



Projet Seine-Aval 5 **HYMOSED**

« Modélisation du fonctionnement HYdro-MORpho-
SEDimentaire de l'estuaire de la Seine »

Volet Modélisation

Annexes du rapport de recherche

Janvier 2018

Coordination : Florent Grasso

I. Sommaire

II. Annexe : Simulations des vagues (WW3) aux Ratelets avec/sans prise en compte du forçage hydrodynamique de MARS3D (surface libre et/ou courants)	3
III. Annexe : Comparaison du modèle hydrodynamique MARS3D curviligne en version non-orthogonale (V9.05) ou orthogonale (V10.12)	5
IV. Annexe : Influences des tributaires de la Seine à l'aval de Poses sur la dynamique hydro-sédimentaire de l'estuaire	6
V. Annexe : Articles soumis à <i>Journal of Geophysical Research – Ocean</i>	11
VI. Annexe : Forçages hydrométéorologiques	13
VII. Annexe : Effet de l'érosion latérale sur les différentiels bathymétriques et sur les quantités draguées par les Grands Ports Maritimes	18
VIII. Annexe : Rappel du paramétrage du modèle en configuration morpho.	19
IX. Annexe : Différentiels bathymétriques élaborés par le GIPSA pendant la période 2009-2012, sur la base des MNT RH du GPMR	27
X. Annexe : Evaluation des bilans sédimentaires	29
XI. Annexe : Comparaison des dragages simulés avec ou sans facteur morphodynamique	31

II. Annexe : Simulations des vagues (WW3) aux Ratelets avec/sans prise en compte du forçage hydrodynamique de MARS3D (surface libre et/ou courants)

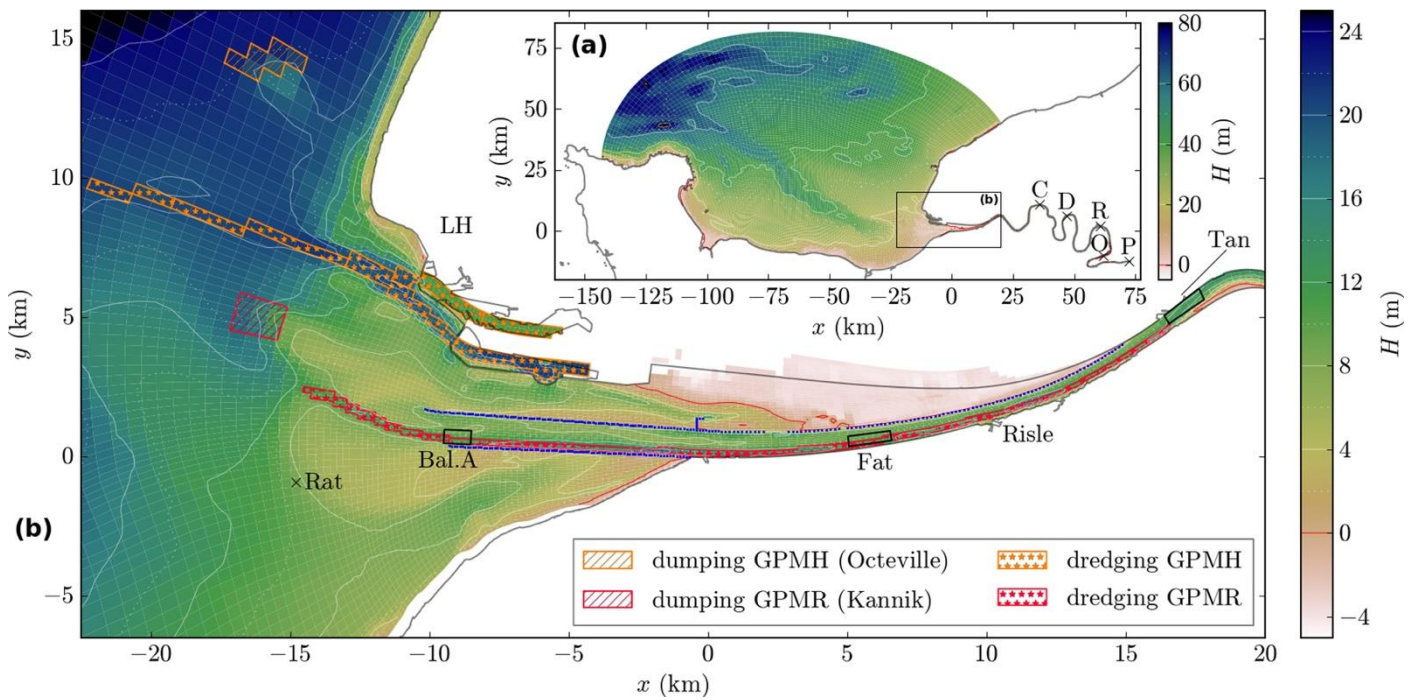


Figure 1. Bathymétrie du modèle MARS3D curviligne de l'estuaire de Seine : (a) allant de la baie de Seine au barrage de Poses 'P' avec (b) un zoom sur la partie aval de l'estuaire. Les étoiles (resp. hachures) représentent les zones de dragage (resp. clappage) du GPMH (orange) et du GPMR (rouge). Les boîtes noires à Balise A 'Bal.A', Fatouville 'Fat' et Tancarville 'Tan' représentent les zones de comparaison entre les SPM simulés et mesurés. Positions spécifiques : Le Havre 'LH', Ratelets 'Rat', Ratier 'Rati', Caudebec-en-Caux 'C', Duclair 'D', Rouen 'R' et Oissel 'O'.

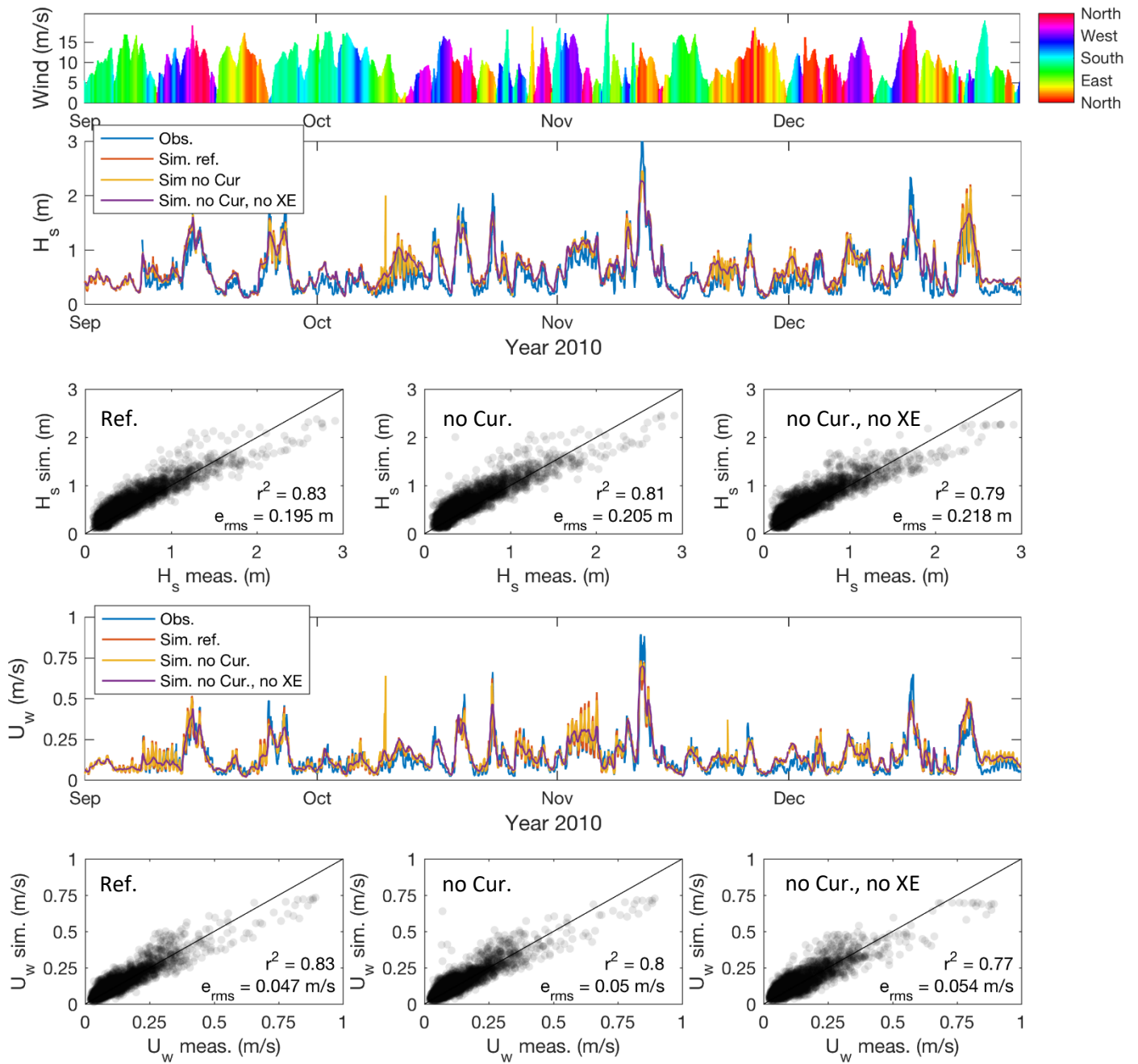


Figure 2. Comparaison des simulations des vagues (WW3) aux Ratelets (cf. Figure 1) avec prise en compte des courants et de l'élévation de la surface libre XE du modèle MARS3D (Ref.), sans le courant mais avec XE (no Cur.) et sans le courant ni XE (no Cur., no XE).

III. Annexe : Comparaison du modèle hydrodynamique MARS3D curviligne en version non-orthogonale (V9.05) ou orthogonale (V10.12)

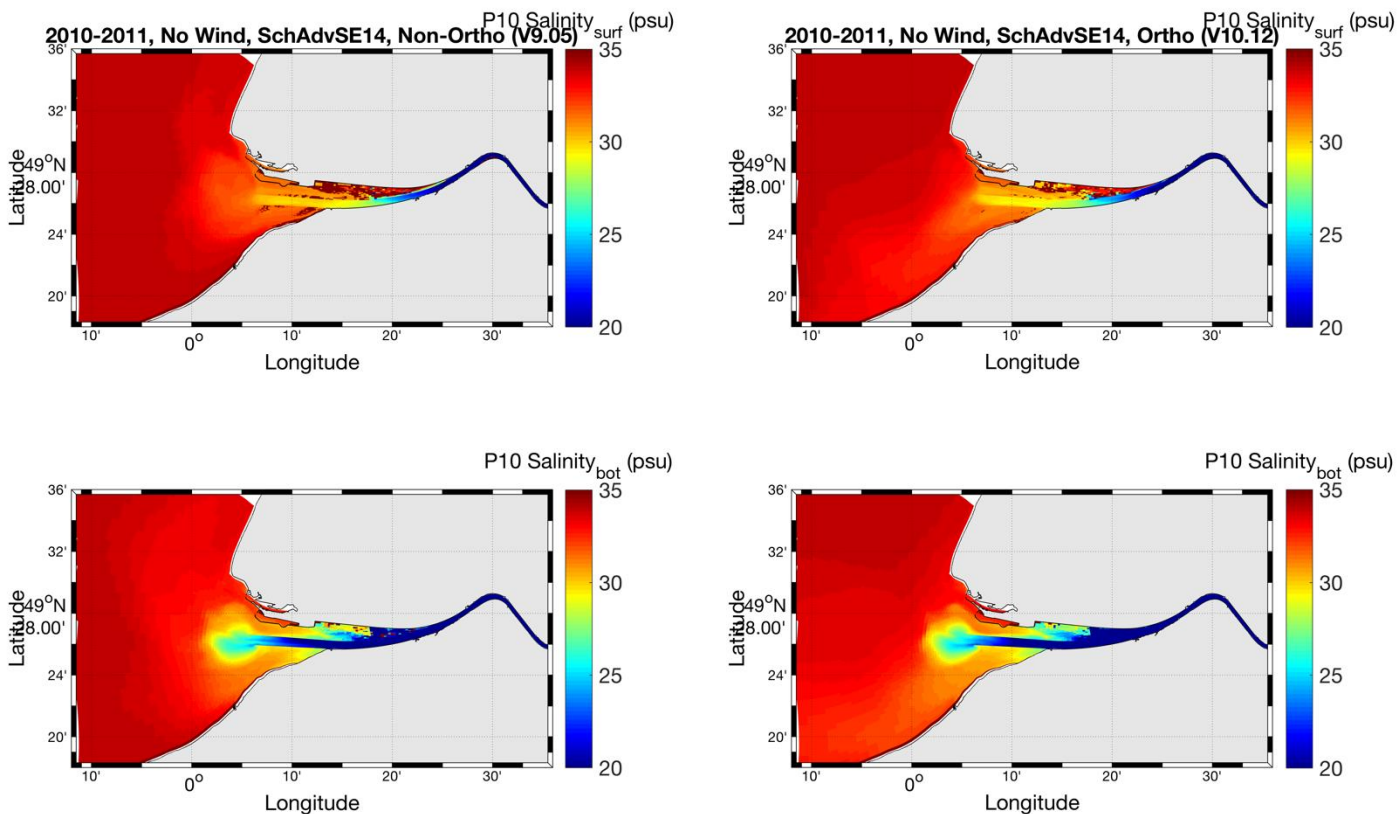


Figure 3. Comparaison du percentile 10 de la salinité (en haut) de surface et (en bas) de fond entre les simulations du modèle MARS3D curviligne en version non-orthogonale (gauche ; référence du projet, V9.05) et en version orthogonale (droite ; V10.12).

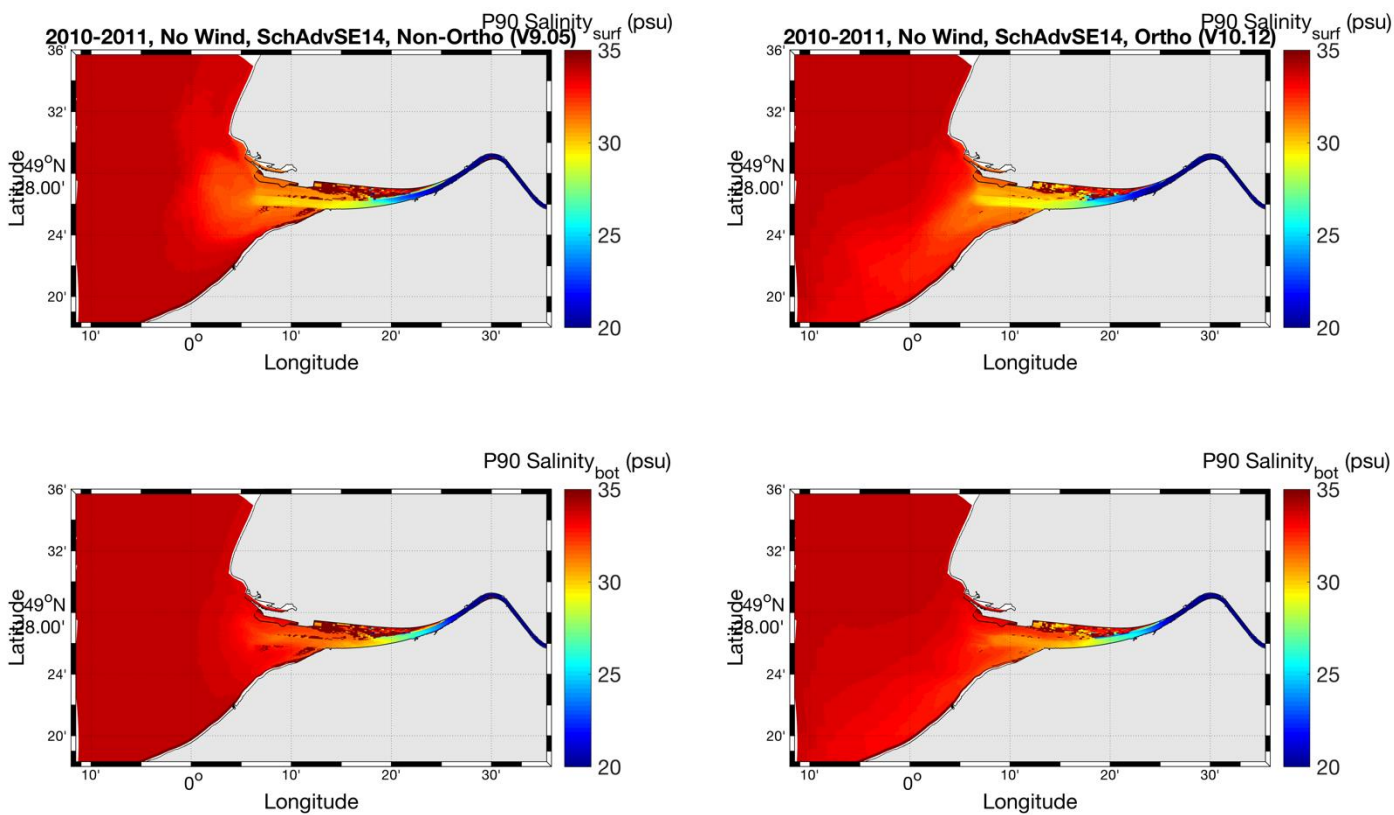


Figure 4. Comparaison du percentile 90 de la salinité (en haut) de surface et (en bas) de fond entre les simulations du modèle MARS3D curviligne en version non-orthogonale (gauche ; référence du projet, V9.05) et en version orthogonale (droite ; V10.12).

