DEVELOPMENT AND VALIDATION OF A SEDIMENT DYNAMICS MODEL WITHIN A COASTAL OPERATIONAL OCEANOGRAPHIC SYSTEM

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Abstract

The rising interest in environmental and ecosystem dynamics have lead coastal oceanographers to not only investigate the "traditional" physical parameters describing the ocean state and its dynamics (*e.g.* temperature, salinity, currents, water levels in coastal areas), but to also account for the dynamics of parameters describing its biogeochemical components. To that end, MARS3D regional and coastal modelling system has been coupled to ecosystem modules (ECO-MARS3D, ECO3M) as well as sediment dynamics modules (MARS3D-SEDIM): sediment, nutrient and primary production contents can be considered as the lower level environment and ecosystem descriptors of the "biogeochemical" ocean. Early investments into physical and biological analysis at the regional scale have led to the development of several operational configurations within PREVIMER since 2006 for physical and biological parameters, providing 3 to 5-day forecasts as well as hindcasts. The more recent introduction of sediment-related parameters into the operational chain required validating computed sediment transport at the regional scale. Such validation is mostly accessible through indirect measurements – namely turbidity measurements in the water column or derived from satellite data.

This paper describes the main features of MARS3D sediment module, the sensitivity analyses and the validation procedures based on dedicated data acquisition, as well as the assessment of the operational configuration focused on the Bay of Biscay continental shelf. Comparison between *in situ* measurements and satellite data shows a fairly systematic overestimation of the satellite-derived SPM in Southern Brittany; this result stresses the need for further investigation regarding the correct quantitative satellite SPM determination at all times and all places. On the other hand, numerical results highlight the difficulty to simultaneously predict the correct magnitude of bottom and surface concentrations.

Introduction

Beyond the obvious link between sediment dynamics and sea-floor or coastal morphology, shelf seas environment and ecosystems dynamics is also related to sediment dynamics through 1) turbidity in the water column, which impacts primary production because of light attenuation, and is a proxy for the suspended particulate matter (SPM) as a possible vector of contaminants, 2) benthic habitat structuration. The main difficulties to successfully model sediment dynamics at the shelf scale derive from a relatively poor knowledge of the key parameters driving suspension and deposition processes (*e.g.* accurate parameterization of the bottom boundary condition - description of the seafloor composition and its consolidation state -, accurate assessment of the erosion fluxes and settling velocities), and from a very limited amount of relevant *in situ* data. The first step in order to propose a reasonable estimate of the sediment dynamics at the regional scale has therefore been to set-up a data acquisition strategy based on long-term moorings investigating the whole water column (Charria *et al.* , this issue). When considering the whole Atlantic / English Channel French continental shelf, an additional difficulty arises from the fact that the Bay of Biscay and the English Channel exhibit very contrasted environments in terms of dynamics (tides and waves), hydrology (stratification) as well as seafloor coverage. *In situ* data and research priorities having been so far focused on the Atlantic coast only, the model assessment will also be focused on the Bay of Biscay continental shelf.

While *in situ* data are scarce, the processing of water colour satellite data provides a fantastic synoptic overview of the surface turbidity, including mineral and organic components. PREVIMER has also ensured the real time processing of MODIS or MERIS spectral reflectance, allowing for daily estimations of chlorophyll and non-algal SPM concentrations according to the methodology described by Gohin (2011). Apart when assessed from water sampling, suspended particulate matter (SPM) quantification (in unit mass per volume) is always indirectly deduced from acoustic or optical measurements. *In situ* measurements – whether acoustic or optical, including longterm time series – usually allow for calibration against actual water samples. This calibration provides a relationship between the recorded signal and a sediment concentration. It is however prone to uncertainties due to the fact that water samples do not span the entire *in situ* data acquisition period: they are most often a one-time procedure, and the calibration they allow is therefore only valid whenever the suspended sediment characteristics match the sediment type that was in suspension during the sampling procedure. However, because of advection or of varying re-suspension intensity, the sediment type in the water column may change in time. Any "steady state" calibration may therefore induce some fairly unknown uncertainty regarding its validity along the recording time. Calibration factors relating the turbidity sensor signal and turbidity inferred from *in situ* samples may for instance vary by a factor 3 at a given position, depending on the tide intensity (spring *vs.* neap, Verney, 2013). To temper this statement, let us mention that when both acoustic and optical signals are simultaneously recorded and exhibit the same variability, a relative steadiness of the suspended sediment type may be inferred, in which case the calibration may be considered valid over the whole record. SPM quantification deduced from satellite water colour processing exhibits the same kind of uncertainty, not to mention errors linked to atmospheric corrections and/or separation between organic and mineral suspended matter. While Gohin (2011) shows very good agreement between satellite and *in situ* low frequency coastal data (REPHY monitoring network), the availability of long time series Southern Brittany for *in situ* surface turbidity showed that the remote concentration may exceed the *in situ* concentration by a factor 2 to 4. The variability is however remarkably well reproduced; this assessment is essential before validating the numerical model.

The sediment module itself computes sediment erosion, advection and deposition for any number of sedimentary variables that may exhibit a sandy or cohesive behaviour. These different types of particles are mixed in the sediment compartment, where their combination affects the mixture behaviour. On the other hand, the use of a large number of sedimentary variables allows a detailed description of the sea floor sedimentary facies. The sediment module conceptual framework allows taking into account fairly complex processes, including flocculation, consolidation and fine vertical discretization of the silt/clay mixtures within the bed. While permitting the representation of a realistic behaviour thanks to accounting for a large range of processes, this complexity also makes model results highly sensitive to initial conditions and parameterization driving the evolution of layers thicknesses. Particularly since these initial conditions and parameters are poorly known at the shelf scale, the modelling strategy consisted in opting for a fairly simple (or even simplistic) configuration, so as to ensure more robust results and a reasonable amount of sediment parameters to investigate.

In situ data and satellite analysis

Because of the scarcity of *in situ* turbidity data along the continental shelf, the project first focused on pertinent data acquisition. Figure 1 shows the location of the long term moorings used for model validation all based on the use of vertical acoustic Doppler current profilers. Greater water depths impose lower acquisition frequency, hence reduced vertical resolution, and a shift in the grain size refraction peak decreasing from about 100 μm for 100kHz down to about 150 μm for 150 kHz. PREVIMER-D4 moorings spanned 7 winter months in 2007-2008 and 5 months in 2009-2010. They were moored at 15 m and 25 m water depths, using 1000 kHz current profilers (also measuring waves, the backscatter signal being used to assess SPM concentrations in the water column). Their design is detailed in Charria *et al*. (this issue). Other moorings were not conceived with any real time data transmission and were more lightly designed, namely with a bottom current profiler (150 kHz, 300 kHz or 600 kHz for water depths ranging from 40 to 150 m), a bottom turbidity sensor and a surface turbidity sensor for the shallower point, in 2011 and 2012. These moorings provided up to one year long time series.

