Wave-induced current in a 3D circulation model

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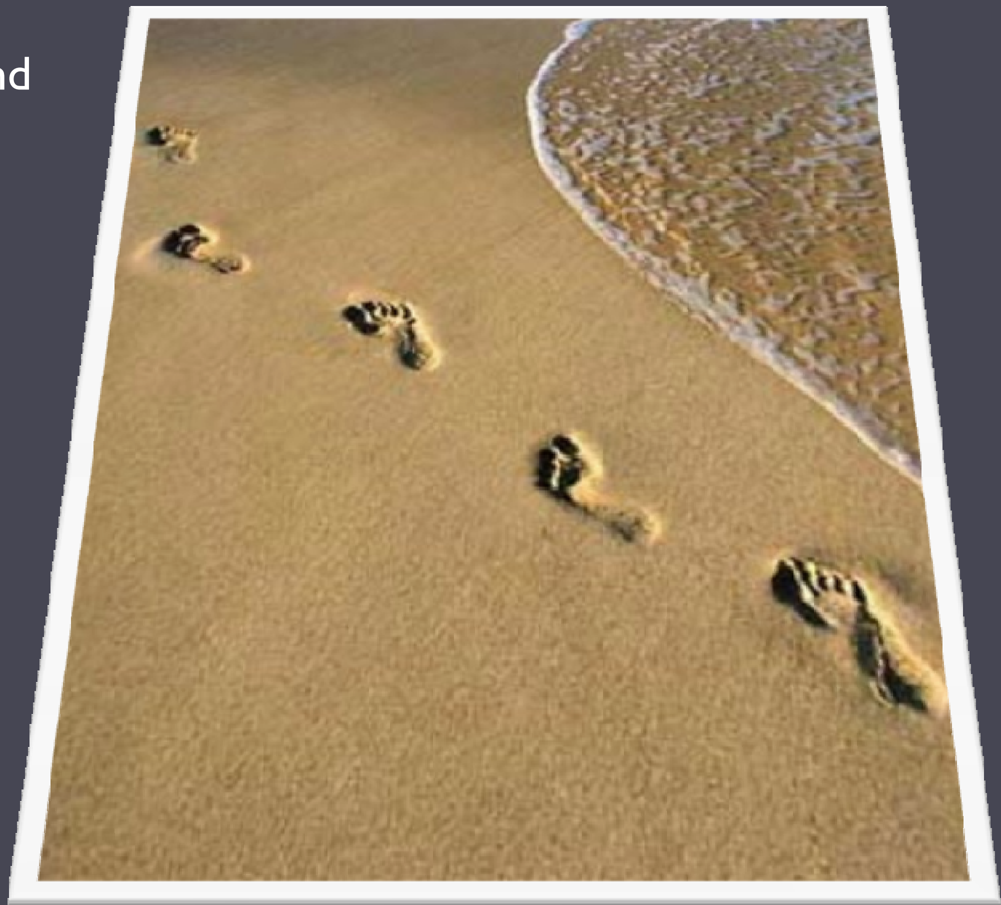


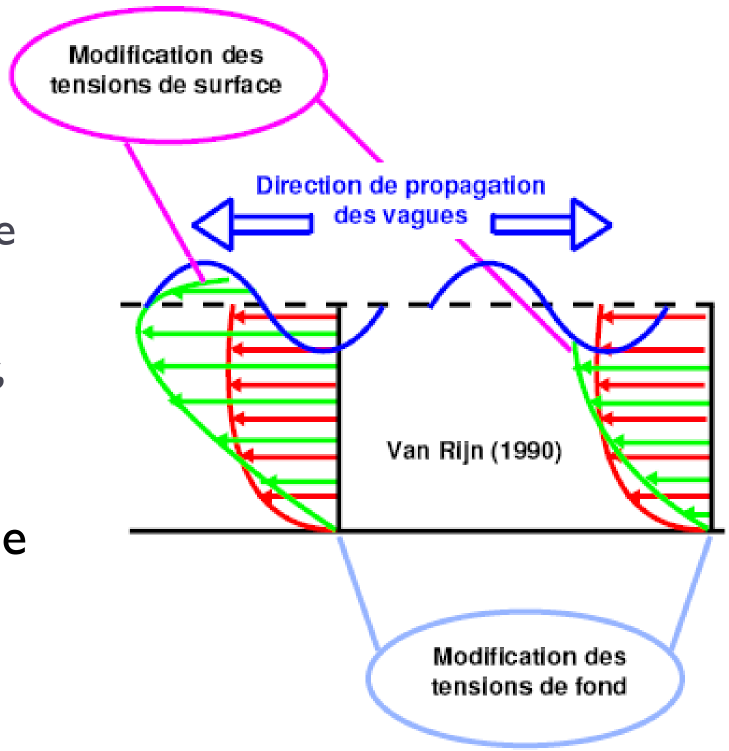
Context of EPIGRAM

- Improve the knowledge of hydrodynamic phenomena in the surf zone and the inner-shelf
- Application on Biscarosse Beach:
  - Academic test
  - Comparison with previous data -> current study of A.-C. Bennis
- And extension to other zones ?

Wave effects on the circulation

The main influences of waves on current are:

- On the bottom (Soulsby et al., 1995): modification of the bottom stress
- At the surface (Donelan et al., 1993)
  - Modification of the roughness lenght and the surface stress
  - on turbulent kinetic energy at the surface with an enhancement by wave breaking (Mellor and Blumberg, 2004) and also on mixed layer formation (Craig and Banner, 1994; Rascle and Ardhuin, 2009).
  - Generation of the Stokes
- Additional mean transport in the surface layer that can be parameterized as radiation stresses (Longuet-Higgins and Stewart, 1962; Phillips, 1977).



D'après Denamiel 2007

Momentum Equations

$$(\hat{u},\hat{v},\hat{w}) = (u,v,w) - (U_s,V_s,W_s)$$

Quasi-eulerian velocities — Lagrangian velocities — Stokes velocities

$$\frac{\partial \hat{u}}{\partial t} + \hat{u}\frac{\partial \hat{u}}{\partial x} + \hat{v}\frac{\partial \hat{u}}{\partial y} + \hat{w}\frac{\partial \hat{u}}{\partial z} - f\hat{v} + \frac{1}{\rho}\frac{\partial p^H}{\partial x} = [f + (\frac{\partial \hat{v}}{\partial x} - \frac{\partial \hat{u}}{\partial y})]V_s - W_s\frac{\partial \hat{u}}{\partial z} - \frac{\partial J}{\partial x} + F_{m,x} + F_{d,x}$$

From Bennis et al. (2011)

Stokes-Coriolis force — Vortex force — Bernouilli's head — Mixing force — Dissipation force

The evolution of C the concentration of a passive tracer is governed by: $$\frac{\partial C}{\partial t} + \frac{\partial uC}{\partial x} + \frac{\partial vC}{\partial y} + \frac{\partial wC}{\partial z} = 0$$

And the mass conservation becomes $$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0$$

In Symphonie :

$$\frac{\partial \hat{u}}{\partial t} + \frac{\partial u\hat{u}}{\partial x} + \frac{\partial v\hat{u}}{\partial y} + \frac{\partial w\hat{u}}{\partial z} - f\hat{v} + \frac{1}{\rho}\frac{\partial p^H}{\partial x} = fV_s + \frac{\partial \hat{u}}{\partial x}U_s + \frac{\partial \hat{v}}{\partial x}V_s - \frac{\partial J}{\partial x} + F_{m,x} + F_{d,x}$$

Boundary Conditions

- At the surface

$$K_z \frac{\partial \hat{u}}{\partial z}\bigg|_{z=\hat{\eta}} = \tau_{a,x} - \tau_{aw,x} + \tau_{wo,x}$$

Wind stress — Atm->wave momentum flux — Wave -> ocean momentum flux

- On the bottom

$$K_z \frac{\partial \hat{u}}{\partial z}\bigg|_{z=-h} = C_D\left(\hat{u}(z)-\hat{u}(-h)\right)\sqrt{\left(\hat{u}(z)-\hat{u}(-h)\right)^2+\left(\hat{v}(z)-\hat{v}(-h)\right)^2}$$

with

$$(\hat{u},\hat{v})|_{z=-h} = 1.5\,(U_s, V_s)|_{z=-h}$$

or :

$$K_z \frac{\partial \hat{u}}{\partial z}\bigg|_{z=-h} = \rho C_D \left\|\vec{\hat{V}_b}\right\| \vec{\hat{u}_b} + \tau_{wob,x}$$

$$\overrightarrow{\tau_{wob}} = -\frac{\epsilon^{wd}\vec{k}}{\sigma} = -\frac{\frac{1}{2\sqrt{\pi}}\rho_0 f_w \left|\overrightarrow{u_{orb}}\right|^3 \vec{k}}{\sigma}$$

Ajout du moment perdu par les vagues par friction sur le fond (Reniers et al. , 2004)

- Lateral boundaries

$$\eta = \eta_F \pm \sqrt{\frac{D}{g}}\left(\hat{u}^N - u_F{}^N\right)$$

with

$$\begin{cases} \eta_F = -\dfrac{J}{g} \\ u_F{}^N = -U_S^N \end{cases}$$

Marsaleix et al. (2006)

Wave induced vertical mixing

The TKE is calculated by:

$$\frac{\partial E}{\partial t} + \frac{\partial uE}{\partial x} + \frac{\partial vE}{\partial y} + \frac{\partial wE}{\partial z} - K_z\left[\left(\frac{\partial u}{\partial z}\right)^2 + \left(\frac{\partial v}{\partial z}\right)^2\right] + \frac{g}{\rho} K_z \frac{\partial \rho}{\partial z} + \frac{\partial}{\partial z}(F_z) - \frac{c_\varepsilon E^{1.5}}{l_\varepsilon}$$

Gaspar et al. , 1990

- At the surface:

$$\begin{cases} F_z = \phi_{oc} \text{ near the surface} \\ F_z = K_v \dfrac{\partial E}{\partial z} \text{ elsewhere} \end{cases}$$

Craig & Banner, 1994 $\Phi_{oc} = \alpha u_*$

mixing length: $l = \kappa z_0$ with $z_0 = 1.6 H_s$

Significant wave height of the wind sea only (Rascle et al., 2008)

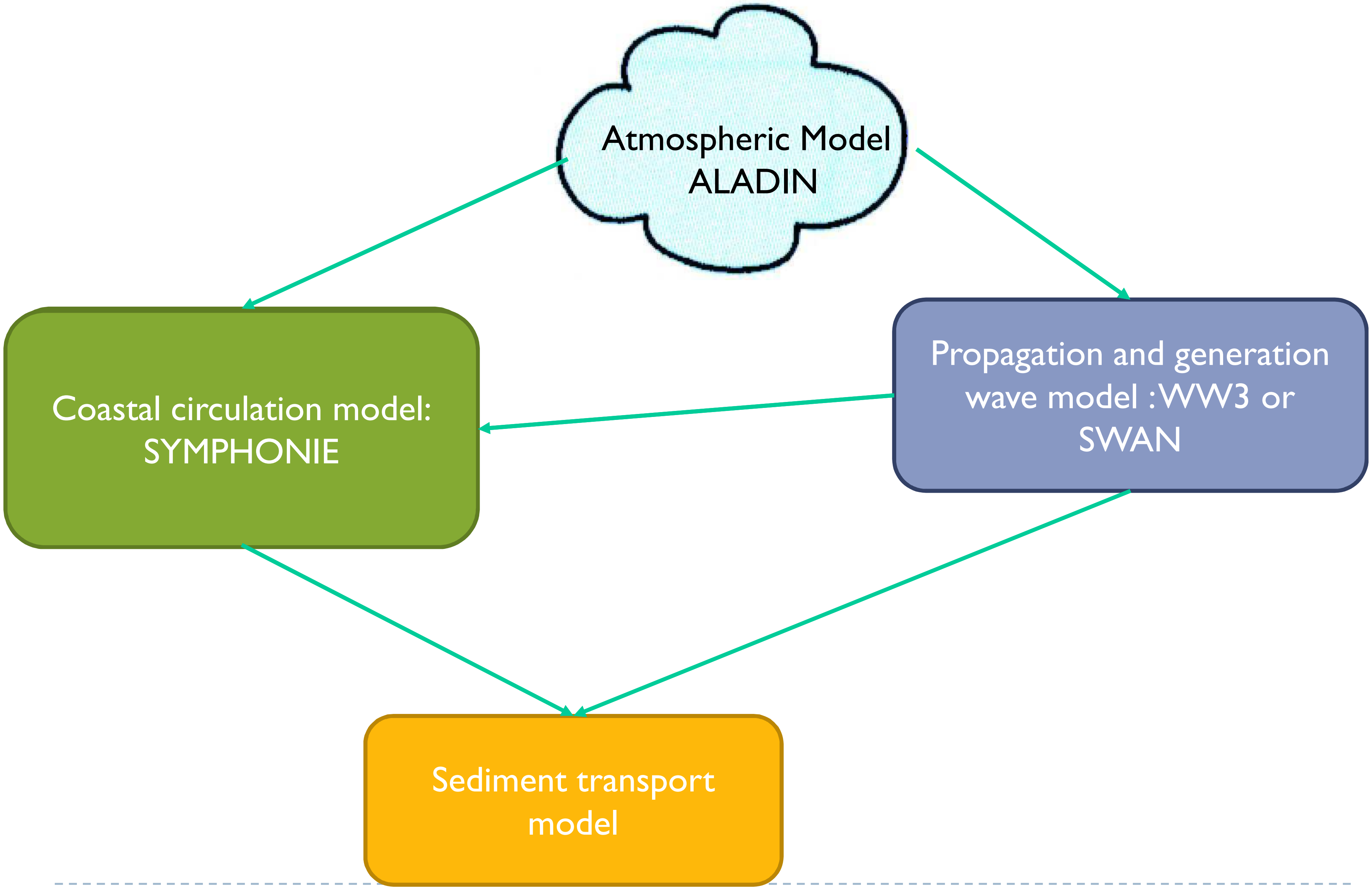
- On the bottom

$$\overrightarrow{\tau_{bot}} = \overrightarrow{\tau_c}\left[1 + 1.2\left(\frac{|\tau_w|}{|\tau_w| + |\tau_c|}\right)^{3.2}\right]$$

