# SEDIMENT TRANSPORT IN THE BAY OF MARSEILLE : ROLE OF EXTREME EVENTS

Romaric Verney[1], Cassandre Jany[2], Benedicte Thouvenin[1], Ivane Pairaud[2], Michalis Vousdoukas[3], Christel Pinazo[4], Fabrice Ardhuin[5] and Philippe Cann[1]

**Abstract**

Human pressures on ecosystems have increased significantly over the last decades, and especially Mediterranean coasts are strongly impacted by the development of big cities and industrialized area, such as the Bay of Marseille. Prior to any investigations on ecological or contamination impacts, it was necessary to understand sediment dynamics and its response to natural extreme events such as storm or heavy rainfall events. In situ observations were dedicated to understand the behavior of bed sediments, and their spatial distribution. A benthic station was deployed for three months to observe the impact of extreme events on hydrodynamics and sediment dynamics in a critical zone of the study area. These measurements were used to calibrate and validate the RHOMA MARS3D/WWIII configuration, both in terms of hydrodynamics, waves and sediment dynamics. Numerical simulations were then analyzed in order to examine the influence of extreme meteorological events on the Marseille coastal physical ecosystem.

**Key words:** *sediment dynamics, large coastal cities, urban pressure, extreme events, wave, rainfall, Marseille*

## 1. Introduction

Mediterranean coastal environments are fragile ecosystems, stressed by natural (extreme) events and human pressure (Boudouresque et al., 2009). The Bay of Marseille constitutes a Mediterranean coastal environment of particular interest due to its unique location within the Gulf of Lions : the bay shelters the second biggest city in France and dense industrial areas and is only episodically under the influence of the Rhone river plume (main contributor of solid fluxes within the Gulf of Lions) (Arfi et al., 2000; Gatti et al., 2006). For centuries large amount of pollutants associated to mineral particles were delivered to the sea through inefficient waste water treatment networks, drained urban catchment areas and port activities (Arfi et al., 2000). In addition to local tributaries, the main tributary is the Cortiou outflow, located within the Calanques Area, an highly patrimonial environment (Figure 1). These sediments settled and constituted large contaminated accumulation areas. The Water Framework Directive and more recently the Marine Strategy Framework Directive imposed to improve water quality, which effectively led the city of Marseille to improve its waste water treatment network and hence considerably reduce solid discharge from tributaries. However, the Mediterranean climate regime is strongly associated to sudden heavy rainfall events, delivering large water fluxes over the water treatment plant capacity limit. In such rare but significant events in term of annual solid fluxes, part of the discharge is diverted to the Huveaune river, flowing into the south bay of Marseille, close to recreational protected areas (Figure 1). The METROC and MASSILIA projects aimed at evaluating the fate of contaminants within the Bay of Marseille from the two

[1] DYNECO/PHYSED, Ifremer, BP70, 29280 Plouzané, France. romaric.verney@ifremer.fr, benedicte.thouvenin@ifremer.fr
[2] LER/PAC, Ifremer, ZP de Brégaillon, 83507 La Seyne sur Mer, France. ivane.pairaud@ifremer.fr; cassandre.jany@ifremer.fr
[3] Forschungszentrum Kuste, Merkurstrasse 11, 30419 Hannover, vousdoukas@fzk-nth.de
[4] Mediterranean Institute of Oceanography (MIO) - UMR 7294 Pytheas Institute (OSU) Aix-Marseille University Station Marine d'Endoume, Chemin de la Batterie des Lions, 13007 Marseille. christel.pinazo@univ-amu.fr
[5] LOS, Ifremer, BP70, 29280 Plouzané, France. fabrice.ardhuin@ifremer.fr

main identified sources : old contaminated deposited sediments or actual discharge from tributaries. Due to the strong affinity of contaminants with mineral particles in suspension, identifying the fate of contaminants requested preliminarily to investigate the sediment dynamics within this pilot site. The objectives of this paper are i) to improve our knowledge on bed sediment behaviour in the Bay of Marseille, analyse their response to extreme meteorological events ii) investigate the role of heavy rainfall events on the local sediment dynamics. A 3D hydrodynamic (Pairaud et al., 2011) and sediment transport model was implemented within the area to investigate these extreme scenarios. Prior to such model analysis, an in situ observation strategy was designed to describe bed sediment features and monitor the response of the coastal environment to natural forcings.

## 2. Measurement strategy

<u>Bed sediment features</u>

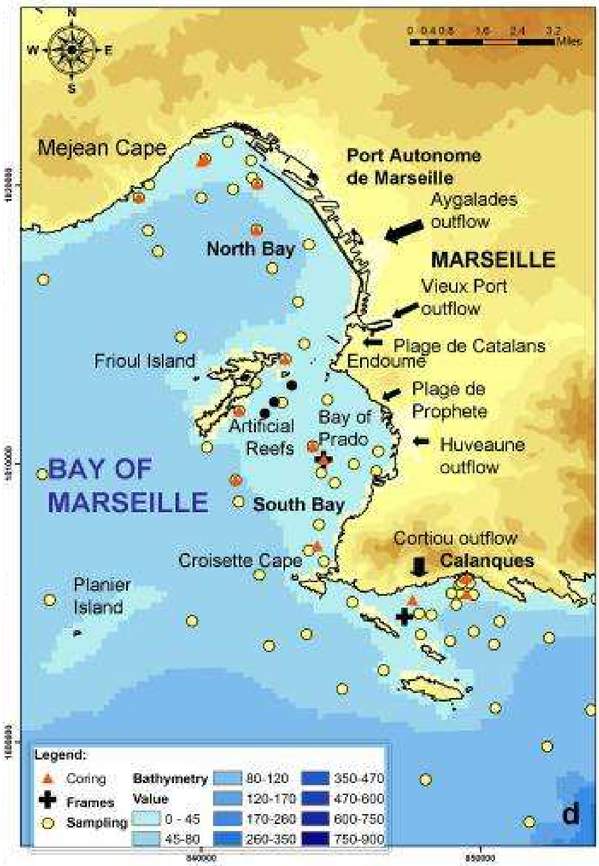
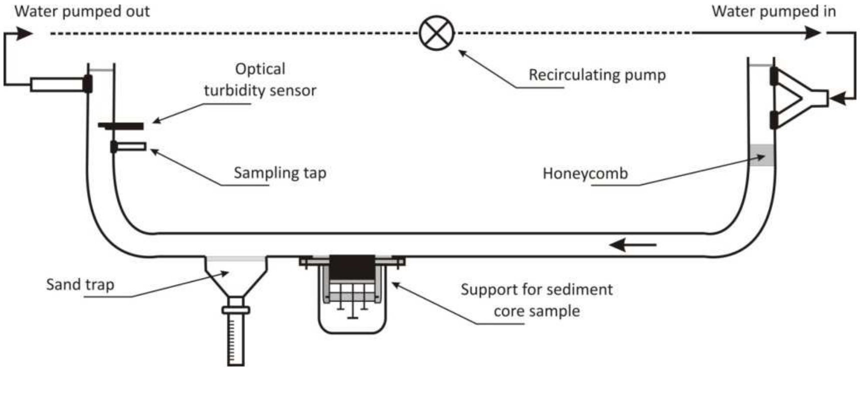



