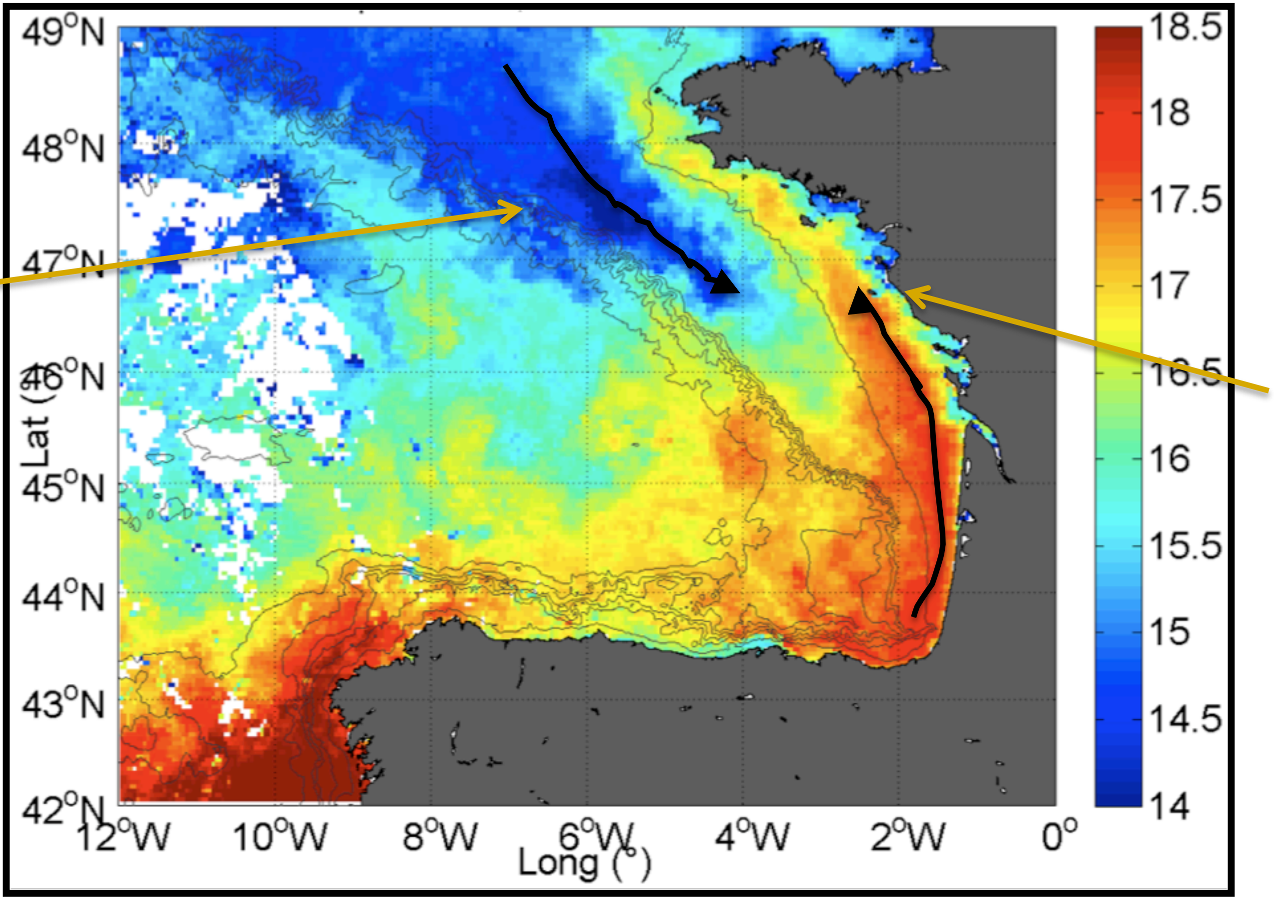
Numerical modelling of autumnal circulation over the bay of Biscay Shelf.



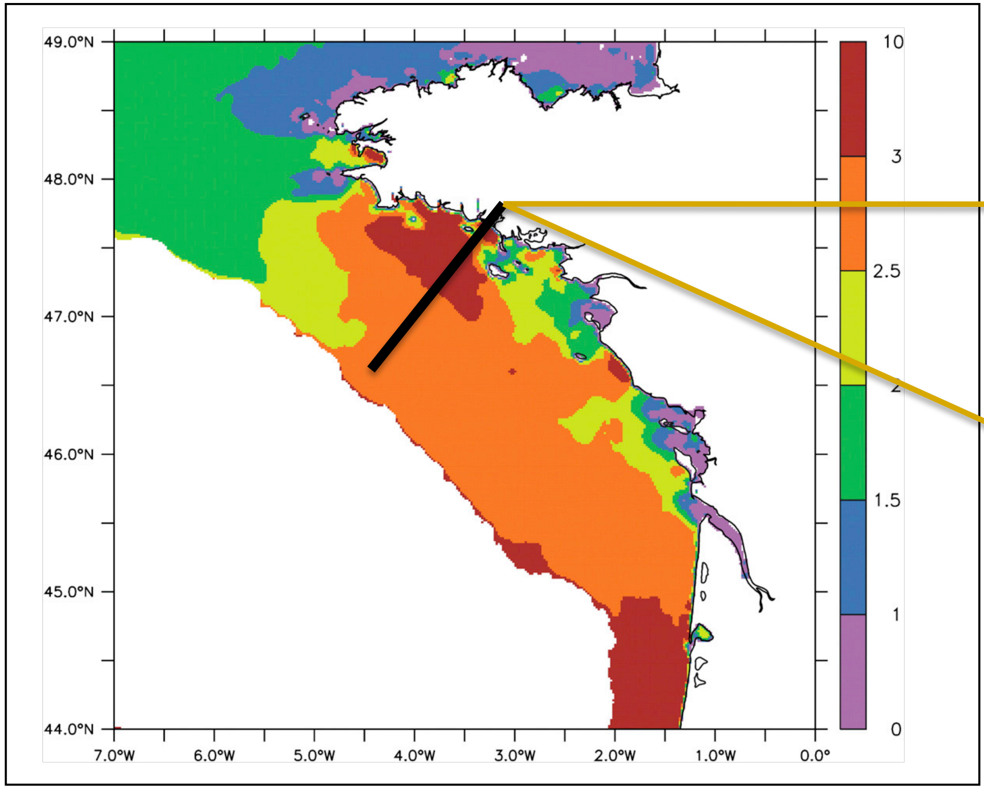
Cold tongue

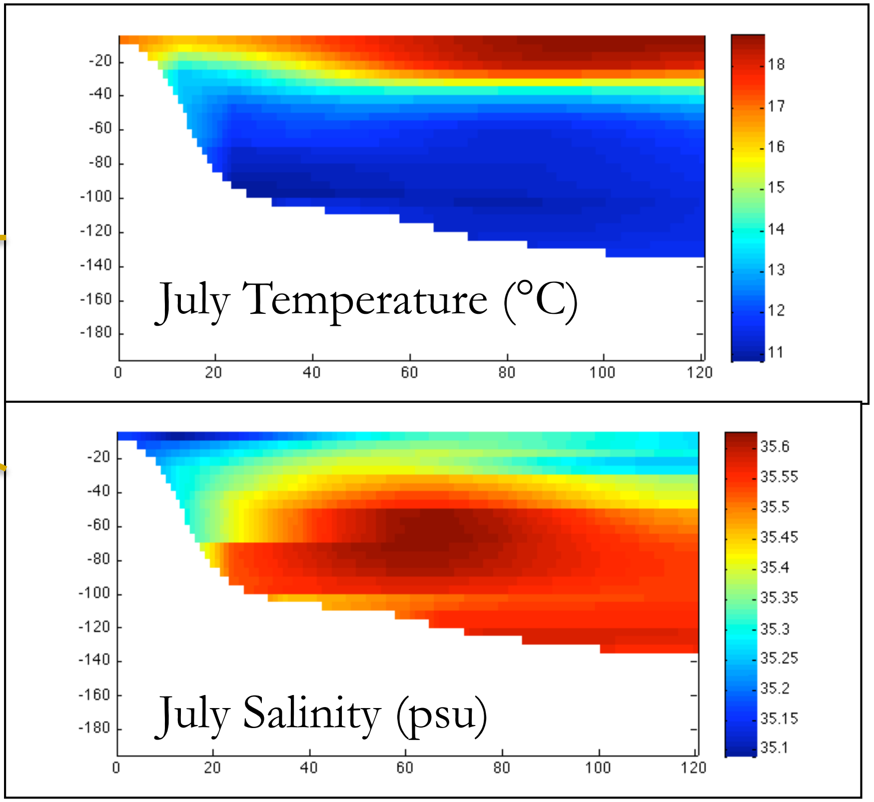
Warm tongue

JONSMOD 2010, Delft.

Dumas F, Lazure P.

Hydrological structure over the shelf





July Temperature (°C)

July Salinity (psu)

Computed Simpson criteria log (H/u3). From Lazure et al, JMS 2008.

Typical summer (July) hydrological structure :
upper panel climatological temperature in july
Lower panel salinity
From Bobyclim : Vandermeirsh et al (www.ifremer.fr/climatologie-gascogne, 2007)

Tidal structures : elevations and currents due to M2

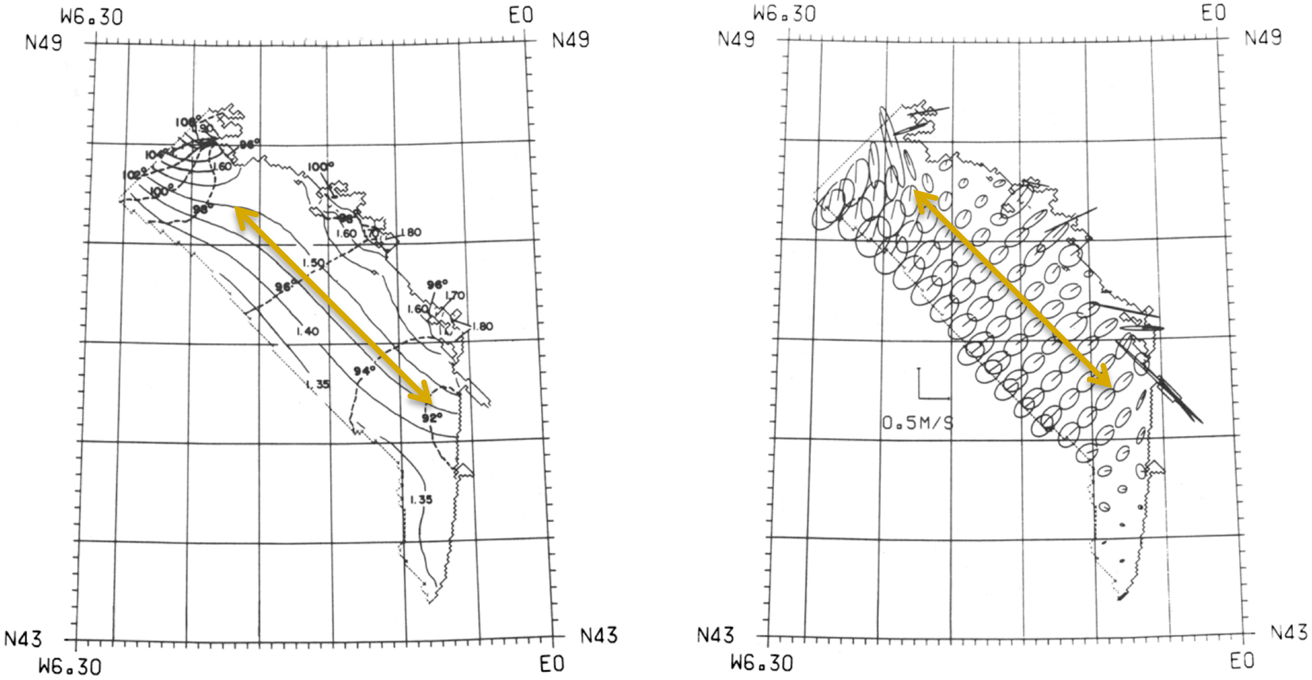


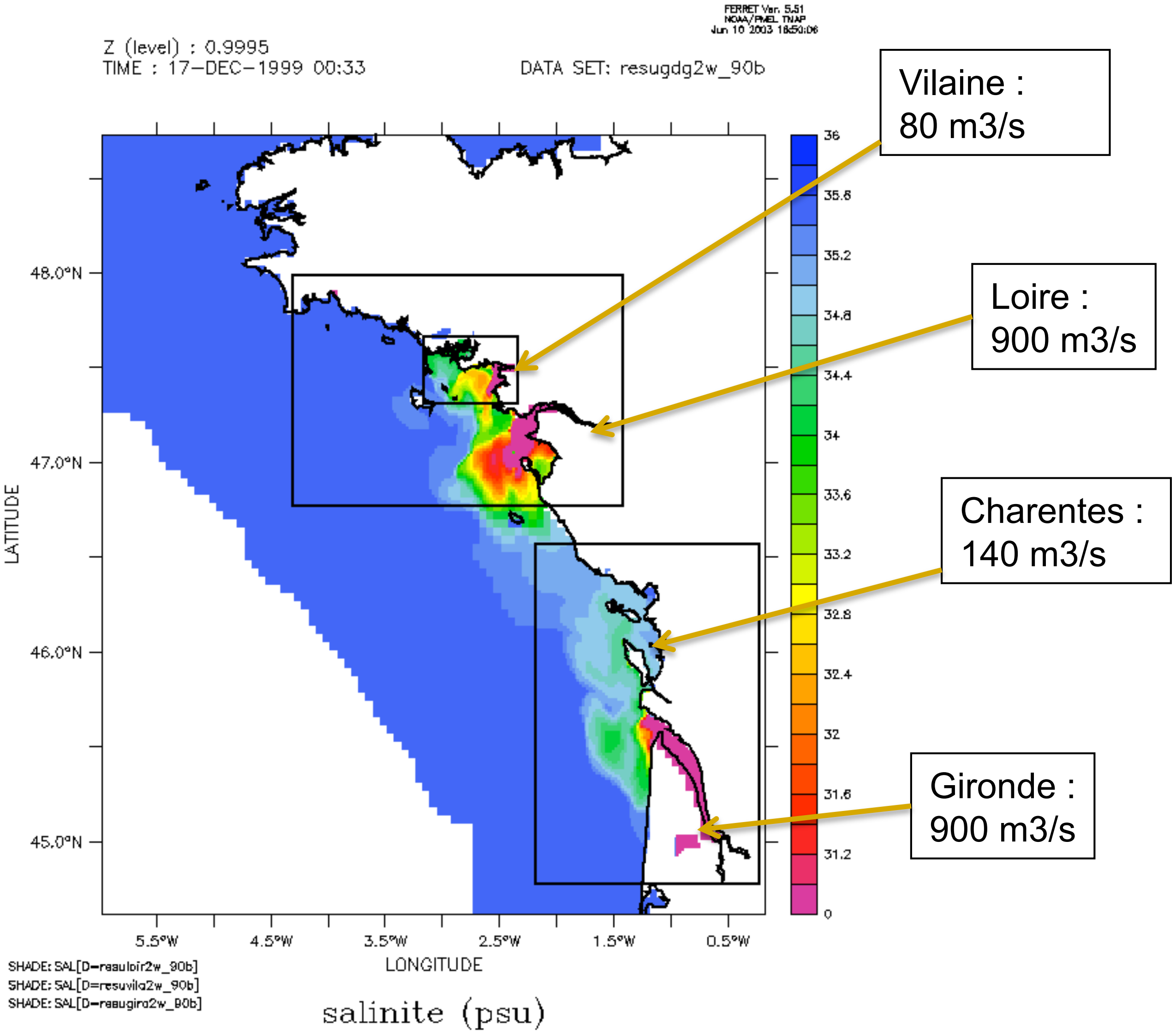
Fig. 7. (a) Computed M_2 amplitudes (m) (solid line) and M_2 phases (°g) (dashed lines). (b) Computed M_2 ellipses.