Soulsby et al., 1995

Bottom stress due to current

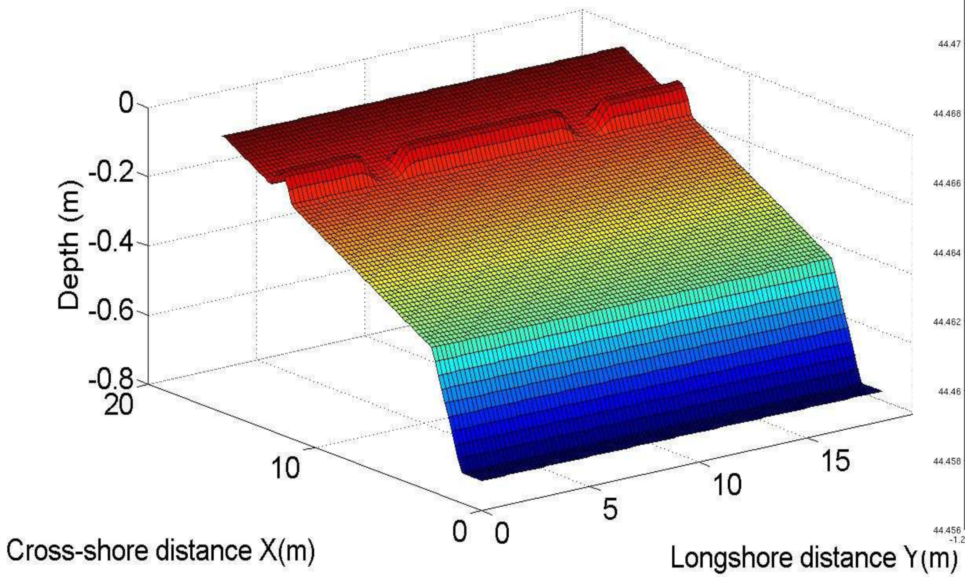
Bottom stress due to wave

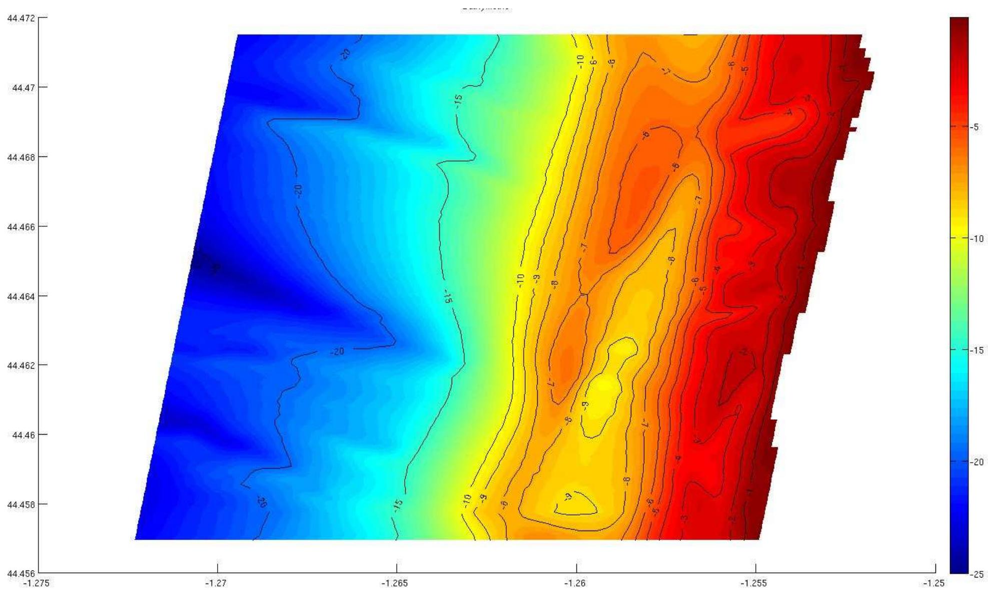

Atmospheric Model
ALADIN
Coastal circulation model:
SYMPHONIE
Propagation and generation
wave model : WW3 or
SWAN
Sediment transport
model

Validation of the model on academic test cases

5 academic tests

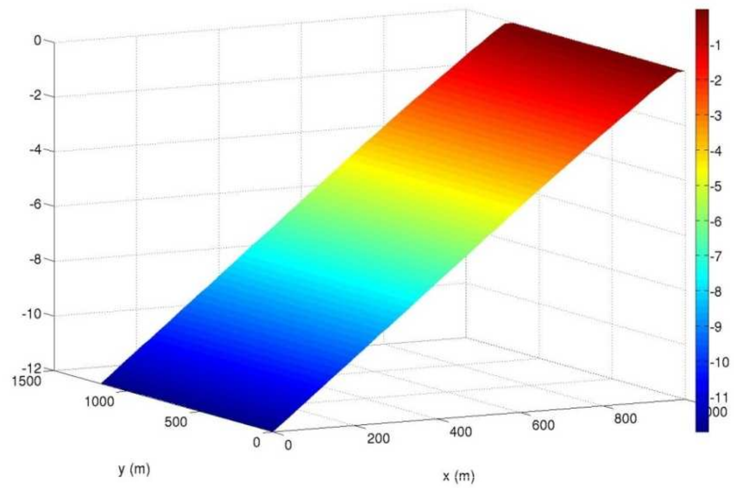
- the plane beach of Haas and Warner [2009]
- Leadbetter Beach (Californie, E.U.) de Thornton and Guza [1986]; Wu et al. [1985]
- Experiments of Hamilton and Ebersole [2001] on a laboratory plane beach
- A barred beach from the laboratory experiments of Haller et al. [2002] and Haas et al. [2003]
- Biscarosse Beach in Aquitaine (Bruneau [2009])



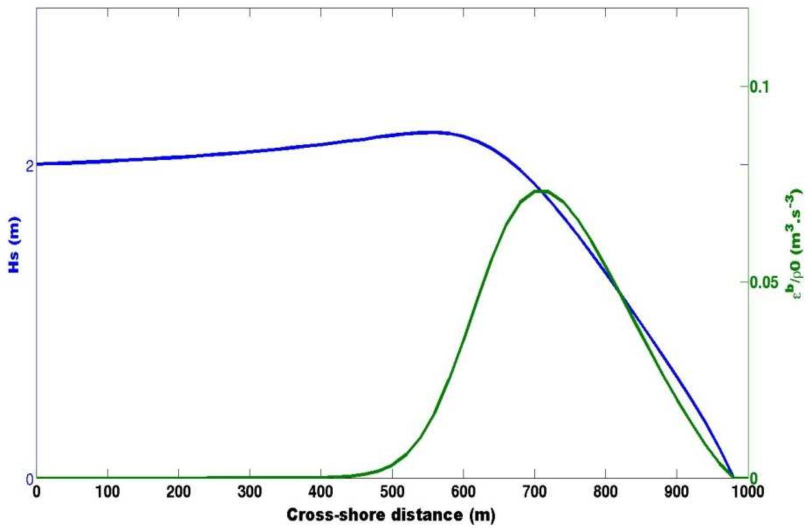


Test case n°1 : the plane beach of Haas and Warner (2009)

- Bathymetry:
  - 1200 x1200 m
  - maximal depth:12m
- Wave characteristic :
  - Hs=2m,
  - T=10s,
  - Incidence angle of 10°
  - Modelled by Swan
  - Jonswap type spectral wave field
- Previously modelled by:
  - Haas and Warner (2009) « radiation stress approach »
  - Uchiyama et al. (2010) « vortex force approach »



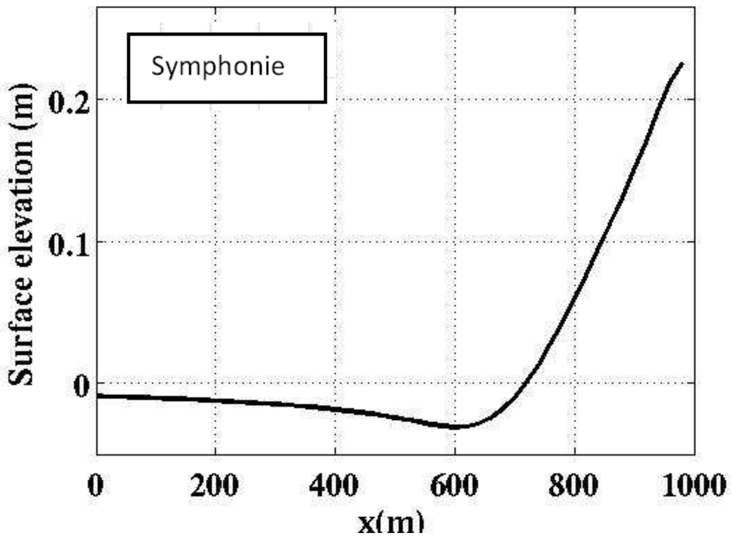
Beach bathymetry

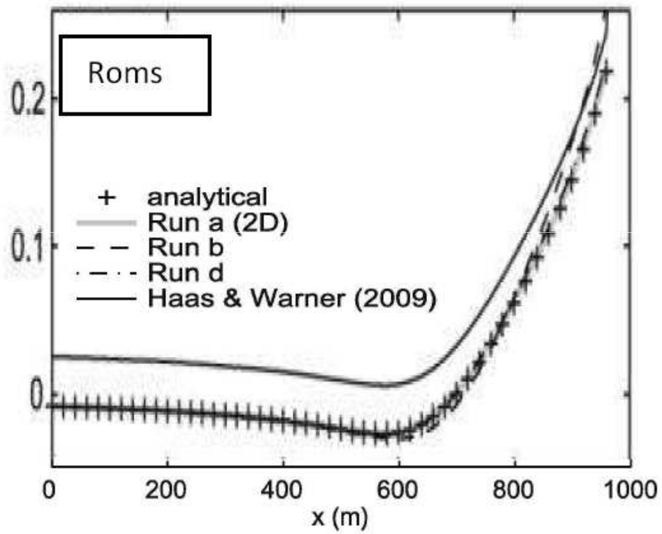


Cross-shore profile of the significant wave height (m) and breaking dissipation rate

10

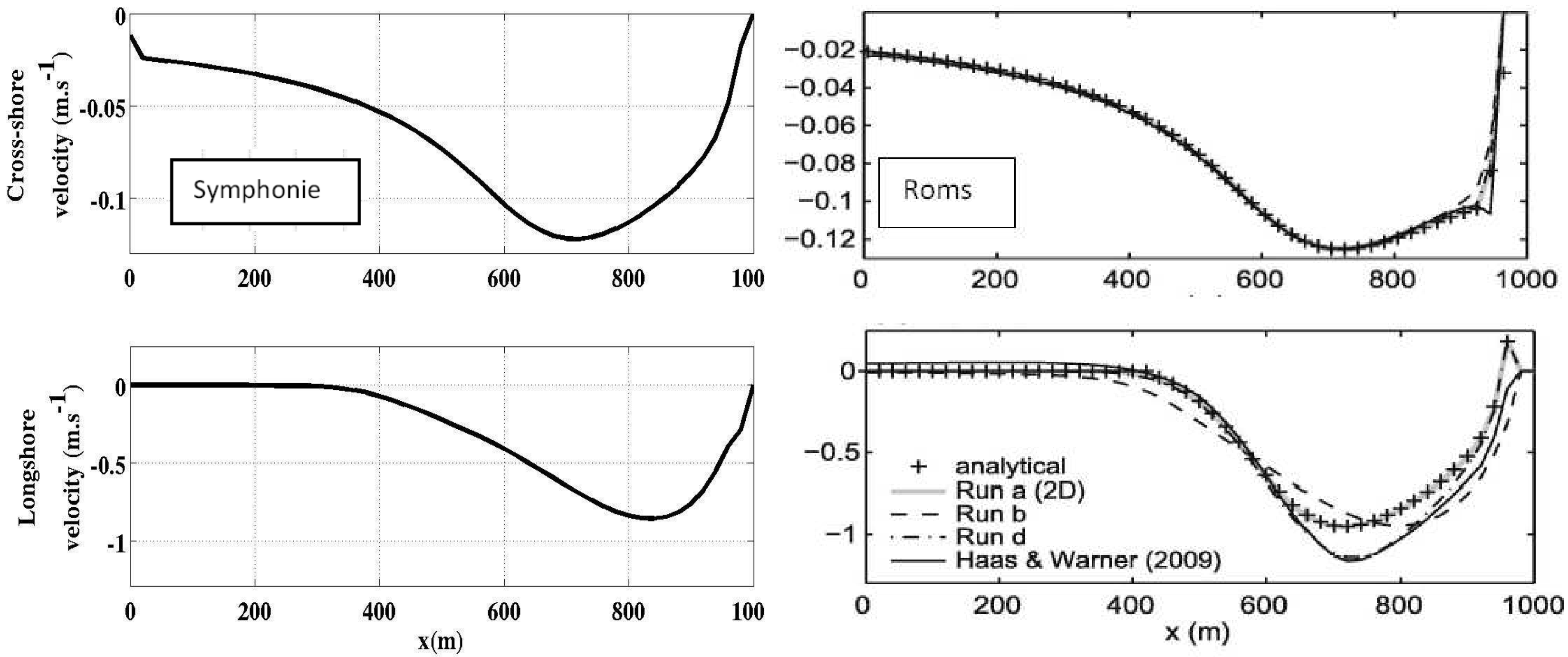
Test case n°1 : the plane beach of Haas and Warner (2009)