Figure 1: The Bay of Marseille : main tributaries and location of i) grab samples, ii) sediment cores, iii) benthic station (frames).

The spatial distribution of bed sediment features was analysed through an extensive sampling program, composed of i) >40 shipeck-grabbed samples (from 2004 to 2006) to estimate bed grain size distribution, water content and sediment concentration, ii) 11 40cm cores collected from a multitube interface corer, in order to preserve the sediment/water interface and realise erodibility tests. These erodibility tests were carried out from the portable erodimeter developed at Ifremer (Figure 2), which determines the critical erosion shear stress and the erosion flux by applying increasing step by step bed shear stress in a small (18 L) recirculating flume. Fine sediment erodibility is monitored with an optical turbidimeter (OBS3) and sand erosion through a graduated sand trap located downstream the test section (here the sediment core). At the end of each test the sand collected inside the trapped is weighted to compute the mass of sediment eroded at each step, while the mass of eroded fine sediment is calculated from the monitored optical turbidity after mass concentration calibration determined from water samples collected during the experiment. These erodibility parameters are important as they control the erosion law used in the sediment transport model.

Figure 2: Schematic view of the Ifremer portable Erodimeter.



In situ monitoring benthic station

The FRAME station is a benthic station dedicated to contaminant quantification. It is composed of a suite of environmental sensors (ADCP, CTD, optical turbidity meter and acoustic altimeter) which control, based on turbidity and wave thresholds, modules dedicated to contaminant measurements. In the present paper only the environmental data are analysed (Vousdoukas et al., 2011). ADCP records current profile (0.5m cell size) every 20 minutes and waves every hour. Optical turbidity meters (Wetlabs ECOBB) were deployed 0.25 and 0.6 m above the bed and collect data every 20min as well as the ALTUS altimeter. The optical sensor was calibrated in mass concentration from laboratory experiments from surface sediment collected on site. The acoustic backscattered signal was corrected from water attenuation and calibrated in mass concentration from suspended solid concentration obtained with the optical sensors. Sediment attenuation was neglected as SSC was always lower than 100mg.l$^{-1}$ on site. The FRAME station was deployed SW from the Cortiou outflow during winter 2008 (20m depth, black cross at the SW of the Cortiou outflow).

**3. Model description**

The hydrodynamic model is based on the MARS3D code developed by Ifremer (Lazure and Dumas, 2008) and was implemented and validated by Pairaud et al. (2011). The RHOMA configuration used in this study is based on a 400m resolution orthogonal grid (251x119 grid points) and 30 level vertical sigma coordinates (refined resolution close to the water surface and the bottom). This regional model is forced at the open boundary by a large scale model (MENOR configuration, André et al 2005, 2009), and by 3h MM5 meteorological fields. Daily river inputs from the Rhone river (Beaucaire station) and all small tributaries are included in the model, with data available from the Compagnie Nationale du Rhone and water resources local authorities, respectively.

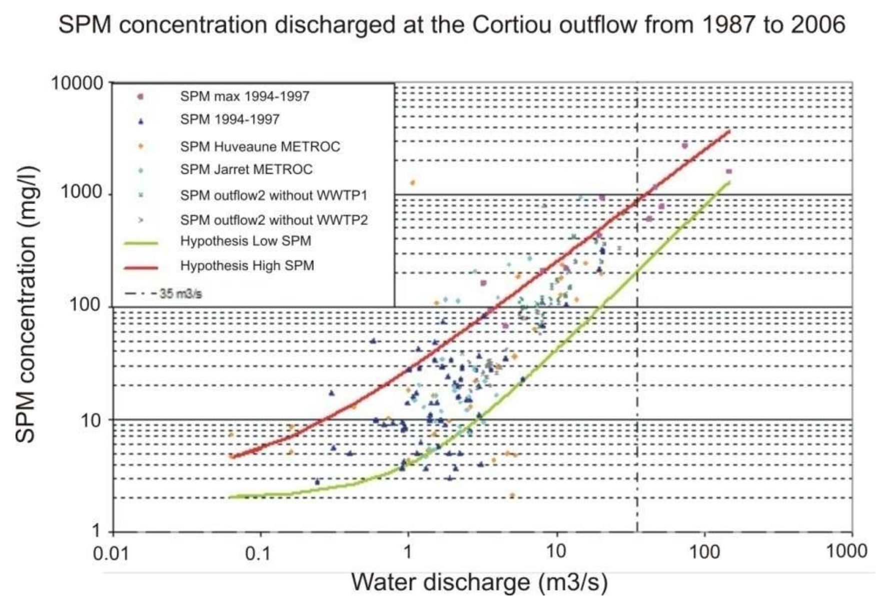



Figure 3. Example of prescribed SPM concentration at tributary outflows based on data available in the literature. Case of Cortiou outflow.