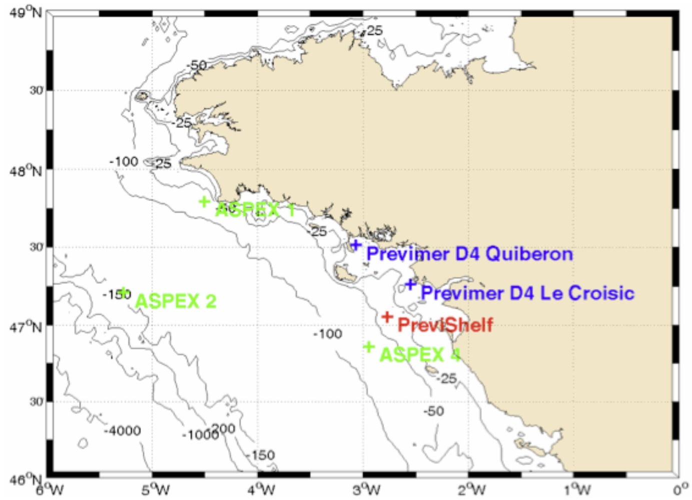


Figure 1: Position of the long term moorings used for model validation.

The strategy behind the use of bottom profilers lies in their capacity to provide wave and current data as well as an estimate of the suspended concentration over the whole water column (Figure 2). The simultaneous use of a near-bottom optical turbidity sensor aims at carrying out some kind of backscatter "calibration" accounting for attenuation with distance and particle load. Once the optical sensor has been calibrated against *in situ* water samples, the backscatter processing is constrained so as to obtain the best possible fit between the optical SPM time series and the profiler SPM time series at the same elevation above the bed. This procedure may lead to reasonable correlation coefficients (*e.g.* Figure 3, R^2=0.78; in cases where suspended sediment composition greatly varies in time, this correlation may be extremely poor, in which case the backscatter signal cannot be used to assess turbidity). The standard deviation in this particular case leads to a factor 2 in the SPM concentration estimate. Figure 3 shows the correspondence between acoustic and optical bottom SPM time series for PREVIMER-D4 Le Croisic. The high frequency oscillations are related to the tide while waves significantly drive the lower frequency signal (Figure 2 and Figure 3 illustrate the same dataset).

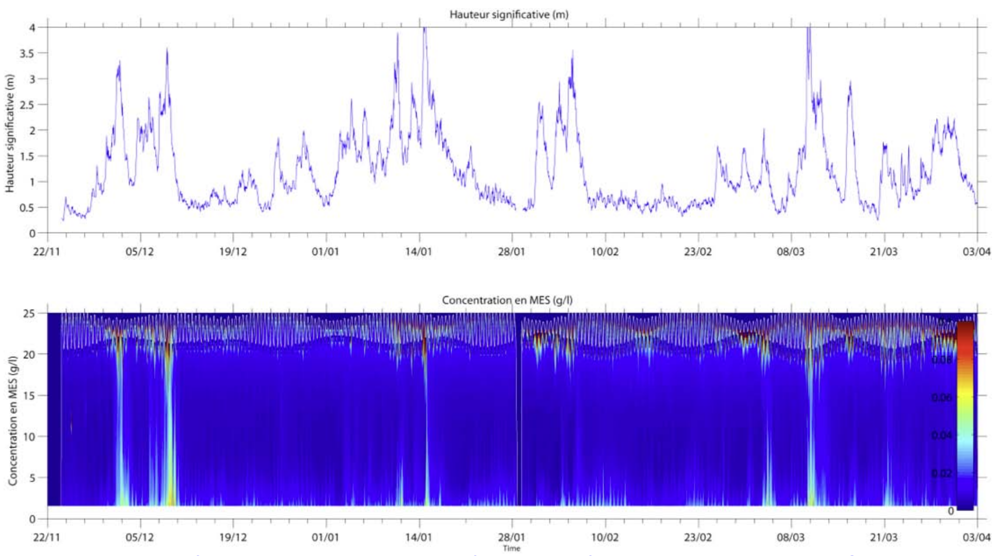


Figure 2 - Top: significant wave height measured from the profiler (m); bottom: calibrated SPM concentration deduced from the profiler backscatter (mg.l-1). PREVIMER-D4 LE Croisic 2007-2008

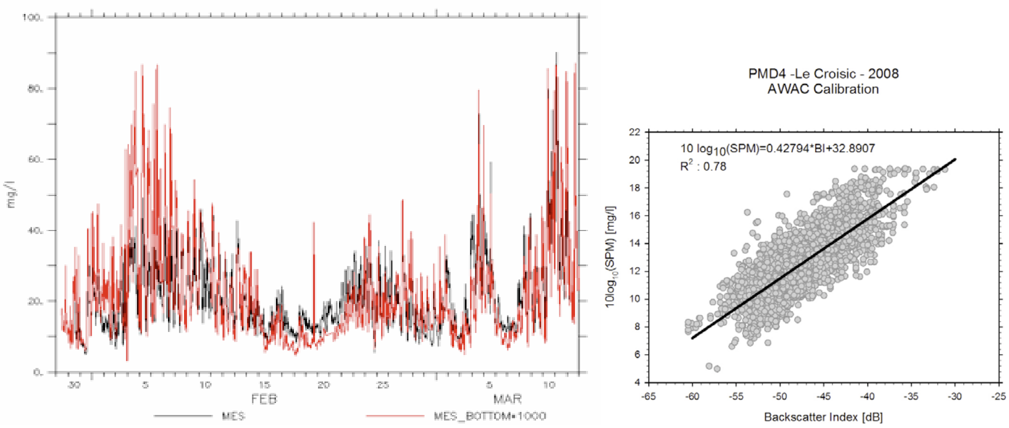


Figure 3 - Left : Bottom SPM concentration (mg/l) measured from the turbidity sensor (red) and from the current profiler at the same elevation (black). Right : Scatter plot showing the optical SPM concentration (log10(mg.l-1)) against the so-called backscatter index (in dB, to be converted to acoustic SPM concentration). PREVIMER-D4 LE Croisic 2007-2008

The use of profiler-derived SPM concentration is however much less reliable in the higher part of the water column, for various reasons including the presence of bubbles at the surface (hence perturbing the acoustic signal), the increase with distance in the attenuation corrections errors and a possible difference in particle size between the upper and the lower parts of the water column (the backscatter calibration is based on bottom SPM only, while finer particles may typically be found higher up in the water column, depending on the local seabed composition, resuspension dynamics and possible advected matter). Only the use of surface turbidity sensors therefore allows a sound assessment of the satellite-derived mineral SPM concentration estimate. Figure 4 shows this comparison for PREVIMER-D4 Le Croisic. Satellite data are only available once a day (with a 500m resolution for MERIS while *in situ* concentrations are recorded hourly (the horizontal print of the insonified cell increases with distance from the sensor, and reaches about 1 m^2 in 20 m water depth). At that location and for the winter conditions encountered from December 2007 to march 2008, the satellite data systematically overestimates the *in situ* measurement, even when the *in situ* turbidity signal is averaged daily in order to smooth out high frequency peaks. The ratio between the two signals varies between 2 and 4 over the investigated period (although Gohin (2011) shows much better agreement between satellite and *in situ* data, but for a lower range of concentrations). A similar ratio between satellite and *in situ* data was found during PREVIMER-D4 Quiberon mooring (2009-2010). Several reasons may explain this discrepancy. One of them lies in the fact that the satellite data processing algorithm is uniform in space all along the French coast, and does not account for the changes in particle reflectance depending on the location. Similar type discrepancies were observed along the Belgium coast on satellite data processed with a different algorithm, and were interpreted as arising from the particular high reflectance of the surface sediments in that area (Fettweiss, *pers. comm.*). It is beyond the scope of this paper to investigate any further the reasons explaining this finding (more *in situ* surface data would be required) or to improve the satellite signal processing (more research would be required). It is however important to remember, when using satellite data to validate surface SPM concentrations 1) that the satellite provides low frequency information compared to *in situ* sensors records and model outputs, 2) that the overall dynamics of the satellite signal is nonetheless very well correlated to *in situ* data, but the quantitative estimates must be considered with care. Their uncertainty may greatly depend on time and space, and more surface *in situ* data (long term time series and surface transects) would be necessary to better qualify the satellite outputs over the whole continental shelf.