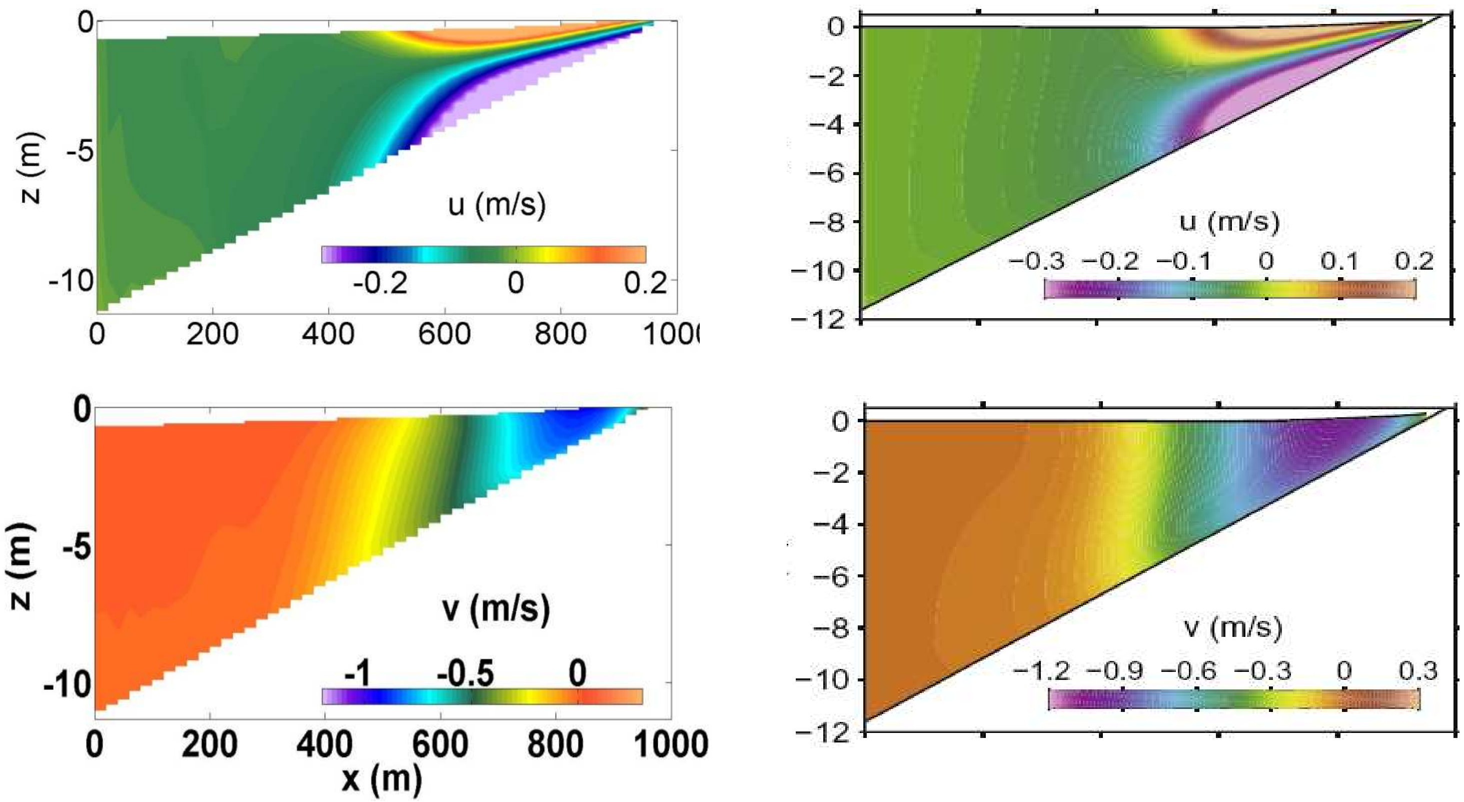
Cross-shore profile of the surface elevation (m) in SYMPHONIE (left) and ROMS (right from UMS10). The shoreline is at right.

Test case n°1 : the plane beach of Haas and Warner (2009)



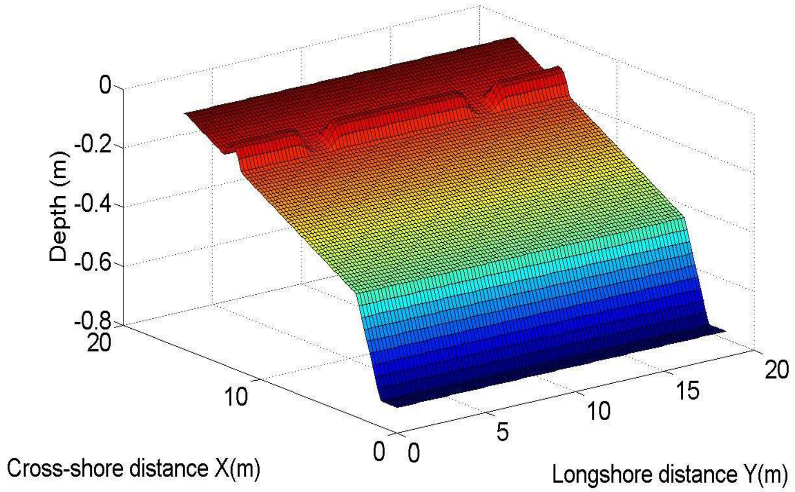
Cross-shore profiles of depth-integrated quasi-eulerian velocities ($m.s^{-1}$) in SYMPHONIE (left) and ROMS (right from UMS10)

Test case n°1 : the plane beach of Haas and Warner (2009)



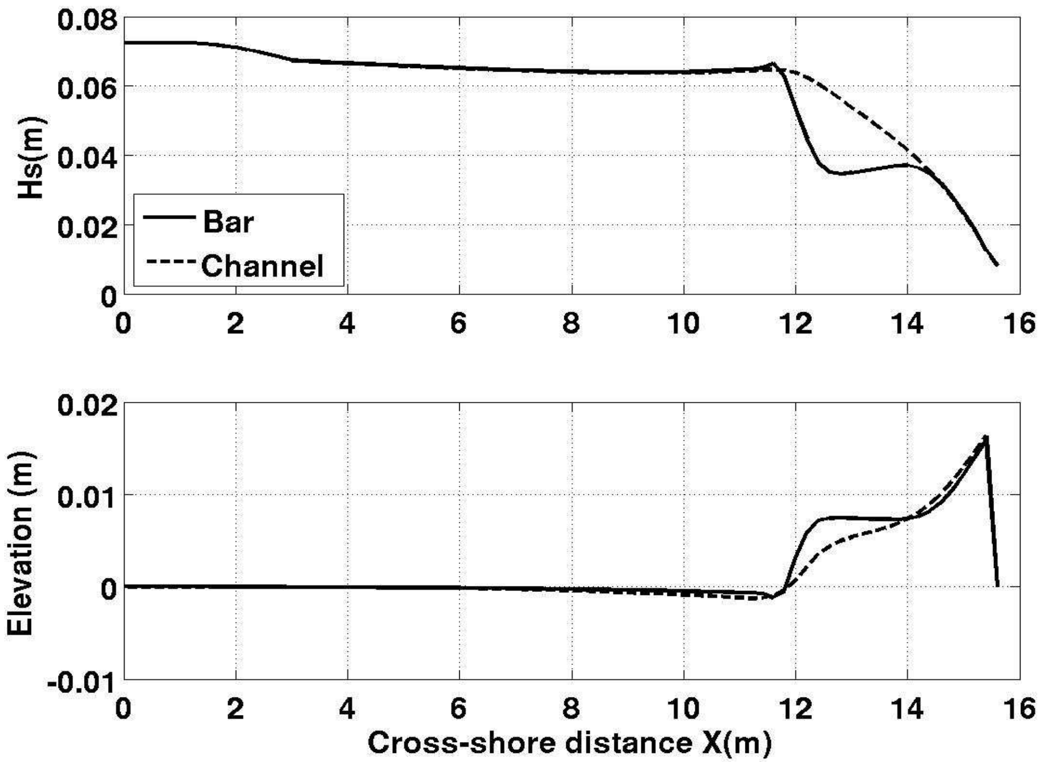
Vertical sections of quasi-eulerian velocities (cross-shore on the top and alongshore on the bottom) in SYMPHONIE (left) and ROMS with run b (right from UMS10)

Test case n°2 : A barred beach with rip current



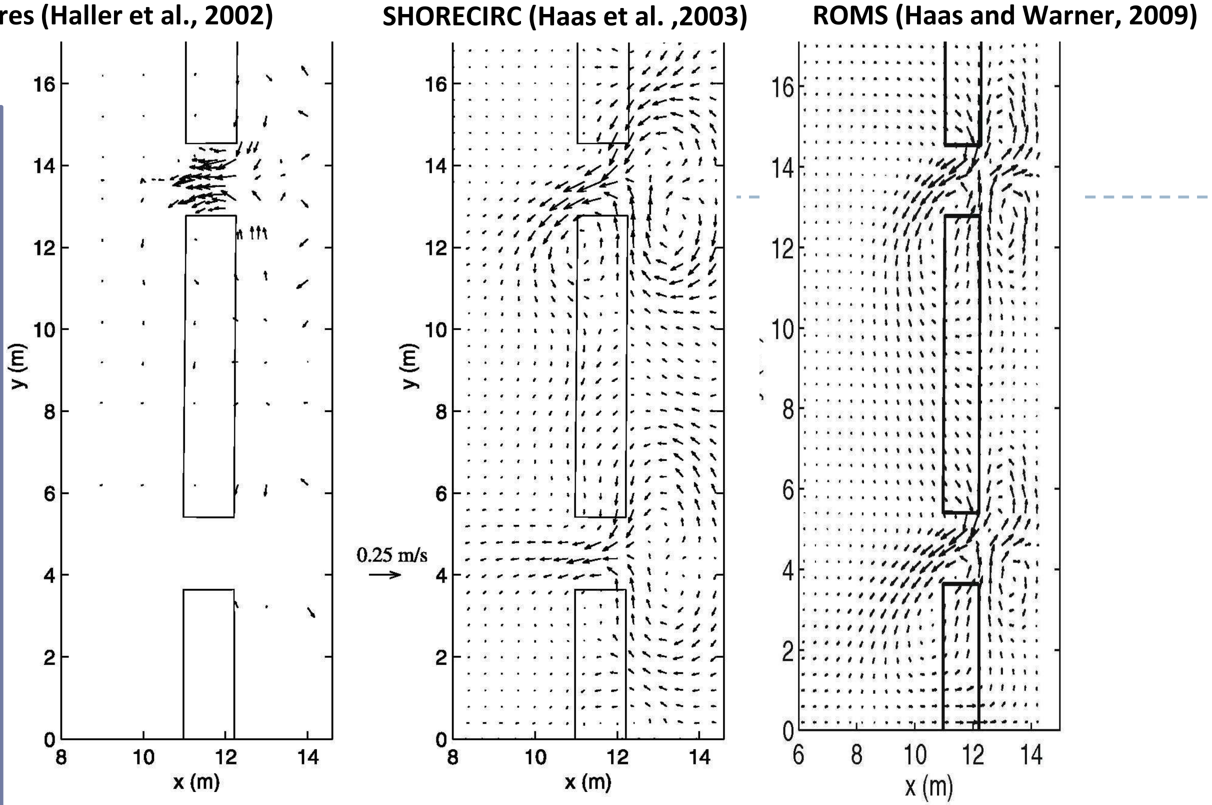
Beach bathymetry

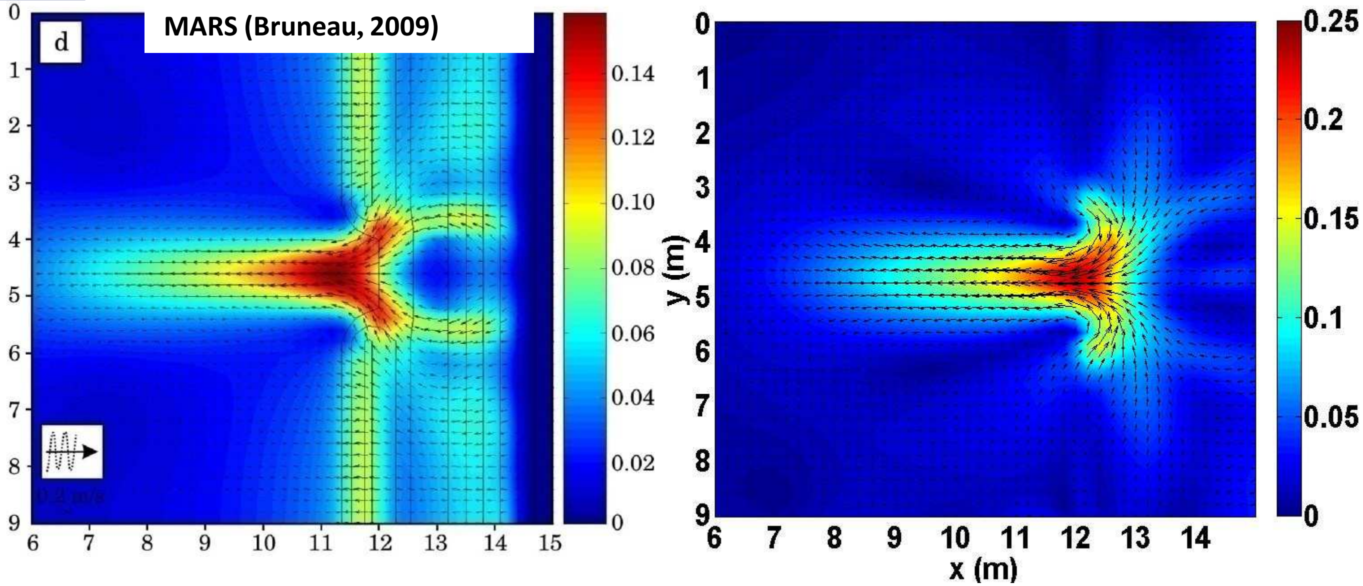
"test B" of Haller al. (2002)