IV. Annexe : Influences des tributaires de la Seine à l'aval de Poses sur la dynamique hydro-sédimentaire de l'estuaire

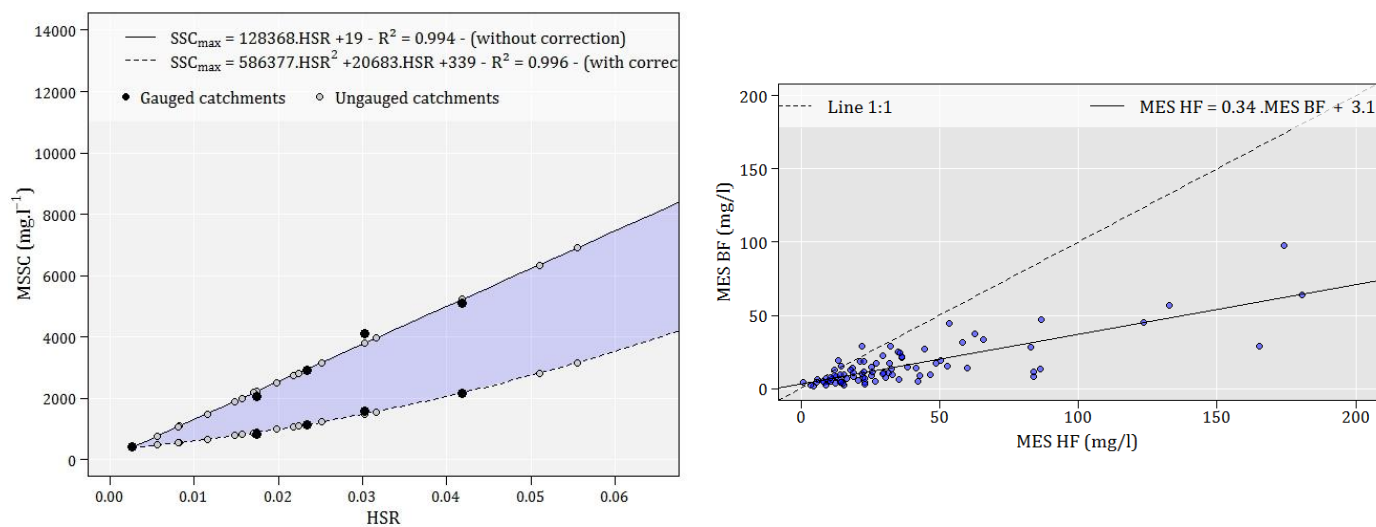


Figure 5. Lois de calibration pour estimer les apports solides des tributaire de la Seine à l'aval de Poses (cf. Rapport AFLUSEINE – SA5).

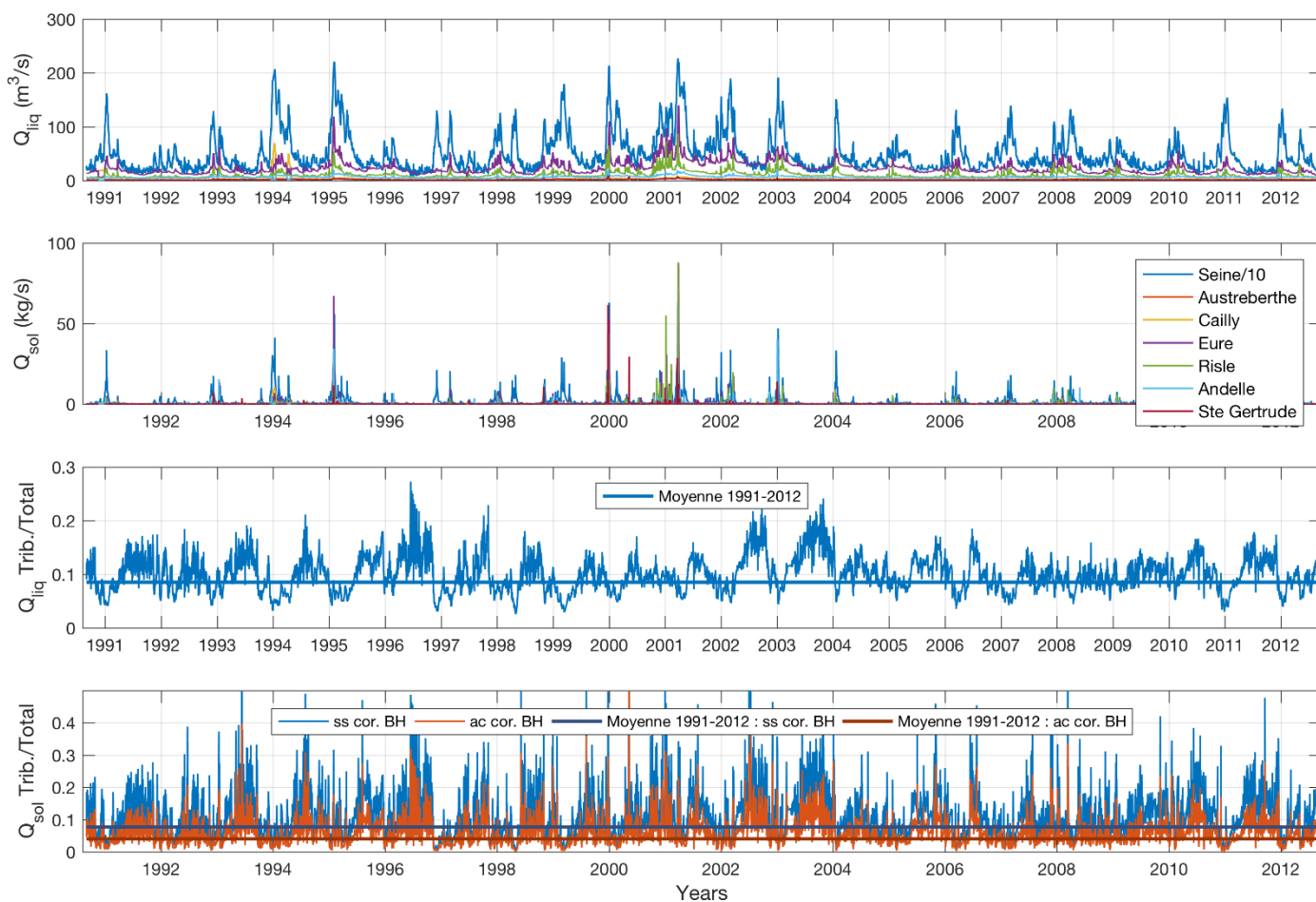


Figure 6. (a) Débits liquides Q_{liq} de la Seine à Poses (divisé par 10) et des tributaires de la Seine à l'aval de Poses, (b) débits solides Q_{sol} de la Seine à Poses (divisé par 10) et des tributaires à l'aval de Poses. Rapport entre les débits des tributaires Q_{Trib} et le débit total de la Seine Q_{Total} pour (c) les apports liquides et (d) les apports solides sans (bleu) et avec (orange) correction. Période 1991-2012.

Analyse d'un cycle vive eau - morte eau pendant lequel le ratio Q_{Trib}/Q_{Total} est particulièrement élevé : période du 11 au 25 juin 1996 – test B [Ref] et test Tacc (avec correction BF) [Trib]

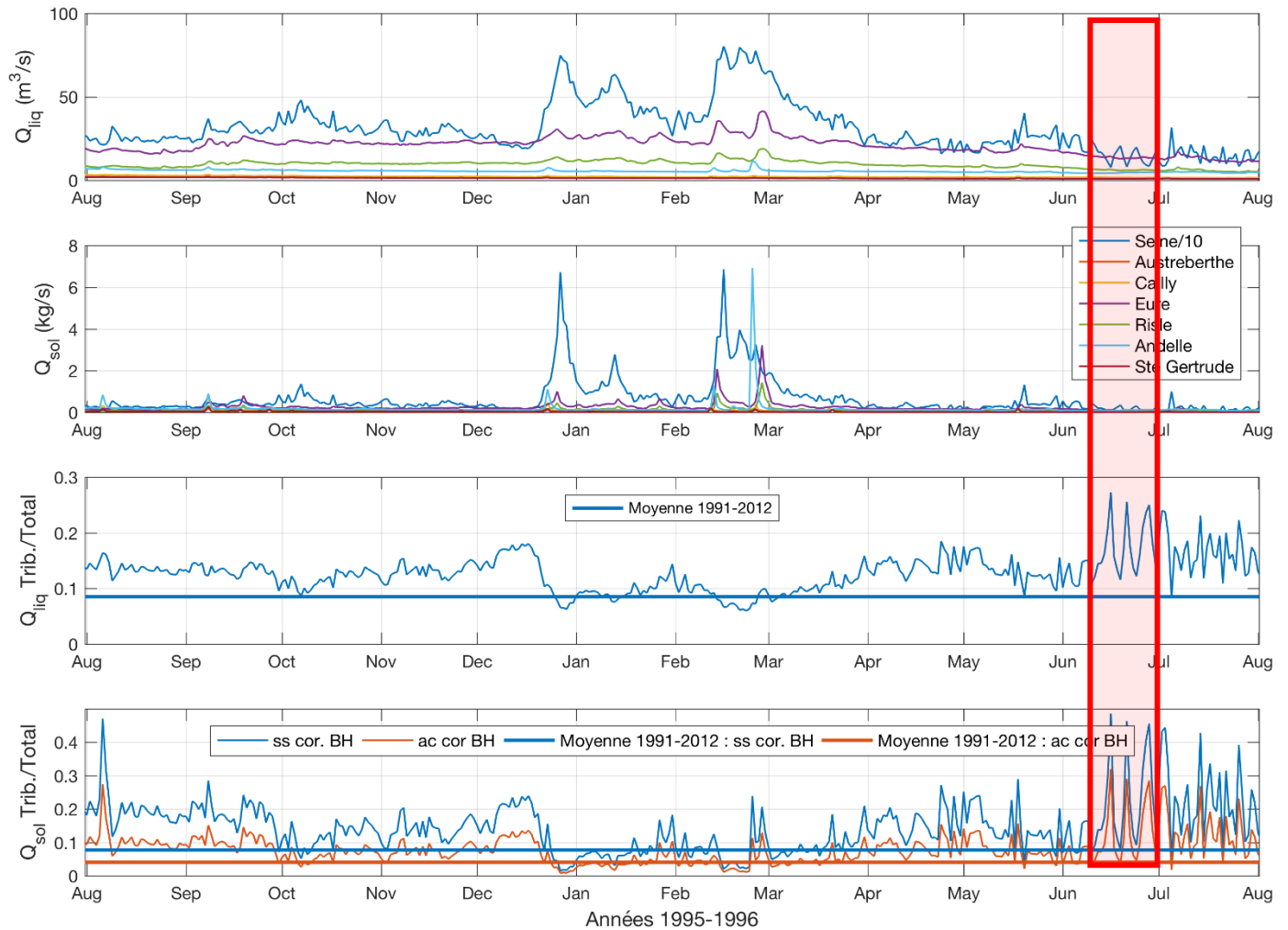


Figure 7. (a) Débits liquides Q_{liq} de la Seine à Poses (divisé par 10) et des tributaires de la Seine à l'aval de Poses, (b) débits solides Q_{sol} de la Seine à Poses (divisé par 10) et des tributaires à l'aval de Poses. Rapport entre les débits des tributaires Q_{Trib} et le débit total de la Seine Q_{Total} pour (c) les apports liquides et (d) les apports solides sans (bleu) et avec (orange) correction. Période août 1995 – août 1996 durant laquelle le rapport Q_{Trib}/Q_{Total} est particulièrement élevé.

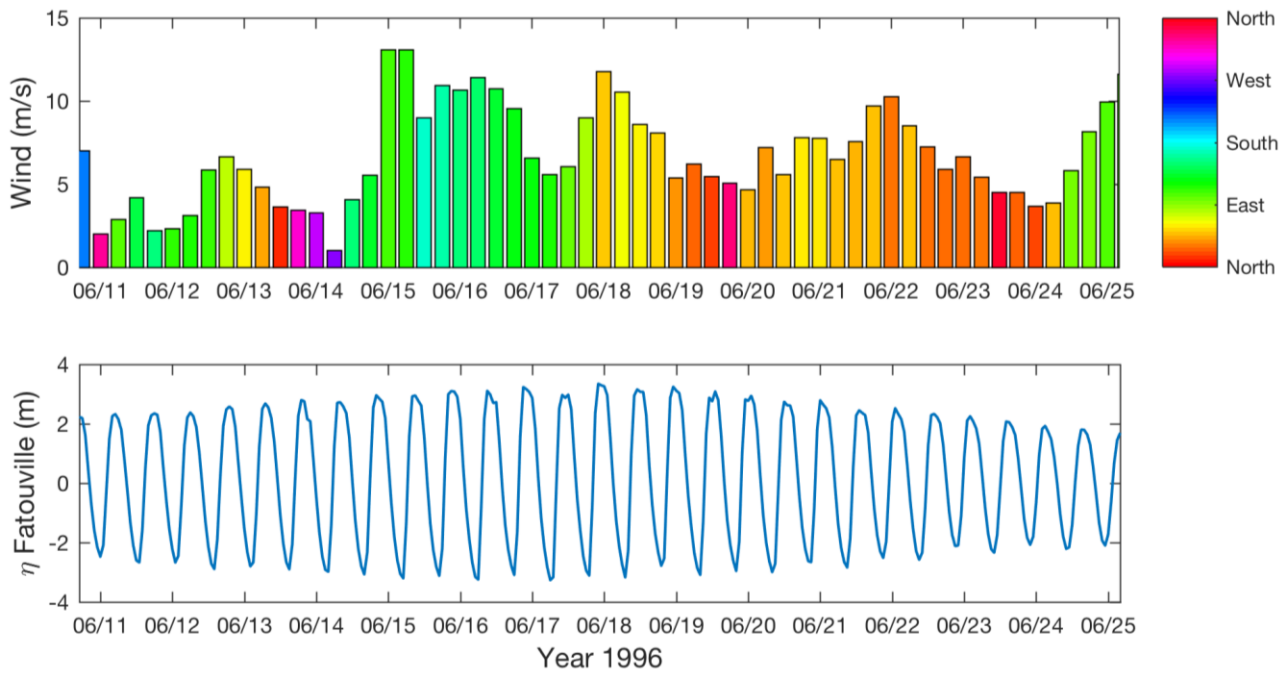


Figure 8. (Haut) condition de vent et (bas) surface libre à Fatouville lors du cycle VE/ME du 11 au 25 juin 1996.

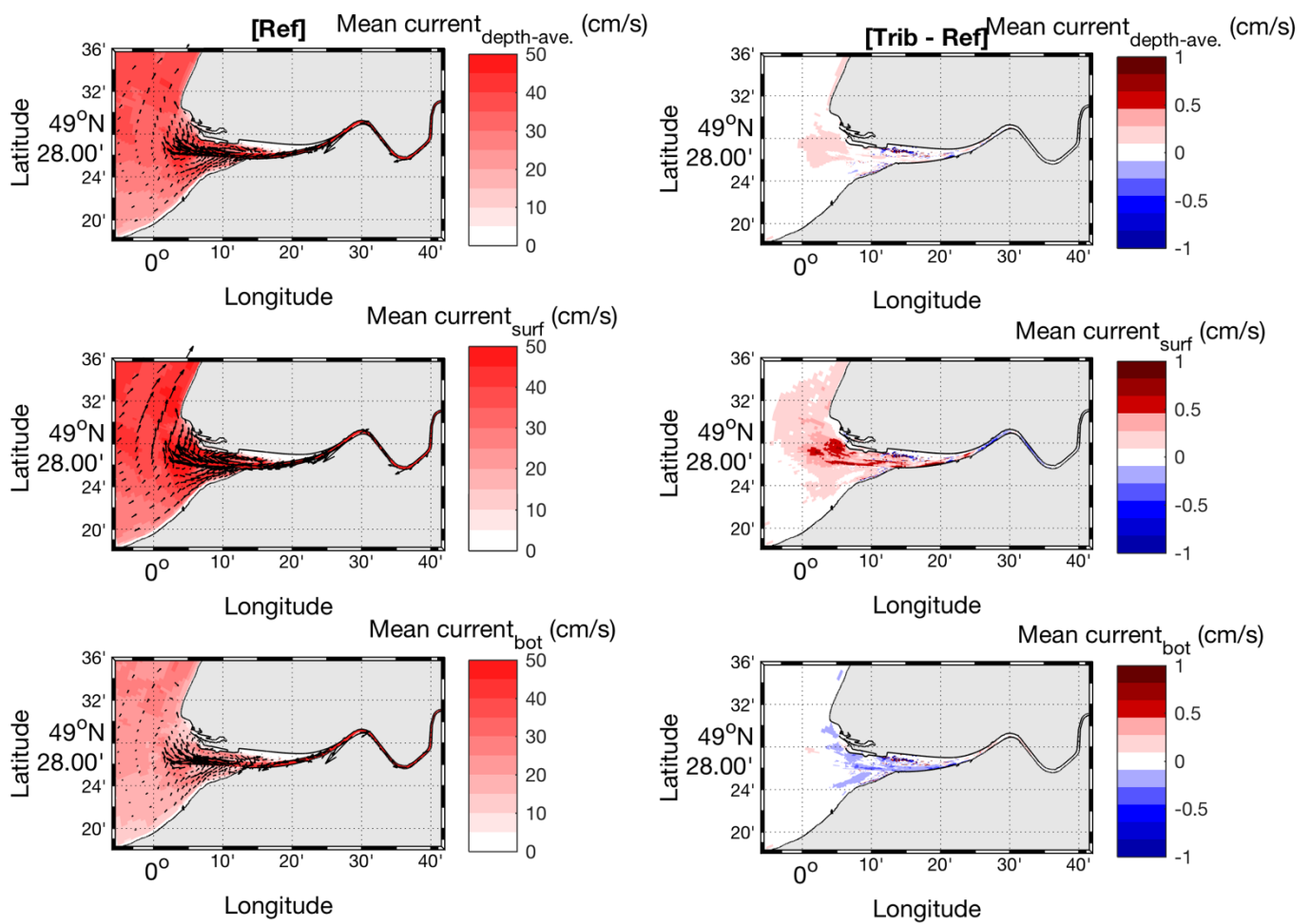


Figure 9. Courant résiduel (haut) moyenné sur la colonne d'eau, (milieu) en surface et (bas) au fond : (gauche) pour le scénario B sans tributaires et (droite) différence entre le scénario Tss avec tributaire et le scénario B. Cycle VE/ME du 11 au 25 juin 1996.