- M2 amplitude 130/160 cm
- M2 currents order of magnitude 20 cm/s

•Homogeneity of these features in the along shore direction

From Le Cann, CSR, 1990

Larg river discharges and wide river plumes



Vilaine :
80 m3/s

Loire :
900 m3/s

Charentes :
140 m3/s

Gironde :
900 m3/s

Typical drifter behavior

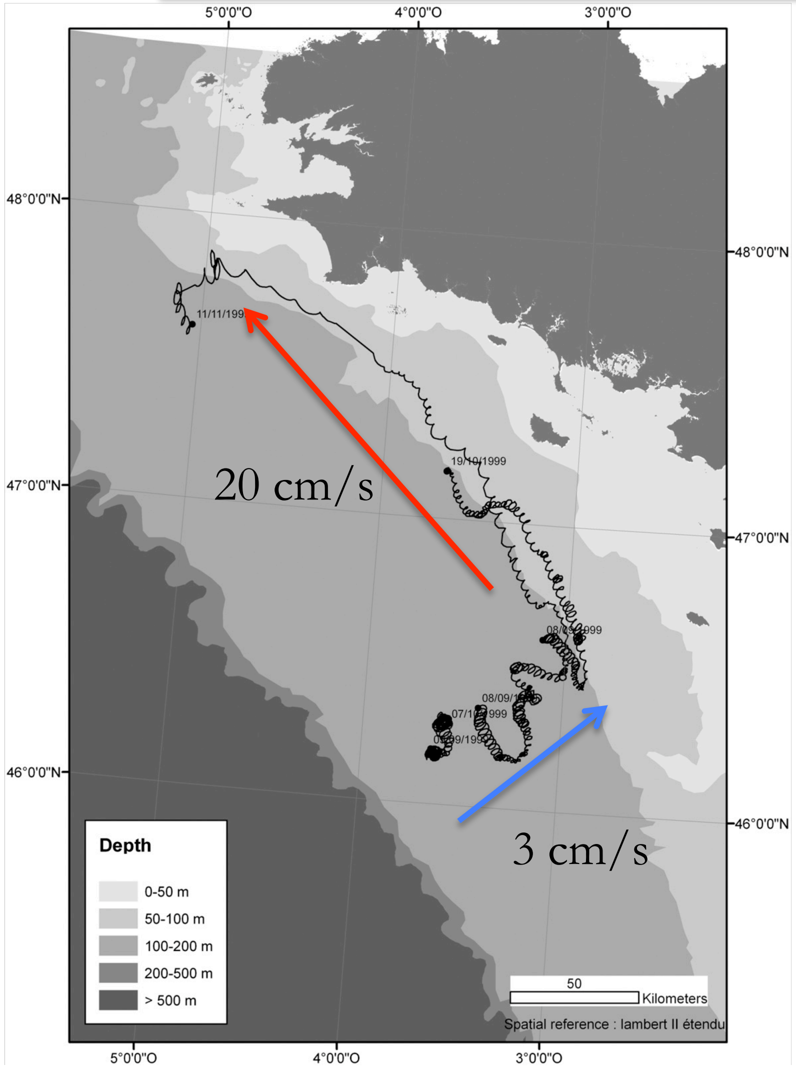
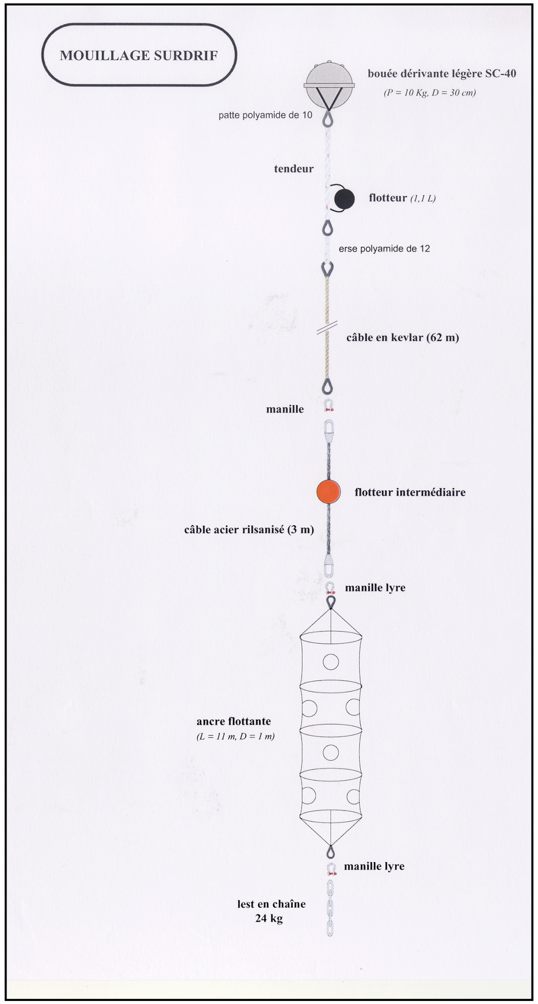


Fig. 3. Trajectories of the three drifters drogued at 65 m in 1999.

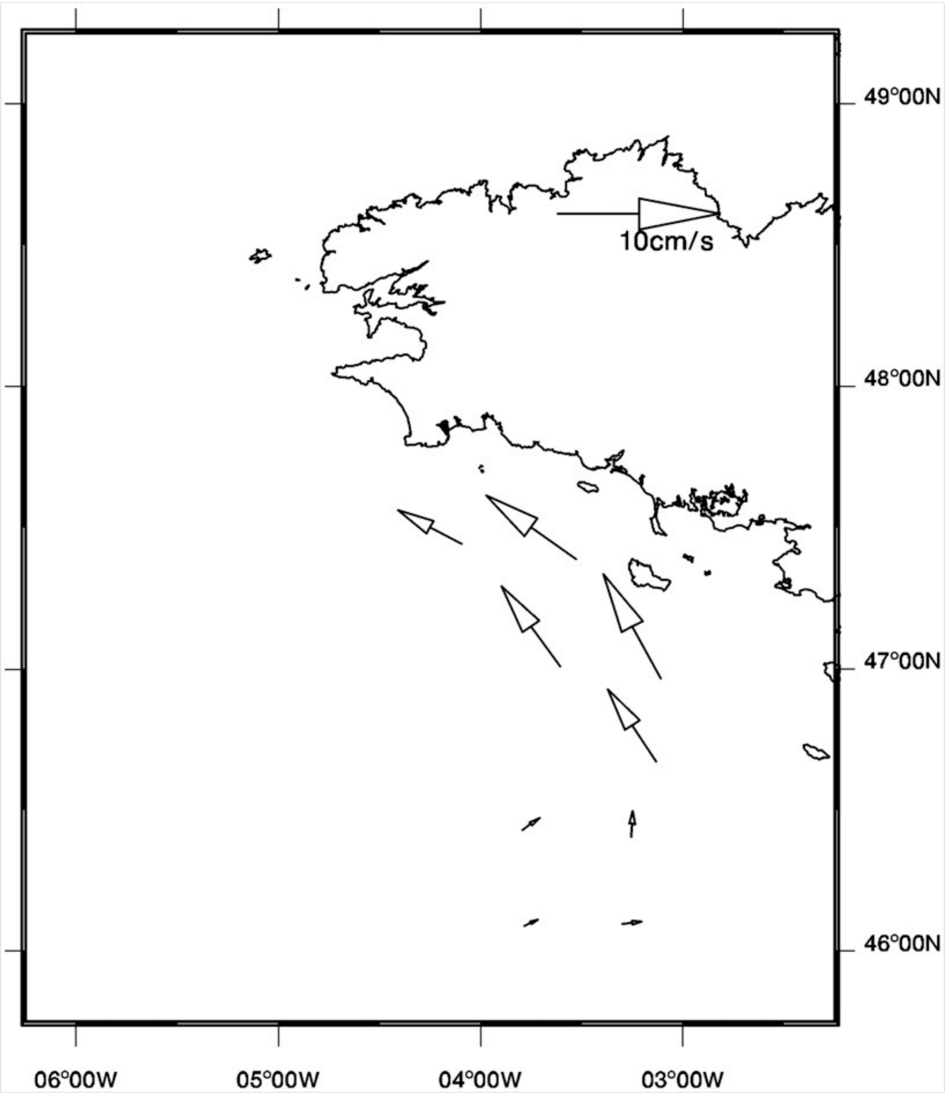
- Satellite tracked buoys (ARGOS)
- GPS localised
- Drogued at 50 m (below Ekman layer : no straight wind influence).
- Repeated observations over years according the same protocol :

1. Three drifters dropped along the same cross-shelf section (190m , 150m, 90m)
2. in the first fortnight of September
3. Drogued below the Ekman layer

- Slow movement of the offshore drifter
- On shore movement of 3 cm/s
- Around 100m isobath : 20 cm/s



Current Climatology from drifter data



Climatology of residual current computed from the drifters track :

- 1998/2003
- 15 September/early November
- 0.5°x 0.5° boxes
- Detided currents (Demerliac filter, low pass filter)
- 730 drifter.day
-

- A climatological poleward currents of about 10 cm/s-1
- located on the 100 m

Hydrological structure over the shelf

The geostrophic balance may be written

$$-f.v_g = -\frac{\partial P}{\partial x}$$

$$f.u_g = -\frac{\partial P}{\partial y}$$

And combining these relations with hydrostatic balance

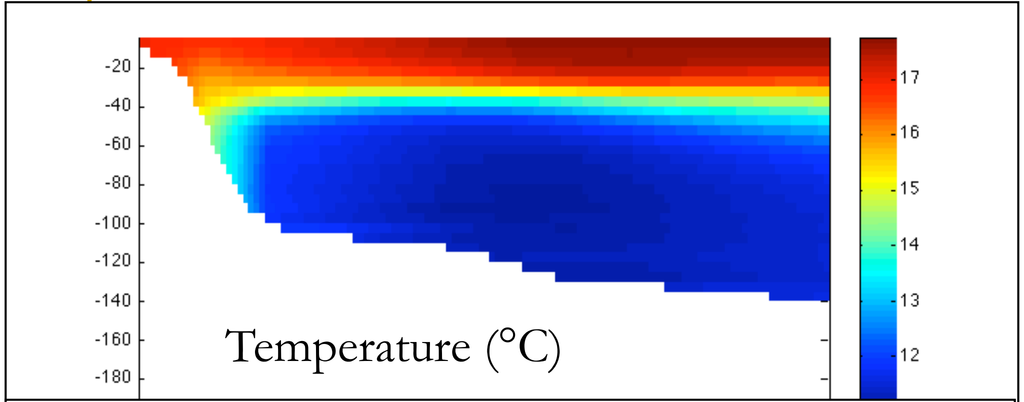
$$\frac{\partial P}{\partial z} = b$$

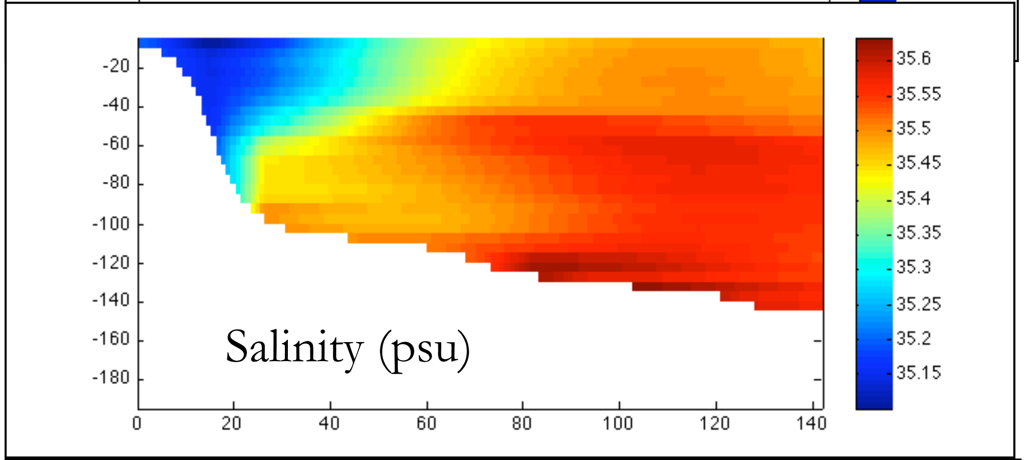
gives

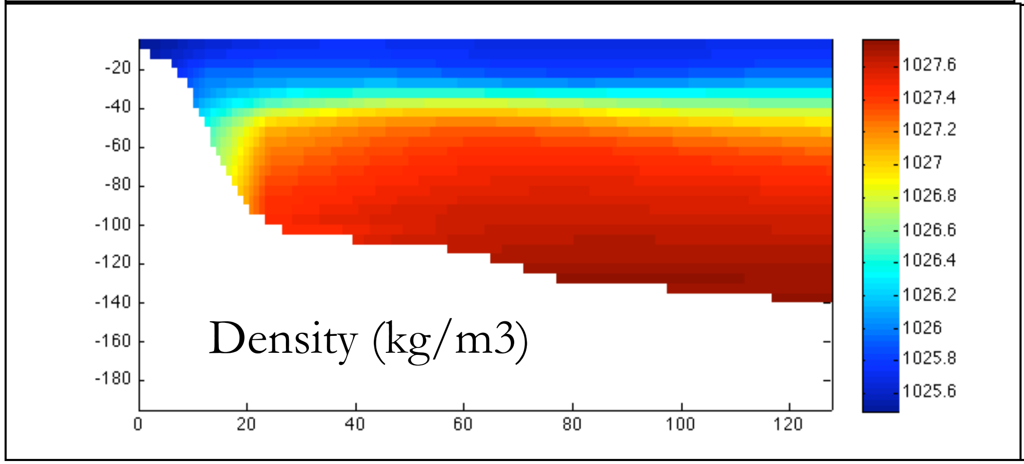
$$-f\frac{\partial v_g}{\partial z} = -\frac{\partial b}{\partial x}$$

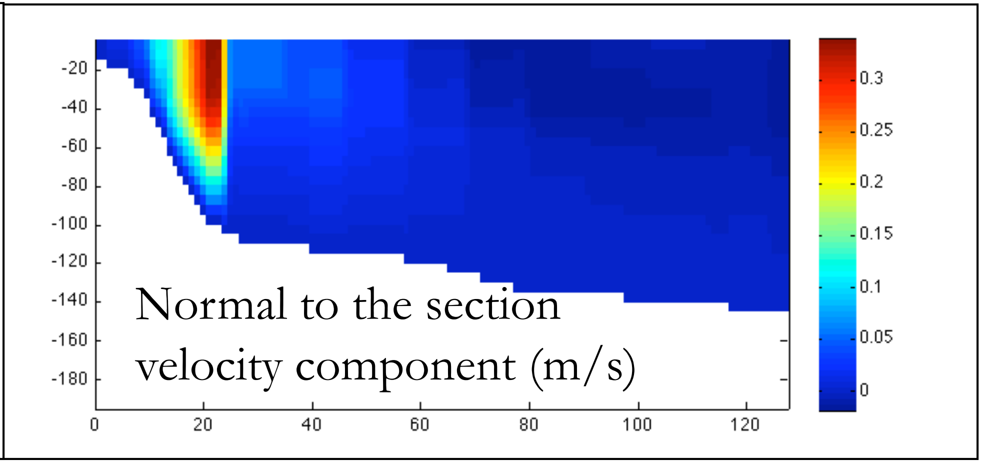
$$f\frac{\partial u_g}{\partial z} = -\frac{\partial b}{\partial y}$$

Reference null, velocity at the bottom, Hill, JMR 1996.