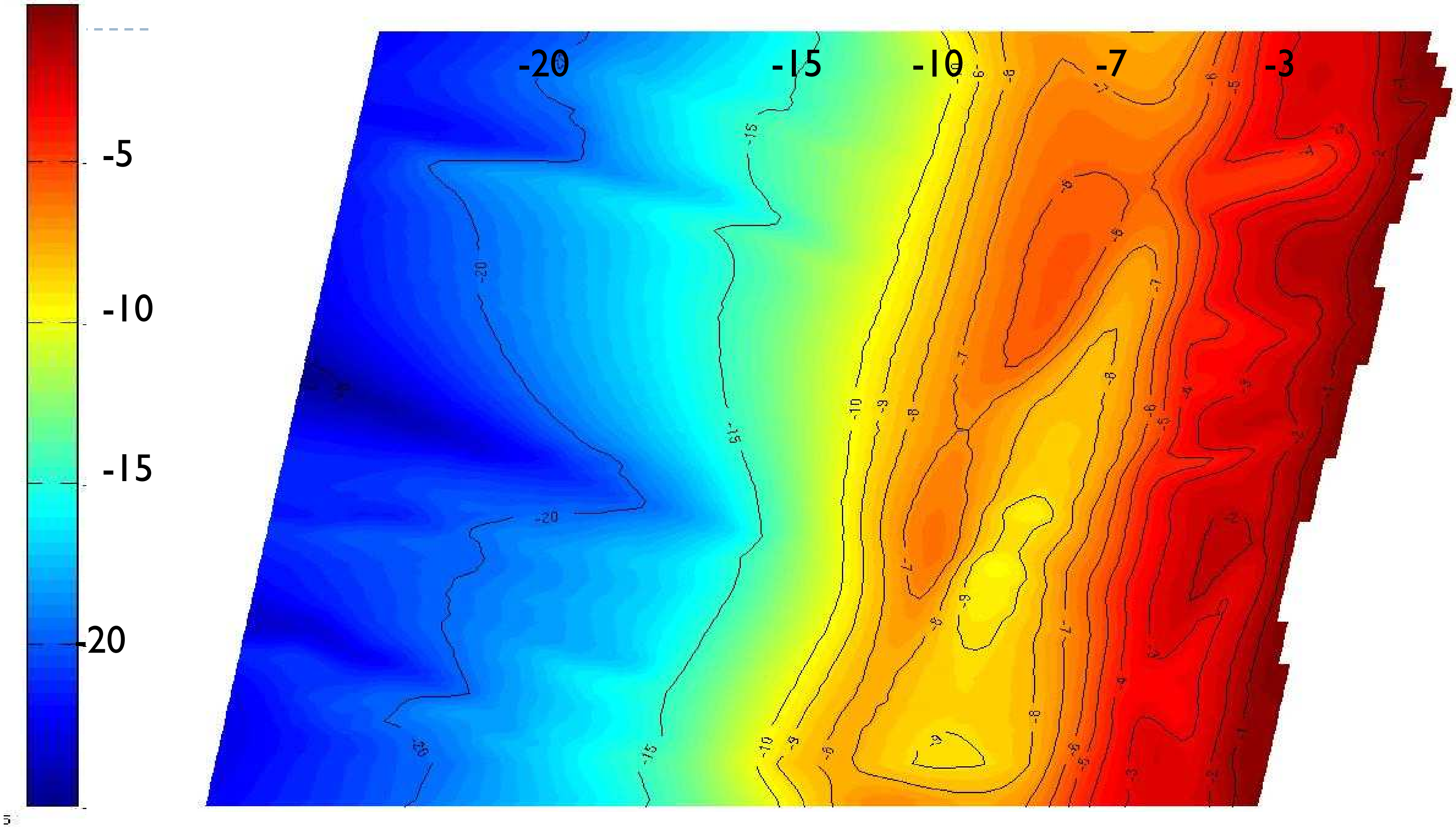
Monochromatic wave
Hs =0.0724 m
T=1s
a perpendicular direction

Comparison of depth-integrated current measured by Haller et al. (2002) (a), with numerical simulations done by SHORECIRC (Haas et al., 2003) (b), ROMS (Haas and Warner, 2009) (c), MARS (Bruneau, 2009) (d) and SYMPHONIE (e)



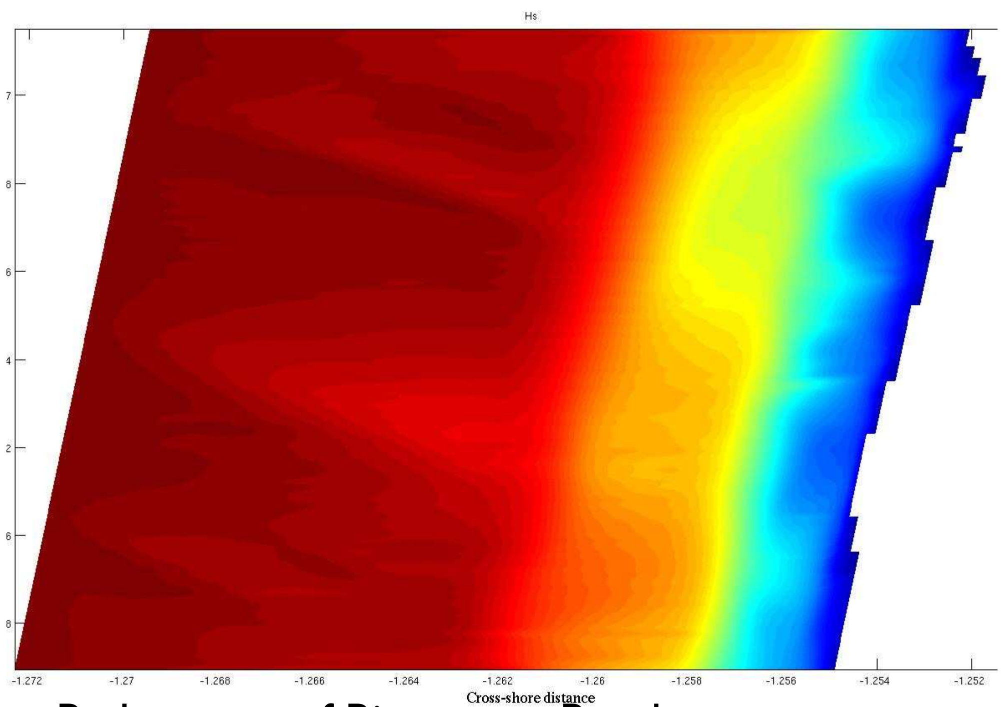


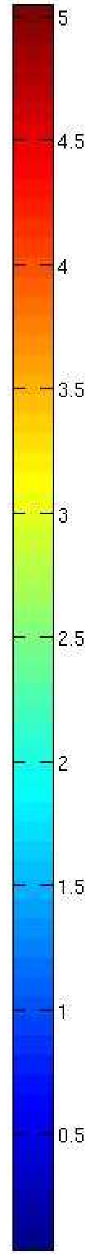
Test on Biscarosse Beach



Bathymetry of Biscarosse Beach (courtesy of N. Bruneau)

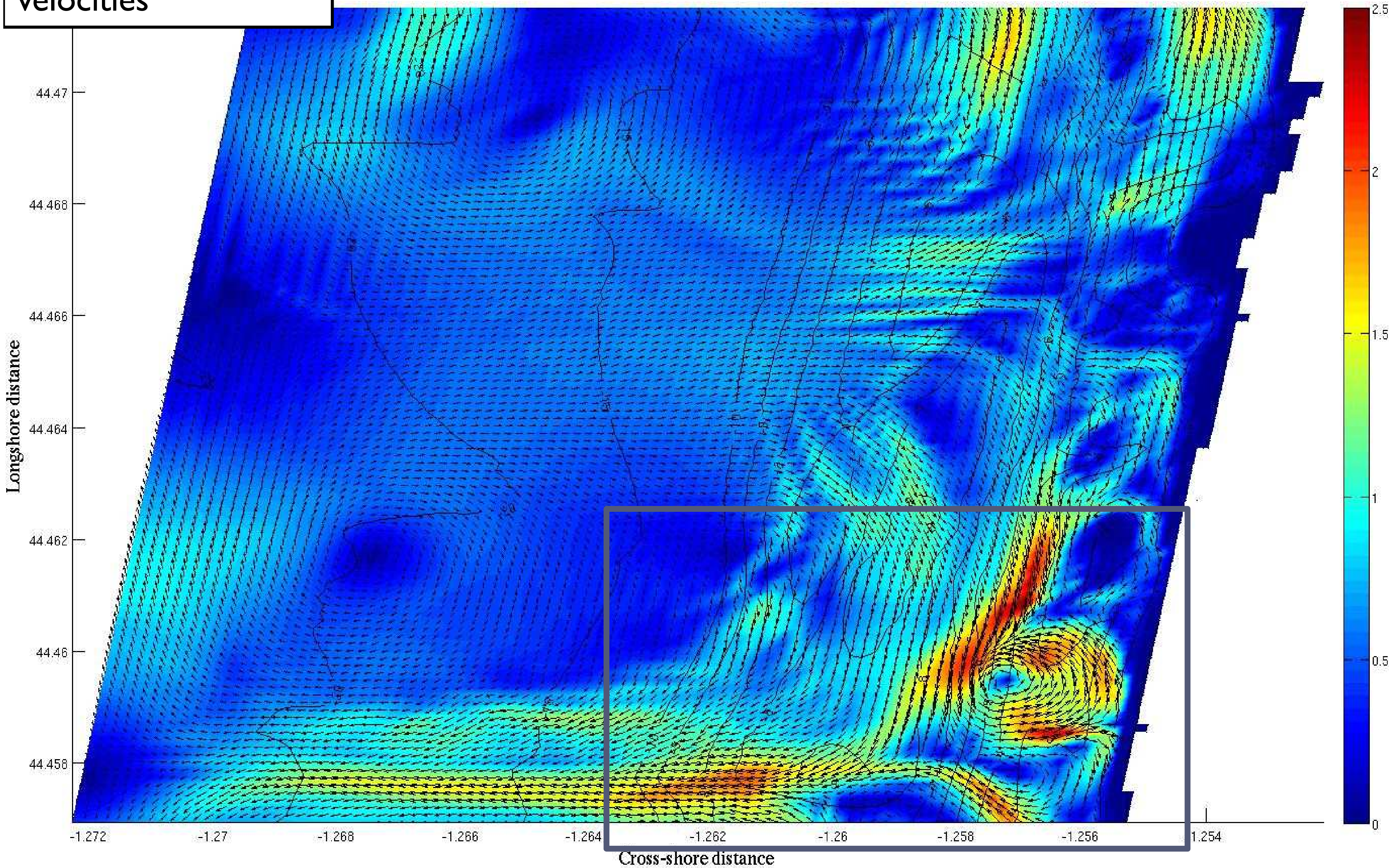
- Jonswap type spectral wave field with non incidence angle, Hs= 5m , T = 10 s
- Extreme W-NW storm