The sediment transport model is based on developments carried out on the SiAM3D model (Le Hir et al., 2011) i.e. : sediment is discretized in thin layers which are created or deleted based on net erosion/sedimentation at each time step, and consolidation processes are neglected. Four sediment classes are used : 3 mud classes (quasi non settling - Ws~0.0001mm/s, light - Ws~0.01mm/s, and heavy - Ws~0.2mm/s) and 1 sand class. In order to save computation time, we hypothesised that eroded sand is directly deposited in the same time step, i.e. sand is not advected into the water column. This allowed to reach reasonable computation times, requested for coupled ecological and contaminant modelling. The Partheniades erosion law (Eq 1) is used and main parameters will be deduced for the erodibility tests.

$$E = E_0 \left(\frac{\tau}{\tau_{ce}} - 1\right) \; if \; \tau > \tau_{ce} \qquad \text{(Eq. 1)}$$

The hydrodynamic and sediment transport model was forced by a sea state model (WAVEWATCH III (R), version 4.06, Tolman 2008, Ardhuin et al. 2010), implemented in the area on an unstructured mesh (Roland 2008, Ardhuin et al. 2009). This allowed to refine mesh size close to the coast (~100m), where this information is the most relevant. The wave model is forced at the open boundary by the regional wave model described in Magne et al. (2010) and forced by ECMWF operational wind analyses. The orbital velocity computed by the wave model from the full wave spectrum is used to calculate a wave shear stress (uniform friction factor), which is used to calculate the total wave-current shear stress.

Bed sediment is first initialized from the interpolation of in situ grab samples. Then the model runs for 2 years to stabilize the sediment bed distribution. The main uncertainty is the sediment concentration and sediment distribution to impose at the tributaries outflows. All available suspended particulate matter data were collected for every tributaries and compared to water discharge, in order to find the best estimate. Due to high data scattering, two scenario were tested (high/low solid fluxes, Figure 3). Similarly, two sediment distributions scenario were tested, based on different heavy/light mud ratios.

## 4. Results

Bed sediment features

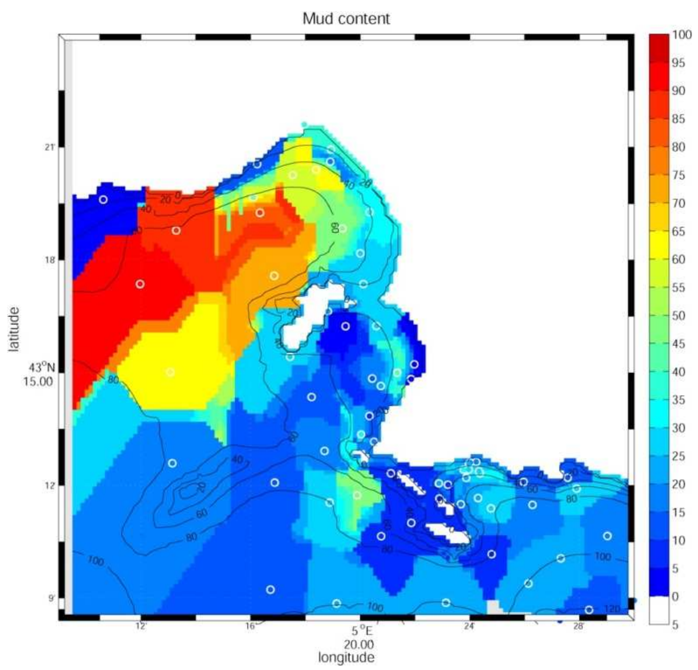



Figure 4. Sediment bed cover in the Bay of Marseille : interpolation of mud content.

The compilation of bed sediment samples collected all over the study area permitted to estimate the spatial distribution of the grain size distribution and water content. These data were then interpolated based on the inverse distance technique but weighted by the bathymetric gradient, i.e. more weight is given to samples on the same isobaths (Figure 4). This method partly compensate the low grid spacing of collected samples off the bay, even if uncertainties remain. Results show that the North bay, the deepest part of the pilot site, is mainly muddy while the South bay is sandy, as well as the Calanques area. Sandy muds are observed in the front of the Cortiou outflow, which demonstrates the presence of fine sediment deposits.

Based on this bed sediment distribution, 11 cores were collected, representative of most of the facies observed on site, and used to estimate erosion parameters. Estimating the critical erosion shear stress ($\tau_{ce}$) is complex as criteria used to determinate the initiation of erosion are not well established. Four methods were used and their results averaged to estimate $\tau_{ce}$ : i) the first grain movement observed by the operator, ii) visual observation of turbidity gradient, iii) the bed shear stress reached when the eroded mass per square meter exceeds 0.02g.m$^{-2}$, iv) when the erosion flux exceeded 0.3g.m$^{-2}$.s$^{-1}$. Results show that the average critical shear stress computed for surface sediments range from 0.2 to 0.3 N.m$^{-2}$. This variability can be roughly explained by the bed composition and a simple threshold relationship is used : $\tau_{ce}$ =0.2N.m$^{-2}$ if the mud fraction is above 60%, $\tau_{ce}$ =0.3 otherwise. Individual erosion rates $E_0$ for each erodibility tests were computed so that the erosion flux calculated from Partheniades fits the measured erosion. Hence all erosion rates were compared to main bed sediment features and $E_0$ was found to be driven by the mud fraction (Figure 5a), characterized by an exponential relationship :

$$E_0 = 21.55\ e^{(-0.09\ F_{mud})}$$

The erosion fluxes computed from the proposed parameterisation of $\tau_{ce}$ and $E_0$ was compared to measured erosion fluxes, and few scattering was observed, excepted for the lowest values of erosion fluxes (Figure 5b). These parameterisation of $\tau_{ce}$ and $E_0$ will be used in the 3D sediment transport numerical model.