Temperature (°C)

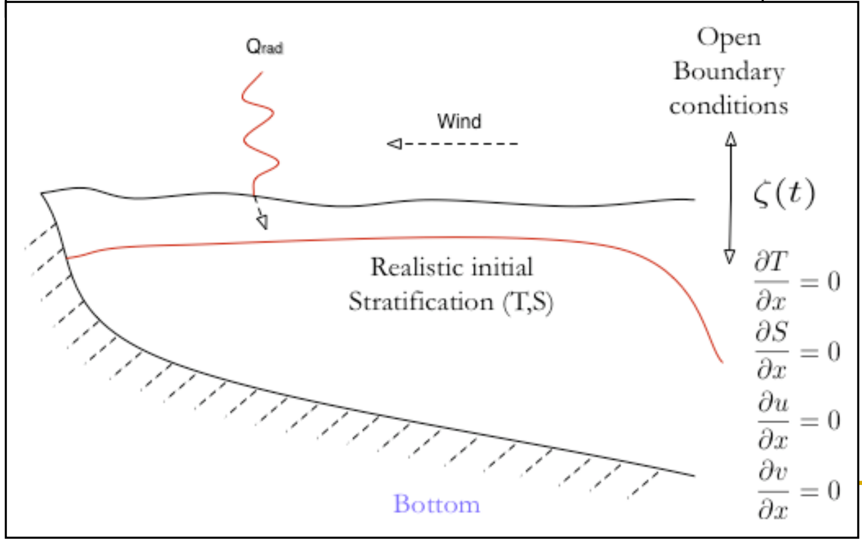

Salinity (psu)


Density (kg/m3)


Normal to the section velocity component (m/s)

2DV approximation model

$$
\begin{aligned}
\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + w\frac{\partial u}{\partial z} - fv - \frac{\partial}{\partial z}\nu\frac{\partial u}{\partial z} &= -\frac{\partial p}{\partial x} \\
\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + w\frac{\partial v}{\partial z} + fu - \frac{\partial}{\partial z}\nu\frac{\partial v}{\partial z} &= -\frac{\partial p}{\partial y} \\
\frac{\partial u}{\partial x} + \frac{\partial w}{\partial z} &= 0 \\
\frac{\partial T}{\partial t} + u\frac{\partial T}{\partial x} + w\frac{\partial T}{\partial z} - \frac{\partial}{\partial z}\nu\frac{\partial T}{\partial z} &= Q \\
\frac{\partial S}{\partial t} + u\frac{\partial S}{\partial x} + w\frac{\partial S}{\partial z} - \frac{\partial}{\partial z}\nu\frac{\partial S}{\partial z} &= 0
\end{aligned}
$$



- 2DV :
  - Horizontal resolution 1km
  - Vertical resolution 30 vertical sima layers
  - Realistic Bathymetry
  - Realistic initial hydrological conditions (extracted from climatology) and tidal forcing (sea surface harmonic composition from CstFrance Simon et al 2006)
  - Schematic Wind (stationnary and homogeneous over the period) and Thermal fluxes (idem + only surface fluxes i.e. no radiative part)

Main features of the model (Lazure et Dumas, ADW 2008)

- Primitive equation model
- Horizontal and vertical Arakawa C grid
- Generalised sigma coordinate (Song and Haidvogel JCP 1994)
- Mode splitting
- Evolved ADI temporal scheme to treat the barotropic mode
- Quick advection scheme (momentum)
- Ultimate quickest Macho tranport scheme
- Bancs découvrants
- TKE turbulent closure scheme (with the double turbulent length scale of Bougeault and Lacarrère, MWR 1989)
- Non linear seawater equation of state (MELLOR, 1985).

Main features of the 3D Configuration

- Horizontal resolution 4 km
- 50 vertical sigma layers (streched to keep resolution in thermocline)
- Realistic met forcings from french Met office Analysis
- Realistic river discharges
- Global model (ORCA-B83, 12 km resolution) solution for initial and open boundary conditions
- Solution over 1998-2007 is analysed
- Intensive validation : comparison to SST images, climatologies, hydrology. Cf Lazure et al, CSR 2009.

Equations 3D résolues

$$\frac{\partial \zeta}{\partial t}+\frac{\partial Du}{\partial x}+\frac{\partial Dv}{\partial y}+\frac{\partial Dw^*}{\partial \sigma}=0$$

$$\frac{\partial u}{\partial t}+L(u)-fv=-g\frac{\partial \zeta}{\partial x}-\frac{1}{\rho_0}\frac{\partial Pa}{\partial x}+\pi_x+\frac{1}{D}\frac{\partial\left(\frac{nz}{D}\frac{\partial u}{\partial \sigma}\right)}{\partial \sigma}+F_x$$

$$\frac{\partial v}{\partial t}+L(v)+fu=-g\frac{\partial \zeta}{\partial y}-\frac{1}{\rho_0}\frac{\partial Pa}{\partial y}+\pi_y+\frac{1}{D}\frac{\partial\left(\frac{nz}{D}\frac{\partial v}{\partial \sigma}\right)}{\partial \sigma}+F_y$$

$$\pi_x=\frac{\partial}{\partial x}\left[D\int_\sigma^1 b\,\mathrm{d}\sigma\right]+b\left(\sigma\frac{\partial D}{\partial x}-\frac{\partial H}{\partial x}\right) \qquad L(A)=u\frac{\partial A}{\partial x}+v\frac{\partial A}{\partial y}+w^*\frac{\partial A}{\partial \sigma}$$

$$\pi_y=\frac{\partial}{\partial y}\left[D\int_\sigma^1 b\,\mathrm{d}\sigma\right]+b\left(\sigma\frac{\partial D}{\partial y}-\frac{\partial H}{\partial y}\right)$$

Mode barotrope

$$\frac{\partial \zeta}{\partial t} + \frac{\partial D\bar{u}}{\partial x} + \frac{\partial D\bar{v}}{\partial y} = 0$$

$$\frac{\partial \bar{u}}{\partial t} = -g\frac{\partial \zeta}{\partial x} - \frac{1}{\rho_0}\frac{\partial Pa}{\partial x} + \frac{1}{\rho_0 D}(\tau_{sx} - \tau_{bx})$$
$$+ \int_0^1 [fv - L(u) + \pi_x + F_x]\mathrm{d}\sigma$$

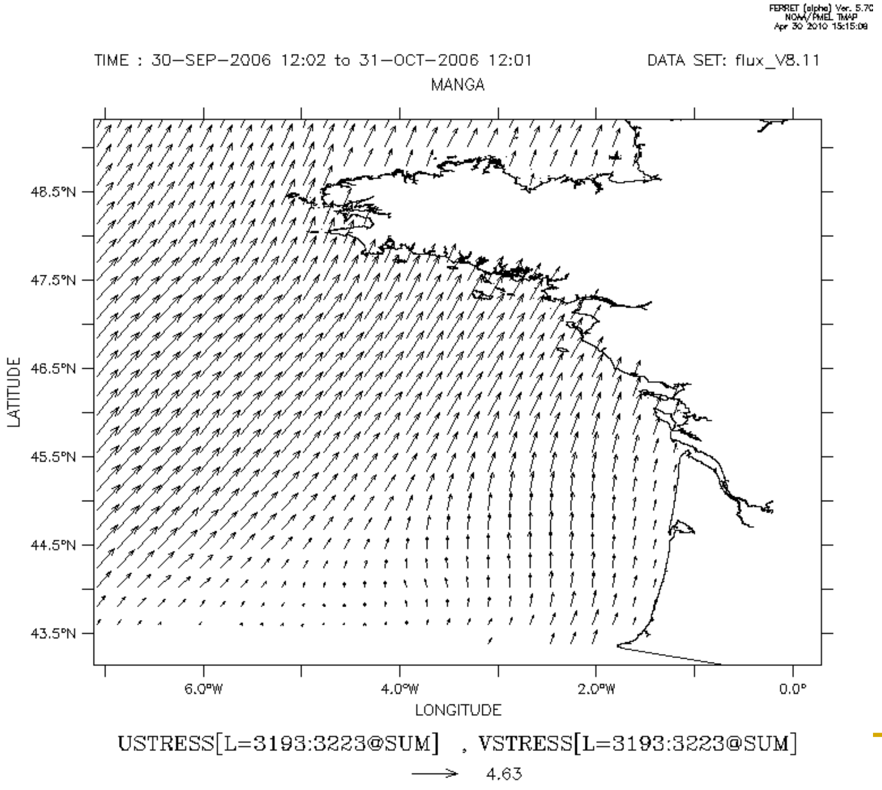
$$\frac{\partial \bar{v}}{\partial t} = -g\frac{\partial \zeta}{\partial y} - \frac{1}{\rho_0}\frac{\partial Pa}{\partial y} + \frac{1}{\rho_0 D}(\tau_{sy} - \tau_{by})$$
$$+ \int_0^1 [-fu - L(v) + \pi_y + F_y]\mathrm{d}\sigma$$

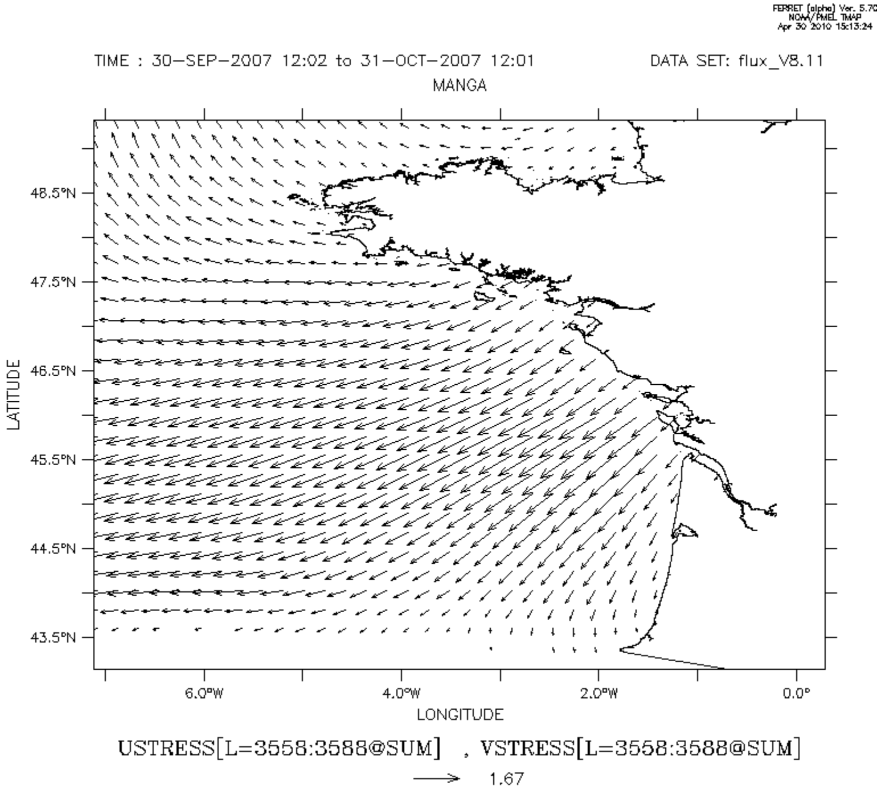
$$G_u = \sum_{k=1}^{k\max}(fvz_k - L(uz_k) + \pi_{xk} + F_{xk})\Delta\sigma_k$$
$$+ \frac{\tau_{sx}}{\rho_0 D_u} - \frac{\tau_{bx}}{\rho_0 D_u} - \frac{1}{\rho_0}\frac{\partial P_a}{\partial x}$$

$$G_v = \sum_{k=1}^{k\max}(-fuz_k - L(vz_k) + \pi_{yk} + F_{yk})\Delta\sigma_k$$
$$+ \frac{\tau_{sy}}{\rho_0 D_v} - \frac{\tau_{by}}{\rho_0 D_v} - \frac{1}{\rho_0}\frac{\partial P_a}{\partial y}$$

Interannual variability : Mean Wind over October 2006 and 2007

$$\|W_{mean}\|^2 = \frac{\sqrt{\left(\frac{1}{T}\int_{t_0}^{t_0+T}\rho_a Cd_s\|\overrightarrow{W}\|W_x\,dt\right)^2 + \left(\frac{1}{T}\int_{t_0}^{t_0+T}\rho_a Cd_s\|\overrightarrow{W}\|W_y\,dt\right)^2}}{\rho_a Cd_s}$$





