Effects of waves on water dispersion in a semi-enclosed estuarine bay

2012 EGU General Assembly
Vienna, Austria

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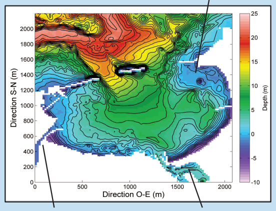
Study site

The bay of *Saint Jean de Luz - Ciboure* is located in the south of the French Atlantic Coast. This meso-macro tidal region is exposed to energetic swells coming mainly from North Atlantic with direction W-NW. The studied bay is semi-enclosed by breakwaters and receives fresh water inflows from two small rivers.

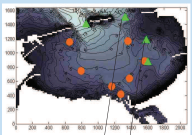


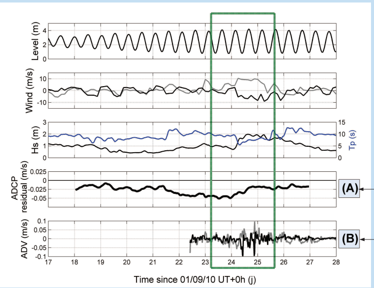
As waves penetrate the bay, a surfzone is regularly observed over a shallow rock shelf in the east part of the area. Except in the vicinity of the shelf or the river channels, currents are generally weak inside the bay.

In addition the frequently very high level of precipitation can cause pollutants to be streamed into the rivers and then further introduced in the bay with freshwater inflows. River plume dynamics is thus a crucial issue for this touristic area.

Field data

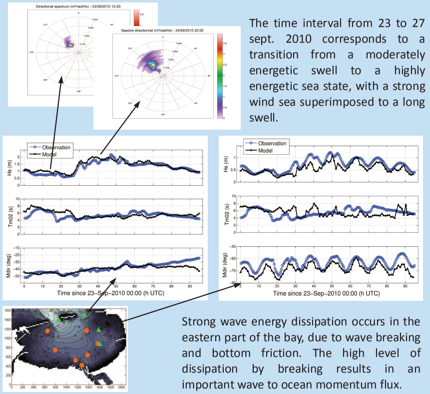
Waves, current, salinity and temperature measurements were performed in the bay during LOREA[*] 2010 field experiment. An array of 4 bottom mounted sensors (green triangles) was deployed during 3 weeks, combined with S/T measurements (orange circles) during one tide cycle following a rain event.





The end of the experiment is characterized by a transition from a moderate swell with (Hs,Tp)=(1m,10s) to an energetic wind sea with (Hs,Tp)=(2m,7s). This sea state evolution appears well correlated with an increase of the tide-residual current in the eastern passe (A) and a longshore current in the surfzone (B).

Wave dynamics

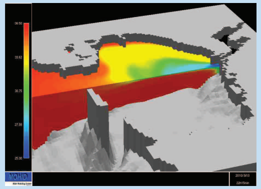


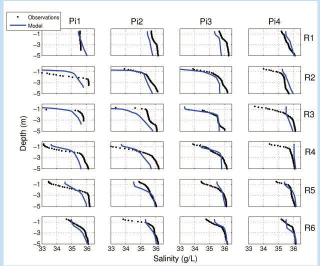
The time interval from 23 to 27 sept. 2010 corresponds to a transition from a moderately energetic swell to a highly energetic sea state, with a strong wind sea superimposed to a long swell.

Strong wave energy dissipation occurs in the eastern part of the bay, due to wave breaking and bottom friction. The high level of dissipation by breaking results in an important wave to ocean momentum flux.

River plume dynamics

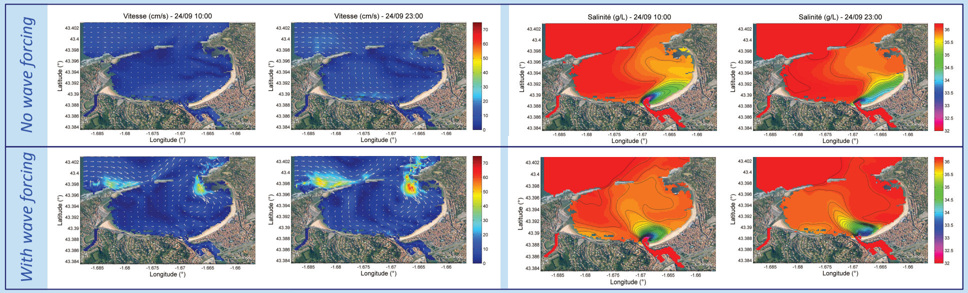
Observed salinity profiles reveal a strong stratification in the bay, more or less depending on the tidal cycle. The typical depth of the lower salinity surface layer is between 1m and 2m. Freshwaters transport and mixing result in different shapes of the salinity profile, well reproduced by the model.