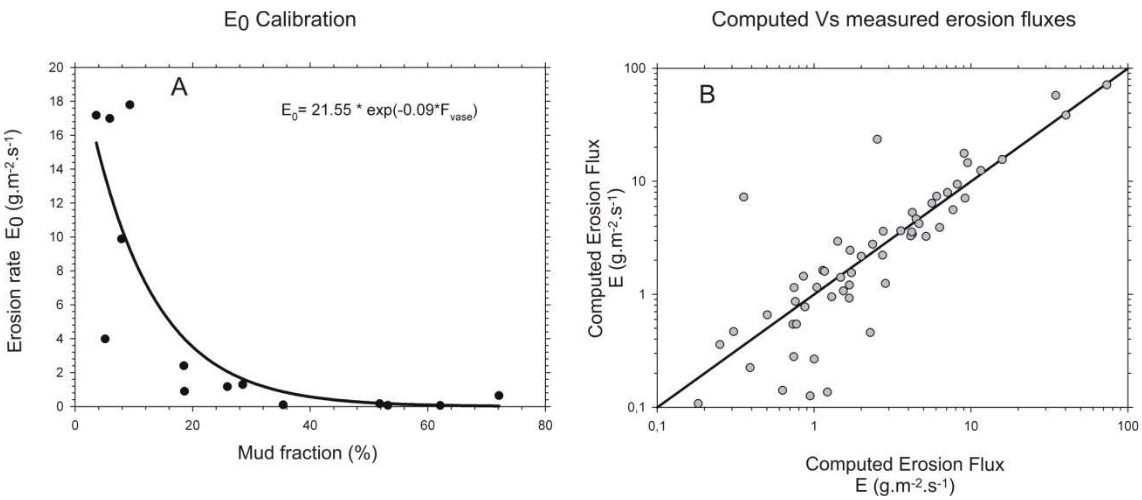



Figure 5. A : Calibration of the erosion rate as a function of the mud fraction from erodibility measurements. B : Measured Vs computed (from the parameterisation of $E_0$ and $\tau_{ce}$) erosion fluxes

<u>In situ observations</u>

During the deployment of the FRAME station, multiple events were recorded : i) heavy rainfall early and late November 2008, and around December 10th and December 14th. These rainfall events induced large water discharge at the Cortiou outflow, up to 30 m$^3$.s$^{-1}$, 10 times the average nominal discharge; ii) extreme wave events, corresponding to wave height up to 2.5m.

Wave events (Hs>1.5m) induces significant increase in SSC close to the bed (up to 100mg.l$^{-1}$, Figure 6). However, these resuspended sediment are not eroded locally (no erosion recorded by the altus at the beginning of the wave event) and hence correspond to suspended sediment eroded certainly at smaller depths and advected to the measurement site by the local circulation. The altimetry measurements confirm this assumption as every significant wave event is linked to a rapid deposition of sediment, the latter being eroded before the end of the wave event. The net balance is close to zero, which means that the site is stable, or could be characterized by a slow accretion (Figure 6). Sediments resuspended during such extreme meteorological events are transported up to 5 to 10 m above the bed, as observed by the ADCP, which means that they could be advected far from the eroded area.

Heavy rainfall events are more difficult to examine as all the events are superposed to wave events. Therefore a focus was made on the extreme rainfall event which occurred around December 14th (Figur e7). This event induced a peak of water discharge at the Cortiou outflow ($35m^3.s^{-1}$) on December 14th, at noon. Discharge decreased down to $10m^3.s^{-1}$ on December the 15th, 1pm. This rain event is combined with a wave event, whose peak is also recorded on December 14th, at noon (Hs>2m). The wave action impacts the seabed dynamic, with, similarly to all other wave events observed over the period, a large transfer of sediments linked to sedimentation/erosion and large bottom suspended solid concentrations (up to $75mg.l^{-1}$). The sudden fresh water turbid inflow at the Cortiou outflow is observed from the turbidity profile computed from the ADCP measurements:  a turbid surface plume (5 to 10m thick, turbidity larger than $100mg.l^{-1}$, still visible 2 days after the rainfall event) is observed few hours after the increase in water discharge at the outflow. The vertical SPM dynamic recorded by the ADCP reveals that two kinds of suspended sediments are flushed out from the outflow : i) relatively fast settling particles which are transferred from the plume layer to the sea bed, inducing bottom turbidity (around $50mg.l^{-1}$) just after the peak of water discharge, and $10mg.l^{-1}$ during all the period, which could be dense macroflocs or soil aggregates ; ii) slow settling particles, assumed being microflocs or very organic macroflocs, constituting the surface plume and advected by the local circulation. Bed altimetry records show intense deposition/erosion event (2cm), with a net balance for accretion of few millimetres, which could be attributed to the settling of suspended particulate matter from the outflow. However, similar conclusions can be made after wave events, and further investigations are required to confirm deposition of riverine material  in this area.