W_{mean}=8.5 m.s^{-1}

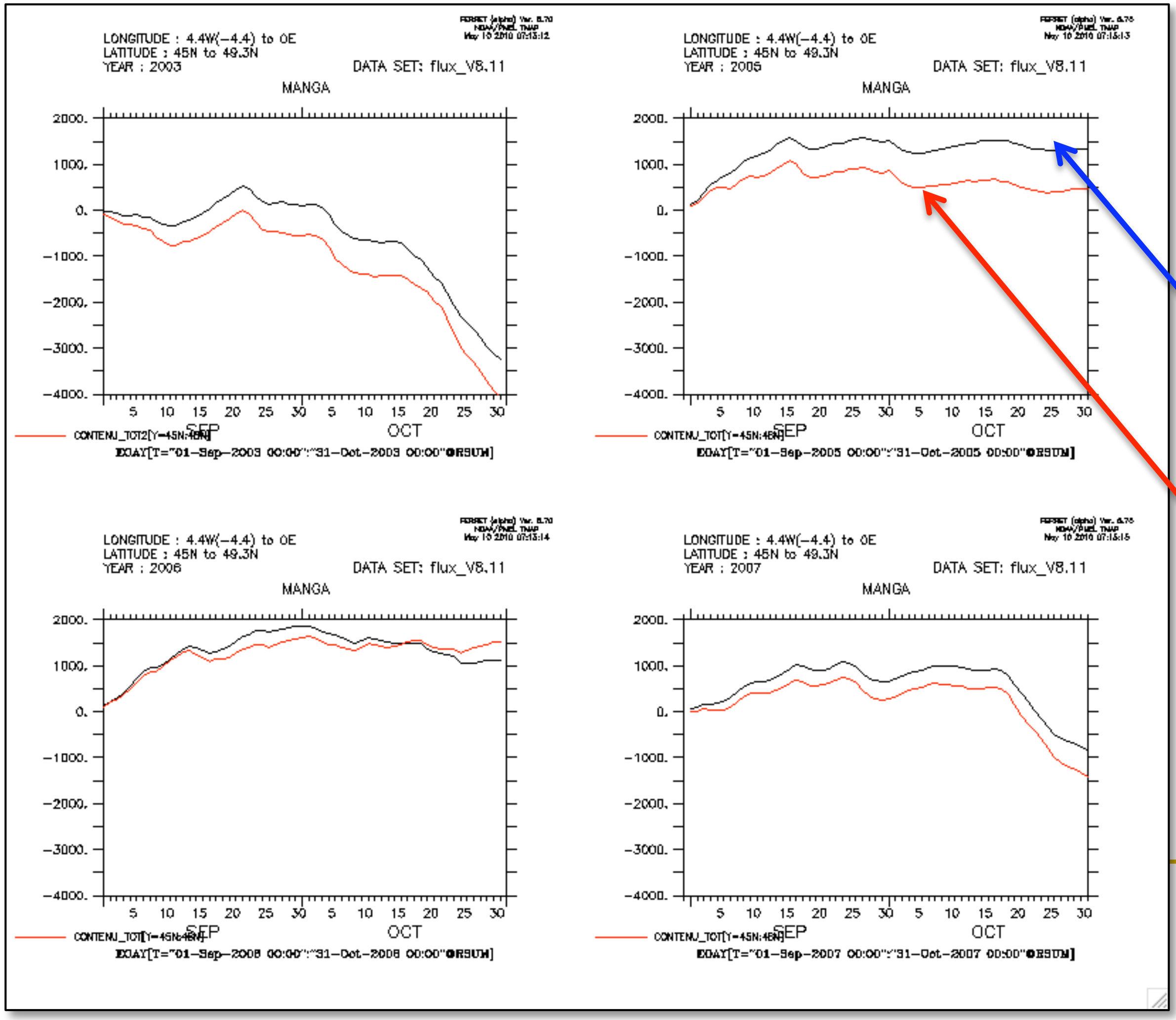
W_{mean}=2.8 m.s^{-1}

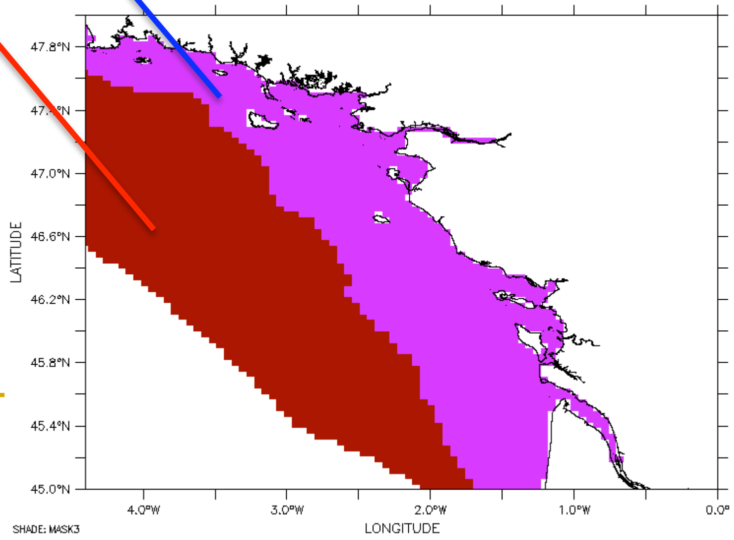
Interannual variability : Cumulated thermal fluxes Sep-Oct

$$Q_{cum} = \sum_i Q_{rad}(t_i) + Q_{IR}(t_i) + Q_{sens}(t_i) + Q_{lat}(t_i)$$

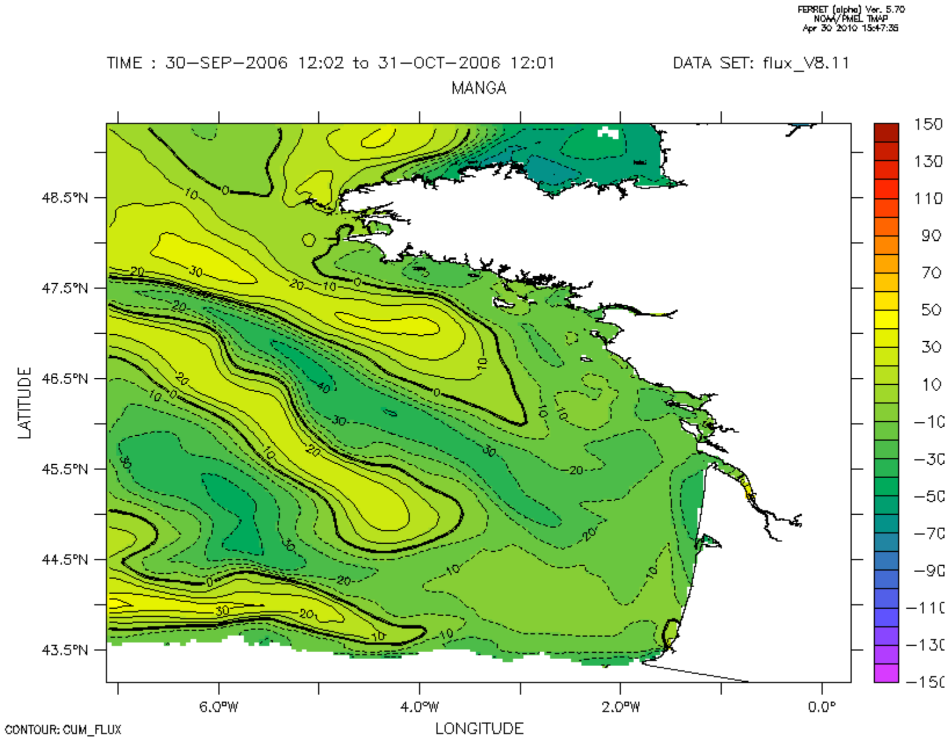
$$Q_{tot} = \frac{Q_{cum}}{n}$$

- No systematic cooling over that period
- 2003 : Q_{tot}=-70W
- Other years -20W < Q_{tot}< 20 W
- No systematic difference between offshore and coastal thermal flux

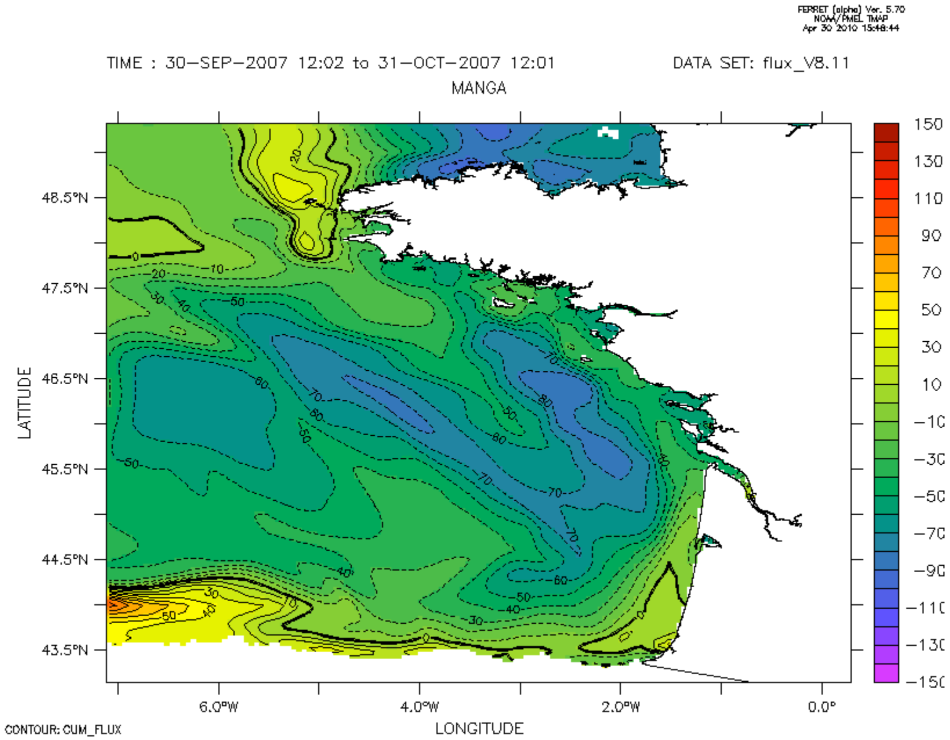




Interannual variability : Mean Thermal fluxes over October 2006 and 2007

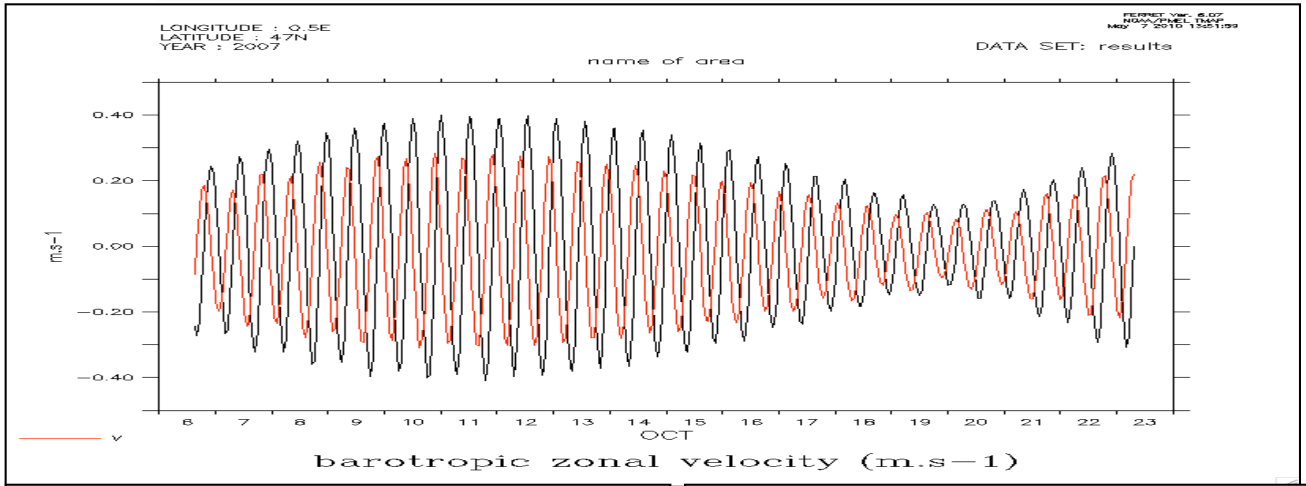


EOA[L=3193:3223@AVE]

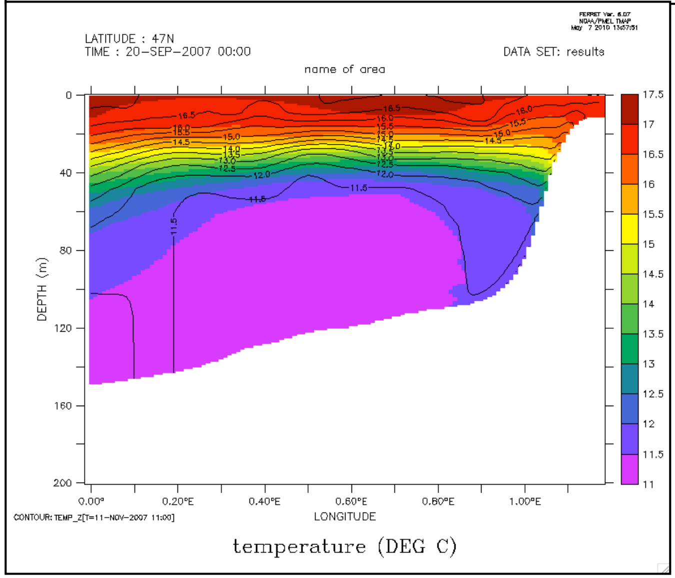


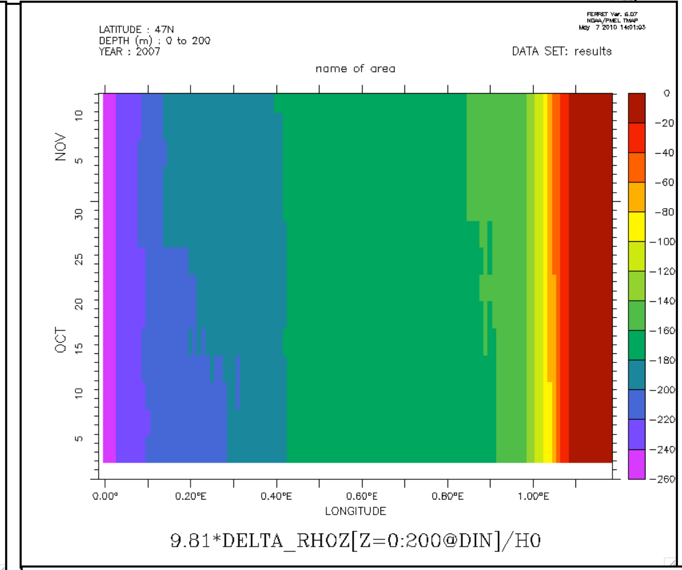
EOA[L=3558:3588@AVE]