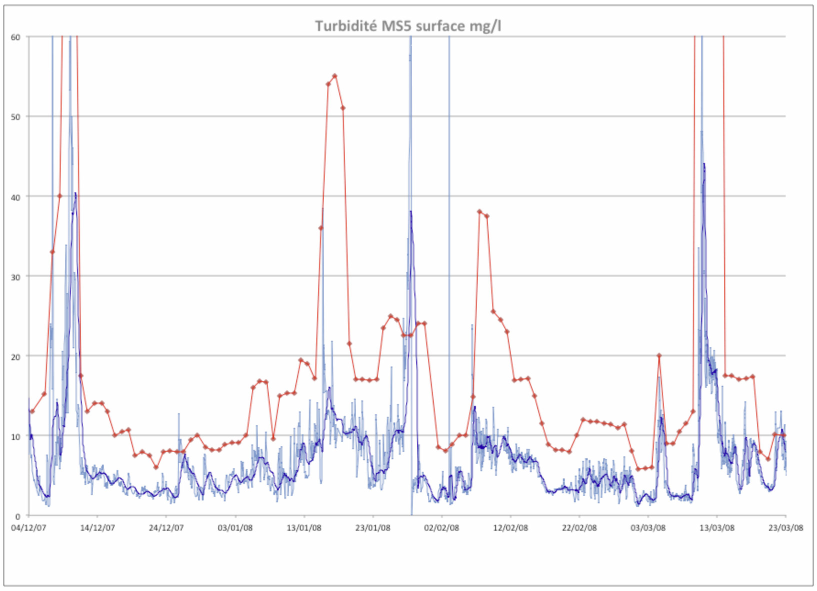


Figure 4: in situ surface turbidity (hourly, light blue; daily average, dark blue; PREVIMER-D4 LE Croisic 2007-2008) and satellite turbidity at the same location (red) mg.l-1.

Model validation described in this paper will focus on the December 2007 – March 2008 period, during which several storms were recorded, separated by long calm spans, hence covering a large variety of situations.

Sediment model description

Model domain and overall principle

The sediment dynamics compartment consists in a juxtaposition of 1DV models simulating the bed “under” each of the hydrodynamic cells (that may be rectangular or curvilinear in MARS3D, Figure 5). The total bed thickness may vary in time and space, and is discretized in cells of irregular thickness, each cell being characterized by its composition (sediment mixture). Depending on the sediment exchanges between the bed and the water column, the overall bed thickness and number of cells may change over time and from place to place, so as may each individual cell thickness and composition. Erosion and deposition processes are driven by the bottom shear stress that is computed from wave and current forcing: wave-induced shear stress is given by WW3 (Ardhuin *et al* this issue) outputs interpolated on the computation grid, while current-induced shear stress is computed from MARS3D hydrodynamic outputs. Erosion fluxes translate into a mass transfer from the bed compartment into the water column. Once in suspension, the sediment is advected along with other dissolved or particulate variables. High settling velocities however require the use of an upwind scheme in the vertical, unlike for other variables (see Berger *et al.*, this issue, for general information regarding numerical schemes). Changes in water density due to high sediment concentrations and changes in bottom roughness may optionally be fed back into the hydrodynamic model. Settling particles eventually reintegrate the bed compartment. Their arrangement in the bed is managed according to Le Hir *et al* (2011).

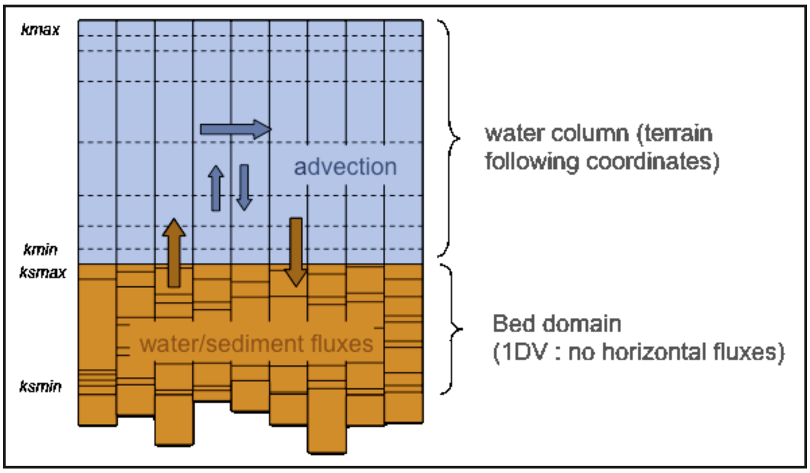


Figure 5: MARS3D-SEDIM grid setting: the bed is discretized in each “sediment column” independently from the neighbouring cells in the horizontal. kmin and kmax are the vertical min and max cell indices in the water column. ksmin and ksmax are the vertical min and max cell indices in the bed compartment

Sediment model

The model computes the dynamics of any number of sediment classes defined for each run. Realistic sediment composition in the bed may therefore be finely described, each facies being represented by a mixture of several sediment classes, in various proportions and concentrations. Sediment classes may exhibit a sandy behaviour ("sands", no cohesion) or muddy behaviour ("muds", cohesive behaviour). The critical shear stress for any mixture depends on the sand/mud proportion in the bed, and the critical erosion shear stress for mud and sand (as a function of bed concentration). Erosion fluxes for mud and sand depend likewise on the individual erosion flux for each sediment type and on the proportions of each type in the bed. Settling velocity for sands is only related to the grain diameter while settling velocity for muds may depend on the concentration in the water column (hindered settling processes) and on flocculation.

The use of terrain-following coordinates in the water column translates into bottom cells of varying thickness in time and space. Deposition fluxes are classically computed as the product between the concentration in the bottom layer (computed in the middle of the cell) and the settling velocity. However, whenever vertical gradients are strong (as is the case for high settling velocities) or when the bottom cell is thick, the actual near bottom concentration – classically computed at a given "reference height" above the bed (2 to 10 times the grain size diameter, van Rijn, 1993) –, is likely to be greater than the concentration in the middle of the cell. An extrapolation technique is therefore used in order to assess the concentration at the reference level, hence the deposition. Horizontal concentration fluxes in the bottom cell are also modified so as to account not only for vertical concentration gradients in that cell, but also for vertical velocity gradients (Waeles *et al*., 2007; Vareilles *et al*., submitted). The reference height being arbitrarily chosen, the deposition magnitude depends on this reference height, and so does the erosion flux. While flume and numerical experiments using monodisperse sediment make it possible to actually derive an expression of the erosion flux variations as a function of the reference height, the erosion flux for realistic configurations remains one of the tuning parameters.

Accounting for suspended sand transport in large realistic configurations may lead to unmanageable computational times because of large settling velocities imposing small time steps for vertical advection. Another particularity of the model is the possibility to compute vertically integrated sand concentration (and advection) in the water column, while all other particles are computed in three dimensions. Following a strategy similar to the strategy described above in order to take into the concentration gradients in the bottom cell, classical equilibrium sand concentration profiles are assumed in the water column (Rouse profile) so as to take into account higher sand concentrations near the bed, and compute realistic deposition. Horizontal sand fluxes also mostly occur near the bed, and would be greatly underestimated if they were computed within a 2D-framework. They are therefore computed as the product over the water column of the "re-constructed" sand concentration profile and a 3D- velocity profile (Vareilles *et al*., submitted).