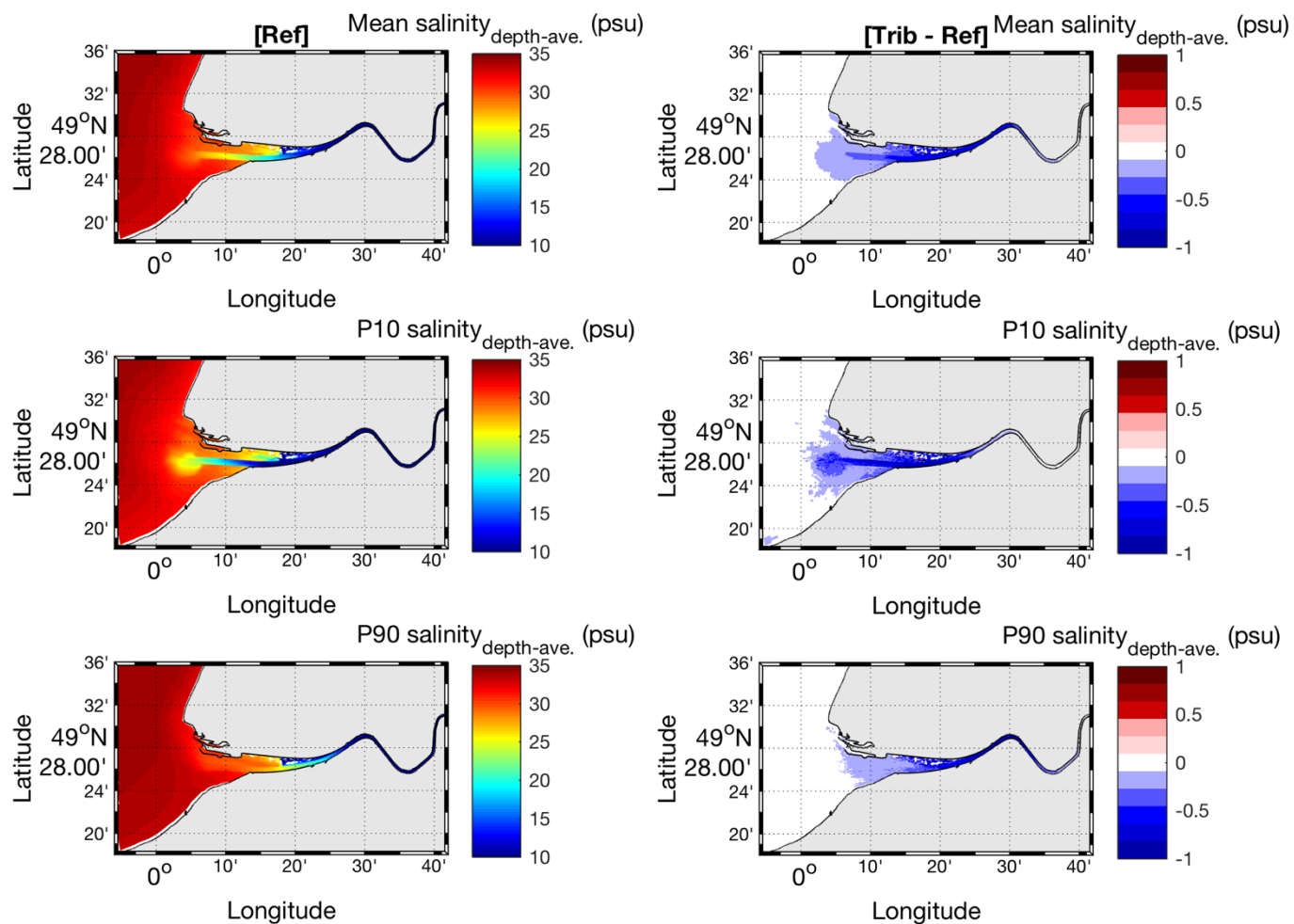


Figure 10. Moyenne sur la colonne d'eau de la salinité (haut) moyenne, (milieu) percentile 10 et (bas) percentile 90 : (gauche) pour le scénario B sans tributaires et (droite) différence entre le scénario Tss avec tributaire et le scénario B. Cycle VE/ME du 11 au 25 juin 1996.

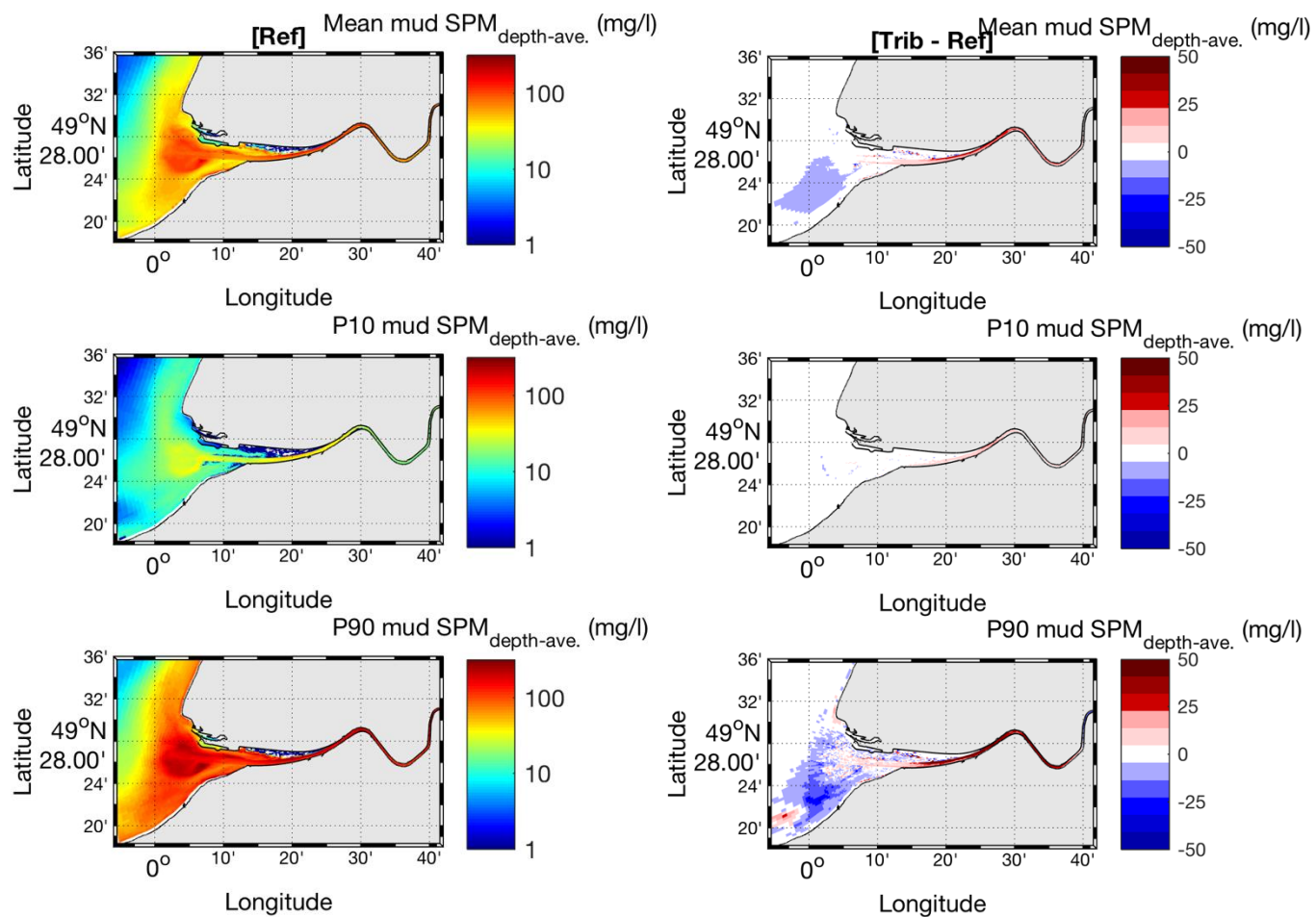


Figure 11. Moyenne sur la colonne d'eau de la concentration en SPM (haut) moyenne, (milieu) percentile 10 et (bas) percentile 90 : (gauche) pour le scénario B sans tributaires et (droite) différence entre le scénario Tss avec tributaire et le scénario B. Cycle VE/ME du 11 au 25 juin 1996.

V. Annexe : Articles soumis à *Journal of Geophysical Research – Ocean*

Suspended sediment dynamics in the macrotidal Seine estuary (France) –

Part 1: In situ measurement analysis and numerical modeling of turbidity maximum dynamics

F. Grasso¹, R. Verney¹, P. Le Hir¹, B. Thouvenin¹, E. Schulz^{1,5}, Y. Kervella², I. Khojasteh Pour Fard^{1†}, J.-P. Lemoine³, F. Dumas^{1‡}, V. Garnier⁴

¹IFREMER – DYNECO/DHYSED, Centre de Bretagne, CS 10070, 29280 Plouzané, France.

²OPEN OCEAN, Recherche et Développement, 15 rue Johannes Kepler, 29200 Brest, France.

³Groupement d'Intérêt Public Seine-Aval (GIPSA), Pôle Régional des Savoirs, 115 boulevard de l'Europe, 76100 Rouen, France.

⁴IFREMER, Univ. Brest, CNRS, IRD, *Laboratoire d'Océanographie Physique et Spatiale* (LOPS), IUEM, 29280, Brest, France.

⁵Leibniz Institute for Baltic Sea Research (IOW), Dept. of Physical Oceanography and Instrumentation, Seestraße 15, D-18119, Warnemünde, Germany.

† Now at the University of Isfahan (UI), Iran.

‡ Now at the Service Hydrographique et Océanographique de la Marine (SHOM), CS 92803, 29228 Brest, France.

Key Points:

- Measurements and simulations bear out the upriver migration of the Seine estuary Turbidity Maximum (ETM) since 1978
- The ETM mass is significantly influenced by tides and waves, but not by the river flow
- The neap-to-spring tidal phasing strongly influences the ETM location and mass through a hysteresis response

Abstract

The main mechanisms responsible for the estuarine turbidity maximum (ETM) formation are now relatively well understood, as the tidal pumping and the vertical circulation. However, the influence of meteorological and wave forcing on ETM dynamics is still not properly grasped and requires further investigation, especially in terms of wave actions. The quantification of ETM mass changes and ETM location translations can only be achieved through the combination of in situ measurements and a realistic numerical model. Hence, this study applied the latter approach on the Seine estuary (France) in order to quantify the ETM location and mass from tidal to hydrological time scales, with a particular interest on wave events. The measured hydrodynamics and sediment dynamics were suitably simulated by a realistic tridimensional numerical model accounting for mud and sand transport processes. Both measurements and simulations show that the Seine ETM migrated few kilometers upstream during the last 35 years. As expected, the ETM location is strongly modulated by semidiurnal and fortnightly tidal cycles with a high reactivity to river flow variations. The ETM mass is clearly related to the tidal range, but it is not significantly influenced by the river flow. The ETM mass is 10 to 50% larger during energetic conditions, meaning that neglecting wave action would result in significantly underestimated the ETM mass. Finally, the neap-to-spring tidal phasing has a strong influence on ETM location and mass through a hysteresis response due to the delay for tidal pumping and stratification to occur.

*Suspended sediment dynamics in the macrotidal Seine estuary (France) –
Part 2: Numerical modelling of sediment fluxes and budgets under typical hydrological and
meteorological conditions*

E. Schulz^{1,2}, F. Grasso¹, P. Le Hir¹, R. Verney¹, B. Thouvenin¹

¹IFREMER – DYNECO/DHYSED, Centre de Bretagne, CS 10070, 29280 Plouzané, France.

²Leibniz Institute for Baltic Sea Research (IOW), Dept. of Physical Oceanography and Instrumentation, Seestraße 15, D-18119, Warnemünde, Germany.

Key Points:

- Sediment fluxes and budgets in the lower Seine estuary are finely quantified under contrasted hydro-meteorological conditions
- Wind/waves, tides and river discharge impact sediment fluxes at specific locations along the estuary
- Seaward sediment export is enhanced during storm events, but counter-intuitively, it is reduced during wet years

Abstract

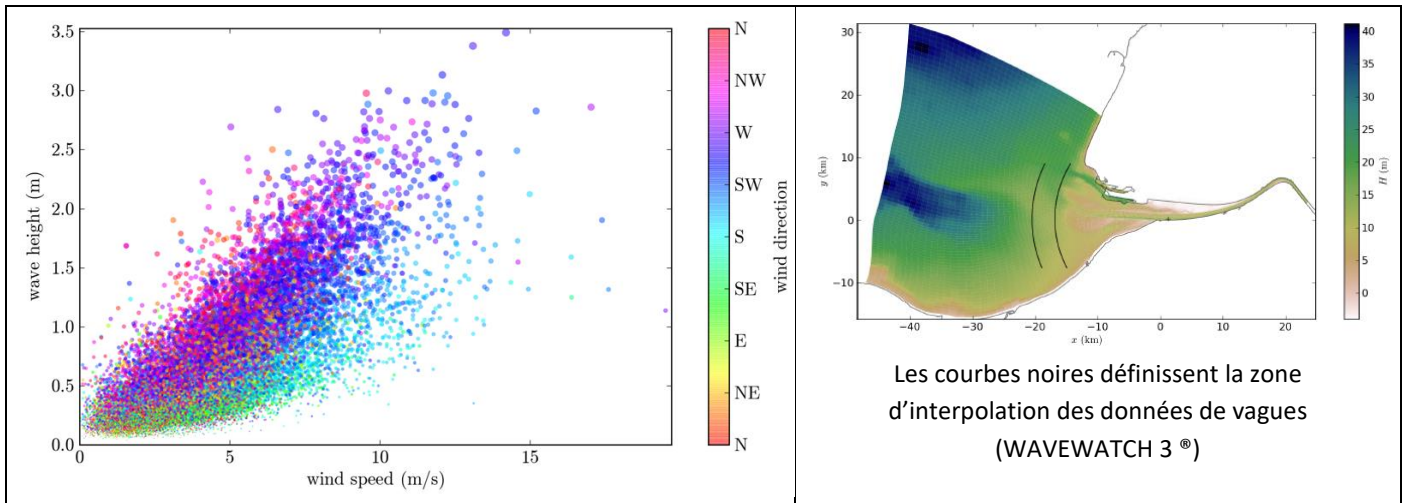
Understanding the sediment dynamics in an estuary is important for its morphodynamic and ecological assessment as well as, in case of an anthropogenically controlled system, for its maintenance. However, the quantification of sediment fluxes and budgets is extremely difficult from in-situ data and requires thoroughly validated numerical models. In the study presented here, sediment fluxes and budgets in the lower Seine estuary were quantified and investigated from seasonal to annual time scales with respect to realistic hydro- and meteorological conditions.

A realistic three-dimensional process-based hydro- and sediment-dynamic model was used to quantify mud and sand fluxes through characteristic estuarine cross-sections. In addition to a reference experiment with typical forcing, three experiments were carried out and analysed, each differing from the reference experiment in either river discharge or wind and waves so that the effects of these forcings could be separated.

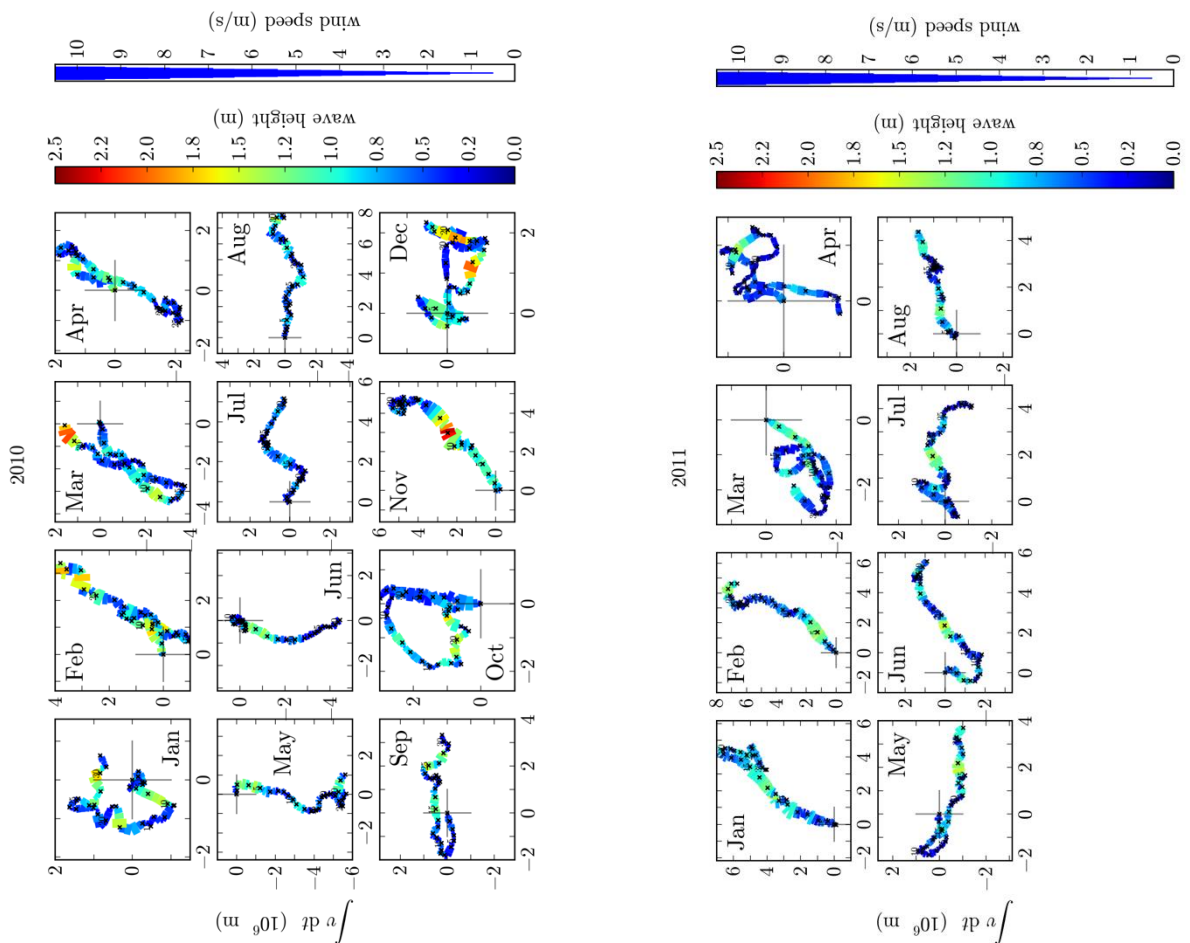
Hydro- and meteorological conditions affect the sediment fluxes and budgets in different ways and at different locations. Single storm events induce strong erosion in the lower estuary and can have a significant effect on the sediment fluxes offshore of the Seine estuary mouth, with the flux direction depending on the wind direction. Spring tides cause significant up-estuary fluxes at the mouth. A high river discharge drives barotropic down-estuary fluxes at the upper cross-sections, but, astonishingly, baroclinic up-estuary fluxes at the mouth and offshore so that the lower estuary gains sediment during wet years. Such a counter-intuitive behaviour is likely to be observed in worldwide estuaries dominated by turbidity maximum dynamics.