Results



Currents are reproduce with the right order of magnitude



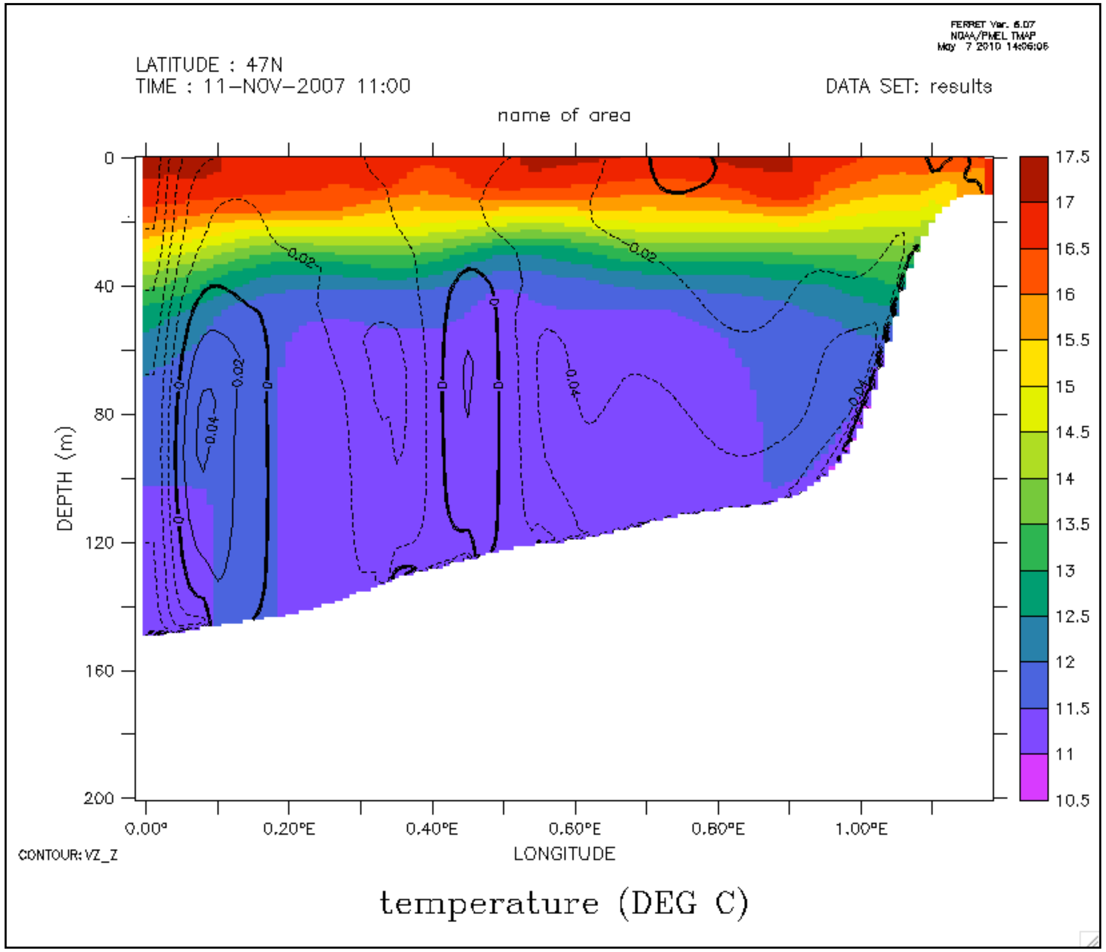


$$APE = \frac{1}{H}\int_{-h}^{\zeta} g(\overline{\rho} - \rho)z\,dz$$

Initial and final Temperature structure

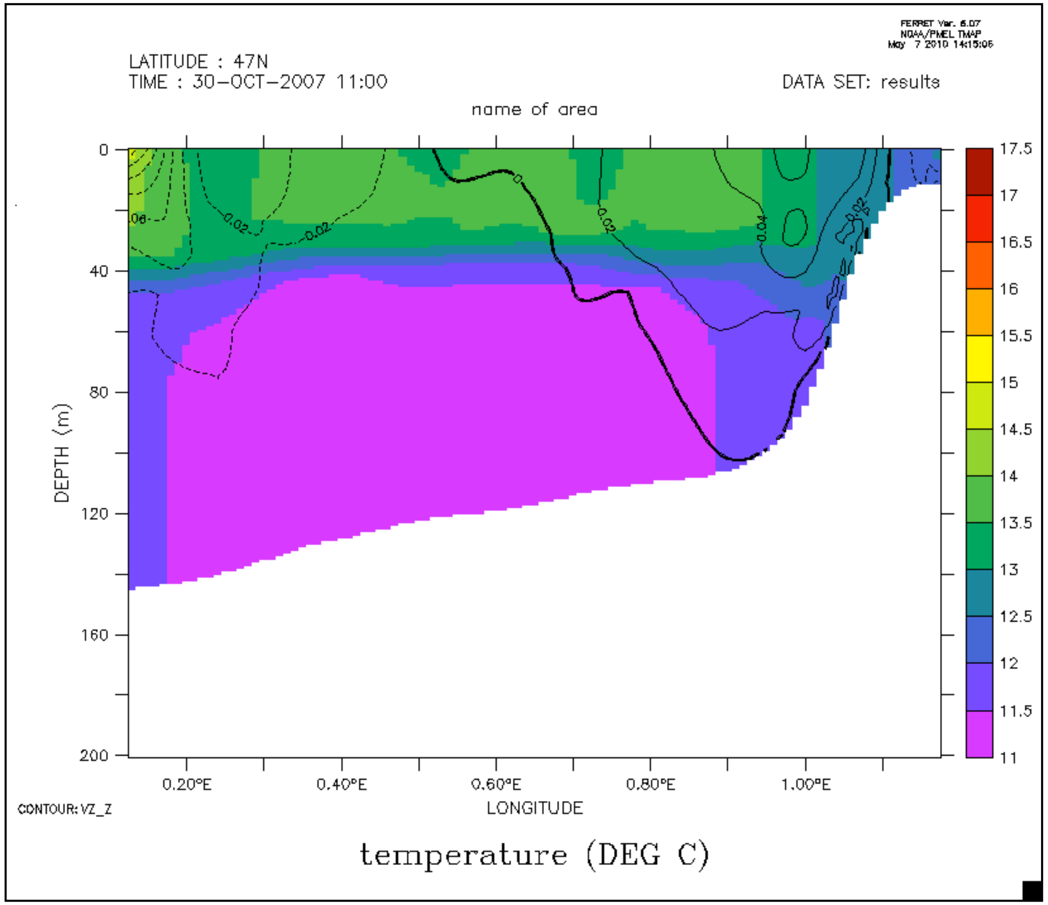
Ovemuller diagram of the Potential energy anomaly

Experience n°1 : tidal mixing



- •Numerical experience conditions :
  - thermal flux set to 0
  - No Wind
  - Realistic tidal forcing
- Results :
  - tidally filtered currents peaks at 4 cm/s
  - no marked bottom front
  - •The tidal mixing is not efficient enough to create a bottom front

Experience n°2 : tidal mixing+negative buoyancy flux

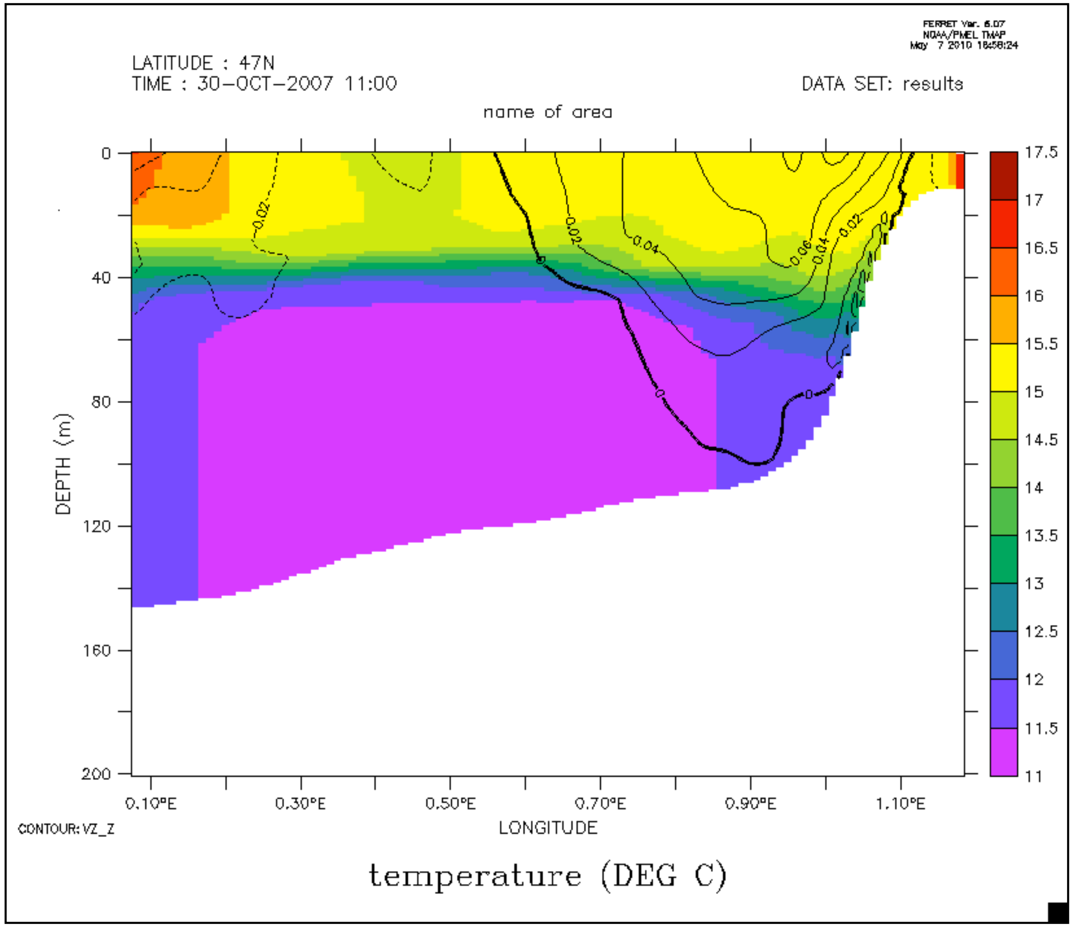


•Numerical experience conditions :

  - thermal flux set to -100 W
  - No Wind
  - Realistic tidal forcing

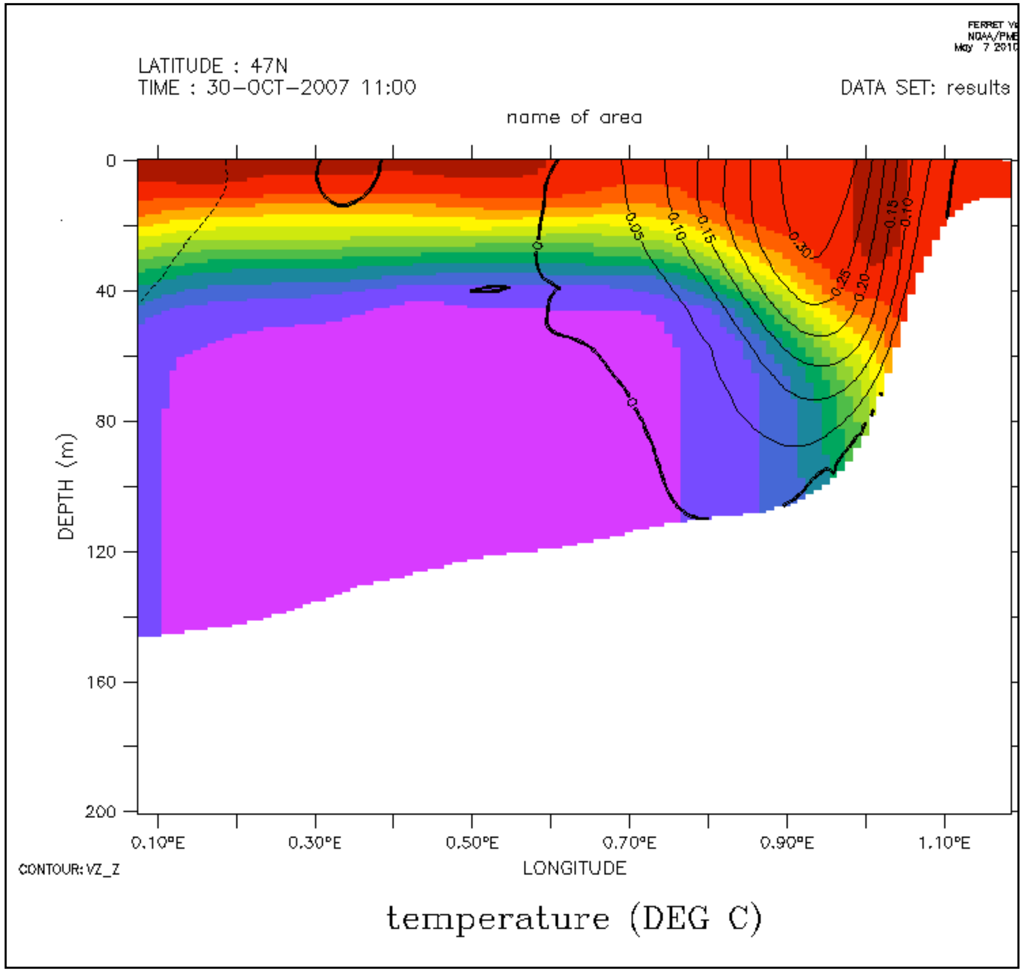
- Results :
  - tidally filtered currents peaks at 4 cm/s
  - no marked bottom front
  - •The tidal mixing together with the negative buoyancy is neither not efficient enough to create a bottom front

Experience n°3 : tidal and wind mixing



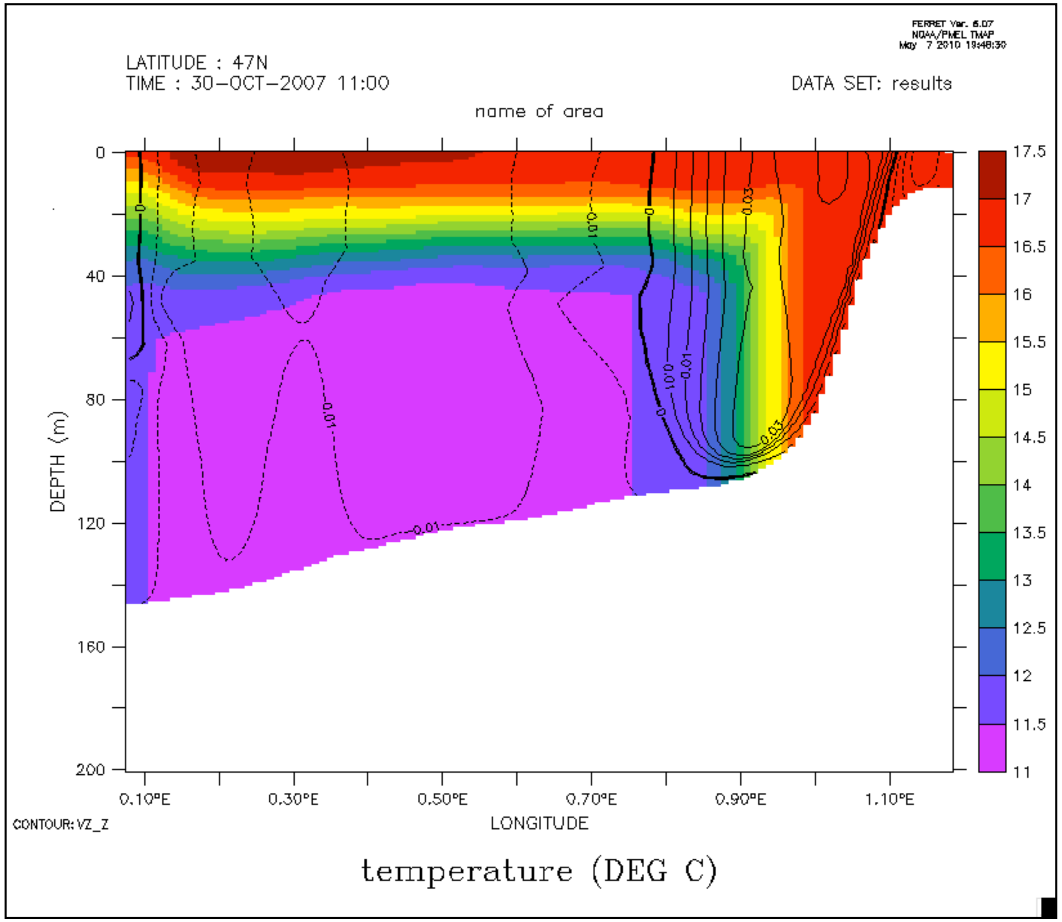
- Numerical experience conditions :
  - thermal flux set to -20 W
  - 15 m/s Wind no incidence
  - Realistic tidal forcing
- Results :
  - tidally filtered currents peaks at 6 cm/s
  - bottom front slightly deeper
  - The tidal mixing, the negative buoyancy associated with strong wind mixing can not afford a sharp bottom front

Experience n°4 : tidal mixing, Ekman transport



- •Numerical experience conditions :
  - thermal flux set to 0 W
  - 5 m/s 40° incidence (downwelling favorable)
  - Realistic tidal forcing
- Results :
  - tidally filtered currents peaks at 35 cm/s
  - marked thermal bottom front
  - •Agree with climatology and