Operational framework

Operational runs for sediment dynamics are carried out at the same time as the hydrodynamic computations for the English Channel and Atlantic coast area (MANGAE4000, Berger *et al*., this issue). The import of real-time hydrodynamic forcing (river discharge, meteorological forcing, offshore boundary conditions) is managed by the operational hydrodynamic framework. The sediment-related added features consist in assigning river sediment discharges (from empirical relationships relating solid discharge with liquid discharge for each river), importing real-time PREVIMER WW3 wave outputs, and initializing the bed composition. Additional model outputs consist in the time varying concentration of all sediment variables in the water column (hourly). The bed composition changes are saved at a lower frequency (daily). The number of sediment cells in the sediment compartment may be fairly large, and a most interesting output of the sediment model lies in keeping track of surface bed evolutions. The decision was thus made to only save the composition of the sea bed integrated over a given thickness. For research purposes, the whole sediment grid may of course be saved at a higher frequency.

Sensitivity analysis and model calibration

A first configuration consisted in ignoring coarse sediments, and considering two cohesive sediment classes: one class representative of river inputs (clay-like, settling velocity of 0.02 $mm.s^{-1}$) and one class representing the initial sea bed coverage (silt-like, 0.1 $mm.s^{-1}$). Critical erosion and deposition shear stresses were set to respectively 0.15 $N.m^{-2}$ and 12 $N.m^{-2}$, erosion flux to 4.10-6 $kg.m^{-2}.s^{-1}$, initial bottom bed concentration set to 400 $kg.m^{-3}$. No consolidation was taken into account. The initial bed coverage respected realistic data (no initial sediment in areas mostly covered with sands, pebbles or rocks). Figure 6 shows reasonable agreement between the near bottom turbidity sensor and the model magnitude during the December 2-12 storm, but the model significantly underestimates the observation after the storm. The same trend is seen from comparing surface model results to satellite data (Figure 7): while computed and observed magnitudes agree during the storm, the model seems to predict much more rapid settling than suggested by the satellite observation.

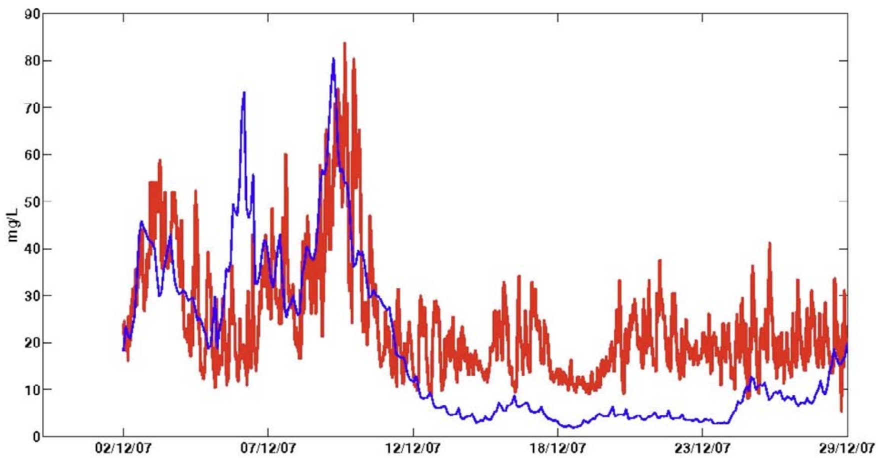


Figure 6 – Time series for the measured (red, optical turbidity sensor) and simulated (blue) bottom turbidity (mg.l-1). PREVIMER-D4 Le Croisic 2007.

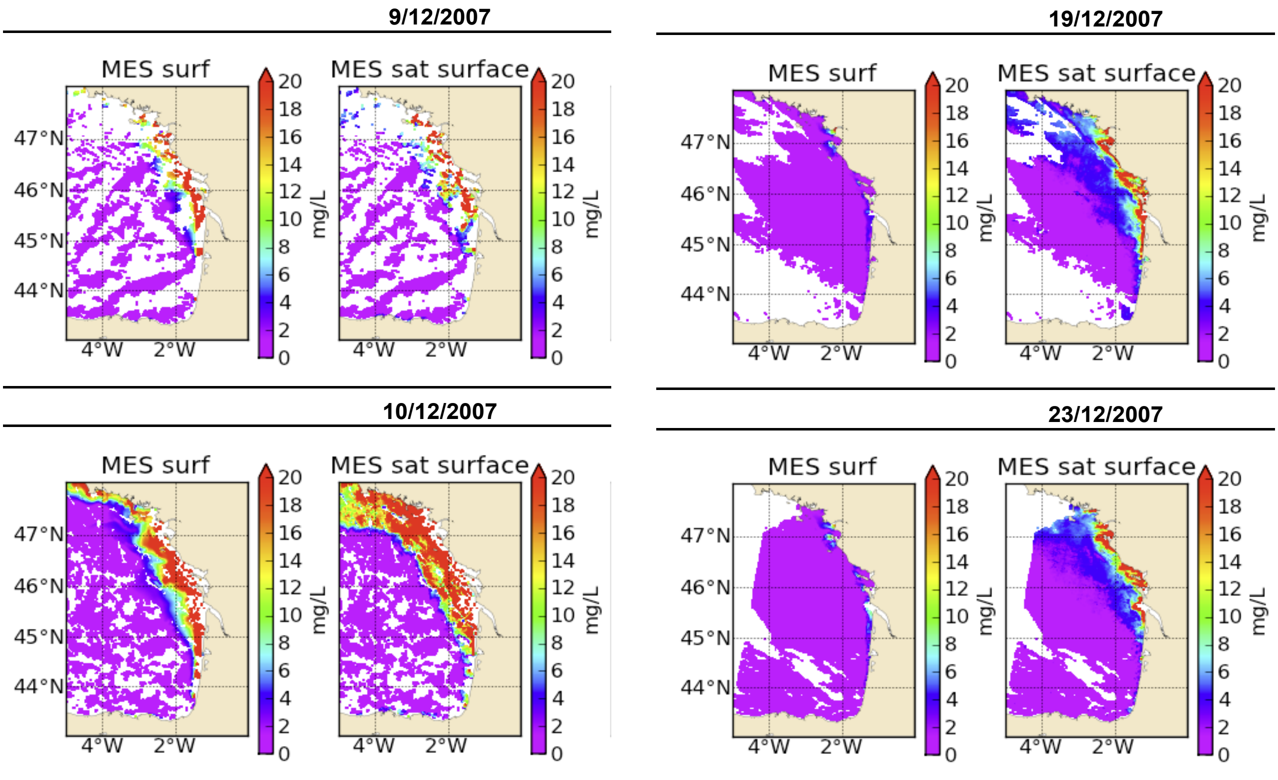


Figure 7 – Left: modelled and satellite surface concentration during the 2-12 December 2007 storm; Right: modelled and satellite surface concentration after the storm.