VI. Annexe : Forçages hydrométéorologiques

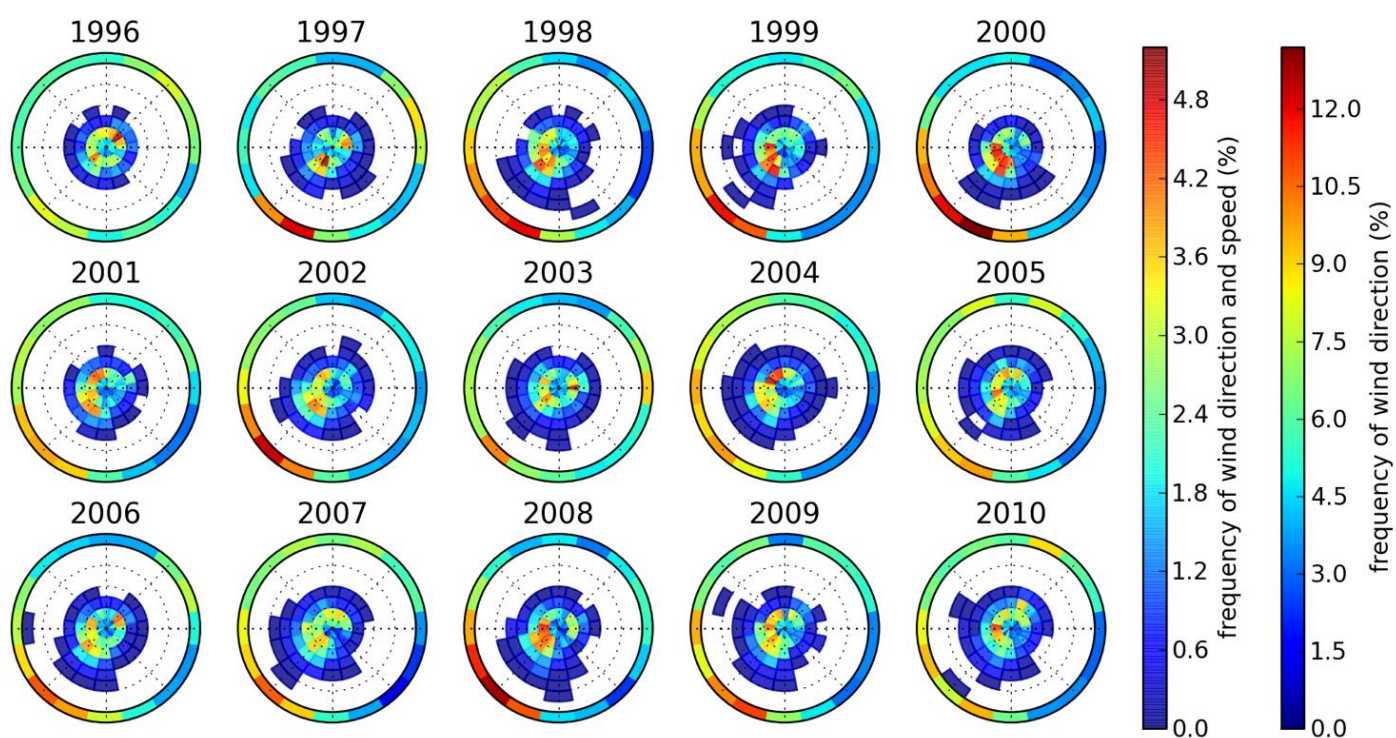
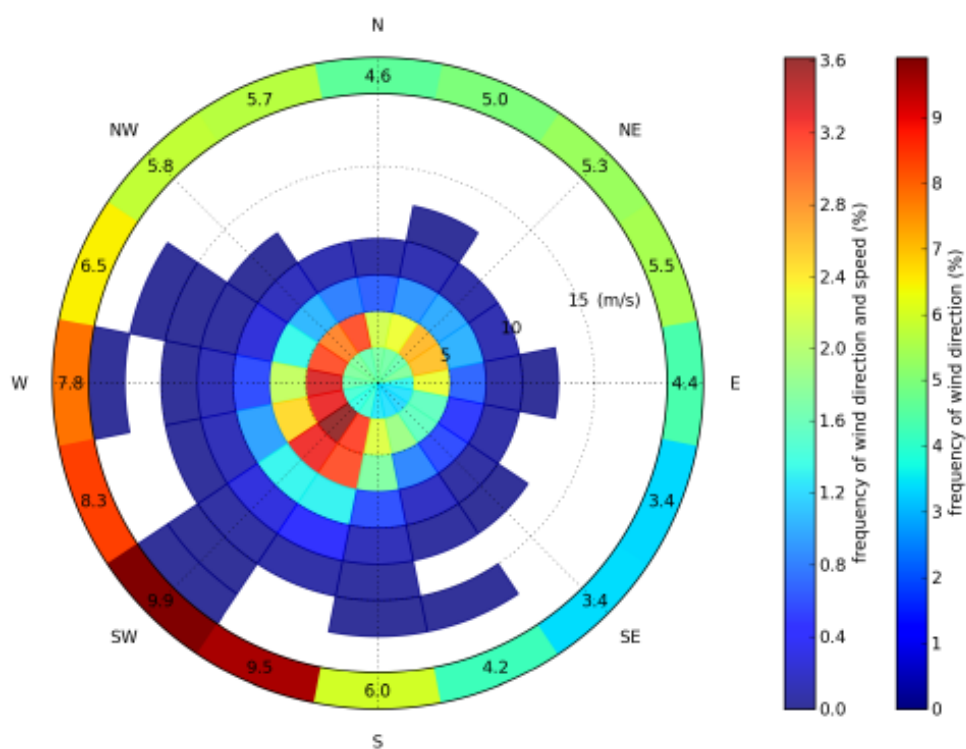
Relation vent vs vagues à l'embouchure de l'estuaire de la Seine [1996-2011]



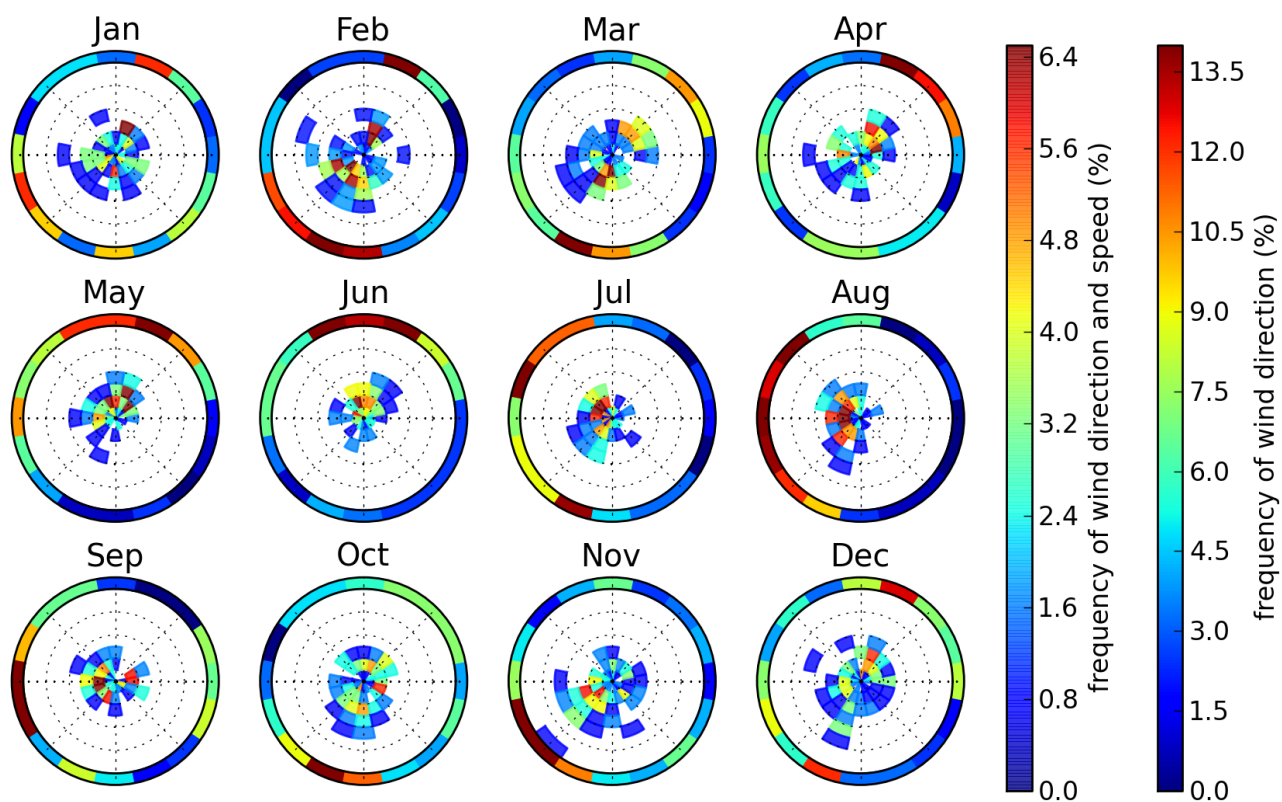
Hodographe intégrés : vent + vagues [2010-2011]



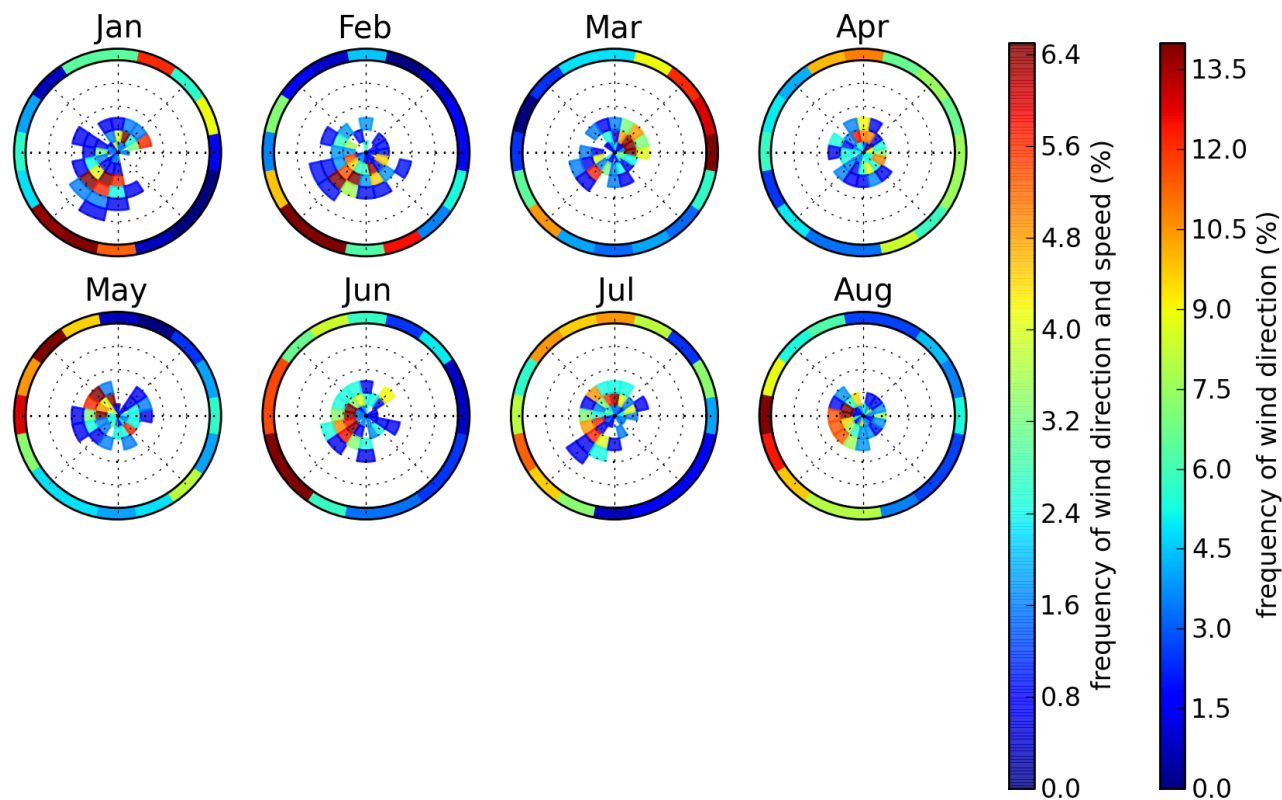
Roses des vents annuelles [1996-2010]

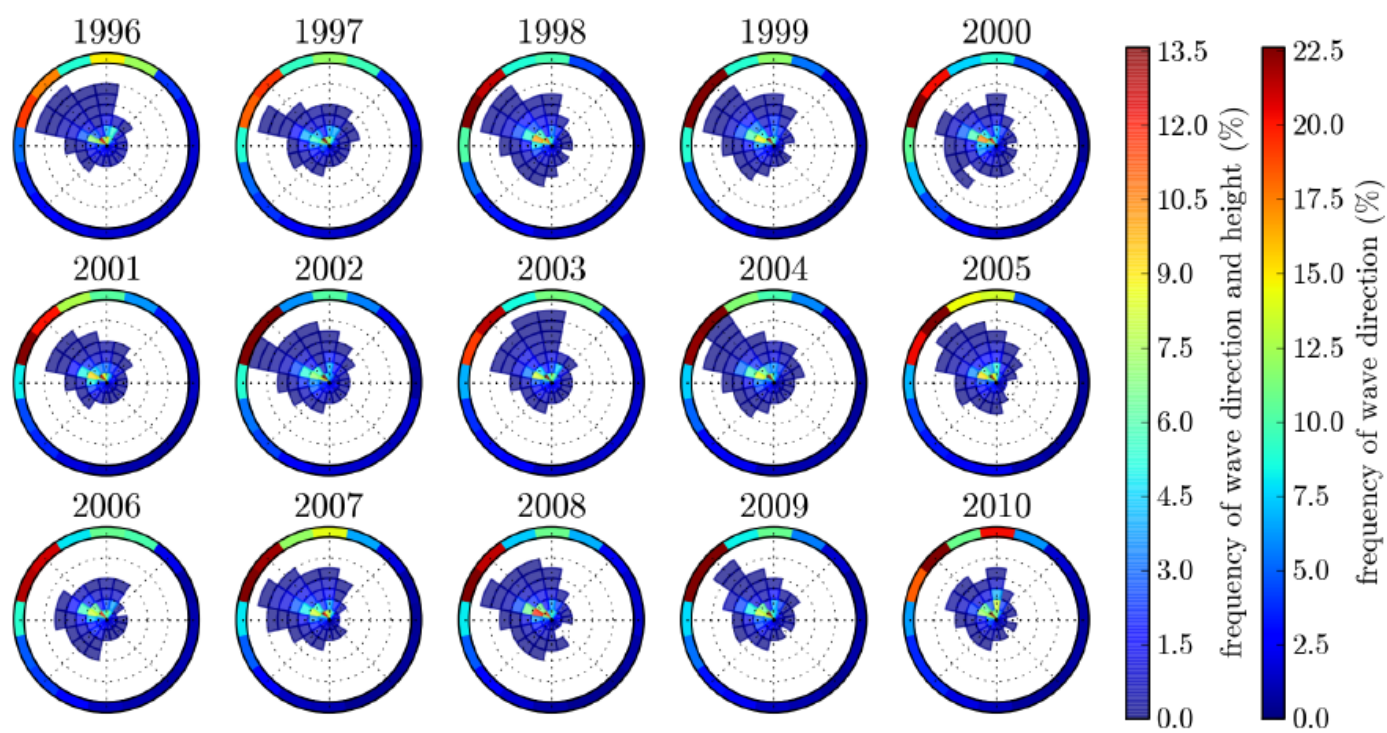
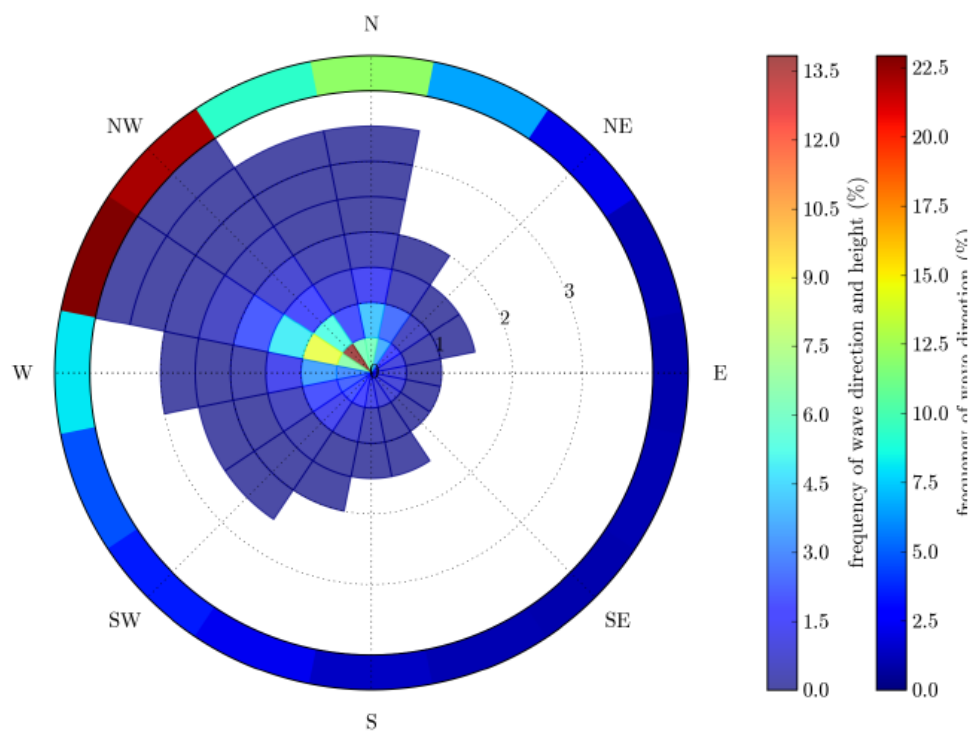