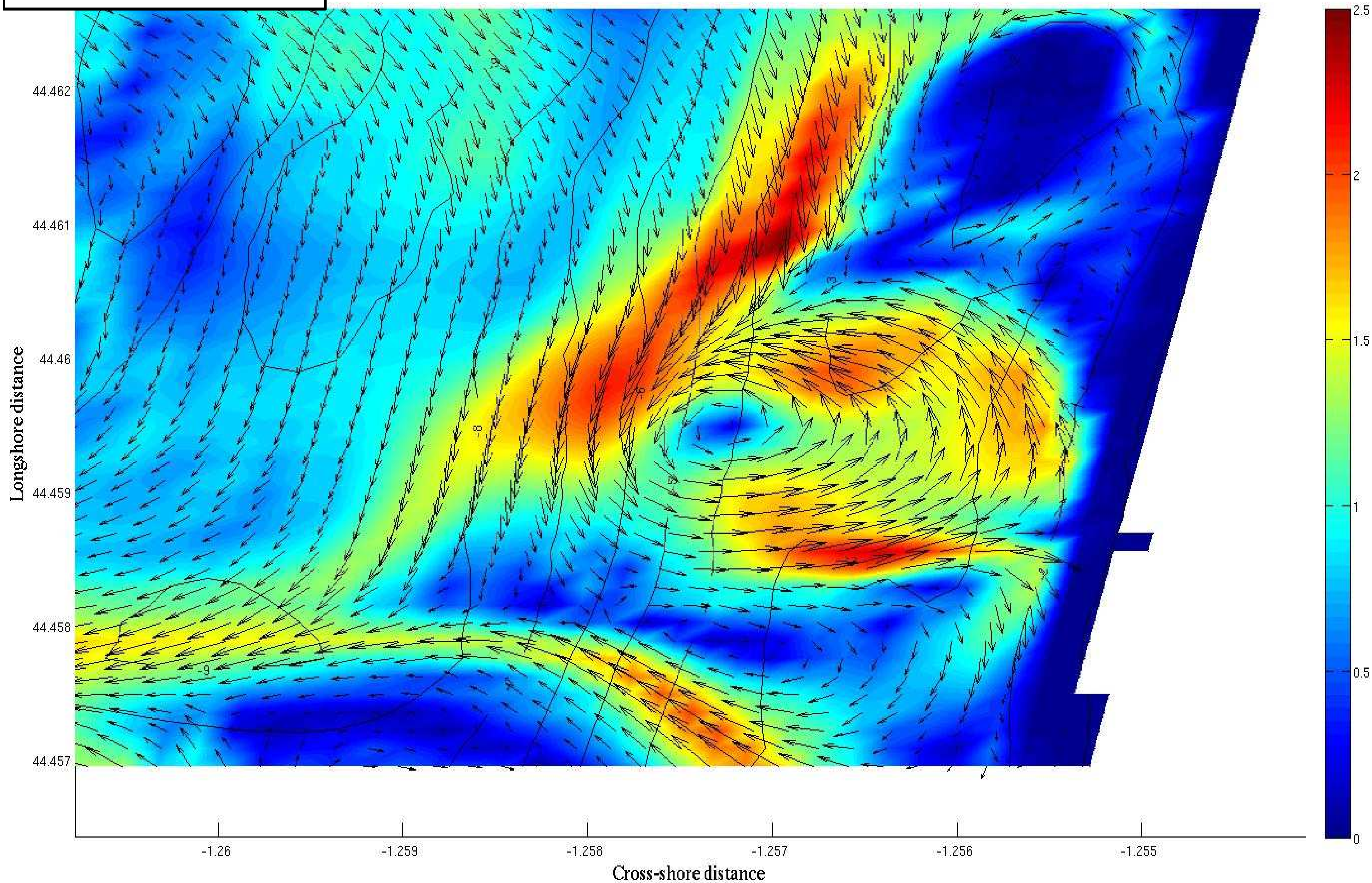
Bathymetry of Biscarosse Beach
(courtesy of N. Bruneau)

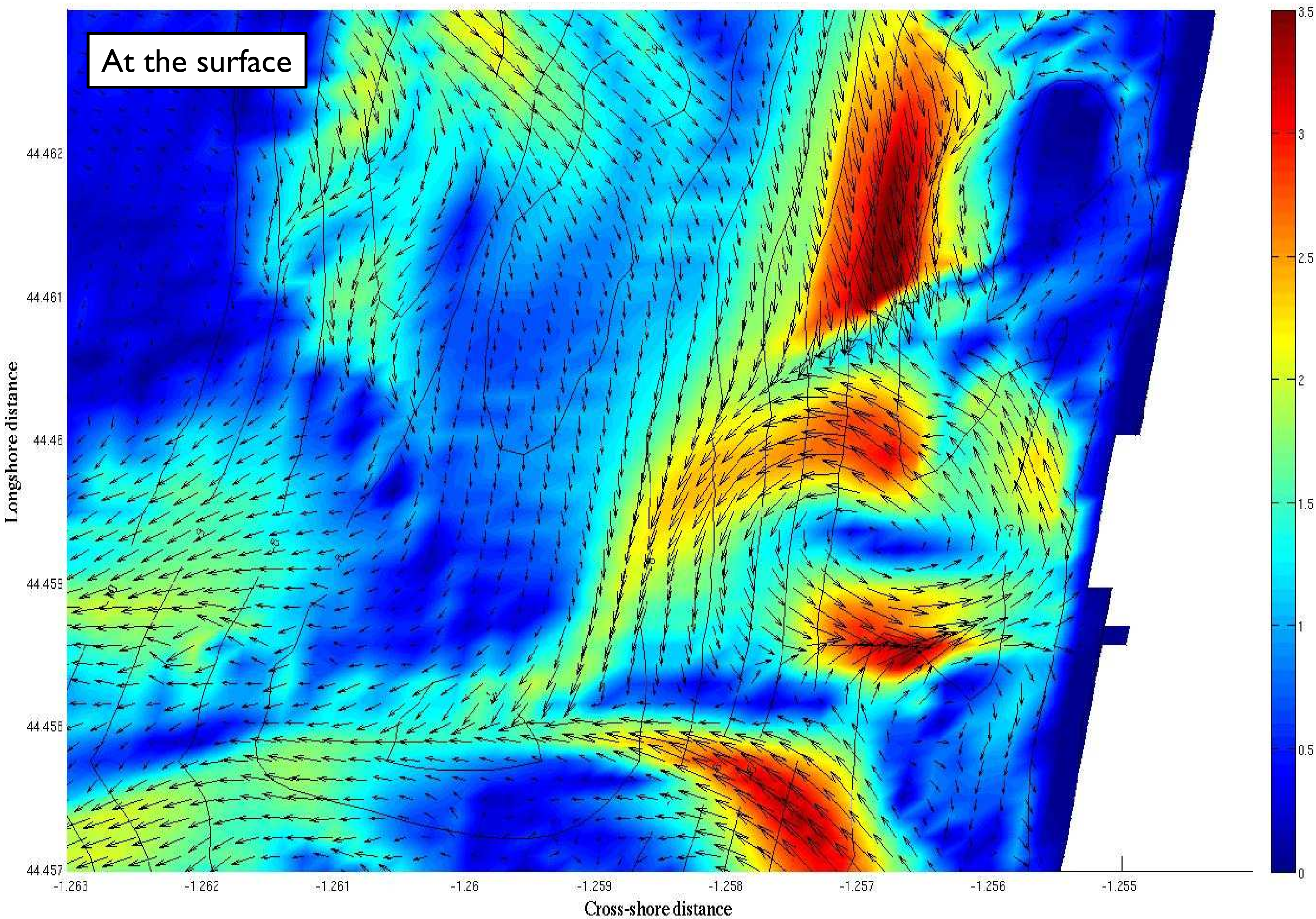
Depth integrated velocities



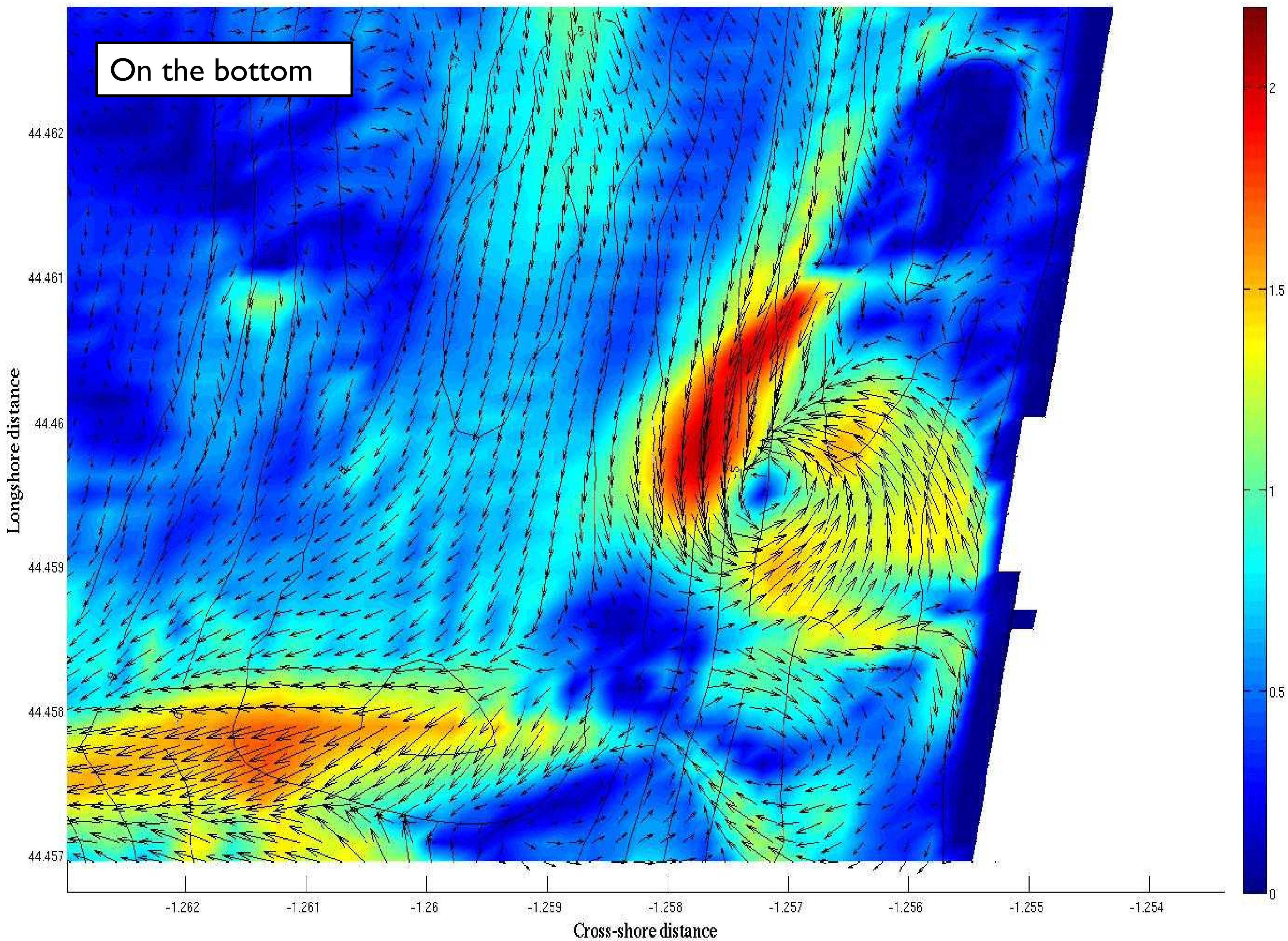
ZOOM

Depth integrated velocities





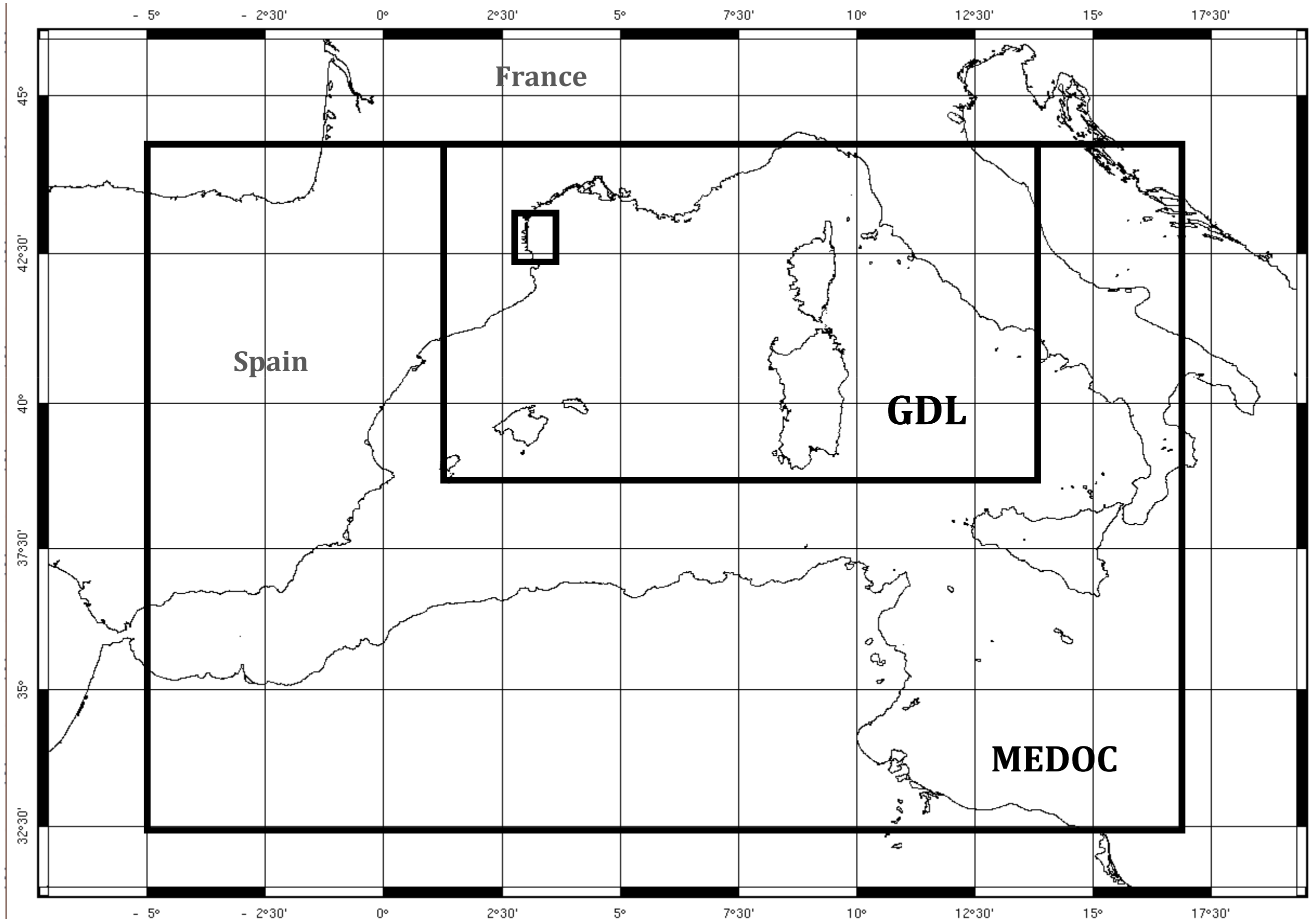
At the surface
Longshore distance
Cross-shore distance
44.462
44.461
44.46
44.459
44.458
44.457
-1.263
-1.262
-1.261
-1.26
-1.259
-1.258
-1.257
-1.256
-1.255
3.5
3
2.5
2
1.5
1
0.5
0