Vertical modelled and observed *in situ* profiles however suggest excessive vertical mixing in the water column during the storm, insufficient resuspension during the following calm period, and an almost complete absence of remaining SPM in the water column after December 13 (Figure 8). These initial results suggested to carry out several sensitivity tests on critical shear stress, erosion flux, initial bottom density, settling velocity. The use of an additional sandy variable and an experiment starting from a uniform initial bed composition made of 50% silt and 50% sand were also tested. Satisfactory results were obtained thanks to the use of 3 variables (sand – vertically integrated computation –, silt and clay, settling velocities of 5 $mm.s^{-1}$, 0.5 $mm.s^{-1}$ and 0.02 $mm.s^{-1}$) and an identical erosion flux for all variables, set to 8.10^{-6} $kg.m^{-2}.s^{-1}$ (configuration later referred to as "reference run"): Figure 9 exhibits encouraging results displaying the monthly average of surface turbidity provided by the model and by satellite data over December 2007. This representation, which was chosen by Sykes and Barciela (2012) when they assessed the quality of their operational POLCOMS turbidity model, is indeed much more forgiving than a thorough investigation of high frequency outputs over the water column. However, it may hide some model (and/or data) discrepancies. In our case, since the satellite absolute SPM concentration seems to be overestimated by a factor two, correct model results may have to predict half the value given by the satellite data (but that may not be true in the English Channel). Moreover, this parameterization induces a significant overestimation of the bottom concentration when compared to moorings.

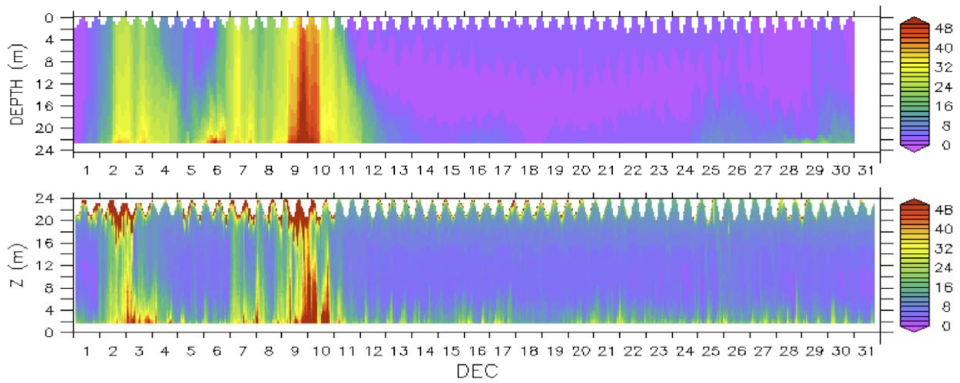


Figure 8 - Upper panel: modelled turbidity in mg.l-1 as a function of time and water depth ("reference run"). Bottom panel: profiler calibrated turbidity (mg.l-1). The red areas near the water surface in the observations represent noise in the acoustic signal. The data can only be reliable up to about 5 m under the surface (for this record)- PREVIMER-D4 Croisic 2007.

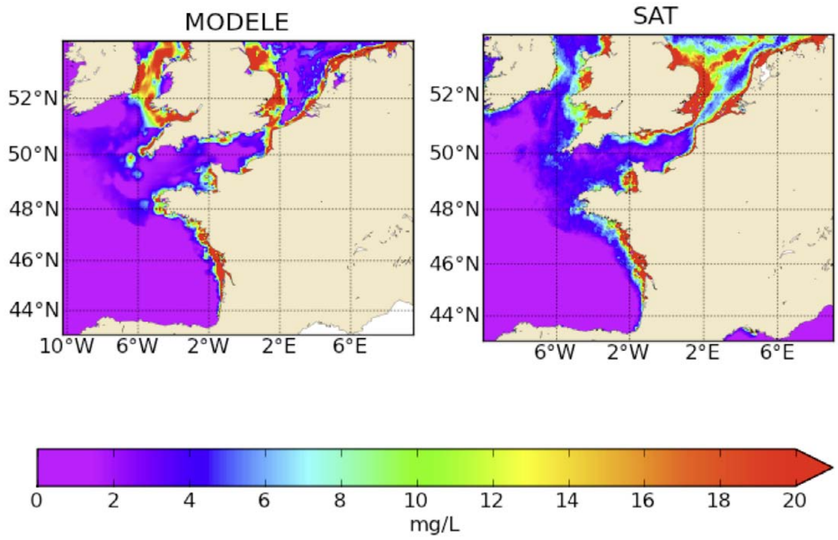


Figure 9 - Computed (left) and satellite (right) surface SPM concentration averaged over December 2007 (mg.l-1)

Sea bed evolution

One of the goals of the regional sediment dynamics model is to assess the variability of the seabed composition. Coastal areas, sandy beaches or muddy tidal flats do exhibit a very strong variability in their seabed morphology and composition, with the creation of temporary fluid mud layers after storms for instance (a maybe more spectacular and visible expression of this variability is the seasonal sand loss on beaches every winter, turning summer sandy beaches into winter pebble fields). The seasonal or interannual sea floor variability at the shelf scale and its possible impact on habitat is however unknown. Predicting this variability should be possible with our model, provided the management of seabed layers is carefully assessed. The influence of the minimum and maximum layer thicknesses allowed in the bed compartment was therefore investigated. In case of sediment mixtures, these parameters may greatly influence results, in particular because the model behaviour is drastically different for a sandy surface sediment or muddy surface sediment. In particular, the active layer thickness changes with the choice of these parameters. The thinner the layers are allowed to be, the more chances there will be of having superimposed layers of pure sand and pure mud (because of their different settling velocities for instance), whereas larger layers will lead to systematic mixing of all sediment types. This investigation showed that the minimum layer thickness had to be of the order of 5.10^{-2} mm or smaller for results to not depend on this thickness anymore, while a maximum thickness of the order of 0.5 mm was more prone to allow the creation of laminations. Figure 10 illustrates how bed thickness and concentration evolve in time (initial 1 cm bed thickness, 10^{-6} mm minimum layer thickness, 10^{-4} m maximum layer thickness).

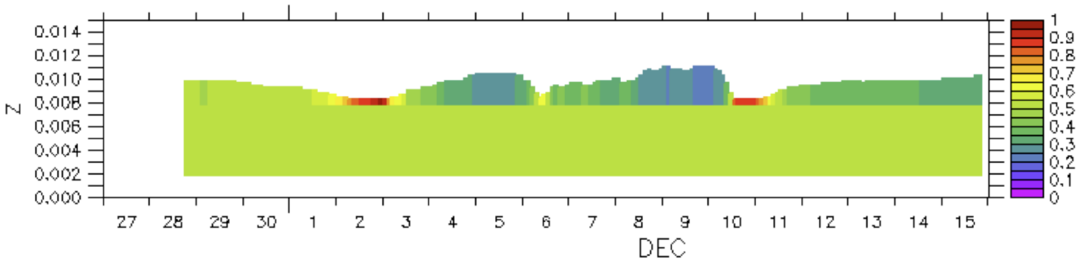


Figure 10 – Time evolution of the bed thickness in a given cell (sediment height in m). The initial bed was a 1 cm thick sediment mixture of 50% sand and 50% clay. The color represents the sand fraction in the mixture. Erosion periods lead to thinning and sand enrichment (going towards warmer colors) while deposition events lead to thickening and mud enrichment (going towards colder colors).