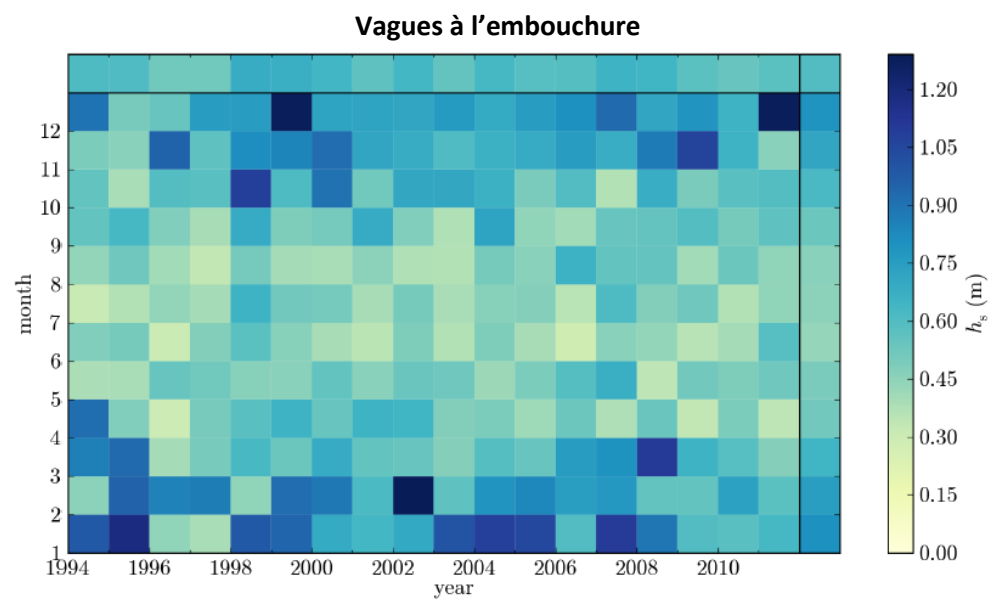
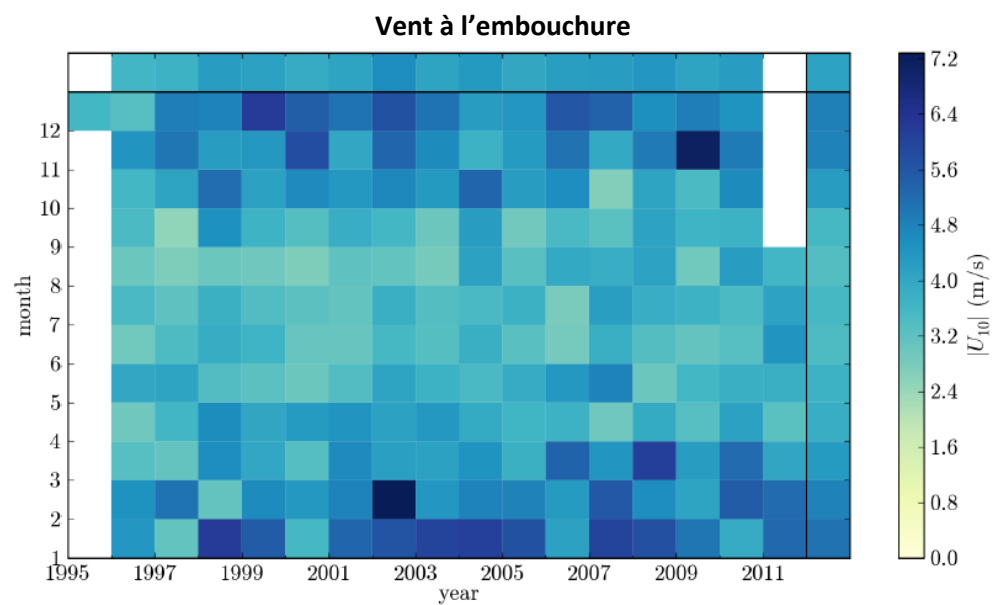
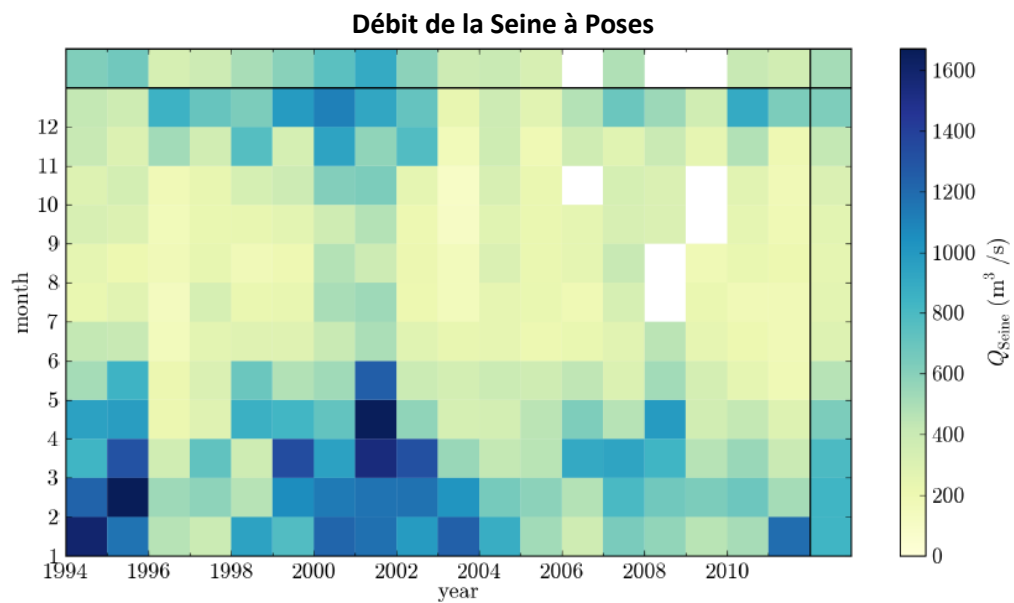
2010



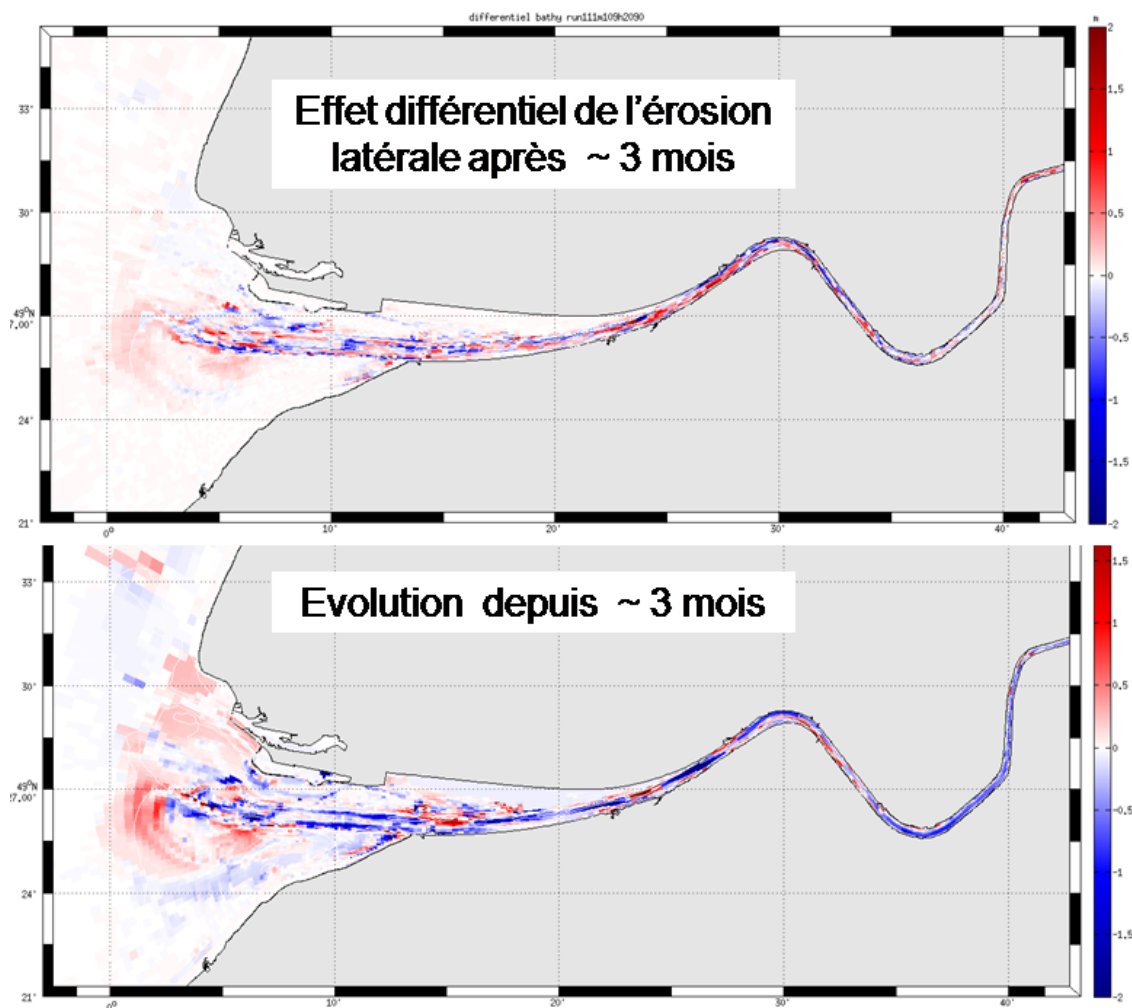
2011



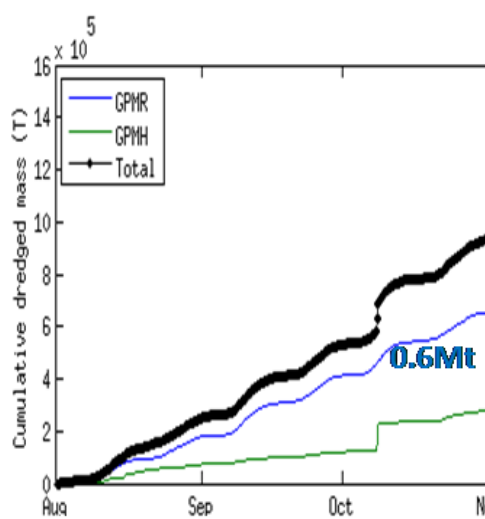




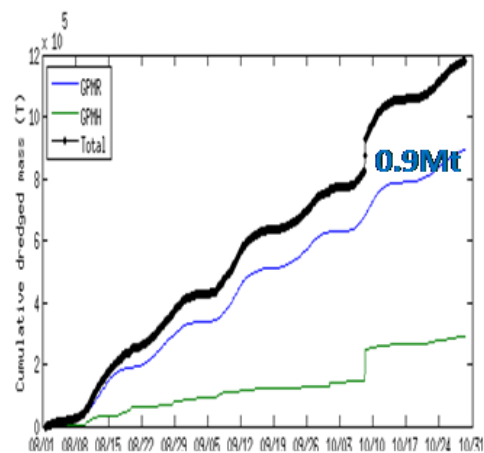
VII. Annexe : Effet de l'érosion latérale sur les différentiels bathymétriques et sur les quantités draguées par les Grands Ports Maritimes



Dragages Rouen : + 40 à 50%



Sans érosion latérale



Avec érosion latérale

VIII. Annexe : Rappel du paramétrage du modèle en configuration morpho.

1) Fichier de description des variables

BEGINNING OF THE FILE DESCRIPTION

data file to define substances or sedimentological, biological, bacteriological and/or biogeochemical variables

Number of variable

NAME of variables USING A UNIQUE WORD (add _ instead of a white)

LONG_NAME of variable (NetCDF OCO format for gridded data products)

STANDARD NAME of variable (NetCDF OCO format for gridded data products)

UNIT of variable

Minimum valid value of variable (NetCDF OCO format for gridded data products)

Maximum valid value of variable (NetCDF OCO format for gridded data products)

different types of allowed variables :

GRAV : gravel (gravier),

SAND : sand (sable)

MUDS : mud (vase)

PART : constitutive particulate variable (part.constitutive)

NoCP : non constitutive particulate variable (part. non constitutive) which has its own settling velocity

SORB : sorbed variable on a constitutive particulate variable (part. non constitutive which has the same settling velocity as its associated constitutive variable)

DISS : dissolved (dissous)

FIXE : fixed (not advected)(fixee)

DRIV : driving variable (forcante)

INTE : intermediate (intermediaire))

[CONTA : if key_contaminant : for a contaminant which could have several species (defined later in another file)]

Units

inside the water column :

GRAV,SAND,MUDS,PART in kg/m3 (required)

SORB,NoCP,DISS choice of unit/m3 of water

FIXE,DRIV,INTE choice of unit

inside the sediment :

GRAV,SAND,MUDS,PART in kg/m3 of total sediment

except for the initial condition : fraction of cseduni

SORB,NoCP choice of unit/m3 of total sediment

except for the initial condition : choice of unit/kg of sediment

DISS choice of unit/m3 of interstitial water (EI)

for variable type CONTA : add the name of the file of the contaminant just one line after the type

CONTA ,| variable type [GRAV,SAND,MUDS,PART,NoCP,SORB,DISS,FIXE,DRIV,INTE]

PCB153_0 ,| file name describing contaminant's characteristics

ONLY for SAND variables : add 2 more lines :

I_sand2D ,| TRUE if this sand variable is treated as 2D variable (used only if key_sand2D)

I_outsandrouse ,| TRUE if using reconstitution of a ROUSE profil for output in water column (used only if ikey_sand2D and I_sand2D is TRUE for this variable)

ONLY for GRAV and SAND variables : add 3 more lines

0.00002 ,| diameter of particle (used only if key_sedim)

10. ,| critical stress of deposition (used only if key_sedim)

2600. ,| density of particle (used only if key_sedim)

ONLY for MUDS,PART,NoCP particulate variables : add 7 more lines (settling velocities)

If NOT key_sedim : choose options (ws_free_opt and ws_hind_opt) =0 and only MIN settling velocity (ws_free_min) and MAX settling velocity (ws_free_max) will be used

If key_sedim : see documentation : <http://www.ifremer.fr/docmars/html/doc.sedim.formul.html#doc-settling>

0 ,| ws_free_opt : choice of free settling formulation : 0 constant, 1 Van Leussen, 2 Winterwerp, 3 Wolanski
.001,.001,.001,1.2,0.0,0.0 ,| ws_free_min, ws_free_max, ws_free_para : min.setl.vel(m/s), max.setl.vel(m/s), + 4 additional parameters (see comment below)
0 ,| ws_hind_opt : choice of hindered settling formulation : 0 no hindered settling, 1 Scott, 2 Winterwerp, 3 Wolanski
.000,.00 ,| ws_hind_para : 2 additional parameters (see comment below)
0.000001 ,| diameter of particle (used only if key_sedim)
10. ,| critical stress of deposition (used only if key_sedim)
2600. ,| density of particle (used only if key_sedim)

ONLY for variables SORB : add 1 more lines :

MES1 ,| exact name of constitutive particulate variable on which the SORB variable is sorbed (or associated)

the 6 additional parameters defining the settling velocity (used only for MUDS, PART and NoCP AND if key_sedim) are :

If ws_free_opt=0 (Ws constant) ==>> (1)=unused (2)= unused (3)=unused (4)=unused
If ws_free_opt=1 (Van Leussen) ==>> (1)=c_factor (2)=c_exponent (3)=VL_a (4)=VL_b
If ws_free_opt=2 (Winterwerp) ==>> (1)= Primary Particle Diameter (2)=aggregation factor (3)=breakup factor (4)=fractal dimension
If ws_free_opt=3 (Wolanski) ==>> (1)= c_factor (2)=c_exponent (3)=unused (4)=unused
If ws_hind_opt=0 (no hindered settling) ==> (1)=unused (2)=unused
If ws_hind_opt=1 (Scott) ==> (1)=phi_factor (2)=phi_exponent
If ws_hind_opt=2 and ws_free_opt=2 (Winterwerp) ==> (1)=gel concentration (kg/m3) (2)=phi_exponent
If ws_hind_opt=3 (Wolanski) ==> (1)=c_constant (2)=c_exponent

For driving variables only (DRIV), one must fill 3 more lignes :

0.000 ,| initial concentration in water column (unit/m3)
0.000 ,| initial concentration in sediment (see unit higher)
0.000 ,| initial concentration in air (unit/m3)

For each state variable (except DRIV and INTE), one must fill 6 more lines

0.000 ,| t90 (function decay : time after which 90% of matter has disappeared) in hour
0.000 ,| uniform atmospherical deposition (unit/m2/s) (unused for FIXE)
0.000 ,| concentration in rainwater (unit/m3 of water)
0.000 ,| initial concentration in water column (unit/m3)
0.000 ,| initial concentration in sediment (see unit higher)
0.000 ,| initial concentration in air (unit/m3)