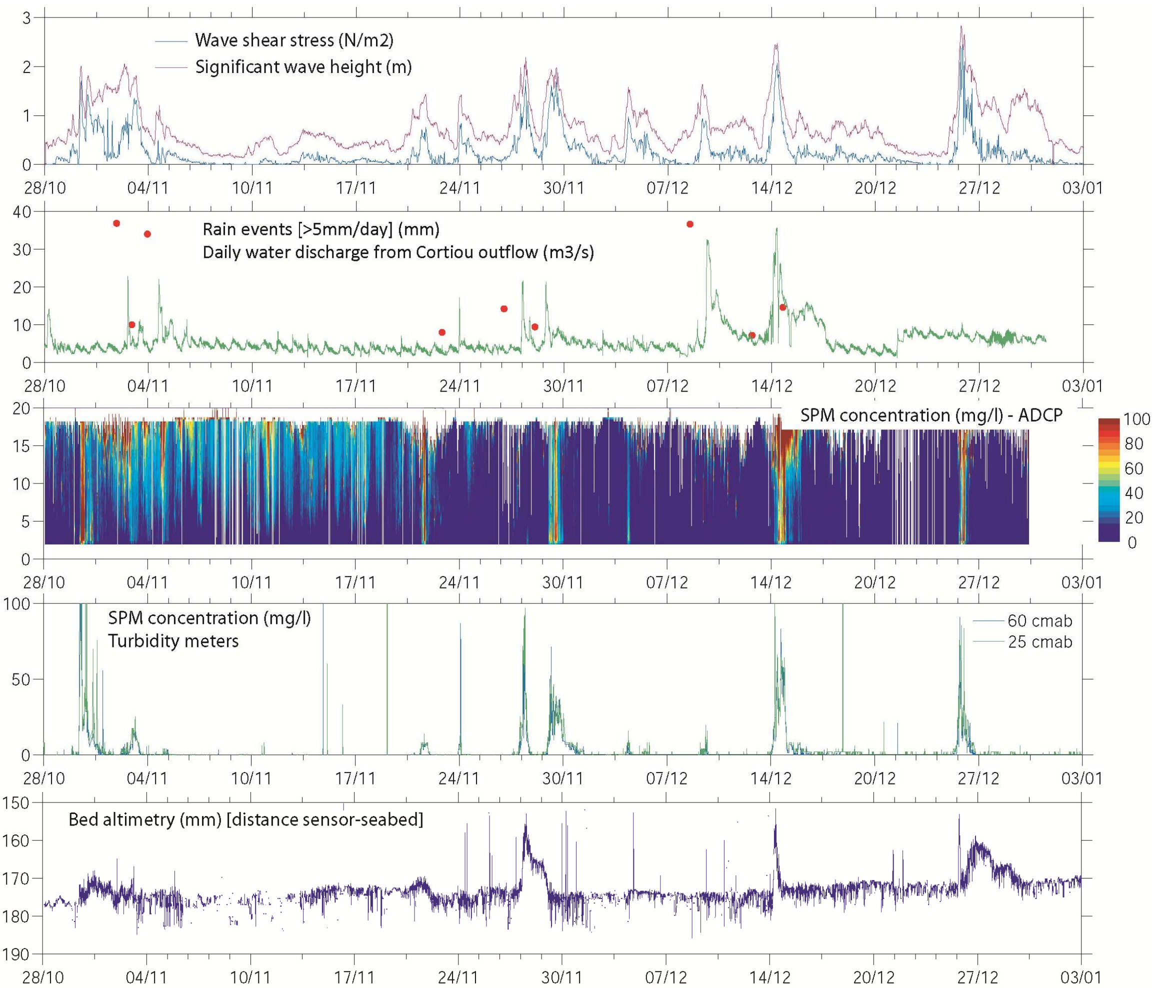



Figure 6 : Hydrodynamics and sediment dynamics at the Cortiou station from october 2008 to januray 2009 : wave hei ght and wave shear stress, Recorded rainfall and water discharge at the Cortiou outflow, SPM concentration in the wate r column, SPM concentration close to the bed (optical turbidity meters), Bed altimetry.