New sensitivity tests were carried out on sediment-related parameters with this better control of the seabed dynamics. For this investigation, priority was given to the comparison between modelled turbidity and *in situ* time series. The initial sediment coverage was derived from a spatial sand and silt repartition obtained after a 4 month long spin-up run, so as to use a bottom description in equilibrium with the model dynamics. This sand and silt repartition exhibits the same overall features as the sedimentological maps of the area (Figure 11). However, this bed sediment distribution corresponds to a situation in the spin-up run when fine sediments were in suspension in the whole domain; since new runs usually start from clear water (apart from the background turbidity), 50 $kg.m^{-3}$ clay were added to this initial sediment coverage so as to not create immediate fine sediment "drainage" from the seabed as soon as resuspension occurs, which would induce artificial sand enrichment in the bed.

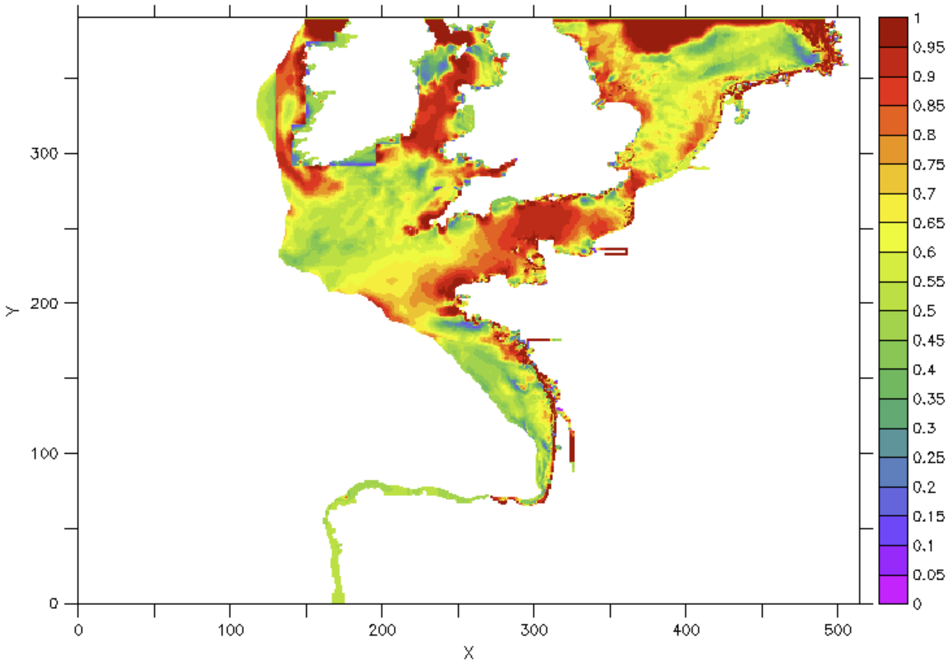


Figure 11 –Sand fraction used in the initial bed composition

The choice was made to adjust results for 3 variables (clay, silt and sand). The offshore background surface turbidity level was also imposed in the model through the initial seeding of clay-like particles in the whole domain (concentration of 1.5 $mg.l^{-1}$).

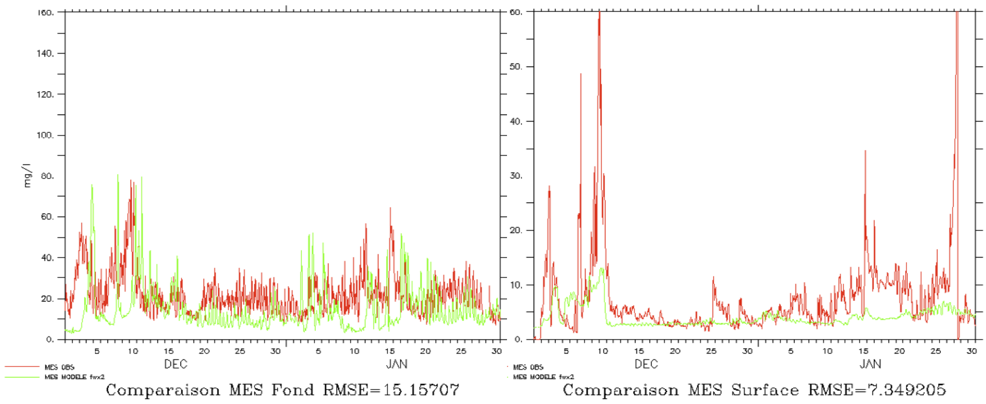


Figure 12 – Measured (red, optical turbidity sensor) and modelled (green) SPM concentration for PREVIMER-D4 Le Croisic (operational parameterization). Left: bottom concentration; Right : surface concentration. z0=0.5 mm. fwref from Soulsby (1993)15:15

The investigated parameters used to calibrate the turbidity signal were once again settling velocity, bottom erosion flux and bottom shear stress, which usually have to be simultaneously adjusted. Settling velocities are chosen so as to reproduce the correct time scale during which suspended sediment stays in the water column after a storm. They were kept to 5 $mm.s^{-1}$, 0.5 $mm.s^{-1}$ and 0.02 $mm.s^{-1}$ for the three variables (*i.e.* flocculation not accounted for). The amount of eroded sediment is driven by the chosen values for the erosion flux and the bottom shear stress. Changing the erosion flux however does not allow differential weighting of the waves and/or tides contributions. These contributions may be assessed when comparing the different suspended dynamics observed in the English Channel (tide-dominated) or along the French Atlantic coast (wave-dominated): the turbidity signal frequency may indeed be more or less correlated to tides or waves. While theoretical or empirical formulations exist to determine tide- and wave-related friction factors (and they are used as first guesses), their accurate estimate can only be assessed through *in situ* turbulence measurements, and their values may greatly vary in time and space. That is the reason why they are still commonly used as calibration factors for resuspension in regional sediment dynamics models.

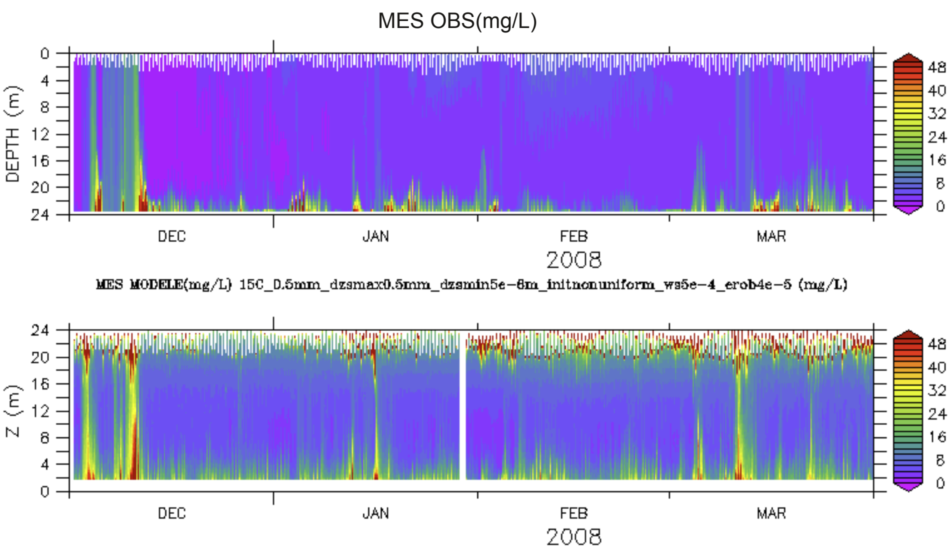


Figure 13 – Modelled (top) and measured (bottom) SPM vertical concentration profile as a function of time (mg.l-1). PREVIMER-D4 Le Croisic (operational parameterization)

After inspection, the erosion flux was set to 8.10^{-6} kg.m^{-2}.s^{-1}. The bed roughness used to compute current-induced bottom shear stress was unchanged (z0=0.5 mm, uniform in space) while the wave friction factor was doubled compared to the reference run (where it was set to Soulsby (1997)'s formulation), therefore increasing resuspension during storms. This parameterization leads to results shown on Figure 12 and Figure 13. The computed turbidity magnitude and variability are satisfactory on the bottom and the lower part of the water column, but they are still underestimated at the surface. Figure 14 shows that increasing tide-induced resuspension manages to increase surface concentration variability and magnitude, but leads to great overestimation in the bottom (which was one of the early "reference run" bias, see Figure 8).