For all the variables

.false. ,| saving in output file
init_cv_name_r ,| Name of substance read from file of initialisation
,| none if not read(IC = 0)
obc_cv_name_r ,| Name of substance read from open boundary conditions file
,| none if not read(OBC = 0)

END OF FILE DESCRIPTION

1 ,| number of variable
gravel ,| name of variable
gravel ,| long_name of variable
gravel ,| standard_name of variable
g.l-1 ,| unit of concentration
0.0 ,| valid_min value of variable
1.0e9 ,| valid_max value of variable
SAND ,| variable type [GRAV,SAND,MUDS,PART,NoCP,SORB,DISS,FIXE,DRIV,INTE]

```

==if SAND variable : add 2 lines below to define l_sand2D and l_outsandrouse used only if key_sand2D
.true.          ,| TRUE if this sand variable is treated as 2D variable (used only if key_sand2D)
.false.         ,| TRUE if using reconstitution of a ROUSE profil for output in water column (used only if ikey_sand2D and
l_sand2D is TRUE for this variable)
==if particulate variable : add 3 more lines for GRAV and SAND, 7 lines for MUDS,PART & NoCP, 1 line for SORB (see above)
0.005           ,| diameter of particle (used only if key_sedim)
1000.           ,| critical stress of deposition (used only if key_sedim)
2600.           ,| density of particle (used only if key_sedim)
==if state variable : add 6 more lines below
0.000           ,| t90 (function decay : time after which 90% of matter has disappeared) in hour
0.000           ,| uniform atmospherical deposition (unit/m2/s) (unused for FIXE)
0.000           ,| concentration in rainwater (unit/m3 of water)
0.000           ,| initial concentration in water column (unit/m3)
1.000           ,| initial concentration in sediment (in fraction [0:1] if SAND, GRAV, MUDS, PART; /kg if SORB/NoCP; /m3 EI if
DISS)
0.000           ,| initial concentration in air
.true.          ,| saving in output file
none            ,| name of substance read from initial condition file
none            ,| name of substance read from obc file
*****
2               ,| number of variable
coarse_sand     ,| name of variable
coarse_sand     ,| long_name of variable
coarse_sand     ,| standard_name of variable
g.l-1           ,| unit of concentrationvariable_r1799_5classes_NUBC_wsVL15_nograv.dat
0.0             ,| valid_min value of variable
1.0e9           ,| valid_max value of variable
SAND            ,| variable type [GRAV,SAND,MUDS,PART,NoCP,SORB,DISS,FIXE,DRIV,INTE]
==if SAND variable : add 2 lines below to define l_sand2D and l_outsandrouse used only if key_sand2D
.true.          ,| TRUE if this sand variable is treated as 2D variable (used only if key_sand2D)
.false.         ,| TRUE if using reconstitution of a ROUSE profil for output in water column (used only if ikey_sand2D and
l_sand2D is TRUE for this variable)
==if particulate variable : add 3 more lines for GRAV and SAND, 7 lines for MUDS,PART & NoCP, 1 line for SORB (see above)
0.000800        ,| diameter of particle (used only if key_sedim)
1000.           ,| critical stress of deposition (used only if key_sedim)
2600.           ,| density of particle (used only if key_sedim)
==if state variable : add 6 more lines below
0.000           ,| t90 (function decay : time after which 90% of matter has disappeared) in hour
0.000           ,| uniform atmospherical deposition (unit/m2/s) (unused for FIXE)
0.000           ,| concentration in rainwater (unit/m3 of water)
0.000           ,| initial concentration in water column (unit/m3)
1.000           ,| initial concentration in sediment (in fraction [0:1] if SAND, GRAV, MUDS, PART; /kg if SORB/NoCP; /m3 EI if
DISS)
0.000           ,| initial concentration in air
.true.          ,| saving in output file
none            ,| name of substance read from initial condition file
none            ,| name of substance read from obc file
*****
3               ,| number of variable
fine_sand       ,| name of variable
fine_sand       ,| long_name of variable
fine_sand       ,| standard_name of variable
g.l-1           ,| unit of concentration
0.0             ,| valid_min value of variable
1.0e9           ,| valid_max value of variable
SAND            ,| variable type [GRAV,SAND,MUDS,PART,NoCP,SORB,DISS,FIXE,DRIV,INTE]
==if SAND variable : add 2 lines below to define l_sand2D and l_outsandrouse used only if key_sand2D
.true.          ,| TRUE if this sand variable is treated as 2D variable (used only if key_sand2D)
.true.          ,| TRUE if using reconstitution of a ROUSE profil for output in water column (used only if ikey_sand2D and
l_sand2D is TRUE for this variable)
==if particulate variable : add 3 more lines for GRAV and SAND, 7 lines for MUDS,PART & NoCP, 1 line for SORB (see above)
0.000210        ,| diameter of particle (used only if key_sedim)

```

```

1000.      ,| critical stress of deposition (used only if key_sedim)
2600.      ,| density of particle (used only if key_sedim)
==if state variable : add 6 more lines below
0.000      ,| t90 (function decay : time after which 90% of matter has disappeared) in hour
0.000      ,| uniform atmospherical deposition (unit/m2/s) (unused for FIXE)
0.000      ,| concentration in rainwater (unit/m3 of water)
0.000      ,| initial concentration in water column (unit/m3)
1.000      ,| initial concentration in sediment (in fraction [0:1] if SAND, GRAV, MUDS, PART; /kg if SORB/NoCP; /m3 EI if
DISS)
0.000      ,| initial concentration in air
.true.     ,| saving in output file
none       ,| name of substance read from initial condition file
none       ,| name of substance read from obc file
*****
4          ,| number of variable
very_fine_sand ,| name of variable
very_fine_sand ,| long_name of variable
very_fine_sand ,| standard_name of variable
g.l-1       ,| unit of concentration
0.0         ,| valid_min value of variable
1.0e9       ,| valid_max value of variable
SAND        ,| variable type [GRAV,SAND,MUDS,PART,NoCP,SORB,DISS,FIXE,DRIV,INTE]
==if SAND variable : add 2 lines below to define l_sand2D and l_outsandrouse used only if key_sand2D
.true.     ,| TRUE if this sand variable is treated as 2D variable (used only if key_sand2D)
.true.     ,| TRUE if using reconstitution of a ROUSE profil for output in water column (used only if ikey_sand2D and
l_sand2D is TRUE for this variable)
==if particulate variable : add 3 more lines for GRAV and SAND, 7 lines for MUDS,PART & NoCP, 1 line for SORB (see above)
0.000100    ,| diameter of particle (used only if key_sedim)
1000.      ,| critical stress of deposition (used only if key_sedim)
2600.      ,| density of particle (used only if key_sedim)
==if state variable : add 6 more lines below
0.000      ,| t90 (function decay : time after which 90% of matter has disappeared) in hour
0.000      ,| uniform atmospherical deposition (unit/m2/s) (unused for FIXE)
0.000      ,| concentration in rainwater (unit/m3 of water)
0.000      ,| initial concentration in water column (unit/m3)
1.000      ,| initial concentration in sediment (in fraction [0:1] if SAND, GRAV, MUDS, PART; /kg if SORB/NoCP; /m3 EI if
DISS)
0.000      ,| initial concentration in air
.true.     ,| saving in output file
none       ,| name of substance read from initial condition file
none       ,| name of substance read from obc file
*****
5          ,| number of variable
mud         ,| name of variable
mud         ,| long_name of variable
mud         ,| standard_name of variable
g.l-1       ,| unit of concentration
0.0         ,| valid_min value of variable
1.0e9       ,| valid_max value of variable
MUDS        ,| variable type [GRAV,SAND,MUDS,PART,NoCP,SORB,DISS,FIXE,DRIV,INTE]
==if SAND variable : add 2 lines below to define l_sand2D and l_outsandrouse used only if key_sand2D
==if particulate variable : add 3 more lines for GRAV and SAND, 7 lines for MUDS,PART & NoCP, 1 line for SORB (see above)
1          ,| ws_free_opt : choice of free settling formulation : 0 constant, 1 Van Leussen, 2 Winterwerp, 3 Wolanski
.0001,.0015,0.003,0.79,0.3,0.18 ,| ws_free_min, ws_free_max, ws_free_para : min.setl.vel(m/s), max.setl.vel(m/s), + 4
additional parameters (see comment below)
0          ,| ws_hind_opt : choice of hindered settling formulation : 0 no hindered settling, 1 Scott, 2 Winterwerp, 3
Wolanski
.000,.00    ,| ws_hind_para : 2 additional parameters (see comment below)
0.000020    ,| diameter of particles
5.          ,| critical stress of deposition
2600.      ,| density of particle
==if state variable : add 6 more lines below

```

```

0.000      ,| t90 (function decay : time after which 90% of matter has disappeared) in hour
0.000      ,| uniform atmospherical deposition (unit/m2/s) (unused for FIXE)
0.000      ,| concentration in rainwater (unit/m3 of water)
0.000      ,| initial concentration in water column (unit/m3)
1.000      ,| initial concentration in sediment (in fraction [0:1] if SAND, GRAV, MUDS, PART; /kg if SORB/NoCP; /m3 EI if
DISS)
0.000      ,| initial concentration in air
.true.     ,| saving in output file
none       ,| name of substance read from initial condition file
none       ,| name of substance read from obc file
*****

```

2) facies sédimentaires

```

! la concentration relative de vase est supposée égale à 600 kg/m3
! on en déduit la concentration totale, égale à 600/(1+f*(600/2600-1)), ou f=fraction sableuse
! cette valeur de csed est respectée tant que inférieure à 1600 kg/m3, correspondat à cvol=0.61
! tous les facies sont revus de la façon suivante :                                csedfacies
! en aout 2015 : facies 1 (substrat dur ) : pas de sédiment initial
!
!          5 vase    4 sab.fin  3 sab.moy  2 sab.gro  1 gravier  fsab bulkdens
! classe
!          5          4          3          2          1
! facies 0 (graviers ? ) : <63µ: 0%, 100µ: 0%, 210µ: 10%, 800µ: 16%, 5000µ: 74% 1 1600
! facies 1 (substrat dur ) : <63µ: 0%, 100µ: 0%, 210µ: 0%, 800µ: 0%, 5000µ:100% 1 1600
! facies 2 (Galets Coquill) : <63µ: 0%, 100µ: 0%, 210µ: 10%, 800µ: 16%, 5000µ: 74% 1 1600
! facies 3 (Graviers ) : <63µ: 0%, 100µ: 0%, 210µ: 10%, 800µ: 16%, 5000µ: 74% 1 1600
! facies 4 (sable grossier) : <63µ: 5%, 100µ: 5%, 210µ: 60%, 800µ: 25%, 5000µ: 5% .95 1550
!nouveau facies 4 (sable grossier) : <63µ: 5%, 100µ: 5%, 210µ: 20%, 800µ: 70%, 5000µ: 0% .95 1550
! facies 5 (sable moyen ) : <63µ: 10%, 100µ: 20%, 210µ: 60%, 800µ: 10%, 5000µ: 0% .90 1500
!nouveau facies 5 (sable moyen ) : <63µ: 10%, 100µ: 10%, 210µ: 35%, 800µ: 45%, 5000µ: 0% .90 1500
!nv 12/02/2017 facies 5 (sable moyen ) : <63µ: 10%, 100µ: 15%, 210µ: 50%, 800µ: 25%, 5000µ: 0% .90 1500
! facies 6 (sable fin ) : <63µ: 15%, 100µ: 25%, 210µ: 50%, 800µ: 10%, 5000µ: 0% .85 1450
!nouveau facies 6 (sable fi) : <63µ: 15%, 100µ: 25%, 210µ: 60%, 800µ: 0%, 5000µ: 0% .85 1450
! facies 7 (sable vaseux ) : <63µ: 30%, 100µ: 25%, 210µ: 45%, 800µ: 0%, 5000µ: 0% .70 1302
! facies 8 (vase sableuse ) : <63µ: 40%, 100µ: 25%, 210µ: 35%, 800µ: 0%, 5000µ: 0% .60 1115
! facies 9 (vase ) : <63µ: 60%, 100µ: 20%, 210µ: 20%, 800µ: 0%, 5000µ: 0% .40 867
!nouveau facies 9 (vase ) : <63µ: 80%, 100µ: 20%, 210µ: 0%, 800µ: 0%, 5000µ: 0% .20 709
! facies 10 (sable ) : <63µ: 10%, 100µ: 20%, 210µ: 60%, 800µ: 10%, 5000µ: 0% .90 1500
! facies 11 (sable/vase ) : <63µ: 35%, 100µ: 25%, 210µ: 40%, 800µ: 0%, 5000µ: 0% .65 1201

```

3) fichier de paramétrage sédimentaire

```

=====
:   NAMELIST FOR SEDIMENT BEHAVIOUR AND MANAGEMENT PARAMETERS
=====
:
:
: namsedim_mudsand : sedimentological parameters in case of the mudsand sediment
:   dynamics model
: namsedim_mixedsed : sedimentological parameters in case of the mixed sediment
:   dynamics model (requires key_sedim_mixedsed)
: namsedoutput : parameters using for output results in the file sediment
:-----
: common to namsedim_mudsand and namsedim_mixedsed
:-----
: fricwav : wave related friction factor (used for bottom shear stress
:   computation)
: l_repsed : boolean set to .true. if sedimentary variables are initialized
:   from a previous run
: filrepsed : file from which the model is initialized for the continuation
:   of a previous run

```



```

: l_consolid : boolean set to .true. if sediment consolidation is accounted for
: l_diffused : boolean set to .true. if diffusion within the sediment is
:               accounted for
: aref_sand : parameter used for sand extrapolation on water column and correct sand transport
:               value by default=0.02 correspond to Van Rijn experiments
:               DO NOT CHANGED IF NOT EXPERT
: dtconsol : consolidation time step
: date_startconsoldiffu : starting date for consolidation and diffusion processes
:-----
: SEDIMENT PARAMETERS
:-----
: SEDIMENT initialization
: l_unised : boolean set to true for a uniform bottom initialization
: z0seduni : uniforme bed roughness (m)
: hseduni : initial uniform sediment thickness(m)
: cseduni : initial sediment concentration (cseduni)
: csed_mud_ini : (only for mixed option) mud concentration into initial sediment (if =0. ==> csed_mud_ini=cfreshmud)
: ksmiuni,ksmauni : lower and upper grid cell indices in the sediment
: sini_sed : initial interstitial water uniform salinity (in the sediment)
: tini_sed : initial interstitial water uniform temperature initiale
:               (in the sediment)
: l_initsed_vardiss : boolean set to .true. if initialization of dissolved variables,
:               temperature and salinity in sediment will be done with concentrations
:               in water at bottom (k=1)
:-----
: NUMERICAL SCHEME WITHIN THE SEDIMENT (namsedim_mudsand only)
: fimpls : facteur implicitation (entre 0 et 1)
: xcvgce : fraction de dttas pour calcul explic. iteratif
:-----
: SEDIMENTARY BEHAVIOUR MIXSED (namsedim_mixed only)
:
: - mixed sediments properties
: cvolmaxsort : maximum volumic concentration of sorted sand
: cvolmaxmel : maximum volumic concentration of mixed sediments
: csed_mud_ini : mud concentration into initial sediment (if =0. ==> csed_mud_ini=cfreshmud)
:
: - erosion :
: activlayer : active layer thickness (m)
: frmudcr2 : critical mud fraction under which the behaviour is
:               purely sandy
: coef_frmudcr1 : such that critical mud fraction under which sandy behaviour
:               frmudcr1=min(coef_frmudcr1*d50 sand,frmudcr2) (old name = eroa1)
: x1toce_mud,x2_toce_mud : toce = x1_toce_mud*(relative mud concentration)**x2_toce_mud
:               (old name = eroa2, eora3)
: n_eros_sand : erosion flux for sand (old name=erob1)
:               min(0.27,1000*d50-0.01)*(tenfo-toce)**n_eros_sand
: E0_mud, n_eros_mud : erosion flux for mud (old name : erob2, erob3)
:               E0_mud*(tenfo-toce)**n_eros_mud
: corfluer1,corfluer2 : correction factors for erosion flux computations
: l_erolat_wet_cell : .true in order to take into account wet cells lateral erosion
:               : prise en compte de l erosion laterale y compris pour les cellules mouillees)
: coef_erolat : slope effect multiplicative factor (facteur multiplicatif pour prise en compte de l'effet de pente)
: coef_tenfons_lat : parametre pour evaluer la contrainte laterale en fonction de la vitesse tangentielle moyenne sur la verticale
:
: - deposition:
: cfreshmud : prescribed fresh deposit concentration (kg/m3)
: dzsmin : minimum sediment layer thickness(m)
: dzsmax : maximum thickness for the superficial sediment layer (m)
: csedmin : concentration of the upper layer under which there is
:               fusion with the underlying sediment cell
:
: - consolidation:

```

```

: cmudcr      : critical relative concentration of the surface layer
:              above which no mixing is allowed with the underlying sediment
:              (equivalent to csmaxmel when using key_mudsand)
: xperm1,xperm2 : permeability=xperm1*d50*d50*voidration**xperm2
:
: - diffusion
: xdifs1,xdifs2 : within the sediment,diffusion=xdifs1*porosity**xdifs2
: xdifs1,xdifs2 : at the water sediment interface,
:               diffusion=xdifs1*porosity**xdifs2
: epdifi       : diffusion thickness in the water at the sediment-water
:               interface
: dtcalconsol   : sub time step for consolidation processes
: csegseg=250.0 : NOT CHANGE VALUE if not expert
: csandseg=1250.0 : NOT CHANGE VALUE if not expert
:
: - bioturbation
: l_bioturb     : boolean set to .true. si taking into account bioturbation diffusion in sediment
: xturbmax      : max diffusion coefficient by bioturbation Db (in surface)
: xturbk        : coef (slope) for bioturbation coefficient between max Db at sediment surface and 0 at bottom
: dbiotu0       : max depth beneath the sediment surface below which there is no bioturbation
: dbiotum       : sediment thickness wherein the diffusion-bioturbation coefficient Db is constant (max)
: frmud_db_min  : mud fraction limit (min) below which there is no Bioturbation
: frmud_db_max  : mud fraction limit (max) above which the bioturbation coefficient Db is maximum (muddy sediment)
:
: - morphodynamic
: l_morphocoupl : .true if coupling module morphodynamic
: l_bathy_smoothing : .true. in order to apply bathymetric smoothing (only when l_morphocoupl .TRUE.)
:                 : BoolÃ©en pour lissage des modifications bathmetriques (seulement si l_morphocoupl .TRUE.)
: MF            : morphological factor (facteur multiplicatif des evolutions morphologiques permettant d'accelerer le temps
:                 : (on suppose que les evolutions morphologiques sur la duree MF*T sont egales a MF * les evolutions calculees sur la
duree T)
: MF            : morphological factor : multiplication factor for morphological evolutions, equivalent to a "time acceleration"
:                 : (morphological evolutions over a MF*T duration are assumed to be equal to MF * the morphological evolutions over
T).
: htncrit_eros  : hauteur critique permettant de limiter l'erosion par faibles profondeurs d'eau
:                 : Le seuil est different selon que la maille est en decouvrement ou recouvrement Hesse Hibma, 2004, page 78)
: htncrit_eros  : critical water height so as to prevent erosion under a given threshold
:                 : (the threshold value is different for flooding or ebbing, cf. Hibma's PhD, 2004, page 78)
&namsedim_mixed
l_fricwave=.true.
l_morphocoupl=.true.
MF = 1.0
fricwav=0.015 !0.015 !0.03 !ref Florent: 0.06, puis 0.015 jusqu'au 182
l_repsed=.true.
filrepsed='save_sedim_20110428000233.nc'
l_consolid=.true.
l_diffused=.false.
l_initsed_vardiss=.true.
dtconsol=600.0
dtcalconsol=30.0
csegseg=250.0
csandseg=1250.0
date_startconsoldiffu='01/08/1010 00:00:00'
l_unised = .false.
z0seduni = 0.0008 !plh:0.0003 FG 0.0005
hseduni = 1
cseduni= 1000.0
csed_mud_ini = 0.0
ksmiuni = 1
ksmauni = 50 ! 1 couche de sediment facies (NUBC) + 1 couche de creme de vase (en local)
aref_sand=0.02
sini_sed=34.0

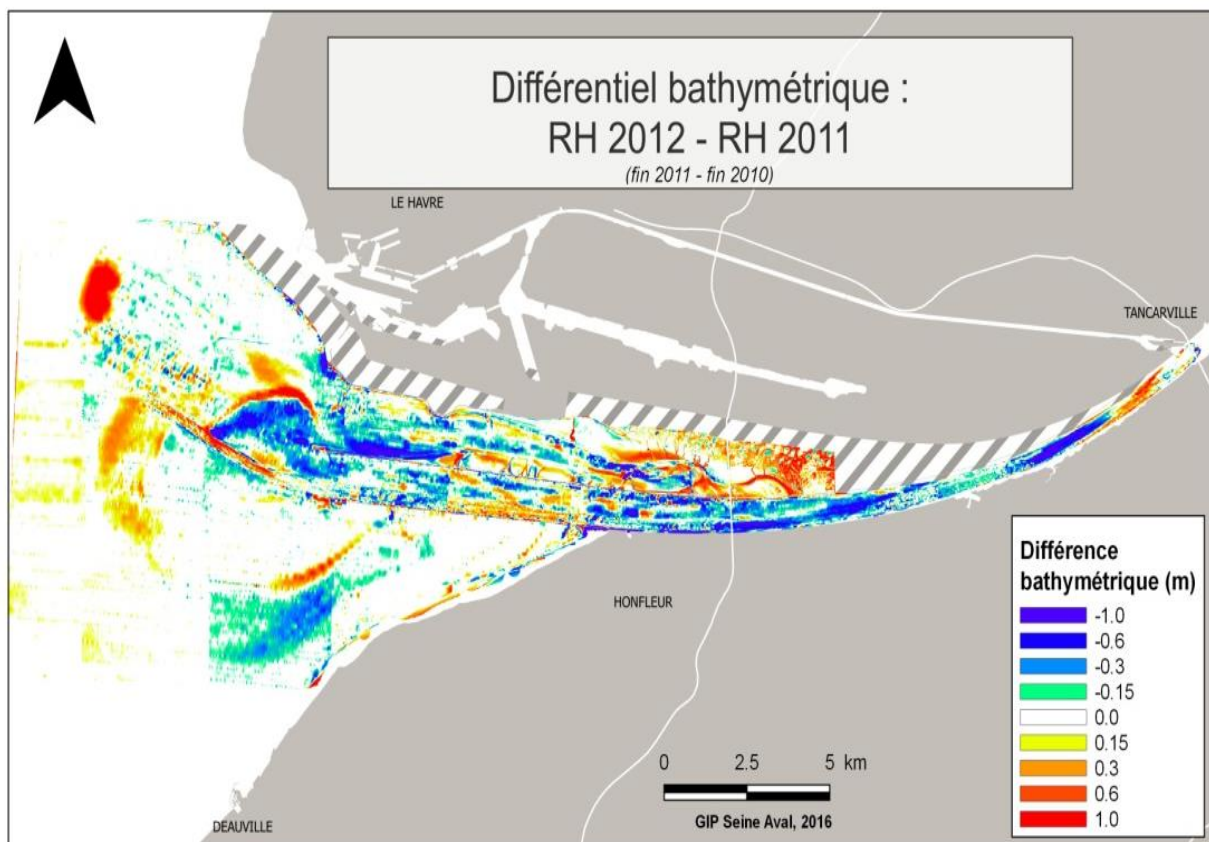
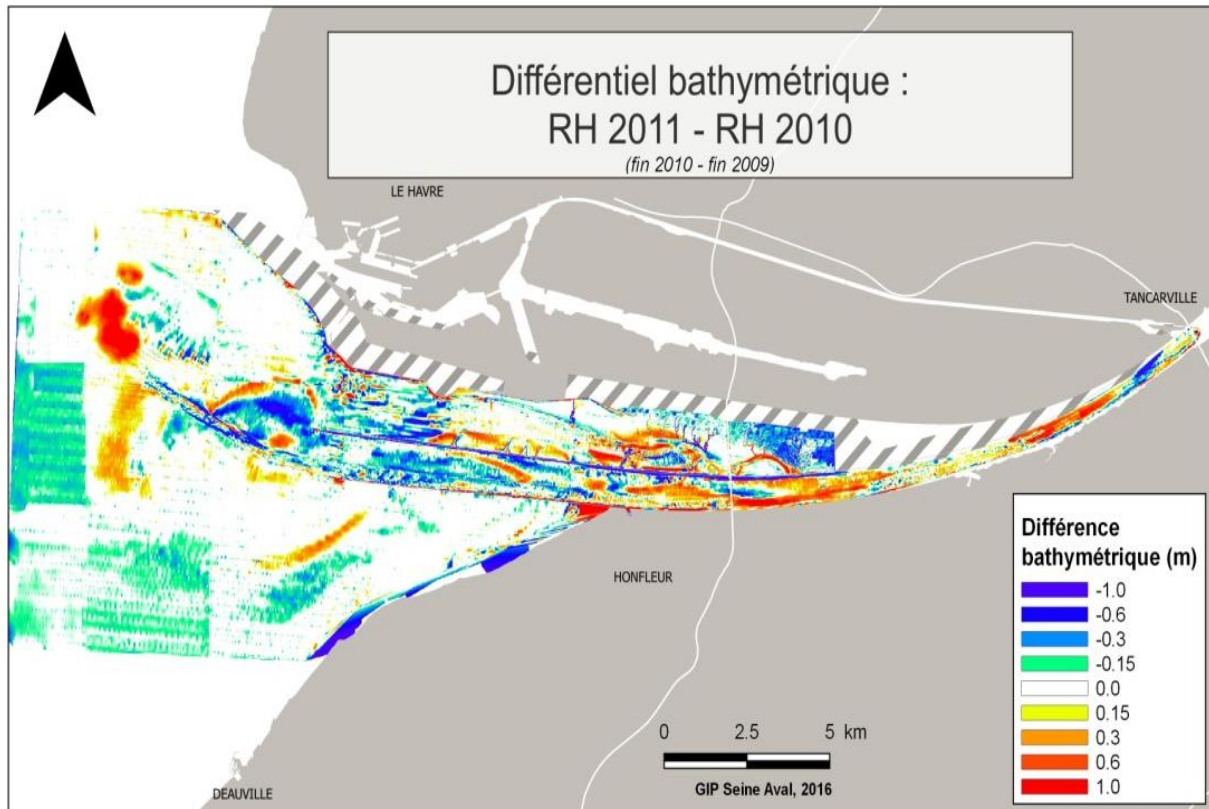
```

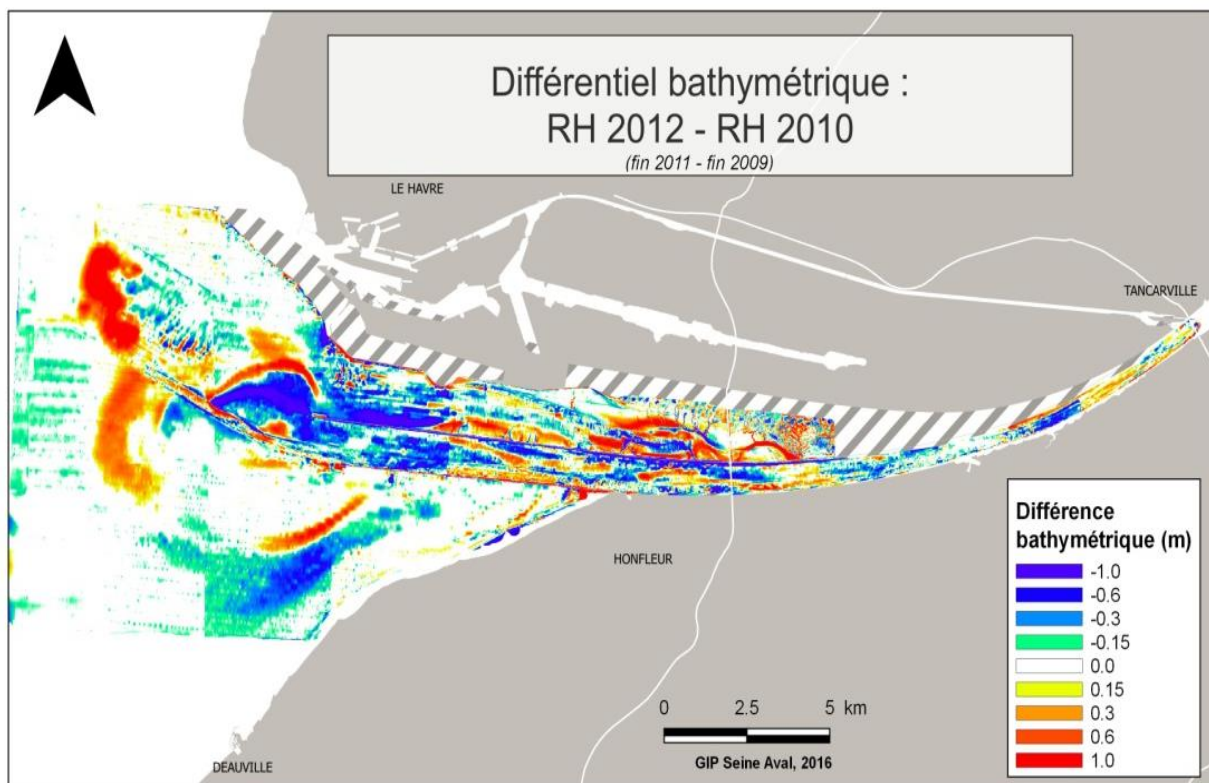
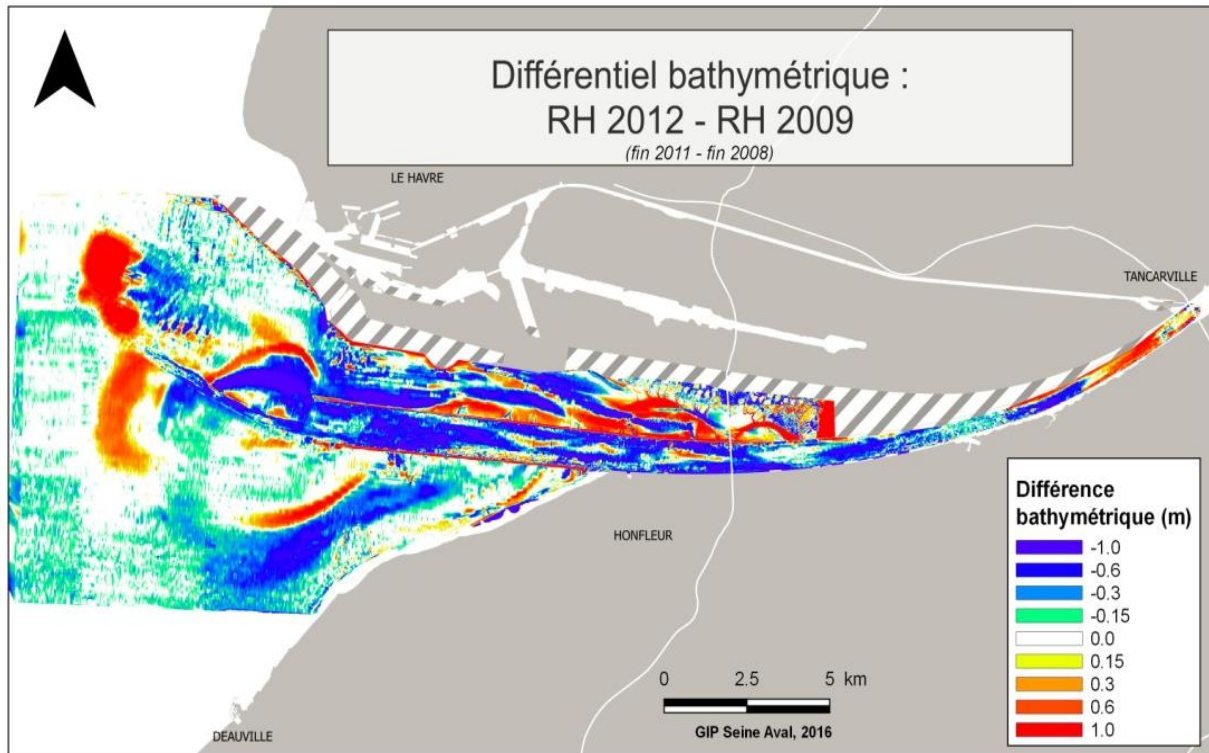
```

tini_sed=10.0
cvolmaxsort=0.61 !ref: 0.58
cvolmaxmel=0.61 !ref: 0.67
activlayer=0.02
frmudcr2=0.7
coef_frmudcr1=1000.
x1toce_mud=1.0e-5 !plh 0.6e-5
x2toce_mud=2.
E0_sand=0.6 !0.8 !0.4 !FG:1.0 !plh:0.5
n_eros_sand=1.6 ! (rapport Marenne-Oleron) !0.5 !1.6
E0_mud=0.0003 !0.001
n_eros_mud=1.
corfluer1=0 !0.01
corfluer2=350.
cfreshmud=100.0 !450.0
dzsmin=1.0e-6 !1.0e-7
dzsmax=0.005
csedmin=30.0 !100.
cmudcr=200.0 !600.
xperm1=4.0e-12 !0.2
xperm2=-6.0 !5.
xsigma1=6.0e5 !1.5e-14
xsigma2=6
xdifs1 = 1.e-8
xdifs2 = 0.0
xdifsi1 = 1.e-6
xdifsi2 = 0.0
epdifi = 0.1
htncrit_eros=0.05
slopefac=0.0 !20.0 ou 50.0
coef_erolat=0.002 !0.002
coef_tenfon_lat=2.5 !2.5
l_erolat_wet_cell=.TRUE.
l_bathy_smoothing=.FALSE.
l_bioturb=.FALSE.
xturbmax=1.157e-09
xturbk=6.0
dbiotu0=0.1
dbiotum=0.005
frmud_db_min=0.6
frmud_db_max=0.8 /