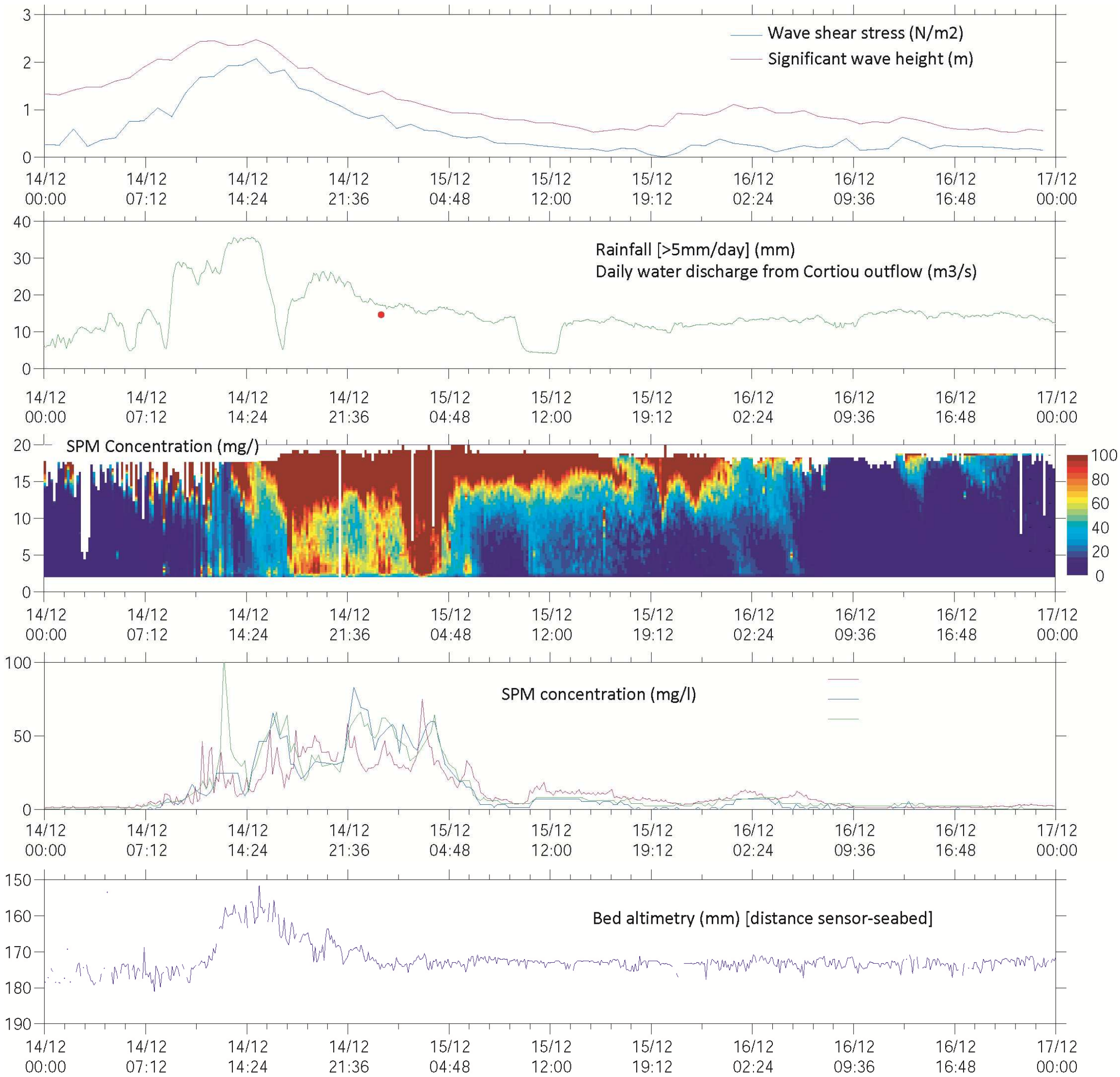



Figure 7 : Hydrodynamics and sediment dynamics at the Cortiou station, focus on a heavy rainfall event on December 14th, 2008 : wave height and wave shear stress, Recorded rainfall and water discharge at the Cortiou outflow, SPM co ncentration in the water column, SPM concentration close to the bed (optical turbidity meters), Bed altimetry.

Model results

Model results were first confronted to in situ observation, in order to validate assumptions especially on the concentration and sediment distribution discharged by outflows. To this aim, ADCP turbidity profiles and simulated SPM concentration profiles (for both heavy and light particles) are compared (Figure 8). Results show that the light particles successfully represented the turbid plume, with similar plume thickness (~5m) and comparable SPM concentration, even if simulated surface SPM are still lower (>50mg.l$^{-1}$) compared to observations (>100mg.l$^{-1}$). Heavy particles dynamics is also correctly represented, with a rapid sedimentation of this material and a peak around December 15th, midnight. Similar comparisons were done on the bottom SPM concentration time series recorded by the optical turbidity meter or simulated by the model, which demonstrated the correct capacity of the model to reproduce the local dynamics.

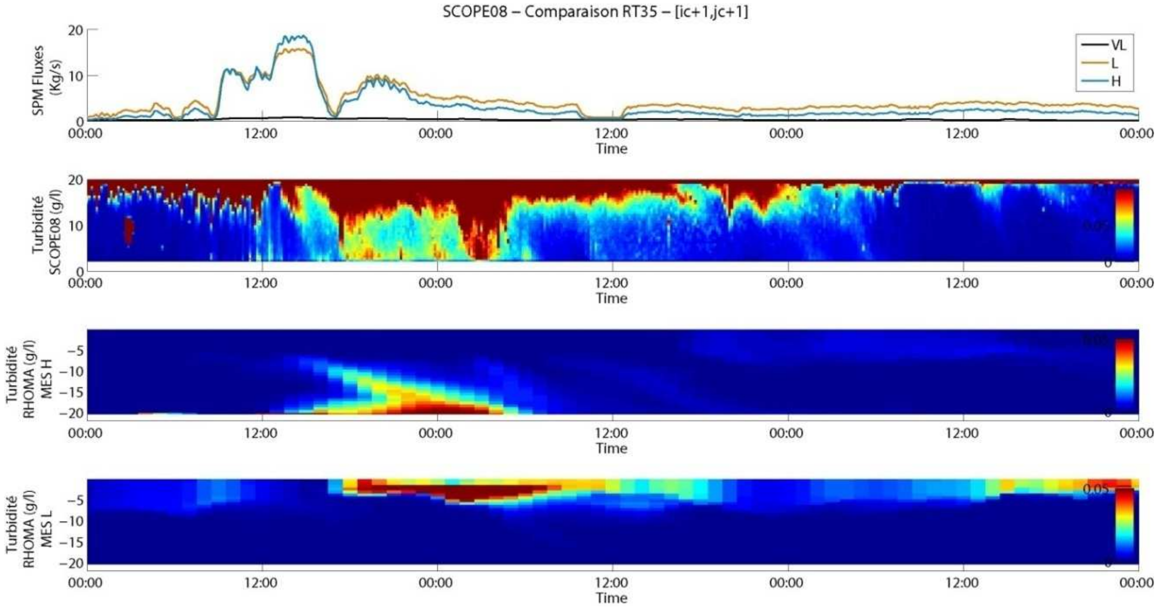



Figure 8 : Comparison between solid fluxes from Cortiou (a), observations (b) and simulated SPM concentrations (hea vy particles, c and light particles, d) close to the Cortiou benthic station.

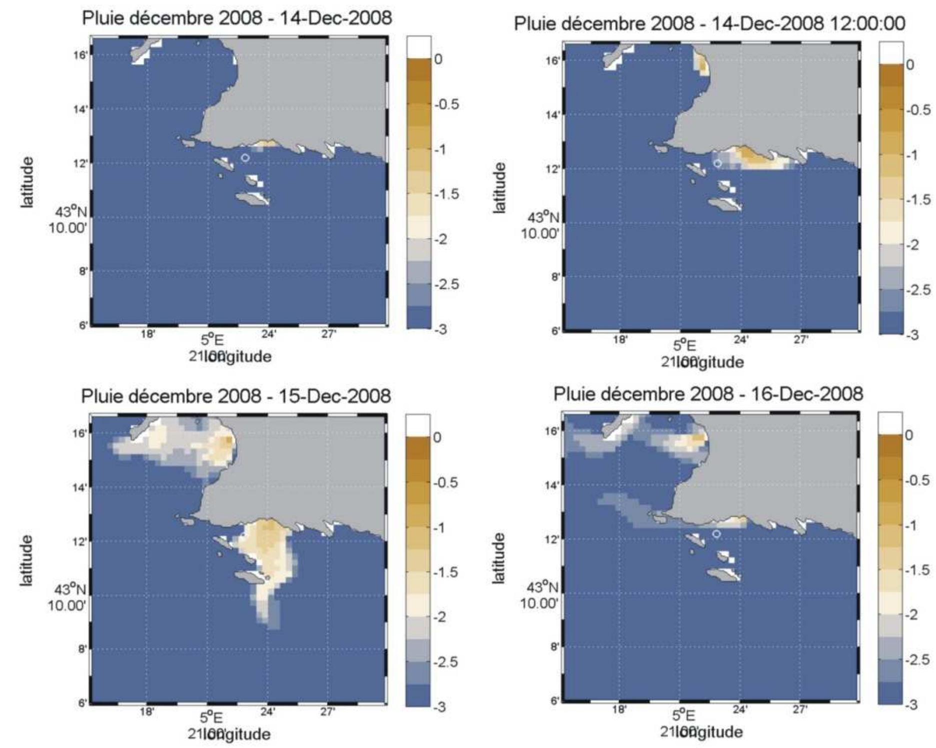



Figure 9 : Simulated surface turbid plume from December the 14th to December the 16th, before and after heavy rainfa ll event. (turbidity in log of SPM, 0=1000mg.$l^{-1}$, -1 100mg.$l^{-1}$...)