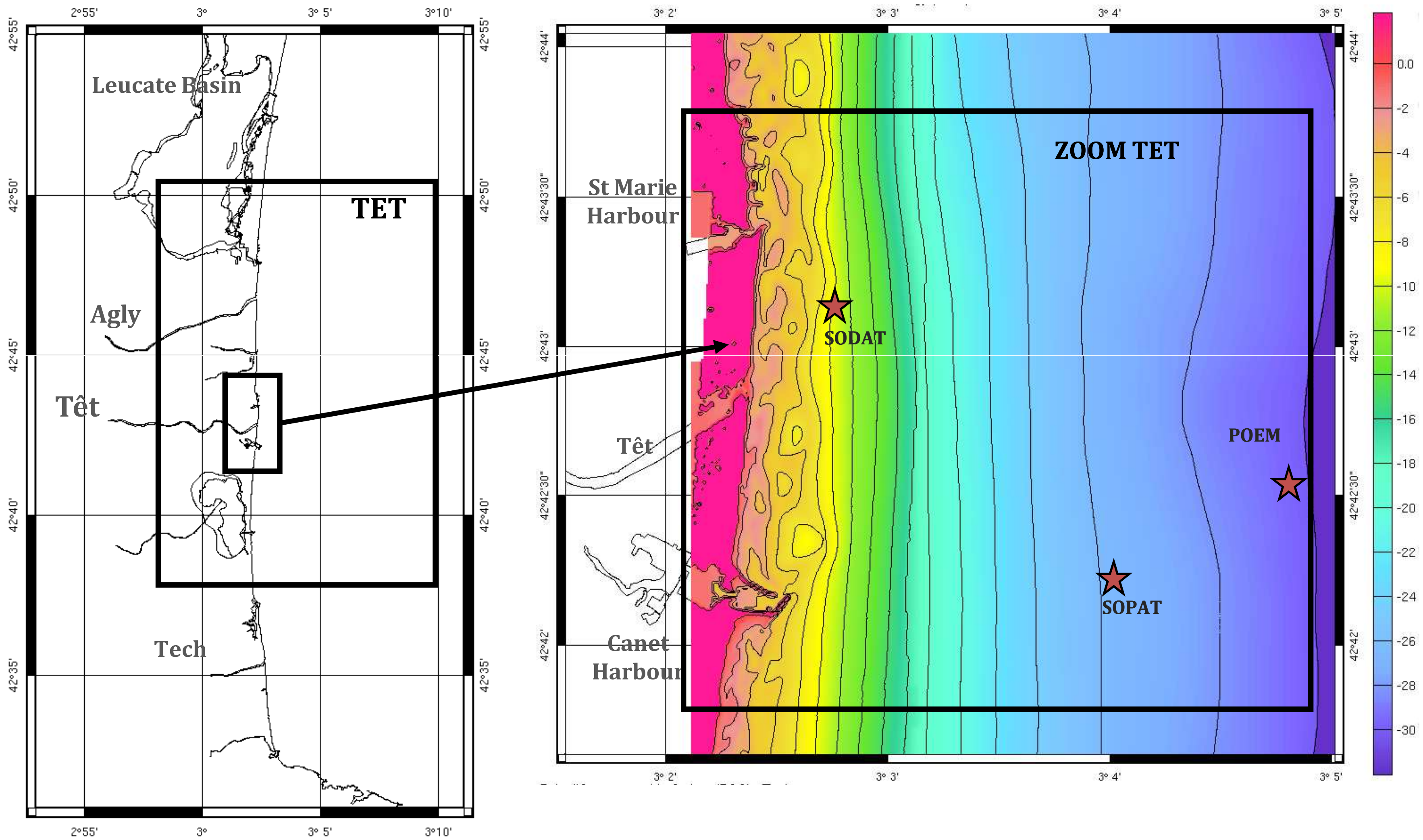
On the bottom
44.462
44.461
44.46
44.459
44.458
44.457
Longshore distance
-1.262
-1.261
-1.26
-1.259
-1.258
-1.257
-1.256
-1.255
-1.254
Cross-shore distance
0
0.5
1
1.5
2

21st February storm in the Têt inner shelf

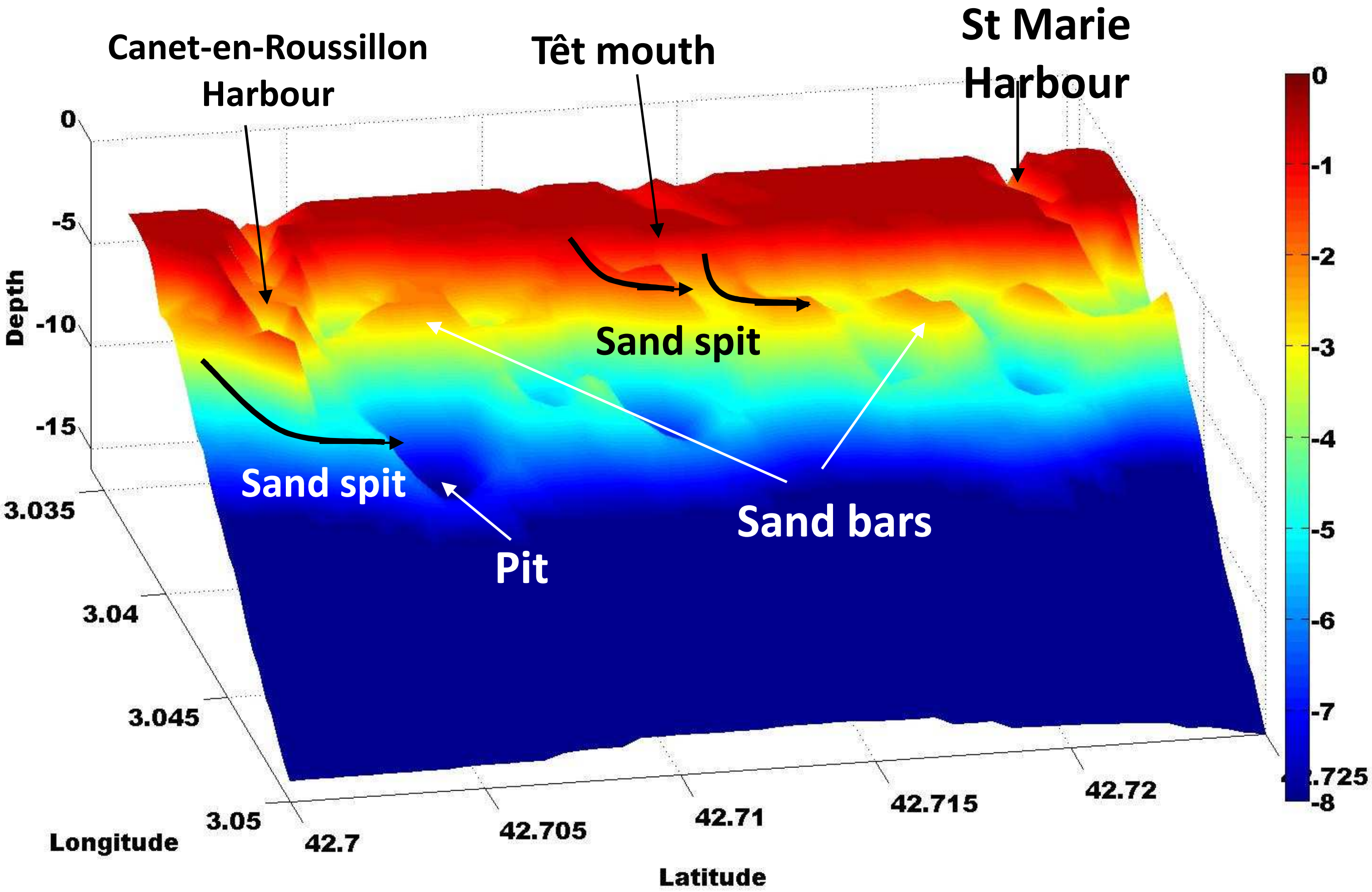
Models implementation



Models implementation



Bathymetrie of the Têt surf zone



Results of the wave model

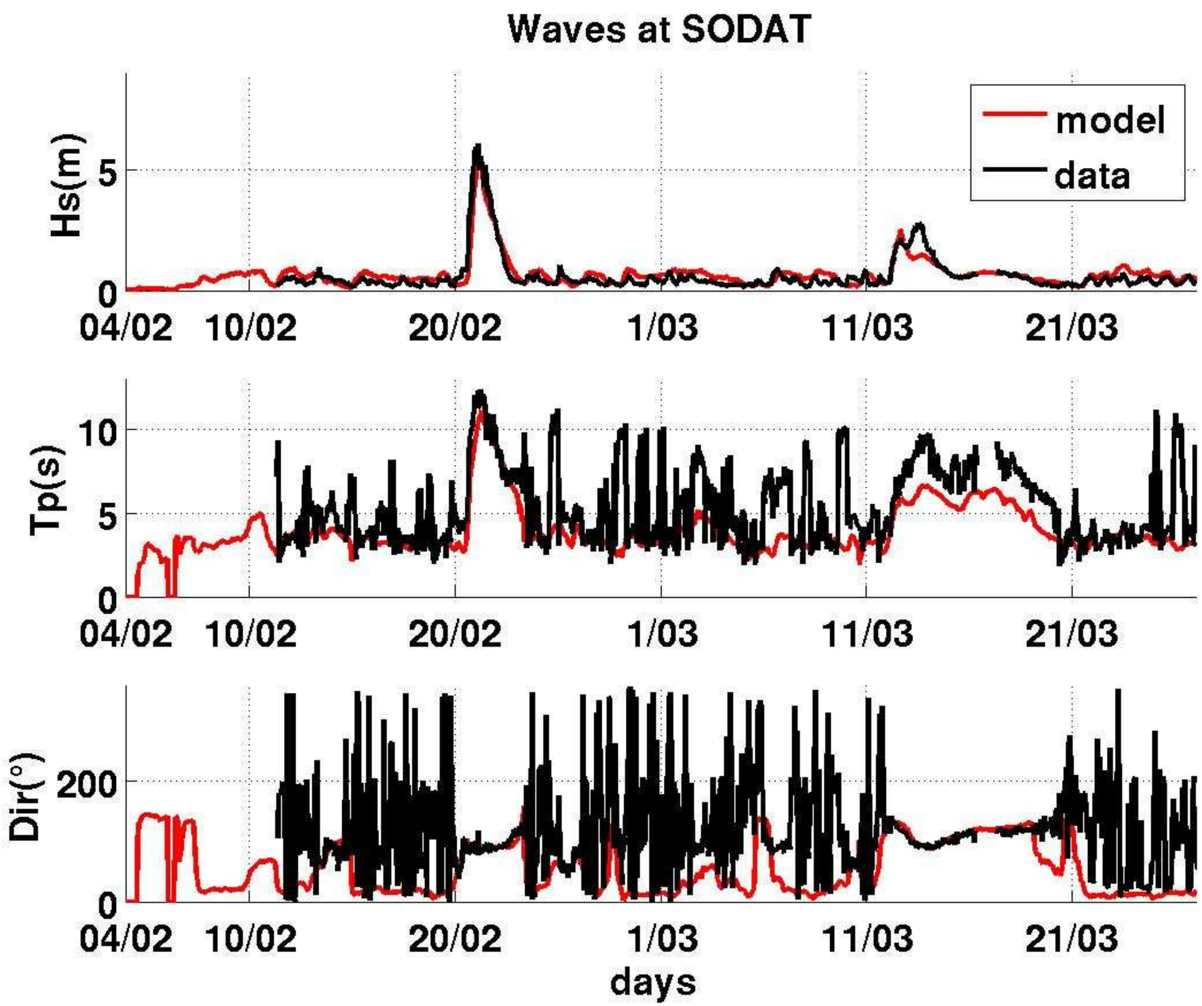
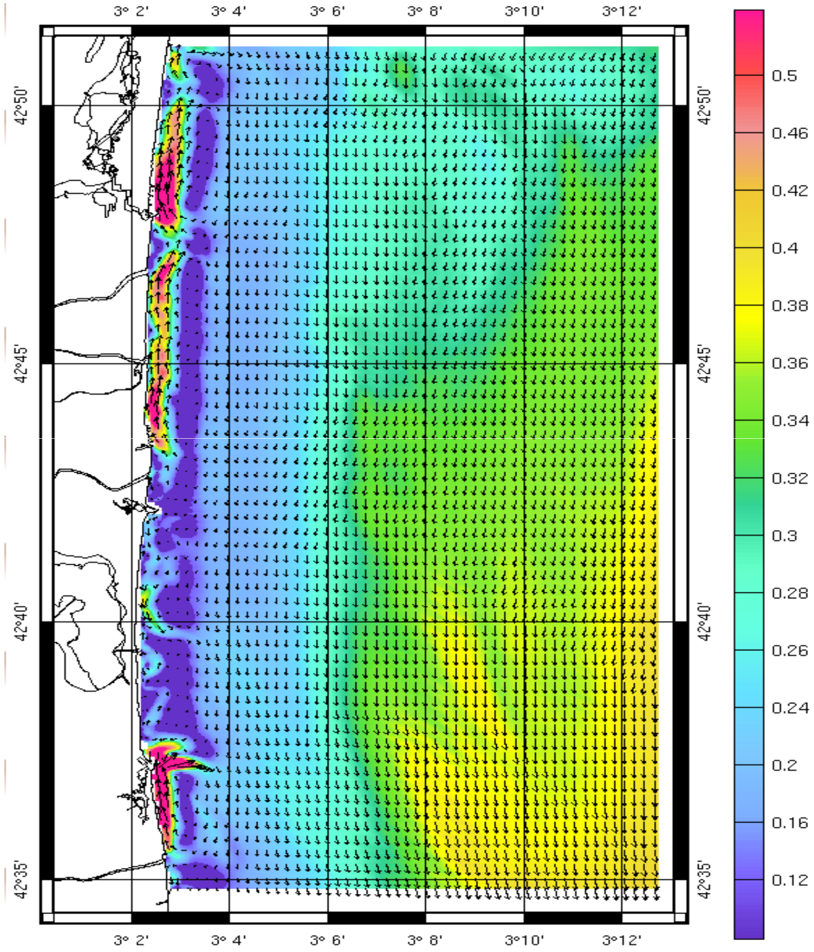
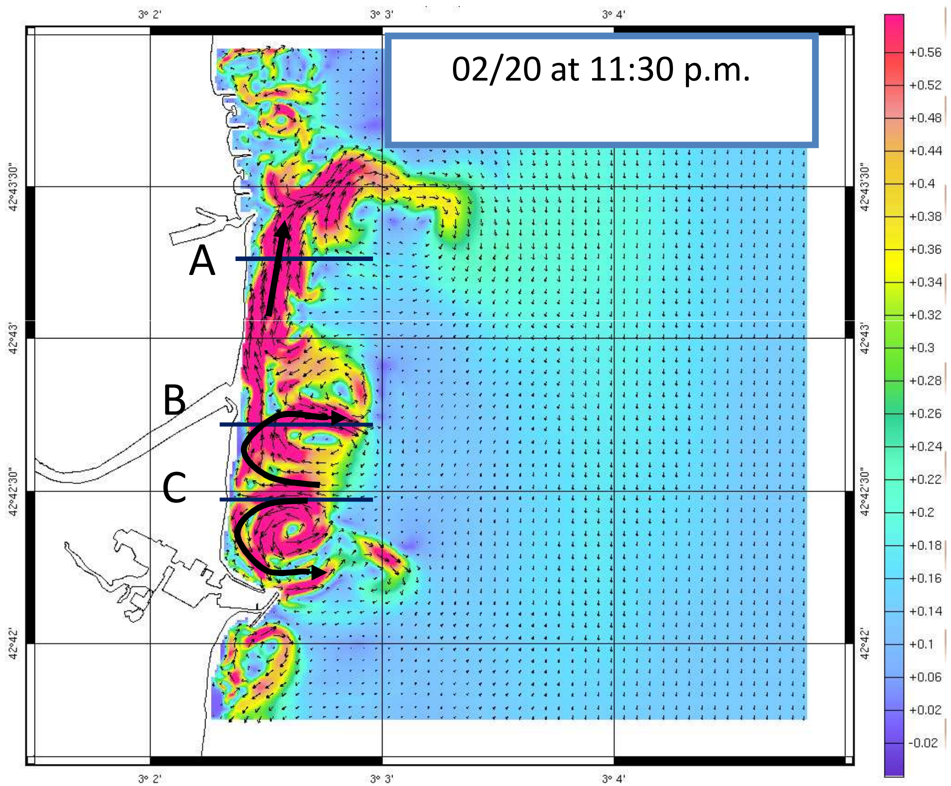