Experience n°4 : tidal mixing, Ekman transport, internal pressure grad

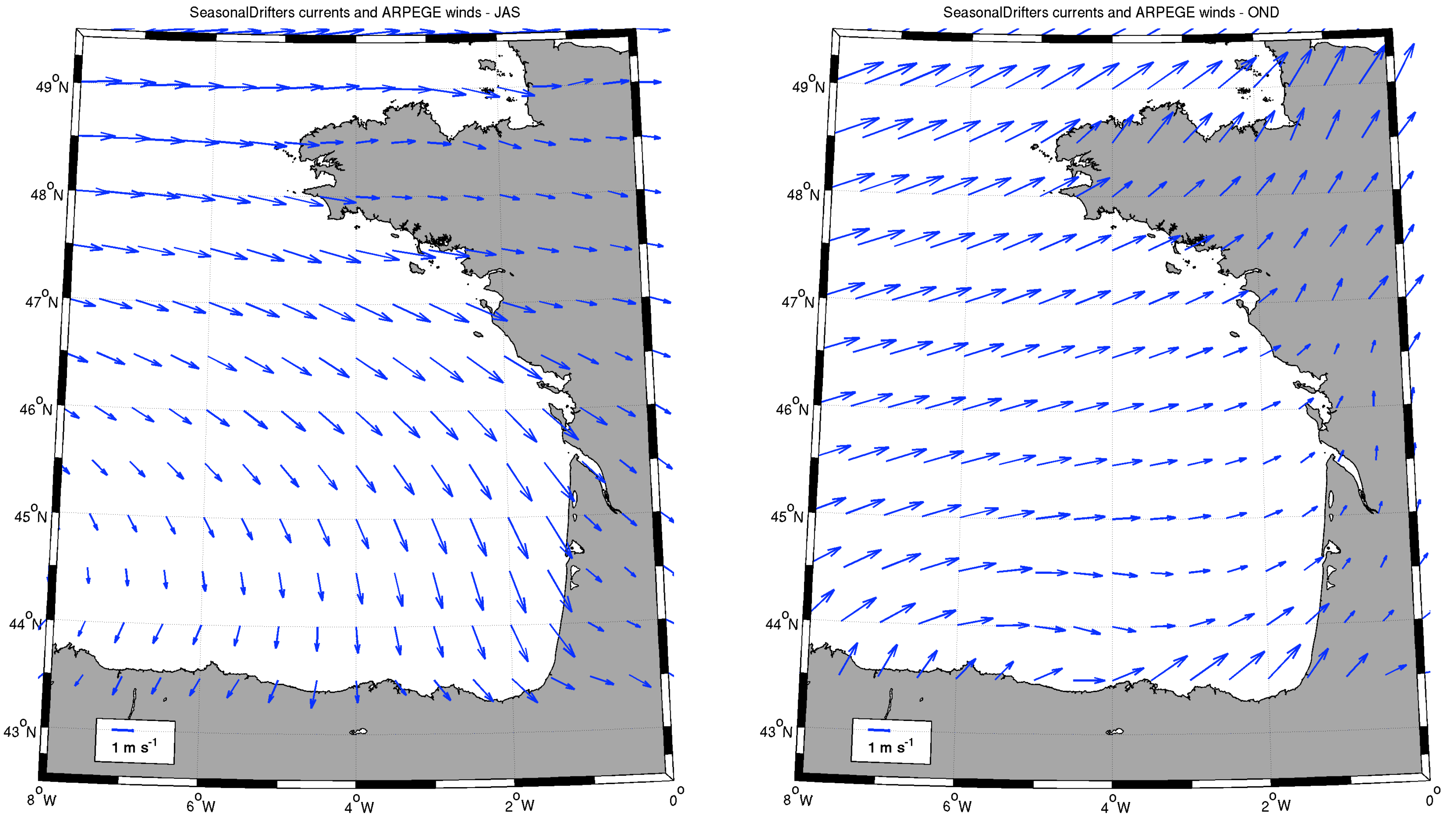


•Numerical experience conditions :

- thermal flux set to 0 W
- 5 m/s 40° incidence (downwelling favorable)
- Realistic tidal forcing
- unplugg internal pressure gradient

- Results :
  - still marked thermal bottom front
  - •But this time tidally filtered current peaks at 4 cm/s

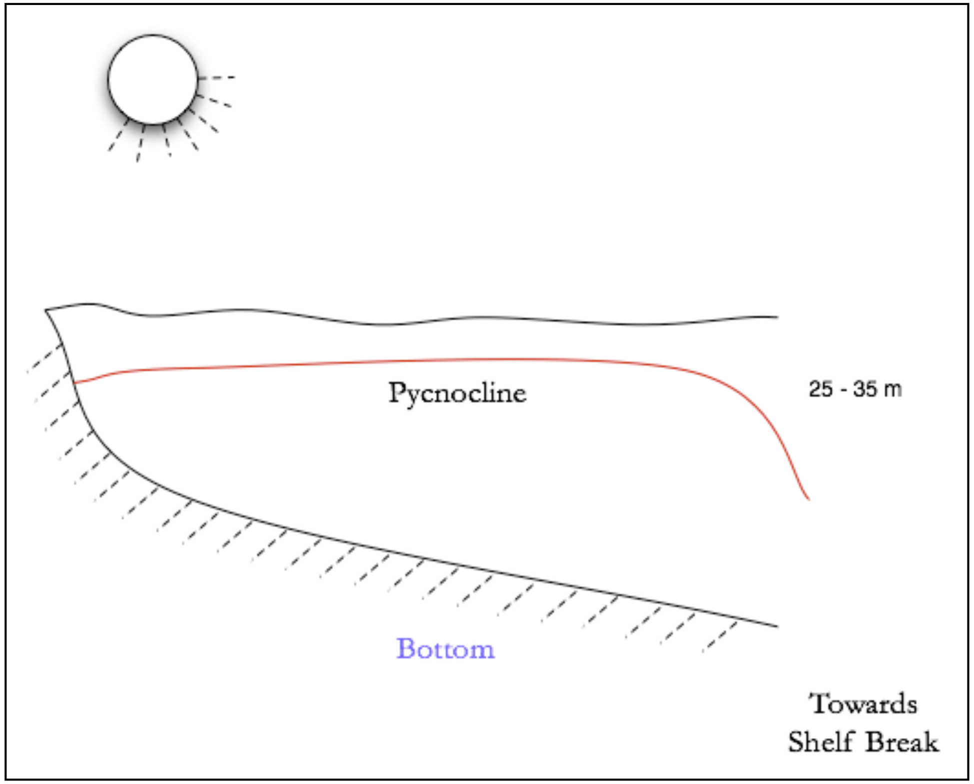
Climatological wind during summer (left) and autumn (right)



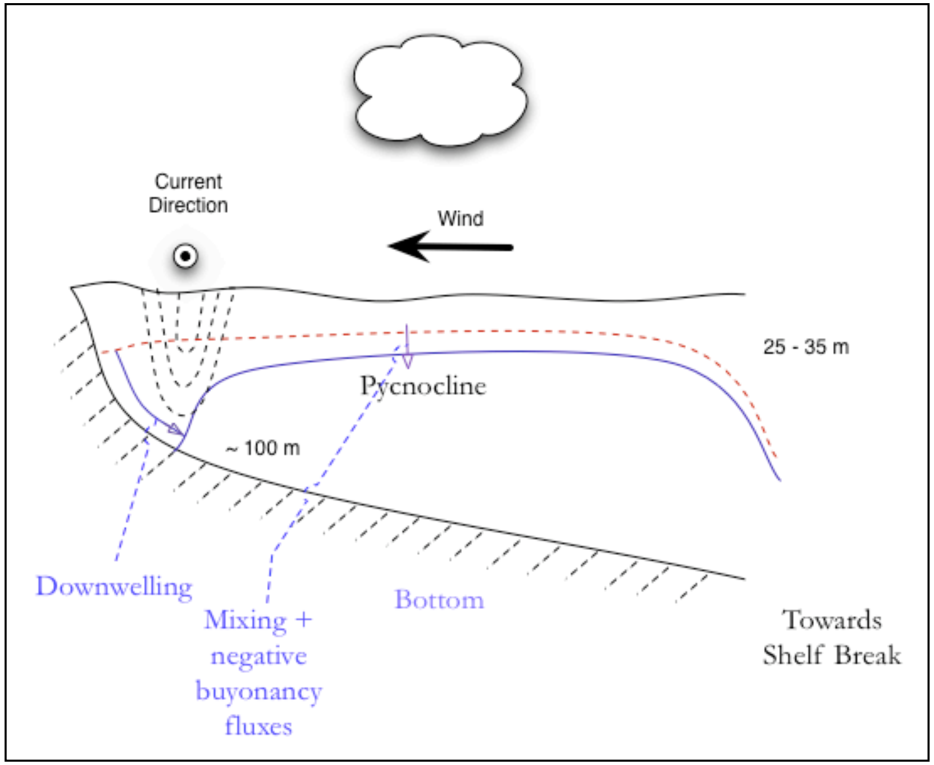
SeasonalDrifters currents and ARPEGE winds - JAS

SeasonalDrifters currents and ARPEGE winds - OND

Phenomelogical description



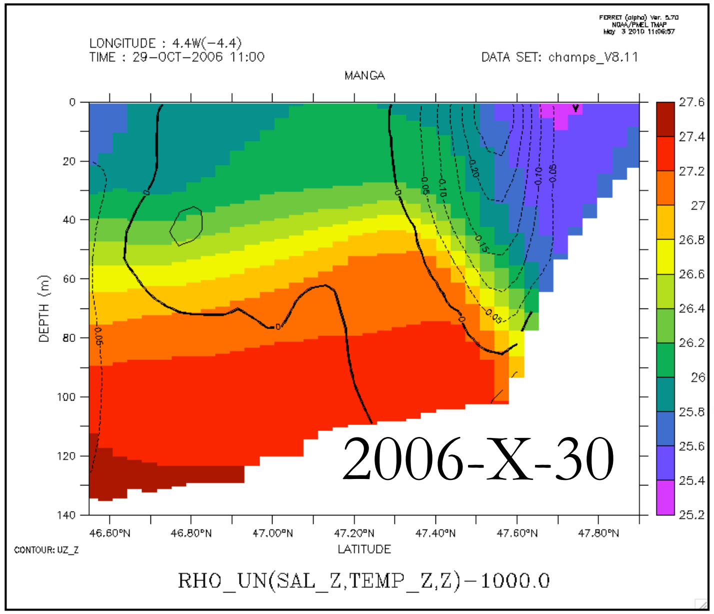
Summer situation

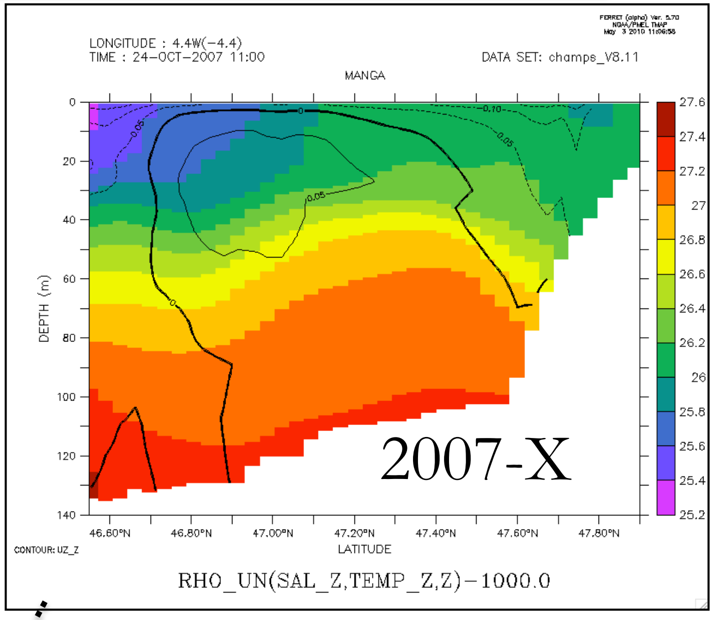


Fall evolution

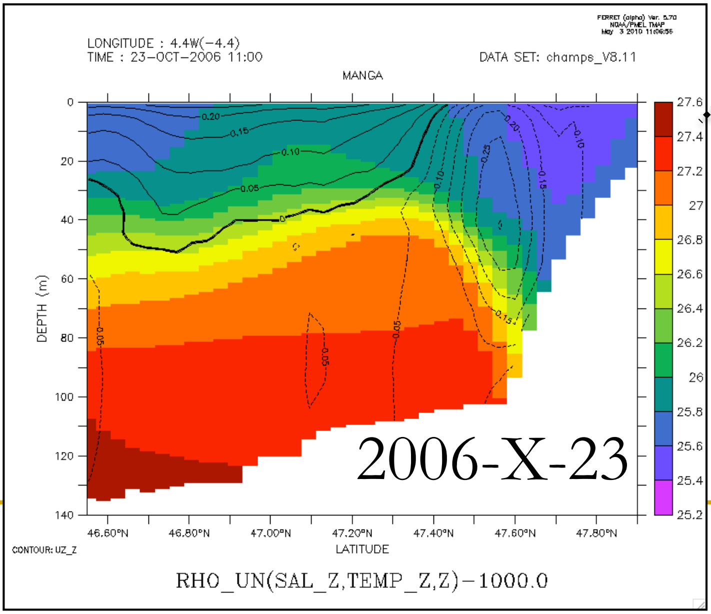
Hydrological and dynamical cross section in the 3D solution