Dynamics during a period with high-energy incident waves

Comparing model results in the surface layer with and without wave forcing illustrates the expected role of waves in the bay circulation. The longshore current induced by waves in the surfzone tends to reduce the accumulation of freshwater in the eastern part of the bay. The plume is advected towards the center and western zone. Beaches of *Saint Jean de Luz* (south-eastern zone) are then less impacted by the river plume.



[*] Littoral, Ocean, Rivers in Euskadi Aquitain. http://www.lorea.eu/. The LOREA project is led by the Conseil Général des Pyrénées Atlantiques (CG64). Rivages Pro Tech contributes to LOREA within the framework of a Research Agreement with the CG64. The results and models developed with LOREA concerning the Bay of SJDLC are also used in an operational water quality management system as part of a collaboration between the city of Saint Jean de Luz, the city of Ciboure and Rivages Pro Tech.

Model data

Flow model

The present work is based on the code MOHID (Martins et al. [2001], Braunschweig et al. [2004]). It is used to represent the bay dynamics under forcings of freshwater inflows, wind, tide and waves.

The original MOHID code has been modified to solve the *Generalized Lagrangian Mean* (GLM) wave-current equations for the quasi-eulerian momentum as proposed by Ardhuin et al. [2008], in the form given by Bennis et al. [2011]. Governing equations for the quasi-eulerian momentum ($\underline{u}$, $\underline{v}$, $\underline{w}$) = (u, v, w) - (u^S, v^S, w^S) are given by

$$\frac{\partial \underline{u}}{\partial x}+\frac{\partial \underline{v}}{\partial y}+\frac{\partial \underline{w}}{\partial z}=0$$

$$\frac{\partial \underline{u}}{\partial t}+\frac{\partial \underline{u}\underline{u}}{\partial x}+\frac{\partial \underline{v}\underline{u}}{\partial y}+\frac{\partial \underline{w}\underline{u}}{\partial z}-f\underline{v}+\frac{1}{\rho}\frac{\partial p^H}{\partial x}=fv^S+\frac{\partial \underline{u}}{\partial x}u^S+\frac{\partial \underline{v}}{\partial x}v^S-\frac{\partial J}{\partial x}+F_{m,x}$$

$$\frac{\partial \underline{v}}{\partial t}+\frac{\partial \underline{u}\underline{v}}{\partial x}+\frac{\partial \underline{v}\underline{v}}{\partial y}+\frac{\partial \underline{w}\underline{v}}{\partial z}+f\underline{u}+\frac{1}{\rho}\frac{\partial p^H}{\partial y}=-fu^S+\frac{\partial \underline{u}}{\partial y}u^S+\frac{\partial \underline{v}}{\partial y}v^S-\frac{\partial J}{\partial y}+F_{m,y}$$

(Stokes drift velocity: u^S, v^S; Wave-induced pressure: J; Turbulent mixing term: $F_{m,x}$)

with boundary conditions

at the bottom
$$\begin{cases} K_M\dfrac{\partial \underline{u}_\alpha}{\partial t}=\tau_{cw,\alpha} \\ \underline{u}\dfrac{\partial h}{\partial x}+\underline{v}\dfrac{\partial h}{\partial y}=\underline{w} \end{cases}$$
(Combined wave and current bottomstress: $\tau_{cw,\alpha}$)

at the surface
$$\begin{cases} K_M\dfrac{\partial \underline{u}_\alpha}{\partial t}=\tau_{a,\alpha}-\tau_{aw,\alpha}+\tau_{wo,\alpha} \\ \dfrac{\partial \eta}{\partial t}+(\underline{u}+u^S)\dfrac{\partial \eta}{\partial x}+(\underline{v}+v^S)\dfrac{\partial \eta}{\partial y}=\underline{w}+w^S \end{cases}$$
(Wind stress: $\tau_{a,\alpha}$; Wave-supported wind stress: $\tau_{aw,\alpha}$; Wave to ocean momentum flux due to breaking: $\tau_{wo,\alpha}$)

Turbulent closure uses a k-ε model, with wave enhanced vertical mixing represented by an increased surface rouhgness length and a source of turbulent kinetic energy at the surface.

The evolution of a conservative tracer *C* is given by $\frac{\partial C}{\partial t}+\frac{\partial uC}{\partial x}+\frac{\partial vC}{\partial y}+\frac{\partial wC}{\partial z}=0$

Wave model

Wave simulations are performed with the phase-averaged spectral wave model WaveWatchIII®, in its version 4.04 (Tolman [2009], Ardhuin et al. [2010]). It includes wind input, nonlinear 4-waves interactions, bottom friction, whitecapping and depth-induced dissipation.

Conclusions

The present study combines field experiment and numerical modelling to investigate water dispersion in an estuarine bay. Although the bay is mostly protected from the open sea, wave induced current and mixing appear to affect significantly the river plume during periods of energetic incident waves. Given the fair agreement between model and observations, numerical results will further be used to investigate the observed correlation between the sea state and tide-residual currents.

References

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