Figure: Comparison of wave parameters between data and WW3 simulation at SODAT (11m)

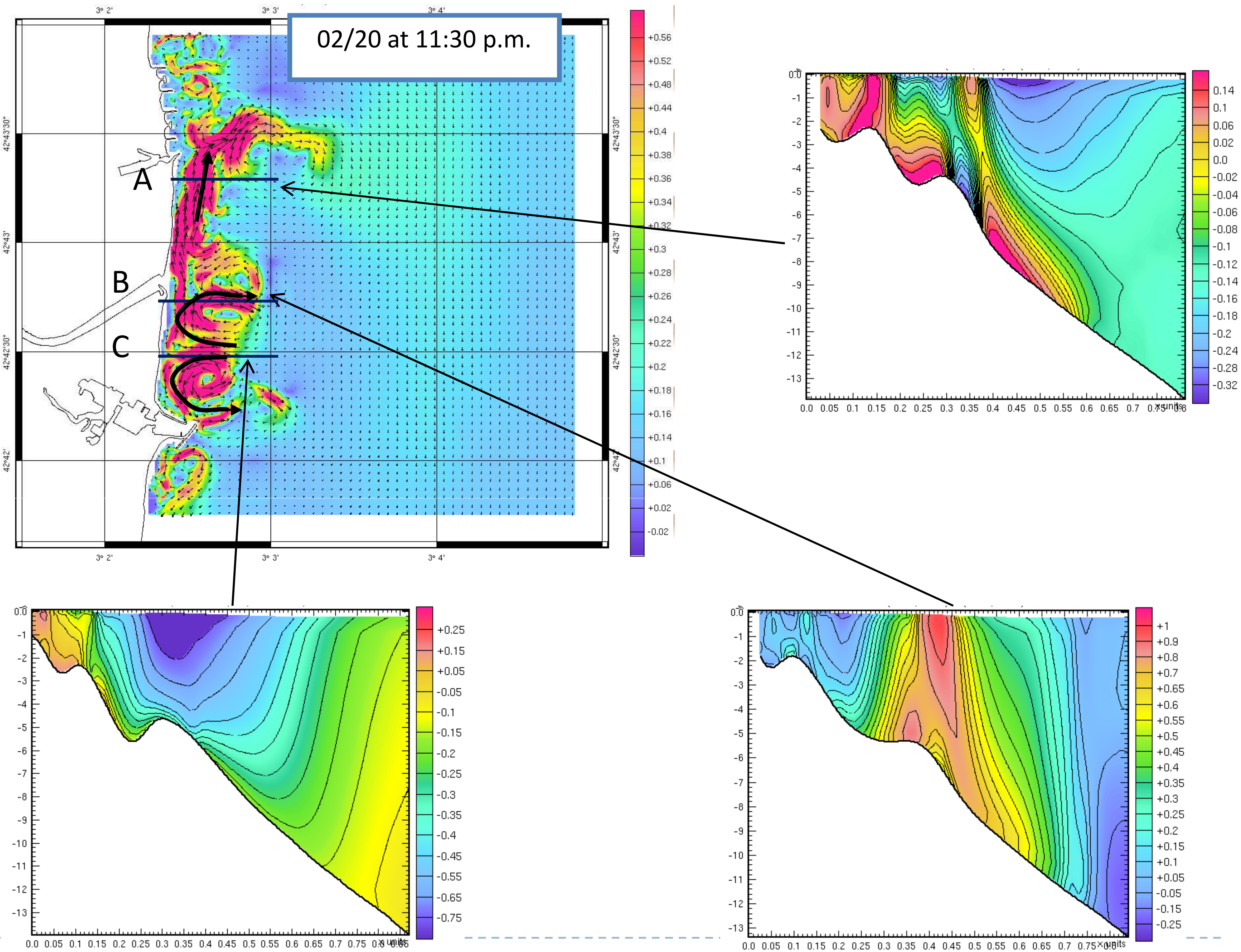
Is it necessary to use all these grids ?

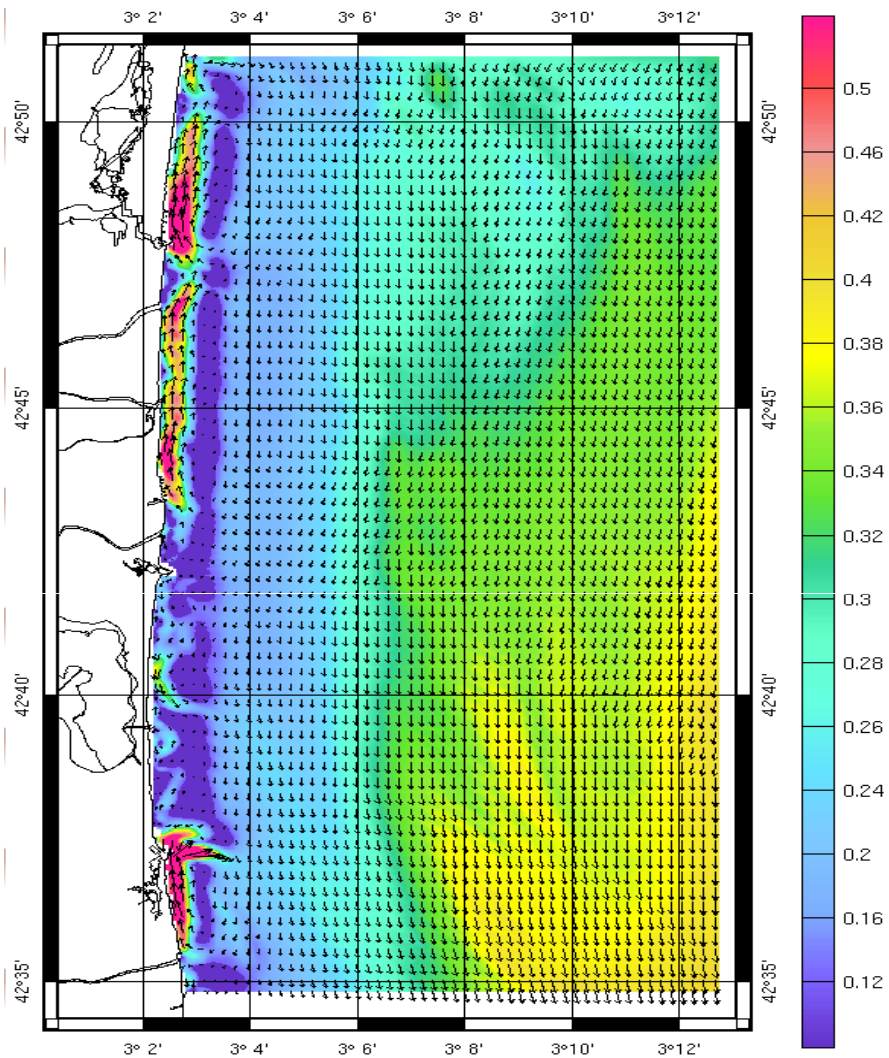


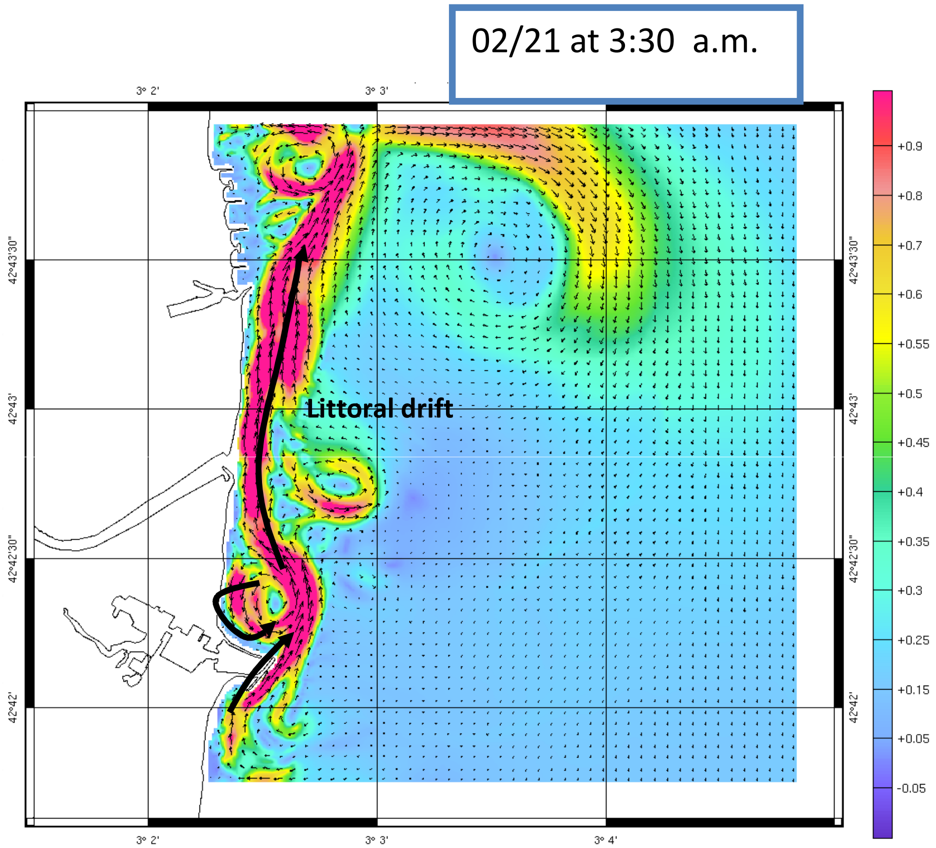
Depth-integrated current at the storm apex on February 2, 2004 at 4h19m, at the TET scale



Depth-integrated current on 02/20 at 11:30 p.m. Location of the three vertical sections is indicated by the horizontal blue lines.