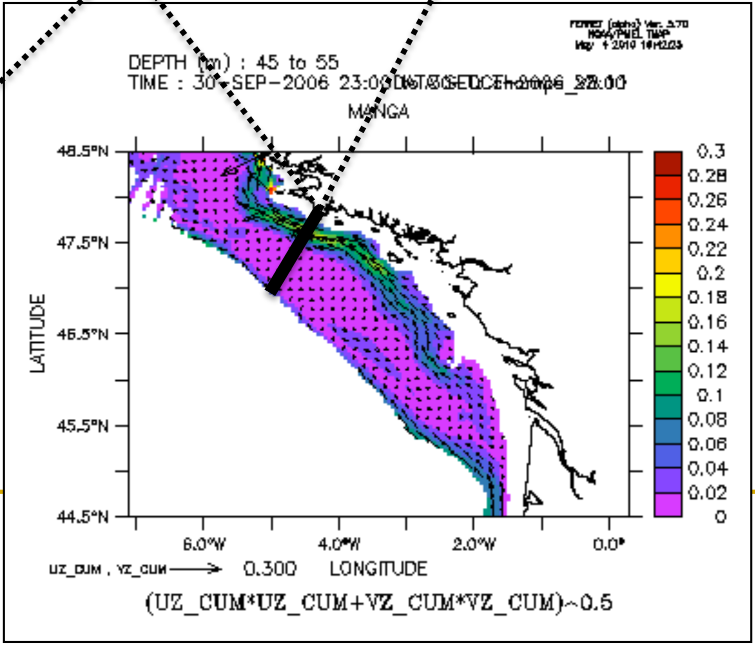
No wind



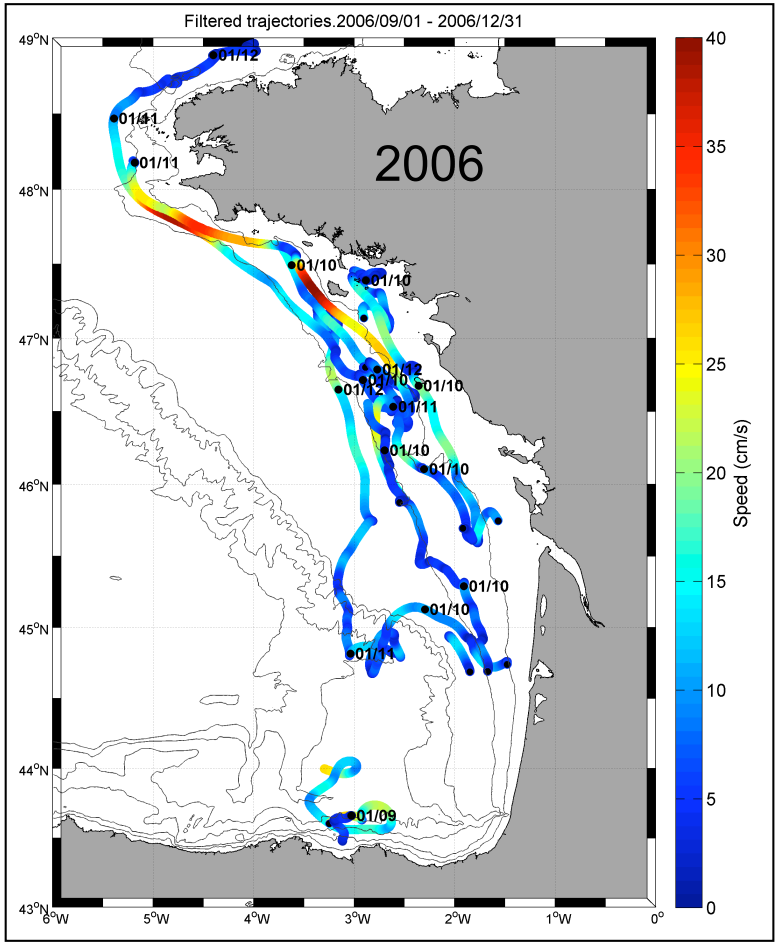


wind

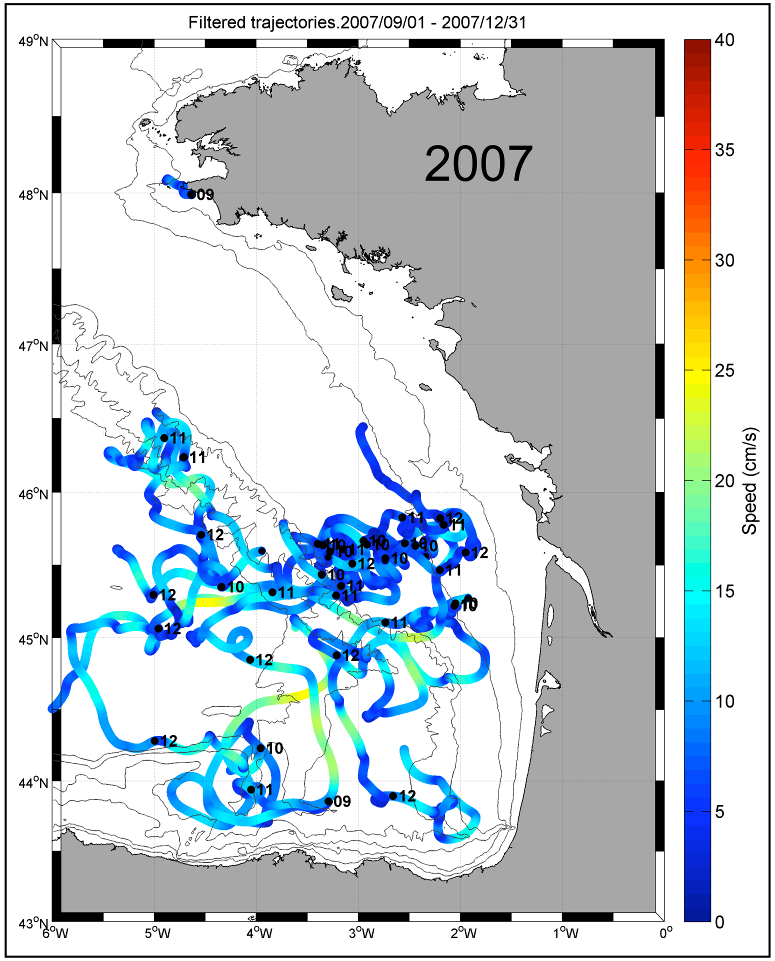




Autumn 2006 contrasted with 2007

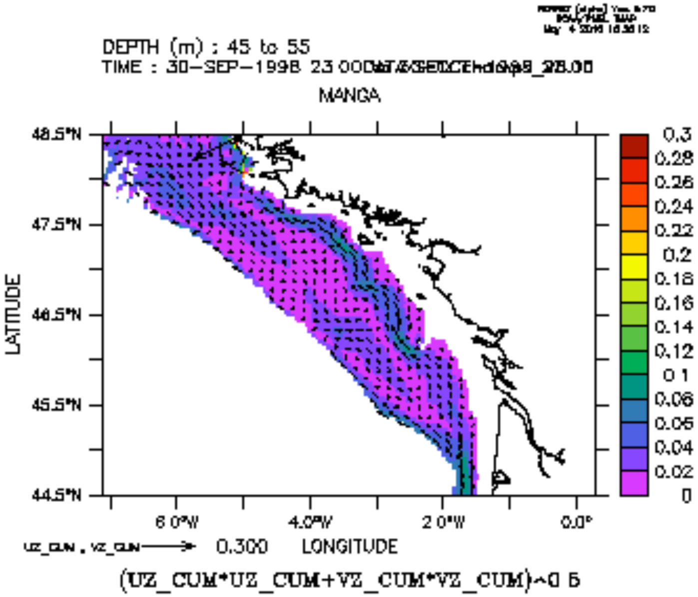


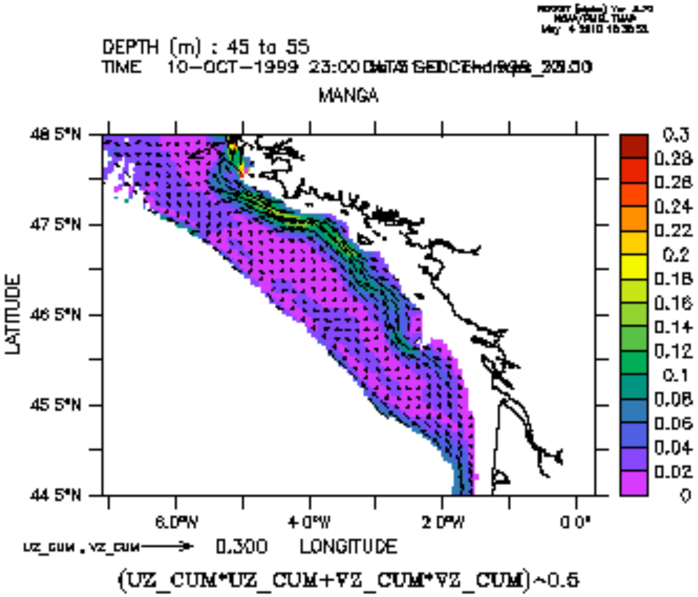
Filtered trajectories.2006/09/01 - 2006/12/31

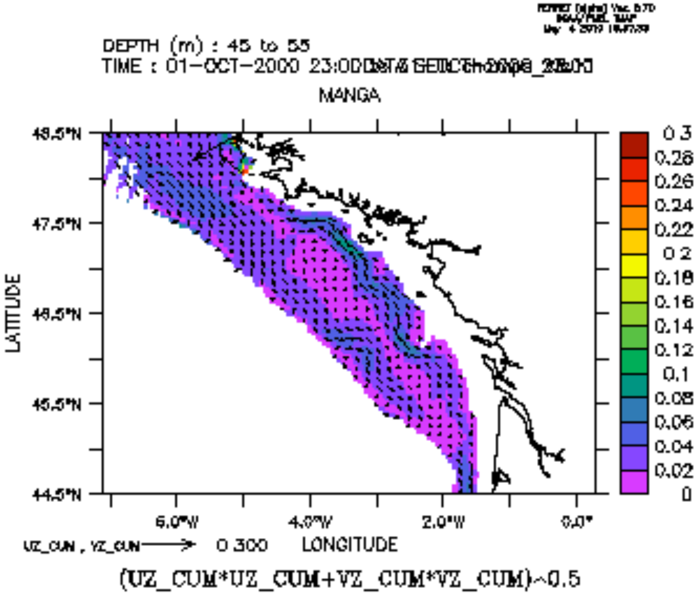


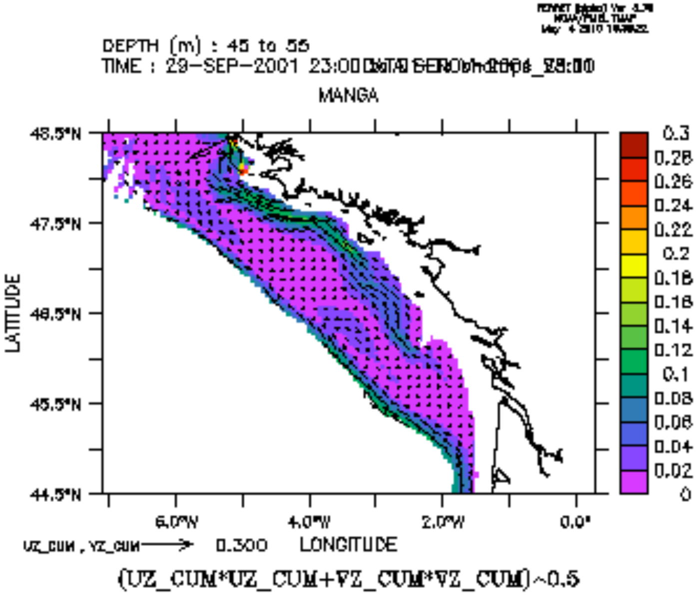
Filtered trajectories.2007/09/01 - 2007/12/31