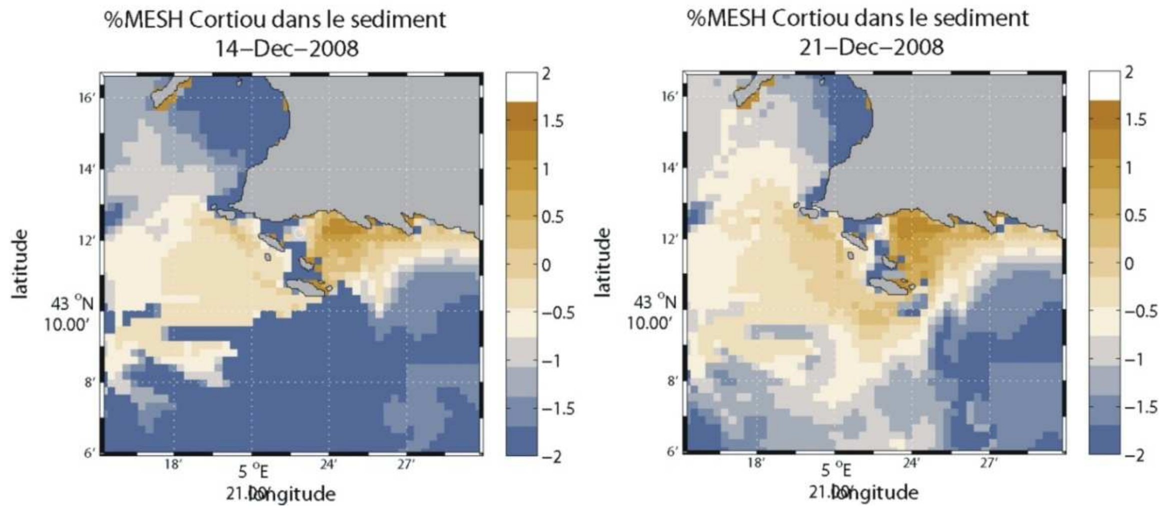



Figure 10 : Percentage of sediment flushed out from the Cortiou outflow simulated in the sediment top layer, before an d after the rainfall event. Percentage in log scale : 1=10%, 0 = 1%...

Simulations were next used to investigate the sediment dynamics induced by the heavy rainfall event, both in terms of spatial extension of the plume and its response to hydrodynamic forcings (Figure 9) and in terms of sediment deposition (Figure 10). Simultaneously to the rainfall event, wind direction moved from SE to N, which promoted the plume extension towards the South, where concentrations above 10mg.l$^{-1}$ were observed off the islands area, and hence facilitating their exportation outside the study area. Large SPM concentrations were also simulated in the South Bay (up to 100mg.l$^{-1}$), where water fluxes are partly flushed out when water discharge exceeds 35m$^{3}$.s$^{-1}$. This situation may be critical as the South bay shelters many recreational activities, which could be directly (turbidity) or indirectly (contaminants) impacted by such events.

The dynamics of SPM rejected through the Cortiou outflow were reproduced in the model, with a specific tracer assigned. This allowed to investigate the fate of SPM (here heavy particles) after entering the coastal system. Figure 10 represents the percentage of heavy particles rejected from the Cortiou outflow within the top sediment layer, before and after the rainfall event. It can be noticed that part of these sediments were deposited close to the outflow, while a low (few percents) but significant part of this material were transferred westward and reached the South Bay. This results cannot distinguish if this transfer is primary (SPM rejected during the rainfall event reached directly a western areas) or secondary (resuspension and transport of SPM rejected prior to the rainfall event and remobilized due to wave action). However, this results demonstrate the clear connectivity between the Calanques areas and the South Bay, and the possible impact of these outflows on the Bay of Marseille.

## 4. Discussion and Conclusions

The in situ observation strategy coupled with the development and validation of a 3D hydrodynamic and sediment transport model allowed to better understand the sediment response to dominant meteorological forcings, i.e. wind/waves and rainfall. A focus was made on the fate of suspended particulate matter eroded from urban areas and discharged to the sea through tributaries. The model, whose behaviour was validated by the in situ observations, is hence an adapted tool to investigate the residence time of sediments, whatever they are recently discharged from outflow or old deposited sediments remobilized by wave events.

Despite the correct agreement between model results and in situ observations, different strong assumptions were made either in order to simplify the model (and lower its computation cost) or because of our lack of knowledge. The first questionable point is the quantity and quality of sediment delivered to the sea.

Because this parameter is not monitored (continuously or regularly, on a daily basis), it was decided to search for direct relationships between water discharge and SPM concentration. Results presented in Figure 3 show how complex and inaccurate such relationships can be, which controls the quality of any numerical simulations. Efficient monitoring systems or further investigations on the relationships between water discharge and SPM concentration are required to improve sediment transport model in the coastal zone. Another issue linked to the sediment input is the characteristics of these sediments, i.e. their nature (sand, soil aggregates, organic flocs...) and their behaviour, in this particular case their settling velocity. In a preliminary approach, SPM were separated in 2 classes, distinguished by their settling velocity. These settling velocities and the SPM distribution were set logically but fully arbitrary. These parameters are essential as they directly control the fate of sediment in the coastal environment. Hence better knowledge on the nature of these SPM, their evolution in time depending on rainfall events, would improve numerical simulation in the future.