An ultimate comparison between model results and satellite data (while being aware of the possible bias between satellite and *in situ* data) suggested a systematic underestimation of the turbidity along the British south coast, and the Belgian and Eastern Channel French coasts. Model results, in situ horizontal profiles using a towed fish, and satellite images of the English Channel after strong storms (Gohin, *pers. comm.*) suggest that advection may not be a major process in driving the spatial distribution of sediment suspension at the shelf scale: the seabed composition is on the other hand a strong determining factor. The deficit of coastal turbidity was therefore attributed to a lack of muddy sediments in the bed (the initial bed was indeed quite sandy along the coast, which is not conform to reality), which was corrected by changing the sand/silt proportion below 20 m water depth in the aforementioned areas.

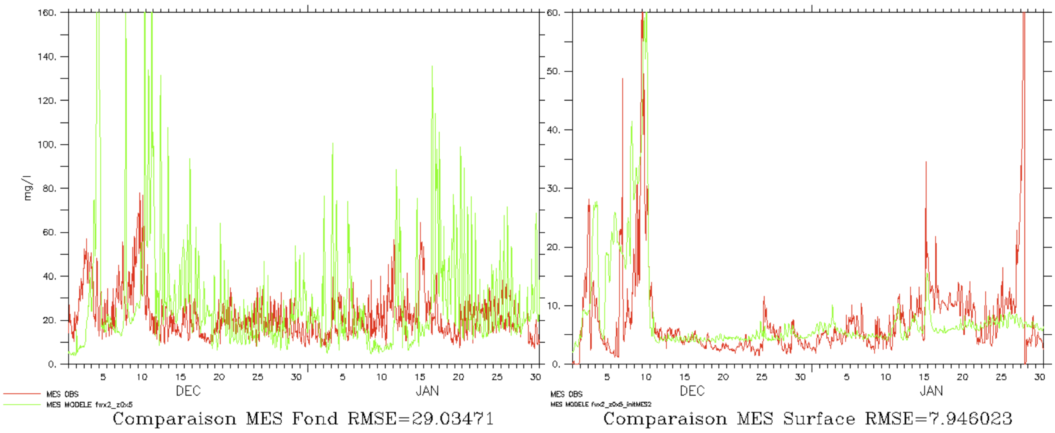


*Figure 14 – Measured (red, optical turbidity sensor) and modelled (green) SPM concentration for PREVIMER-D4 Le Croisic. Left: bottom concentration; Right : surface concentration. z0=5 mm. fw = 2*fw$_{ref}$*

This latter parameterization was chosen for operational runs, which have been computed since September 2013. Further comparisons to existing data need to be carried out in order to improve this parameterization, and a systematic calibration/validation procedure would greatly benefit from a more systematic data acquisition strategy covering French coastal waters. More *in situ* surface concentration data would be of utmost importance so as to improve the confidence we can have in satellite-derived SPM concentrations, which remain a precious source of systematic (cloud dependant) synoptic coverage.

Influence of horizontal grid resolution

Particularly along the French Atlantic coast, sediment resuspension is highly related to wave action. While bathymetric gradients on the shelf are usually fairly smooth, they are obviously much sharper in shallow areas, precisely where wave influence is felt the most. The horizontal resolution of most regional models (of the order of 2-3 km for structured grids) usually remains fairly coarse compared to the bathymetric gradients encountered for water depths lower than 20 to 40 m. The sediment dynamics model does exhibit a spatially variable behaviour (because of the space variability in sea bed composition or even bed roughness), but this parameterization does not account for any sub-grid processes. A first investigation of the effect of resolution on turbidity results has therefore been attempted, using a local coastal two-way zoom of 500 m resolution inserted into a 2500 m resolution operational configuration (GirondePertuis500 inserted into MANGAE2500). Figure 15 shows the bathymetric schematization in both configurations. WW3 operational computations (see Ardhuin *et al.*, this issue) are run on an unstructured grid of about 200 m resolution near the coastline, and take into account current and water depth refraction computed from a 2D MARS hydrodynamic configuration (see Pineau *et al*., this issue). Identical wave model outputs were projected on to the 500 and 2500 m grids, and used to compute wave-induced bed shear stress in both models. Figure 16 illustrates, for several depth ranges, the relative wave-induced shear stress variation only due to grid refinement. The refinement induces a quasi systematic increase in wave-induced shear stress, of increasing magnitude as water depth gets shallower. Over January 2010, this increases amounts to 80 to 200% for a bathymetry of 5-10 m below mean sea level, 40-110% for 10-20 m bathymetry, up to 50% for 20-40 m bathymetry. The figure 16 also shows the spatial distribution of differences for a given date: the coarse resolution not only prevents waves from propagating in areas sheltered by islands, but also significantly underestimates wave action as soon as water depth reaches 15-20m (*e.g.* west coast of the islands).

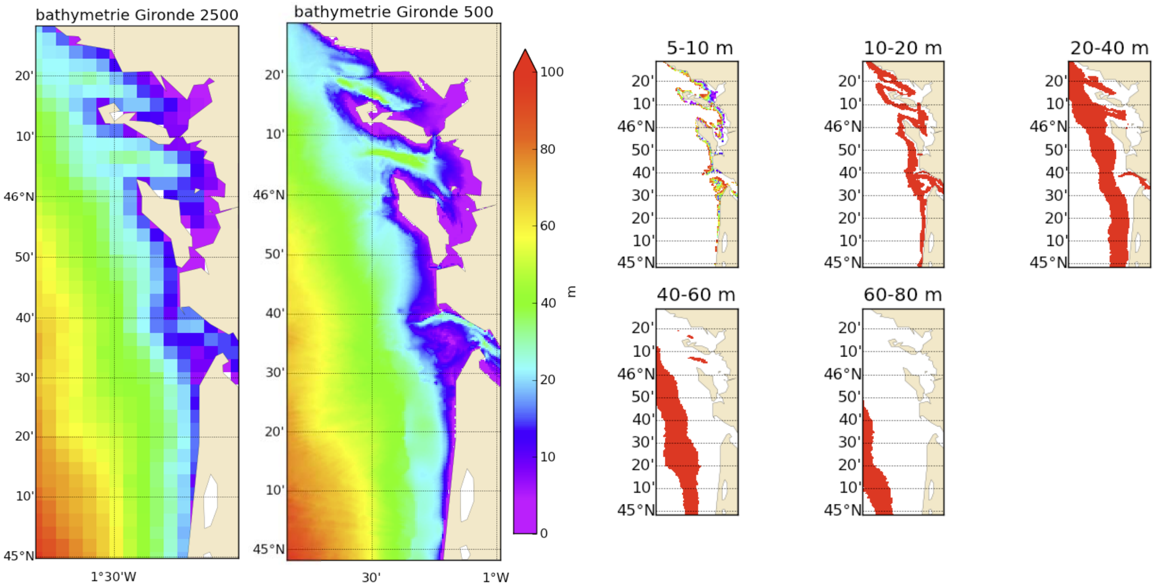


Figure 15 – Left : Gironde-Pertuis bathymetry as described in a 2500m and a 500m resolution grid. Right : Bathymetric strata used to compare model outputs on both resolutions according to water depth.