02/20 at 11:30 p.m.
A
B
C





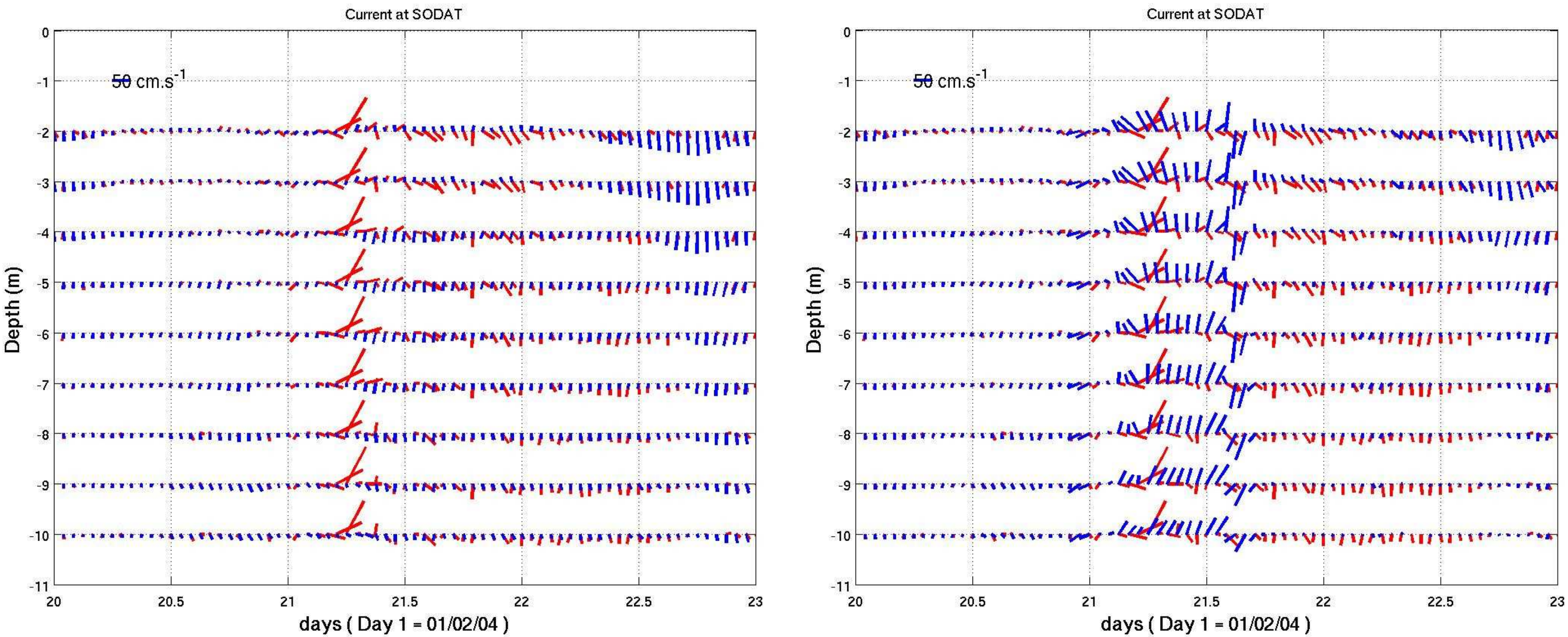
Depth-integrated current at the storm apex on February 21, 2004 at 4h19m, at the TET scale

Depth-integrated current on 02/21 at 3:30 am.

Comparison data/model

Simulation sans forçage par la houle

Simulation avec le forçage par la houle



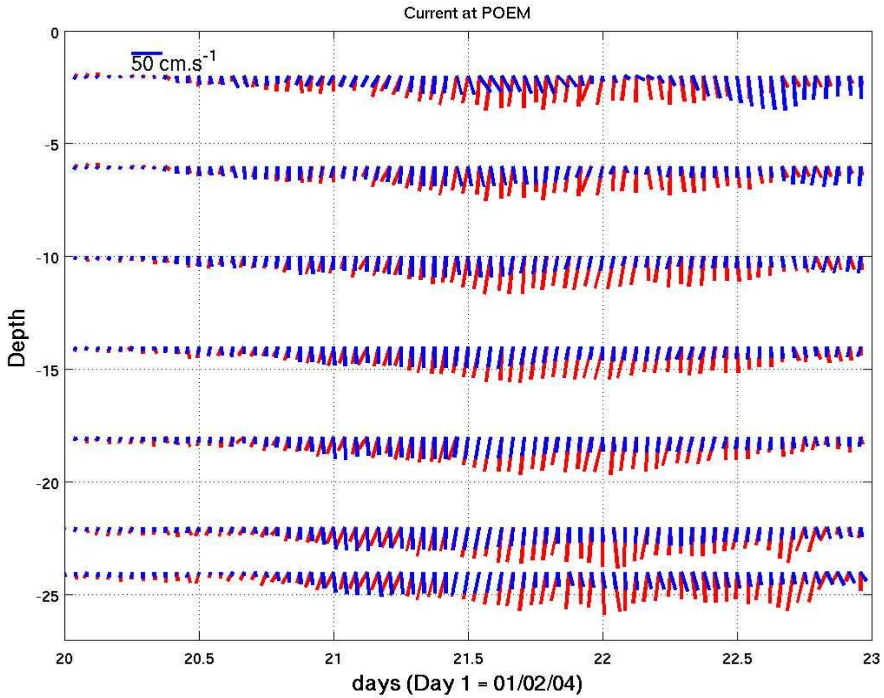
Simulation

Data

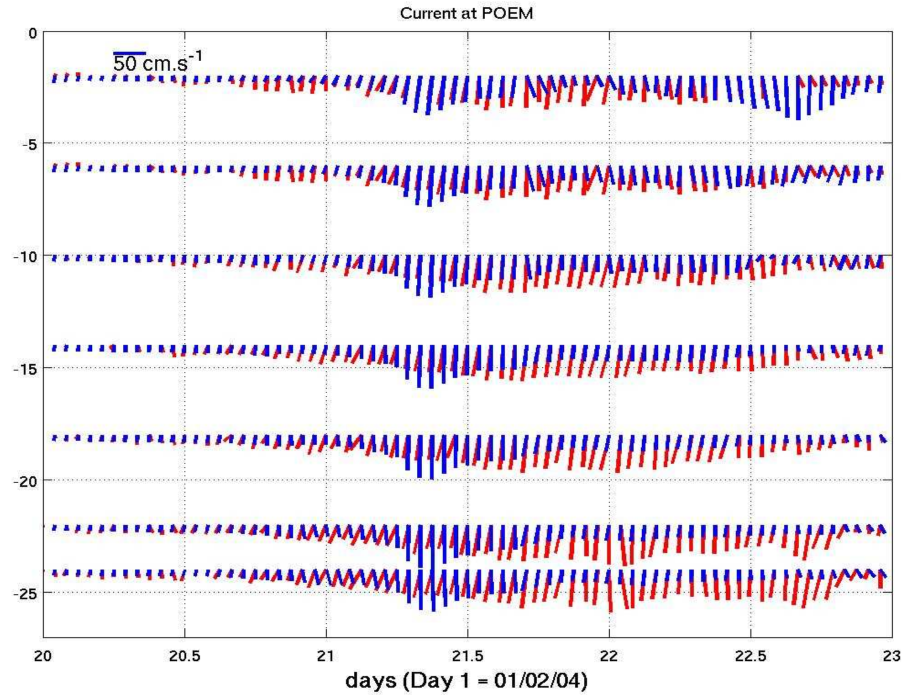
Comparison of time series at the three instruments, between the measured current and the simulated current. Left: the simulation is performed without the wave forcing, and right: the simulation is performed with the wave forcing.

Comparison data/model

Simulation sans forçage par la houle



Simulation avec le forçage par la houle



Comparison of time series at the three instruments, between the measured current and the simulated current. Left: the simulation is performed without the wave forcing, and right: the simulation is performed with the wave forcing.

Simulation

Data

Conclusion & Perspectives

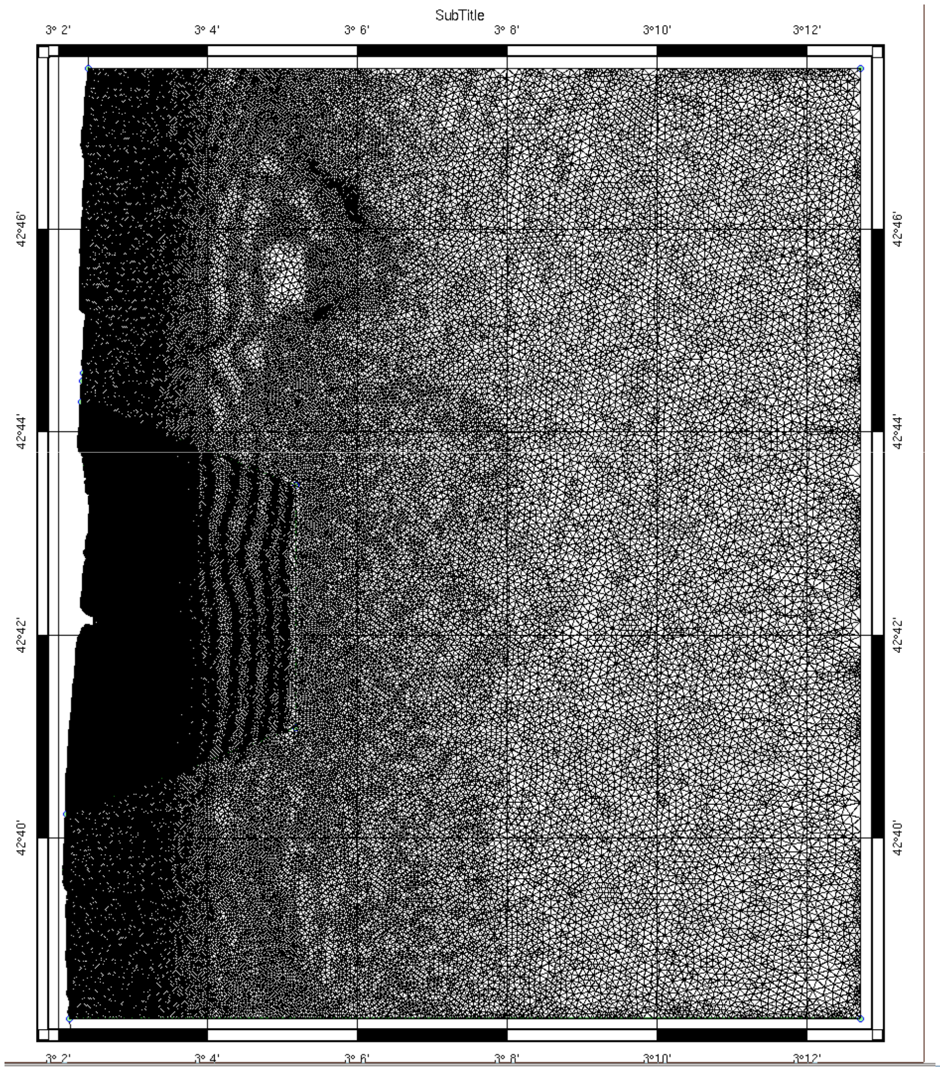
Conclusion:

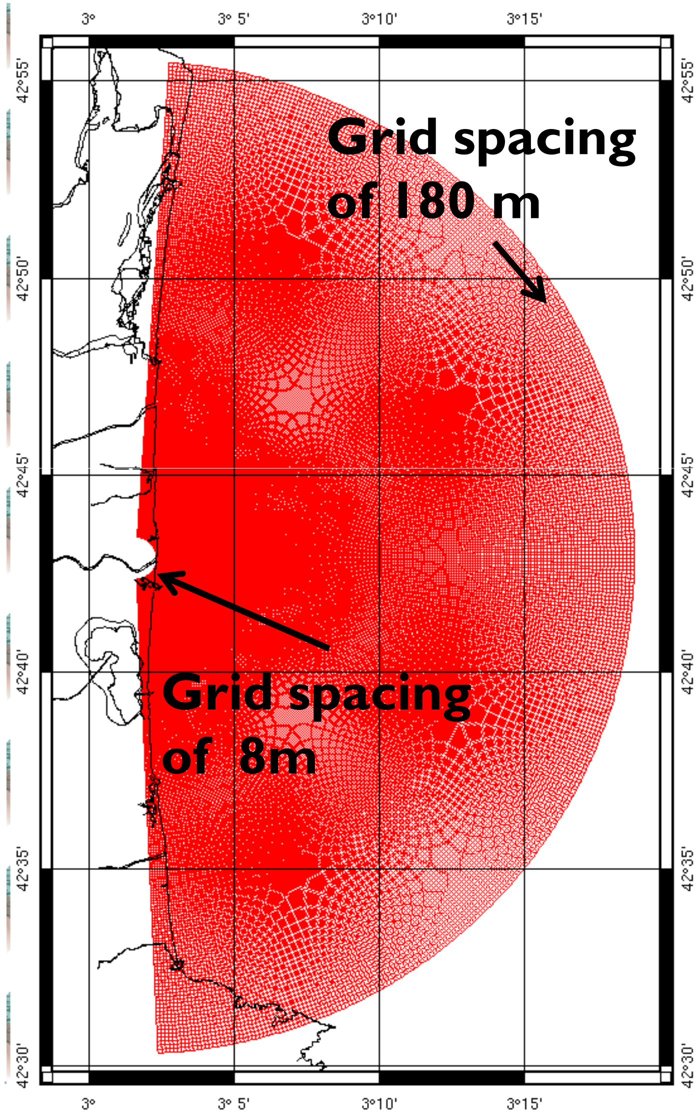
- Implementation and validation of a 3D circulation model forced by a wave model, that can be used from the surf zone to the global scale.

Perspectives:

- Addition of a sediment transport model
- Use of unstructured grids to avoid the boundary effects with Clément Mayet & Florent Lyard (LEGOS)

Unstructured grid in WW3 and circular grid in SYMPHONIE





Thank you !!