Mean Current over October from 75m-65m 1999/2001

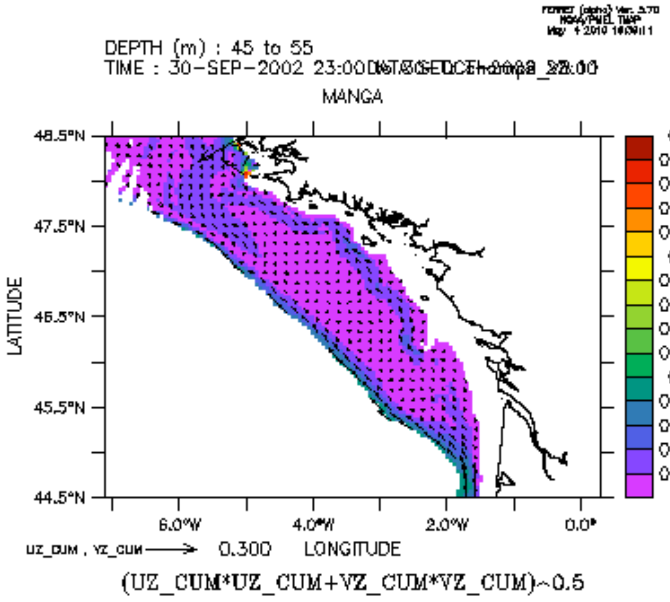


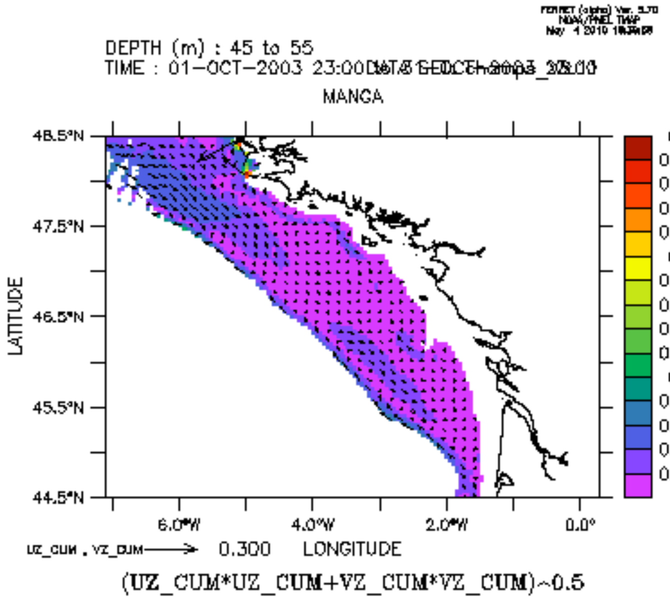


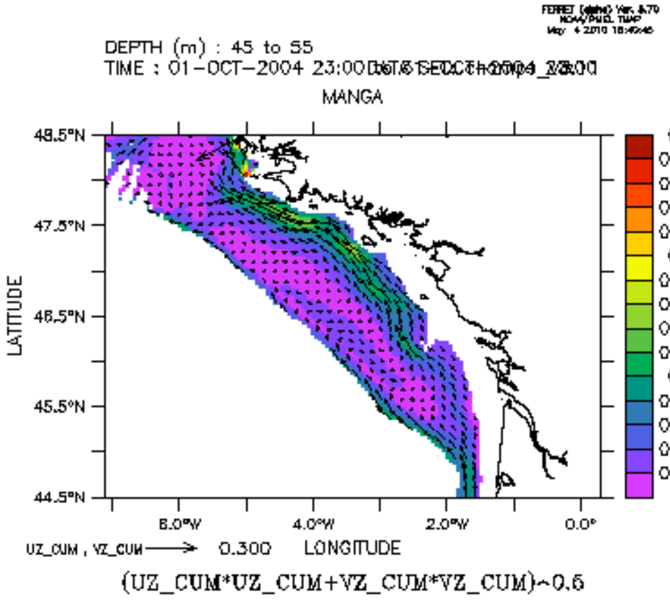


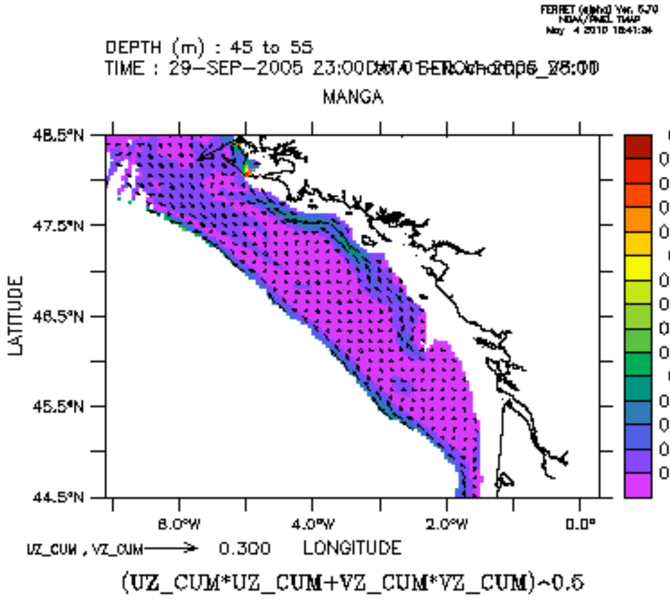


Mean Current over October from 75m-65m 2002/2005

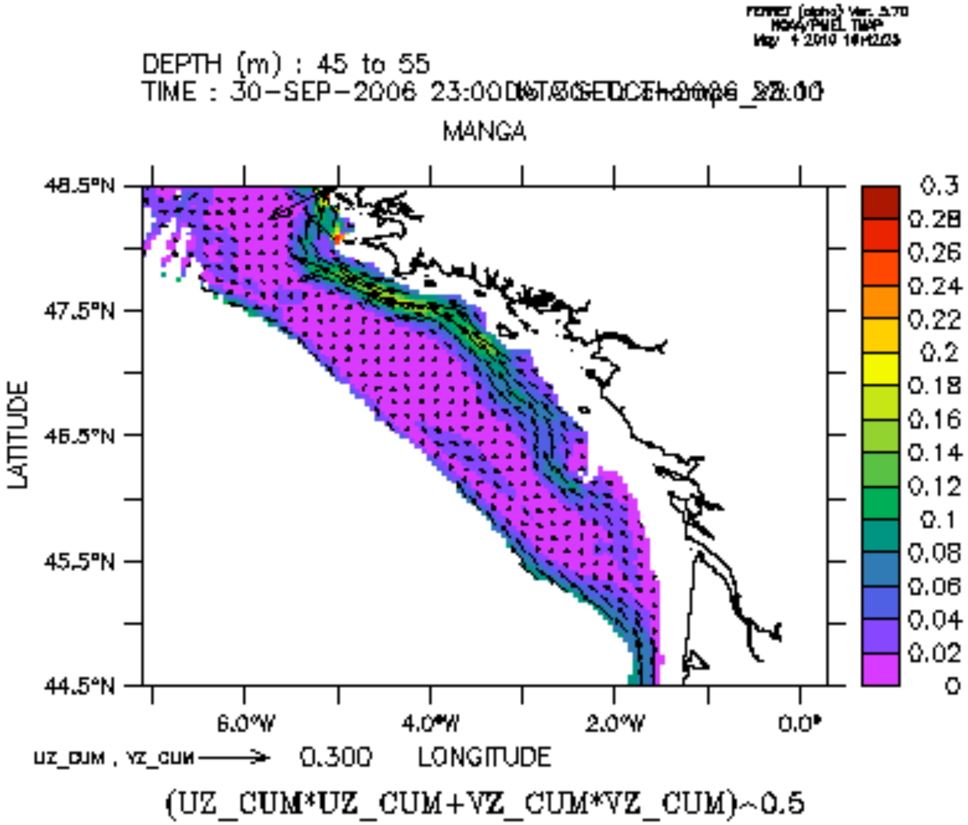


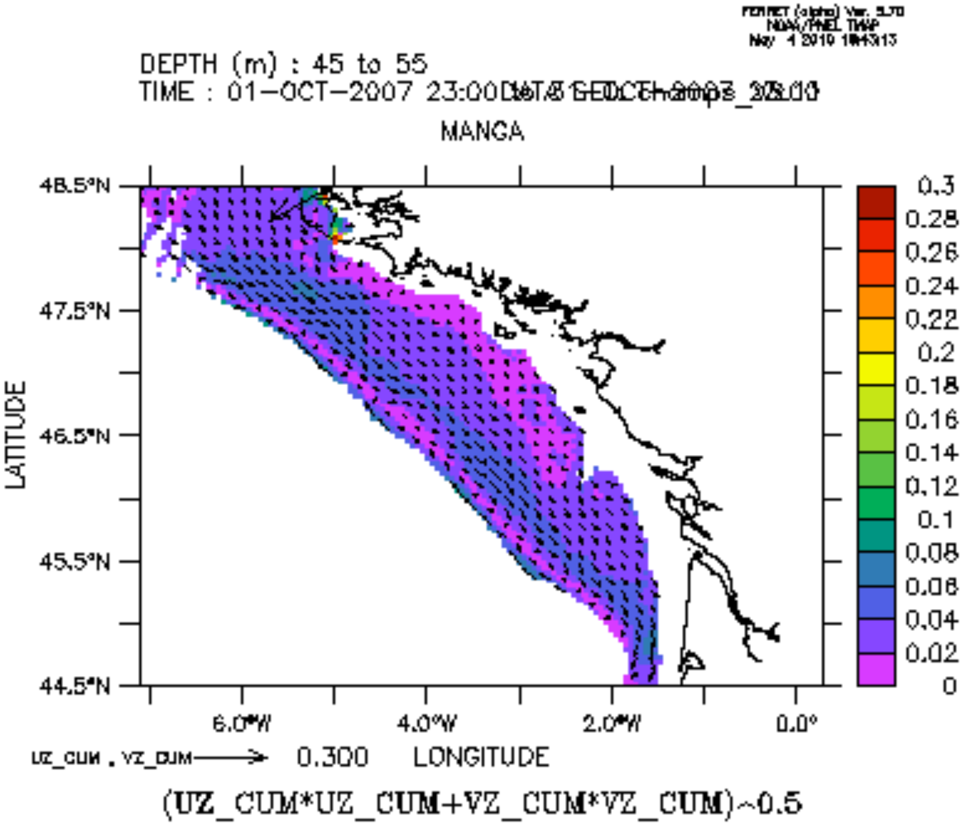




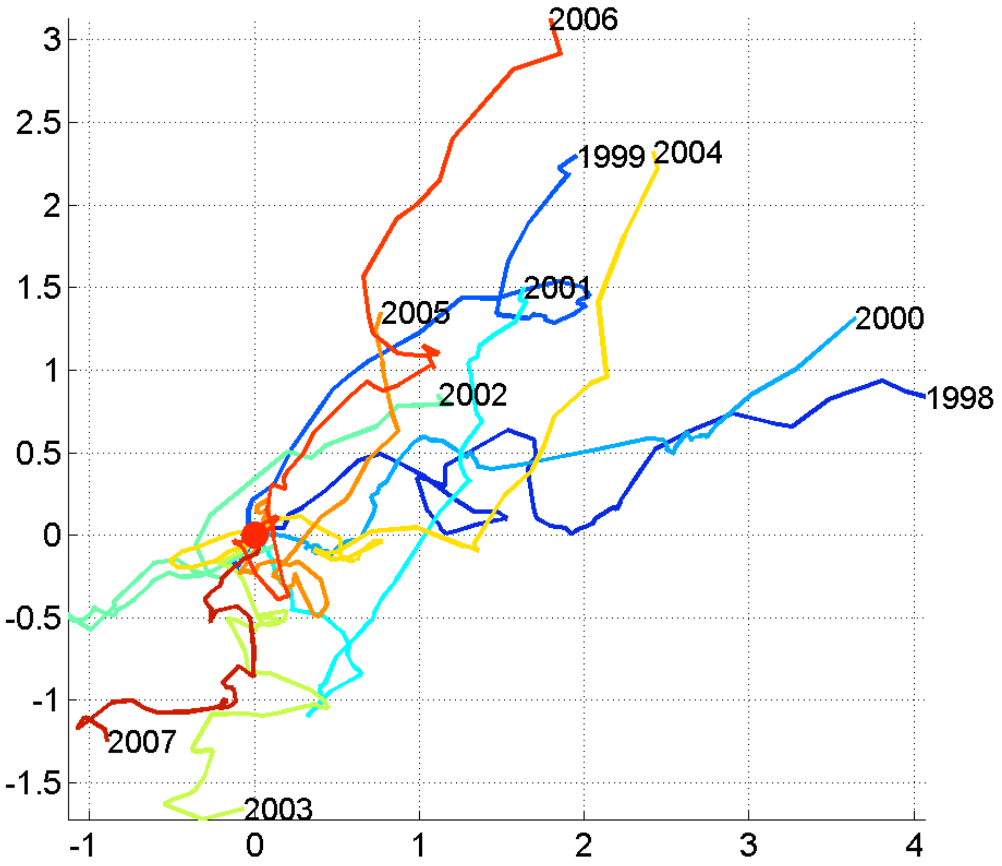


Mean Current over October from 75m-65m 2006/2007



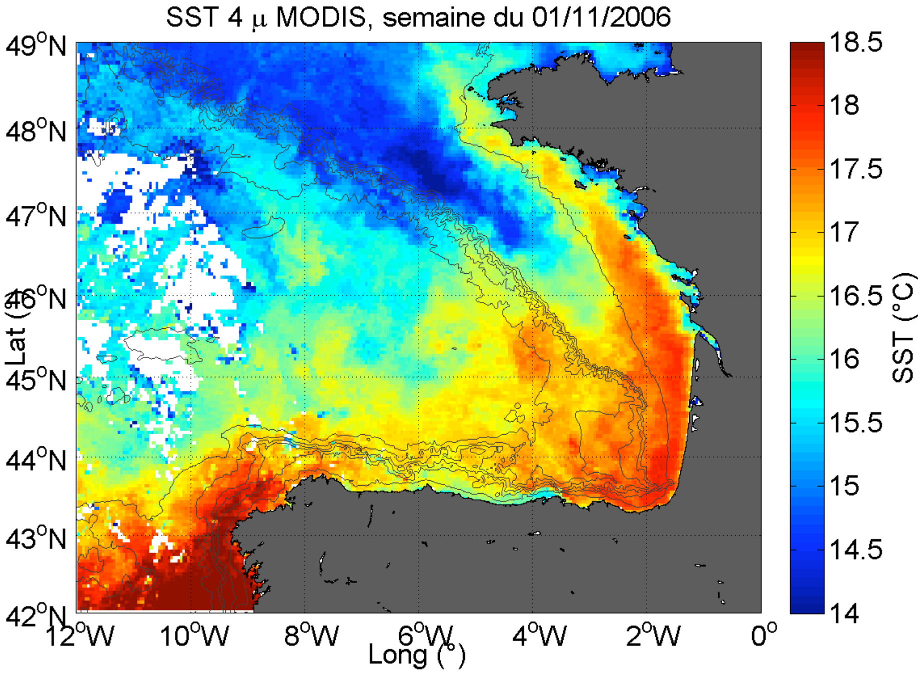


Interranual variability of september-October wind(1998-2007)

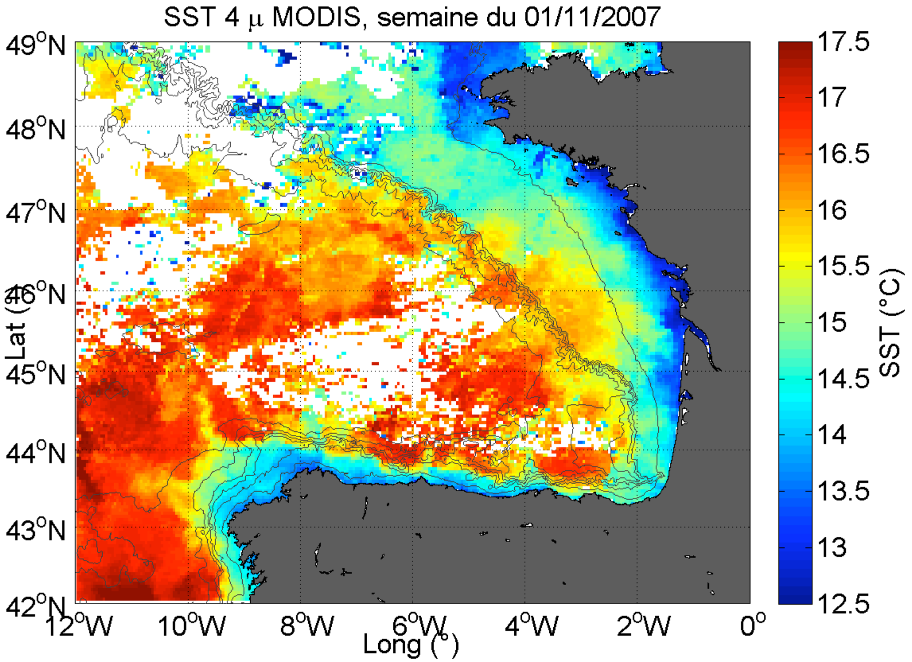


Progressive vector diagram of wind stress : $\rho_a Cd_s \left\| \vec{W} \right\| (W_x, W_y)$

Interannual variability of surface tongues

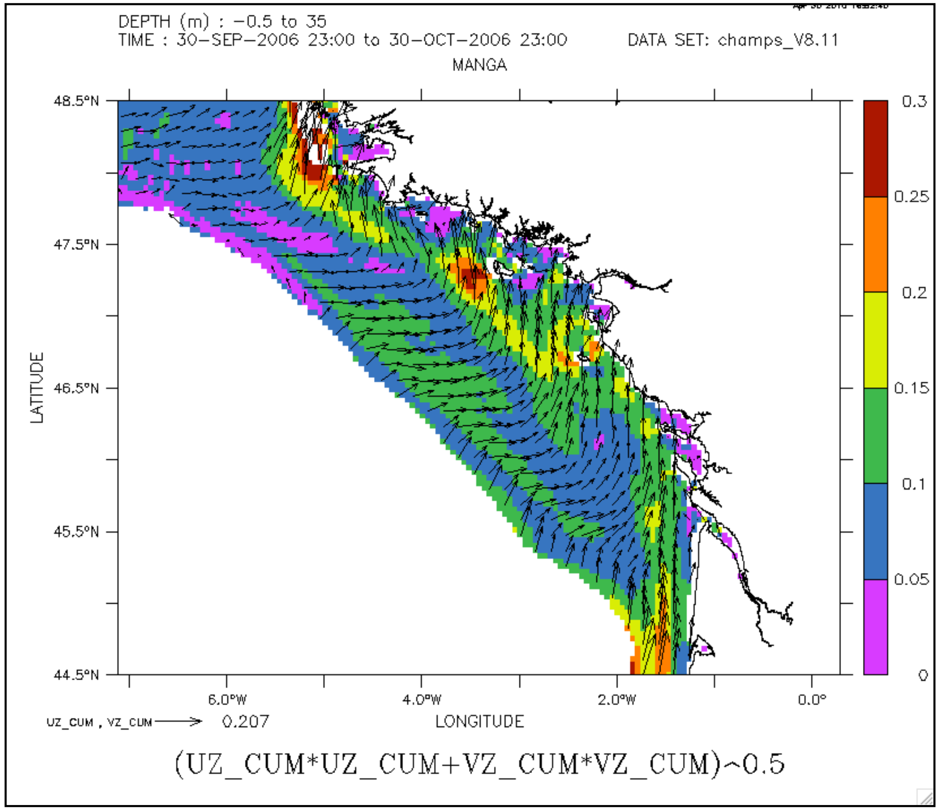

SST 4 µ MODIS, semaine du 01/11/2006

2006

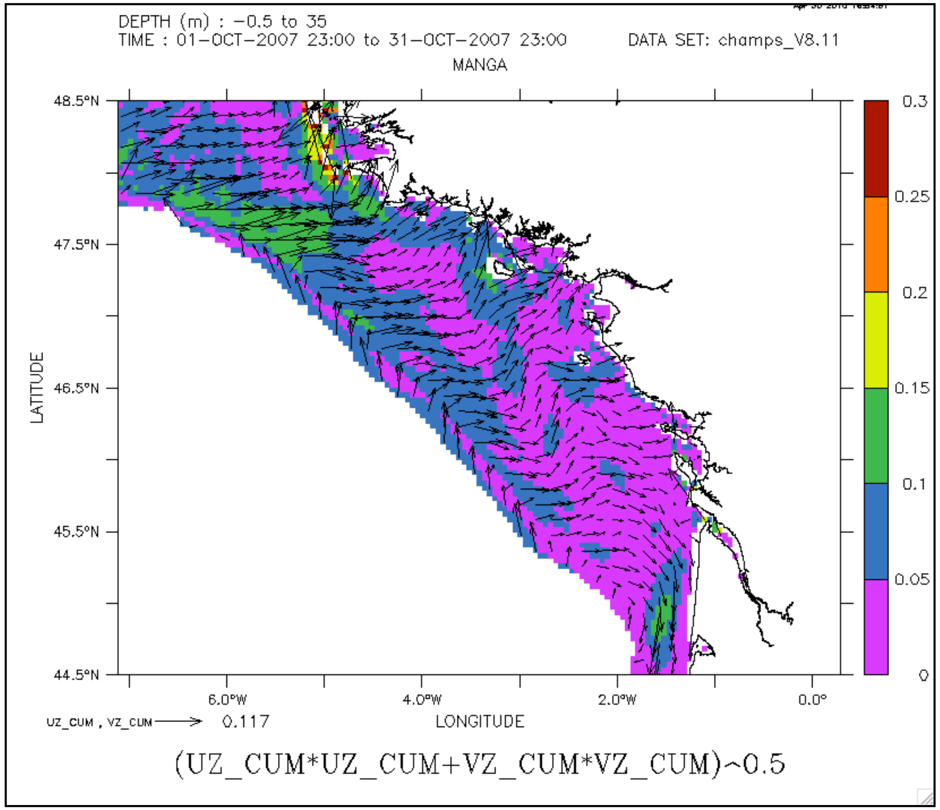

SST 4 µ MODIS, semaine du 01/11/2007

2007

Mean October eulerian surface currents (0-30 m)



October 2006



October 2007

Conclusions

- Autumnal currents may peaks at 35 cm/s
- Some tenth of kilometers wide (~40 km)
- Centered around 100m isobath
- Highly variable from year to year :
    - 2003, 2007 : no autumnal circulation
    - 1999, 2004, 2006 : strongest circulation (35 cm/s)
- Downwelling favorable wind seems to be the key processes
- All the processes that tend to lighten surface water (positive buoyancy fluxes, fresh water trapped at the coast, low vertical mixing) reinforce the autumnal circulation
- Investigate in further details the influence of the wind : weight of strong short events or cumulated effects, analyse 2D wind structure with respect to the basin geometry…

The End