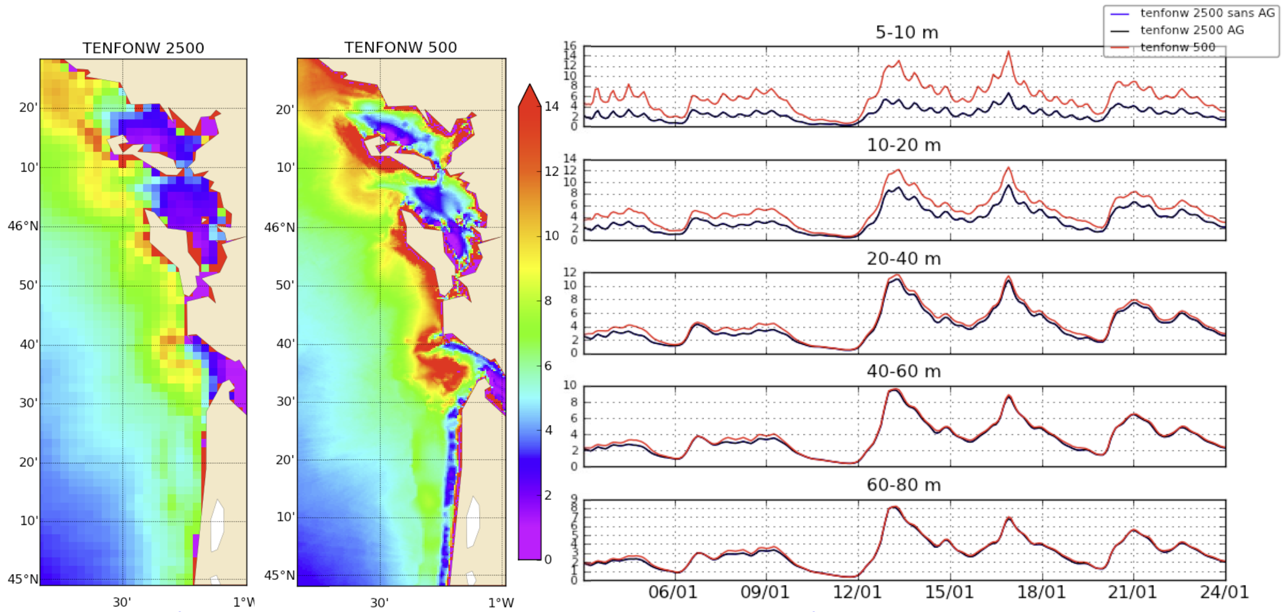
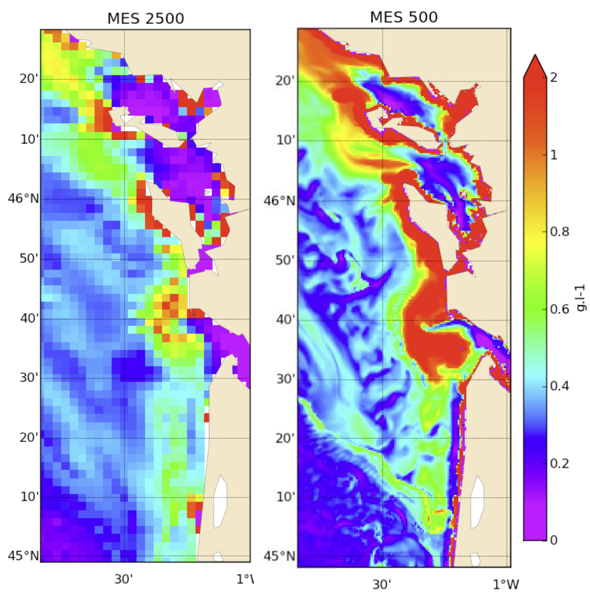


Figure 16 – Left : Wave-induced shear stress (N.m-2) as described in a 2500m (left) and a 500m (right) resolution grid. Right : Wave-induced shear stress averaged over 5 ranges of water depth, as a function of time, computed on the 500m resolution grid (red) and the 2500m resolution grid (black).



In these conditions, otherwise identically parameterized configurations for sediment dynamics will predict very different SPM concentration patterns. Differences will not only result from a different expression for forcing parameters: while current-induced shear stresses are almost identical for both configurations, the refined circulation exhibits structures that are likely to also impact overall sediment fluxes. Apart from the sharp differences in SPM concentration magnitude, Figure 17 for instance exhibits how the increased resolution allows the representation of submesoscale structures. Their influence on long term sediment budgets and fluxes remains to be investigated.

Figure 17 - Modelled near-bottom concentration on January 16, 2010. Left: 2500m grid; right : 500m grid (identical parameterization for both configurations)

Conclusion

A sediment dynamics model predicting turbidity levels and monitoring seabed coverage evolutions has been coupled to MARS3D MANGAE4000 operational configuration. The model computes erosion, transport and deposition of 3 types of variables, namely sand, silt and clay. Several sensitivity tests were carried out on two kinds of parameters: 1) parameters driving the vertical discretization in the sediment compartment, and describing the initial distribution of sediments in the domain, 2) parameters driving the sediment behaviour in the water column (mostly erosion and settling). While the repetitiveness of satellite data make them a precious source of information for model validation, errors linked to their absolute quantification are not fully known, which makes it hazardous to fully rely on this source to validate the model. However, their time variability was shown to exhibit very good agreement with surface SPM concentration measured from optical turbidity sensors.
In situ data from moorings were so far privileged in order to parameterize the configuration, knowing this parameterization does no allow any convincing comparison with satellite data (Sykes and Barcilea (2012) mention similar discrepancies between buoys and satellite data). We made it a definite choice to use fairly simple formulations for the bottom shear stress and bed roughness computations, erosion fluxes (which were identical for all sediment types) and settling velocity. Ignoring processes such as flocculation and consolidation was also a definite choice: the uncertainty regarding the space variability of all parameters required to properly take into account these processes is so large, that it was considered more reasonable to focus on adjusting a more reduced number of parameters, and judge whether or not such simplifications could still lead to reasonable results. A few experimental runs (not shown) took into account flocculation in the determination of settling velocity, using empirically determined flocculation parameters. Those runs led to fairly different results from those shown here, and that would have required new adjustments for all other parameters driving sediment dynamics (erosion fluxes, critical erosion threshold) without necessarily adding any more realistic results. Including the most advanced state of the art formulations for all sediment related processes is another challenge, particularly when trying to validate procedures on well constrained academic configurations (see Warner *et al*. (2008), for instance, for some aspects such as wave-current interaction or the use of ripple predictors). But the benefits of this complexity to simulate fairly unknown dynamics at a regional scale remains to be addressed.

On the other hand, the influence of some fairly “fundamental” features such as the impact of turbulence schemes and resolution require immediate attention. The model apparent incapacity to simultaneously reproduce accurate bottom and surface magnitudes for SPM concentration for instance suggests insufficient vertical mixing in some cases. Whether increasing horizontal resolution in shallow water is likely to modify overall sediment fluxes at the shelf scale still has to be inferred – which would impose either a two-way zoom strategy as allowed thanks to AGRIF, or the use of unstructured grids.

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