```

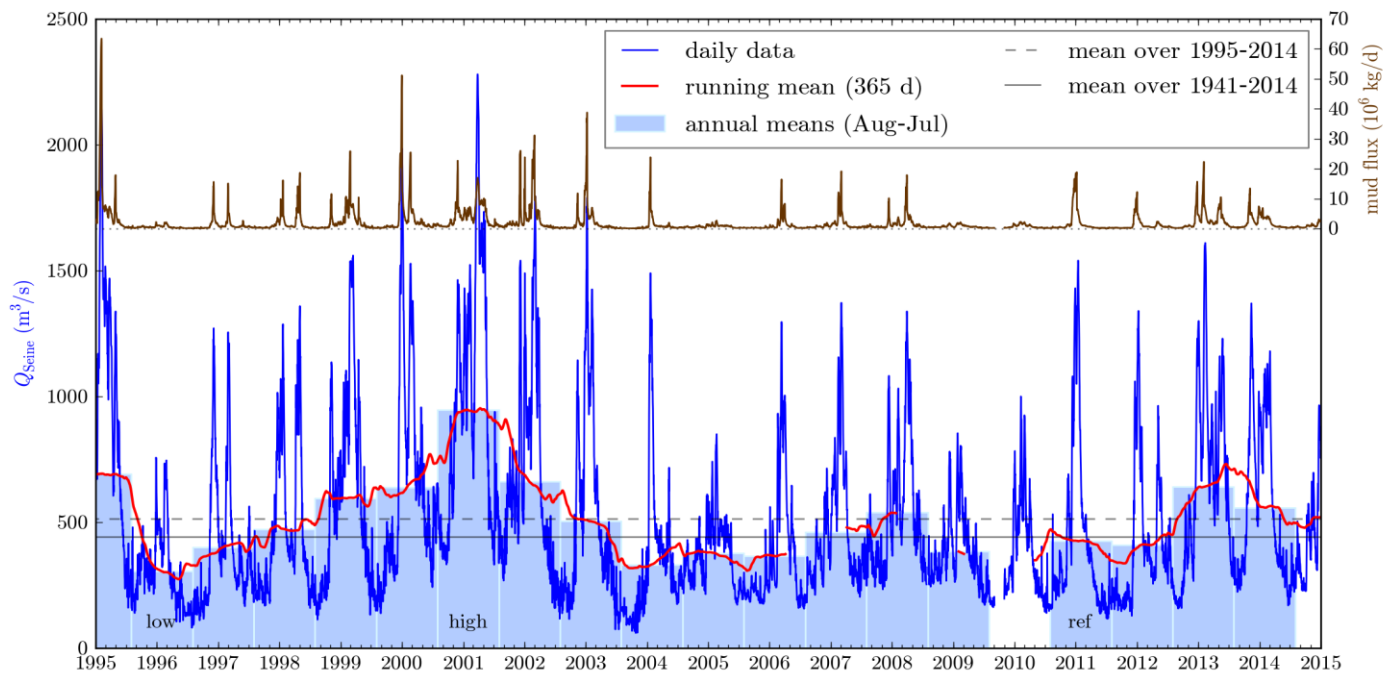
IX. Annexe : Différentiels bathymétriques élaborés par le GIPSA pendant la période 2009-2012, sur la base des MNT RH du GPMR



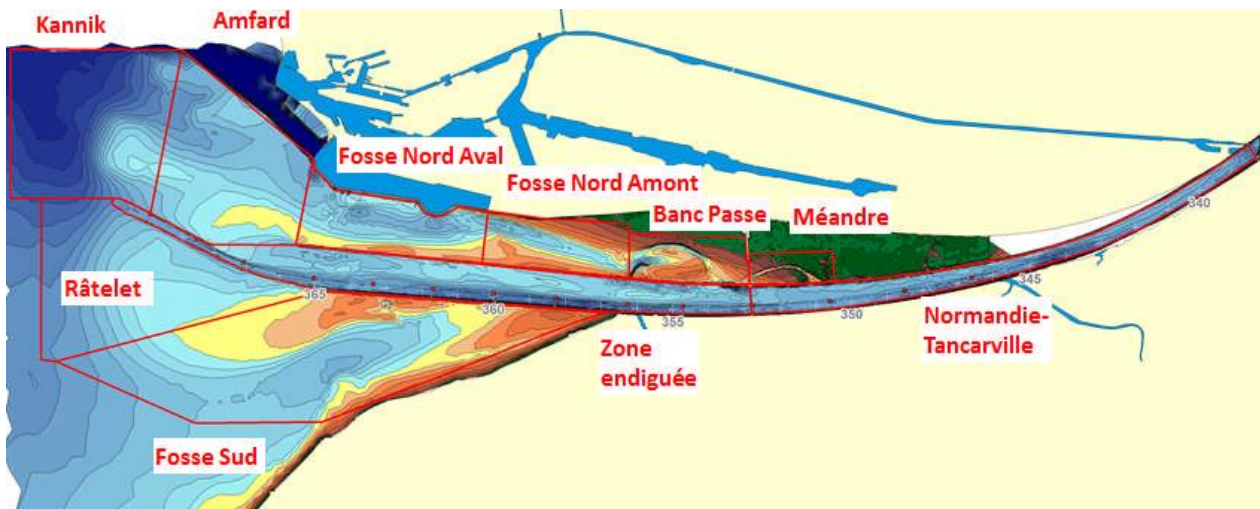


On observe que le différentiel 2012-2010, qui court sur la période fin 2009 - fin 2011, présente une structuration des érosions/dépôts conforme à celle constatée pour la période 2009-2012, et encadre la période août 2010/juillet 2011 sélectionnée pour la validation des résultats morphodynamiques. Ce différentiel sur 2 ans reste notre référence "observations" pour la distribution des tendances érosion/dépôt.

La figure ci-dessous rappelle le régime de débits qui a prévalu pendant cette période de référence : le débit moyen se situe très légèrement en dessous de la moyenne 1995-2014.

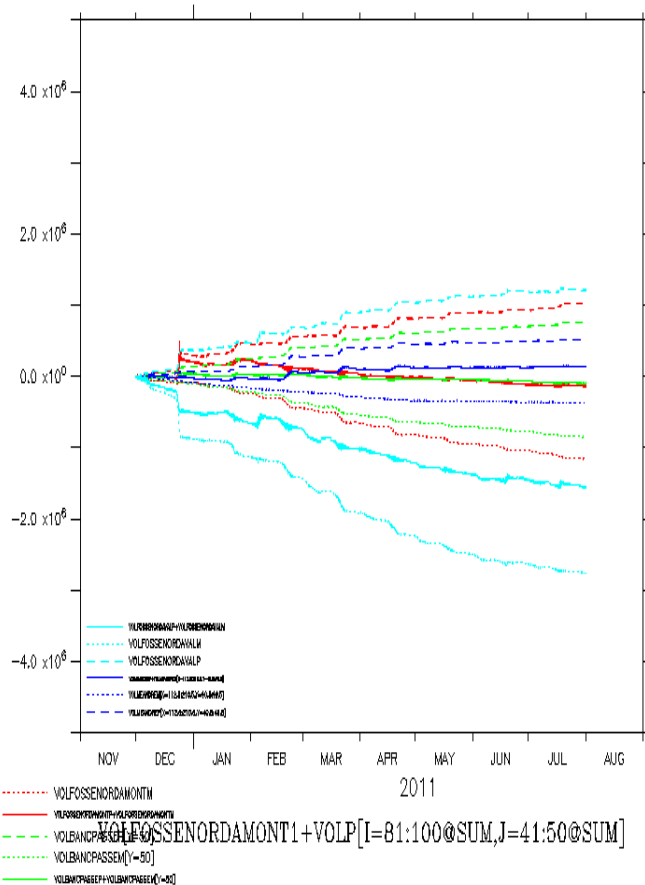
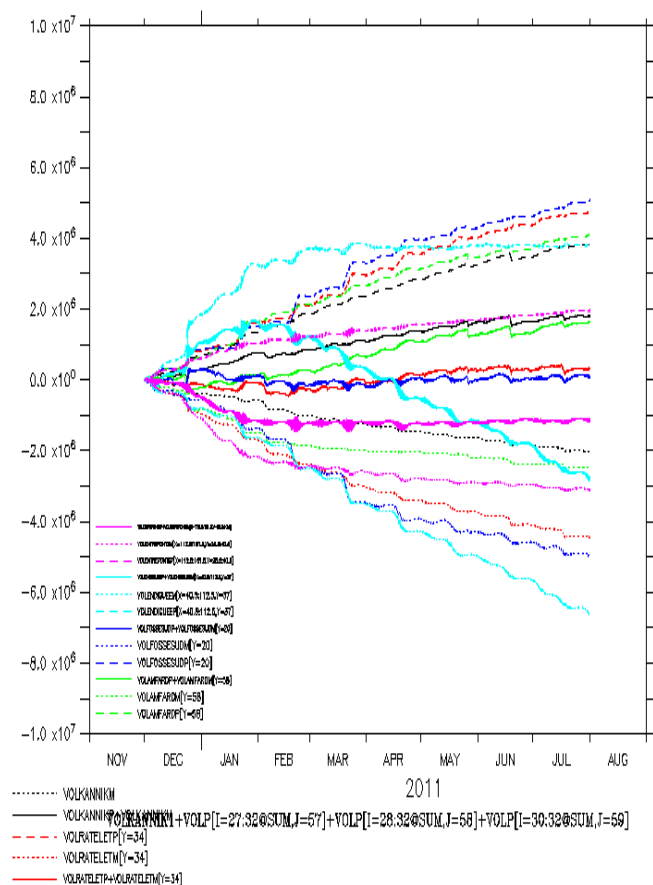


X. Annexe : Evaluation des bilans sédimentaires

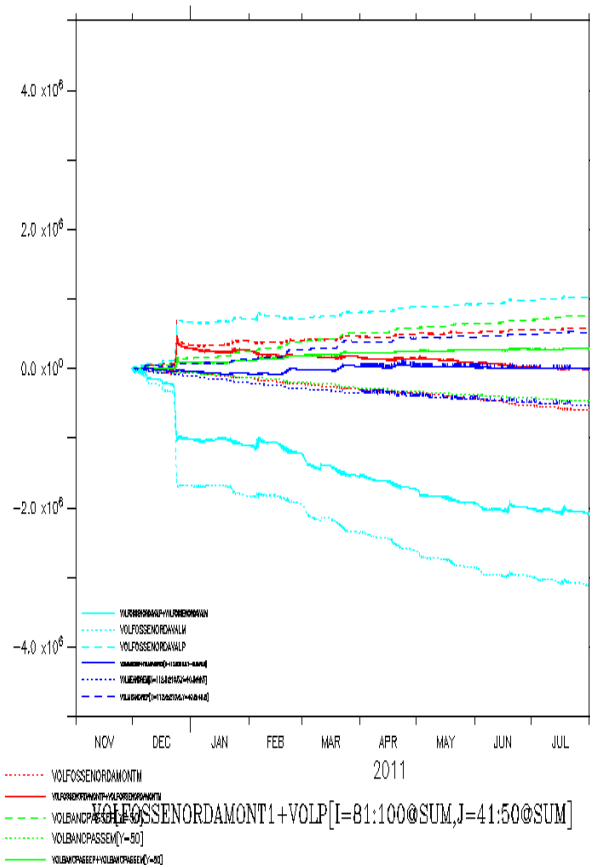
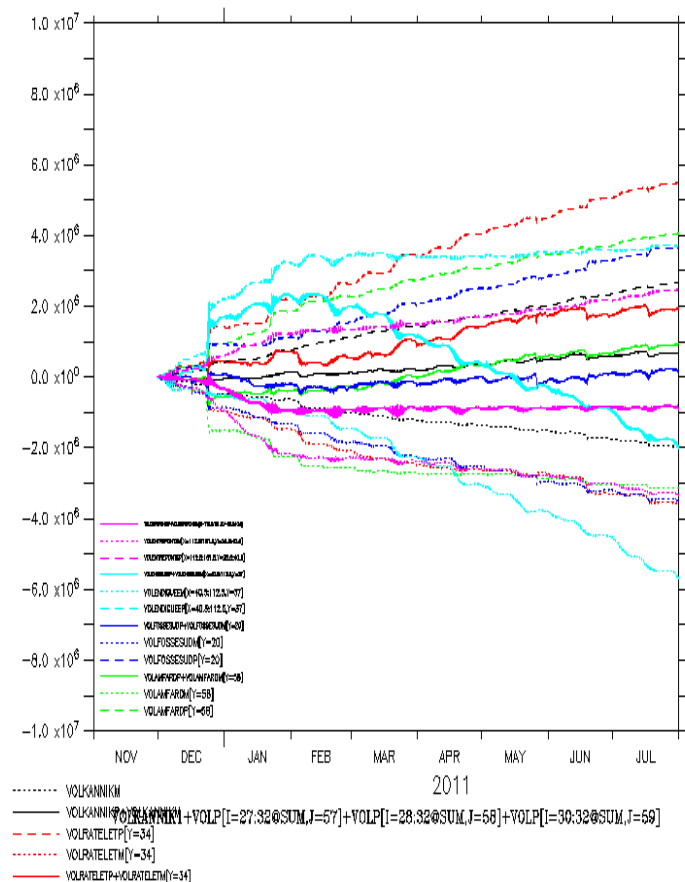


Carte des secteurs pour évaluation des bilans érosions/dépôts

Évolutions par secteurs, run 229, référence morpho

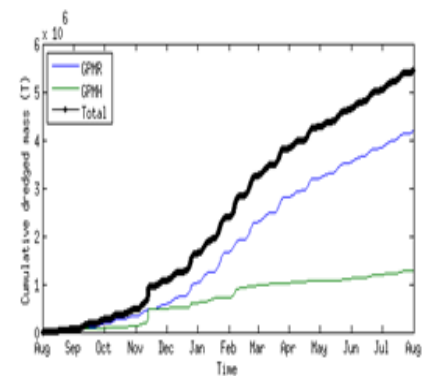
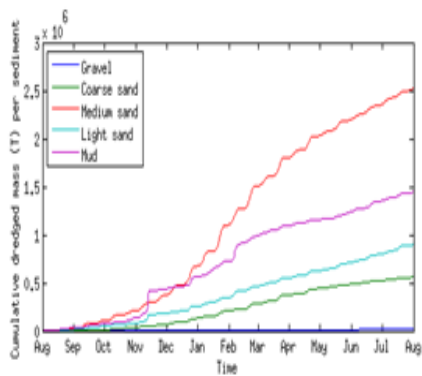
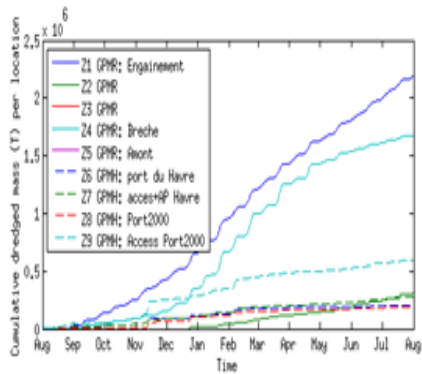


Évolutions par secteurs, run 257 frottement fort & déferlement

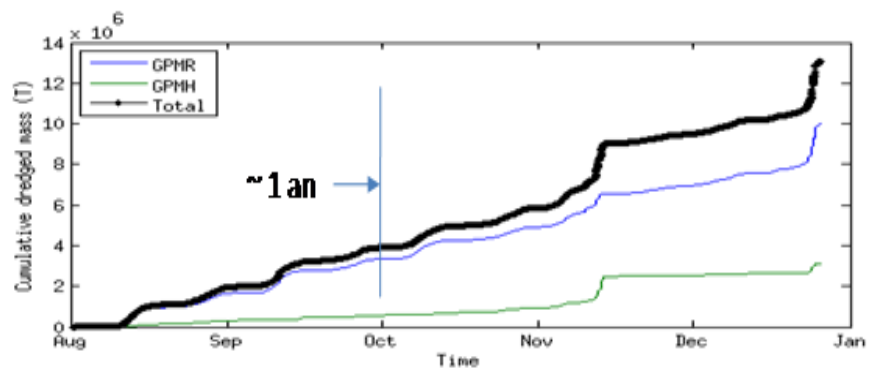
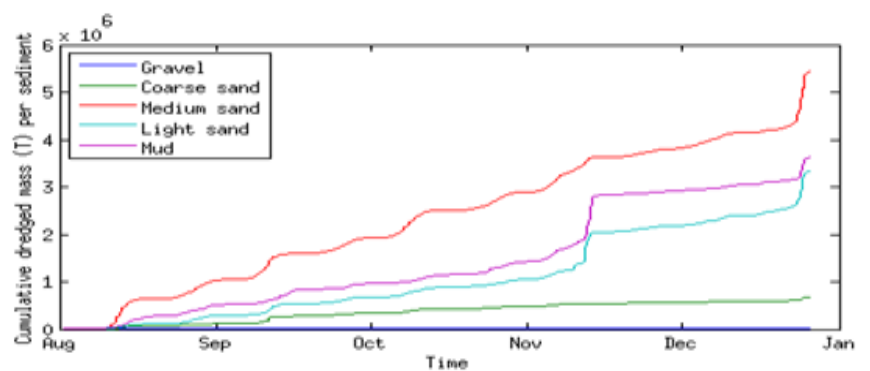
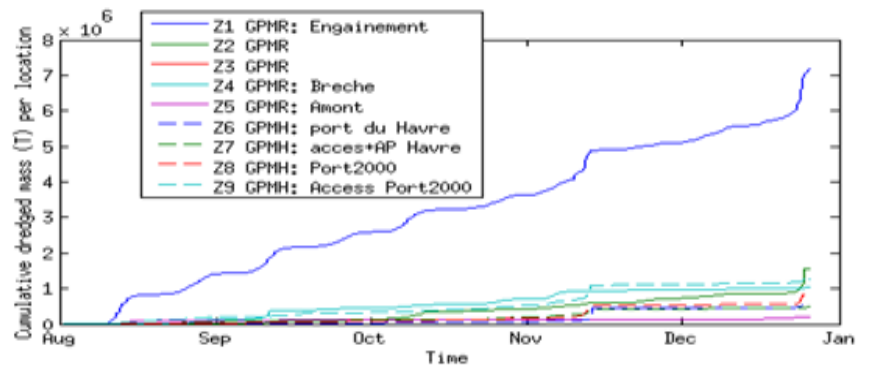


XI. Annexe : Comparaison des dragages simulés avec ou sans facteur morphodynamique

MF=1



MF=6



POUR PLUS D'INFORMATIONS SUR LE GIP SEINE-AVAL

www.seine-aval.fr

CONTACT

Groupelement d'Intérêt Public Seine-Aval
Pôle Régional des Savoirs
115, Boulevard de l'Europe
76100 ROUEN
Tél : 02 35 08 37 64
gipsa@seine-aval.fr

En cas d'utilisation de données ou d'éléments de ce rapport, il devra être cité sous la forme suivante :

Grasso F. (coord.), Le Hir P., 2018. Projet HYMOSED : Modélisation du fonctionnement HYdro-MORpho-SEDimentaire de l'estuaire de la Seine – Volet Modélisation », Annexes du rapport de recherche du programme Seine-Aval 5, 32 p.

Le GIP Seine-Aval ne saurait être tenu responsable d'évènements pouvant résulter de l'utilisation et de l'interprétation des informations mises à disposition.
Pour tout renseignement, veuillez contacter le GIP Seine-Aval.

Les membres financeurs du GIP Seine-Aval sont :