The sand behaviour as simply coded in the model may also be criticized. The main reason for such assumption was the necessity to get a fast running model, then easily coupled to ecological and contaminant transport models. However, the main consequence was the absence of transport of sand, which could impact the ability of the model in reproducing the depostion/erosion events observed with the altimeter.

Finally, uncertainties remain concerning the estimation of SPM concentration in the surface plume. Acoustic calibration was made with sediment from the bed, and one can expect that SPM constituting the plume may have completely different characteristics, which may imply different calibration. Including optical measurement below the surface, coupled with regular water sampling, would help in improving the quality of SPM measurements at the surface.

Posidonia meadows are historically present in the bay of Marseille. Their spatial extension dramatically decreased over the last decades, however they still cover significant parts of the seabed in the studied area. Vegetation is known to strongly influence sediment dynamics in coastal areas, promoting accretion and stabilizing bed sediments (Gacia et al., 1999; Ganthy et al., 2013). The presence of posidonia fields on the seabed was ignored as a first approach in this study. This compartment may potentially change significantly sediment dynamics in critical areas (especially the South bay) and should be accounted for in further studies in order to improve our knowledge and realism of numerical models.

## Acknowledgements

The work presented was funded by the Agence de l'Eau Rhone Méditerranée Corse, EC2CO INSU and IFREMER (Institut Français de Recherche pour l'Exploitation de la Mer).

## References

Alberola, C., and C. Millot. 2003. Circulation in the French mediterranean coastal zone near Marseilles: the influence of wind and the Northern Current. Continental Shelf Research 23 (6):587-610.

André, G., Garreau, P., Fraunie, P., 2009. Mesoscale slope current variability in the Gulf of Lions. Interpretation of in-situ measurements using a three-dimensional model. Continental Shelf Research 29 (2), 407-423.

André, G., Garreau, P., Garnier, V., Fraunié, P., 2005. Modelled variability of the sea surface circulation in the North-western Mediterranean Sea and in the Gulf of Lions. Ocean Dynamics 55, 294-308.

Ardhuin, F., Rogers, E., Babanin, A., Filipot, JF., Magne, R., Rolant, A., van der Westhuysen, A., Queffelou, P., Lefevre, JM., Aouf, L. and Collard, F., 2010. Semi-empirical dissipation source functions for wind-wave models: part {I}, definition, calibration and validation. Journal of Physical Oceanography, 40 (9) 1917-1941.

Ardhuin F., Marie L., Rascle N., Forget P. and Roland A. (2009). Observation and estimation of Lagrangian, Stokes and Eulerian currents induced by wind and waves at the sea surface. Journal of Physical Oceanography, 39 (11) 2820-2838.

Arfi R., A. A., Bellan-Santini D., Bellan G., Laubier L., Pergent-Martini C., Bourcier M., Dukan S., Durbec J-P., Marinopoulos J., Millot C., Moutin T., Patriti G., Petrenko A. 2000. Impact du grand emissaire de Marseille et de l'Huveaune détournée sur l'environnement marin de Cortiou - Etude bibliographique raisonnée 1960-2000. Rapport de la ville de Marseille:137 pp.

Boudouresque C.F., Bernard G., Pergent G., Shili A., VERLAQUE M., 2009. Regression of Mediterranean seagrasses caused by natural processes and anthropogenic disturbances and stress : a critical review. *Botanica marina*, 52 : 395-418

Gacia, E., Granata, T.C. and Duarte, C.M., 1999. An approach to measurement of particle flux and sediment retention within seagrass (*Posidonia oceanica*) meadows. *Aquatic Botany*, 65: 255-268.

Ganthy, F., Sottolichio, A. and Verney, R., 2013. Seasonal modification of tidal flat sediment dynamics by seagrass meadows of Zostera noltii (Bassin d'Arcachon, France). *Journal of Marine Systems*, 109-110:S233-S240.

Gatti, J., A. Petrenko, J.-L. Devenon, Y. Leredde, and C. Ulses. 2006. The Rhone river dilution zone present in the northeastern shelf of the Gulf of Lion in December 2003. Continental Shelf Research 26 (15):1794-1805.

Jany C, Zebracki M., 2012. METROC : Evaluation des apports de containants chimiques de la matropole marseillaise au !milieu marin. Rapport Ifremer DOP/LER-PAC/12-02 Convention AERM&C / Ifremer n° 2009-0351. 140pp

Lazure, P. and Dumas, F., 2008. An external-internal mode coupling for a 3D hydrodynamical model for application at regional scale (MARS). *Advances in Water Ressources*, 31: 233-250.

Le Hir, P., Cayocca, F. and Waeles, B. 2011. Dynamics of sand and mud mixtures : a multiprocess-based modelling strategy. Continental Shelf Research, 31, S135-S149.

Magne R., Ardhuin F., Roland A. (2010). Prévisions et rejeux des états de mer du globe à la plage. European Journal Of Environmental And Civil Engineering, 14(2), 149-162. http://dx.doi.org/10.3166/EJECE.14.149-162

Pairaud, I.L., J. Gatti, N. Bensoussan, R. Verney and P. Garreau, 2011. Hydrology and circulation in a coastal area off Marseille: Validation of a nested 3D model with observations, Journal of Marine Systems, 88, 20-33.

Roland, A. 2008. Development of WWMII : Spectral wave modelling on unstructured meshes. PhD Thesis, Technische Universität Darmstadt, Institute of Hydraulic and Water resources Engineering.

Tolman, H. L. (2008). A mosaic approach to wind wave modeling. Ocean Modelling, 25, 35-47.

Vousdoukas M.I., , R. Verney, F. Dufois, C. Pinazo, S. Meulé, D. Sauzade, Ph. Cann, T. Plomaritis, 2011. Sediment dynamics in the Bay of Marseille: hydrodynamic forcing versus bed erodibility. Journal of Coastal Research, doi: 10.2112/JCOASTRES-D-10-00122.1, 27 (5): 942-958.