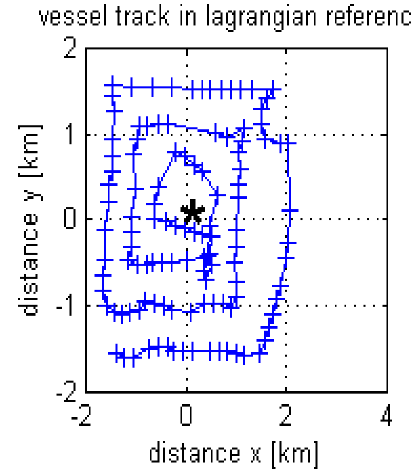
Navigation lagrangienne pour la mise à l'eau du traceur Résultats des tests, en mer, du logiciel de nav. lagrangienne

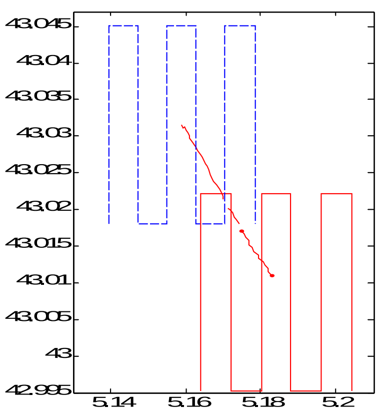
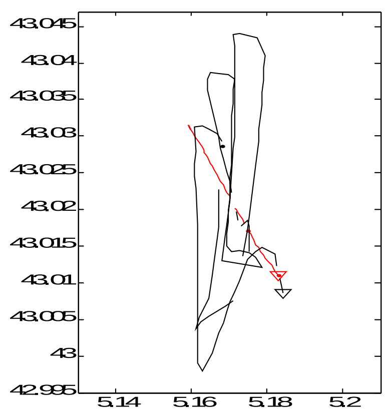
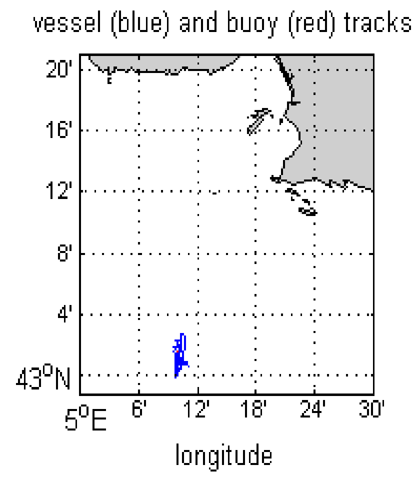
LATEX 00 9-11 juin 2007

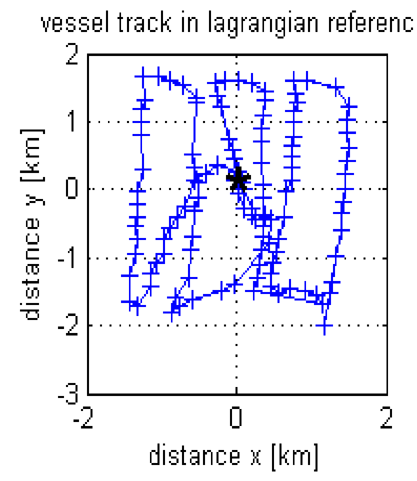
théorique | réelle | réelle zoom out | repère lagrangien







FINE

LATEX00

POM flow chart