CROCO

Coastal and Regional Ocean COmmunity model

Review of Some Sediment Test Cases

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CROCO Advanced Course 20 jan. 2022

Sediment test cases

- **Motivations** :
    - Isolate specific sediment processes / test some flux interpolation schemes … with low computational resources
    - Initiate comparisons between sediment model in a unified hydrodynamic framework Croco
        - See which processes are present within each model (different schemes, vertical grid, morphodynamic management ...)
        - Establish the qualities and shortcomings for each

- **Codes used in Croco** ?
    - **Sediment USGS** (U.S. Geological Survey model): native one, from the UCLA/ROMS Communauty / USGS , Blaas et al. (2007), Warner et al. (2008) and Shafiei et al. (2021) (Contact in Croco team → P.Marchesiello, R.Benshila, G.Morvan)
    - **Mustang model** (MUd and Sand TrAnsport modelliNG) from Ifremer / Dhysed (Contact in croco team → F. Dumas, M.Caillaud)

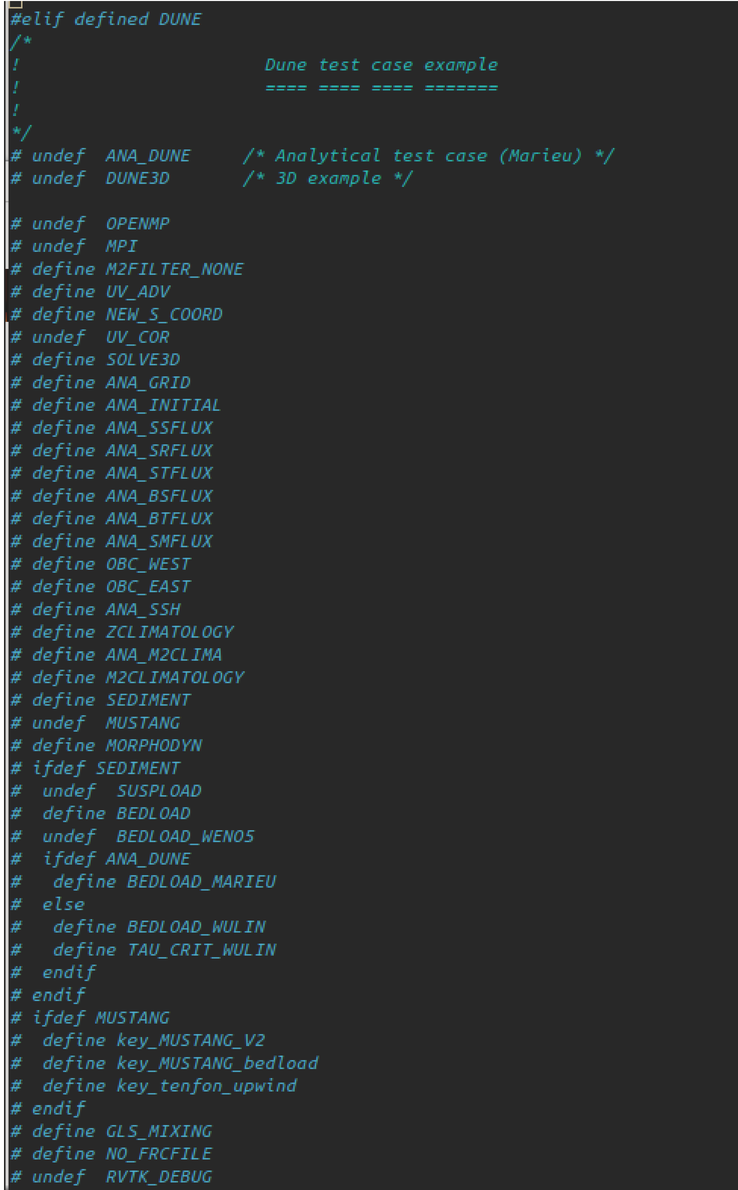
DUNE test cases

* Purpose ?

- test the capacity of the model to simulate the migration of an idealised gaussian shaped dune
- test bedload process only
- check if the dune is steepening downstream while propagating
- check how sands are sorted as long as the dune evolves

* Sub cases :

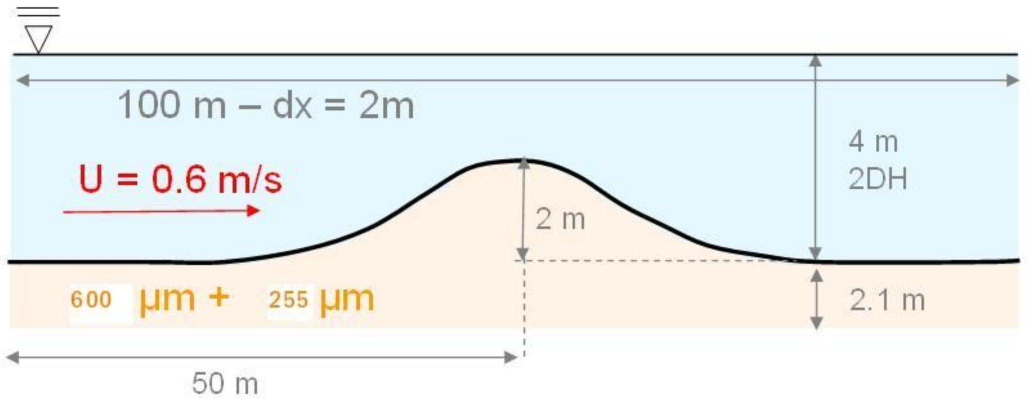
- **DUNE3D** : the same than **DUNE** but in 3d ! from Ifremer / Dhysed (*Channel*)
- **ANA_DUNE** : Analytical case from Marieu & al 2007, Long et al 2008 (to compare the dune migration with analytical solution of the bedload transport equation)



```
#elif defined DUNE
/*
!                       Dune test case example
!                       ==== ==== ==== =======
!
*/
# undef  ANA_DUNE     /* Analytical test case (Marieu) */
# undef  DUNE3D       /* 3D example */

# undef  OPENMP
# undef  MPI
# define M2FILTER_NONE
# define UV_ADV
# define NEW_S_COORD
# undef  UV_COR
# define SOLVE3D
# define ANA_GRID
# define ANA_INITIAL
# define ANA_SSFLUX
# define ANA_SRFLUX
# define ANA_STFLUX
# define ANA_BSFLUX
# define ANA_BTFLUX
# define ANA_SMFLUX
# define OBC_WEST
# define OBC_EAST
# define ANA_SSH
# define ZCLIMATOLOGY
# define ANA_M2CLIMA
# define M2CLIMATOLOGY
# define SEDIMENT
# undef  MUSTANG
# define MORPHODYN
# ifdef SEDIMENT
#  undef  SUSPLOAD
#  define BEDLOAD
#  undef  BEDLOAD_WENO5
#  ifdef ANA_DUNE
#   define BEDLOAD_MARIEU
#  else
#   define BEDLOAD_WULIN
#   define TAU_CRIT_WULIN
#  endif
# endif
# ifdef MUSTANG
#  define key_MUSTANG_V2
#  define key_MUSTANG_bedload
#  define key_tenfon_upwind
# endif
# define GLS_MIXING
# define NO_FRCFILE
# undef  RVTK_DEBUG
```

DUNE (default)

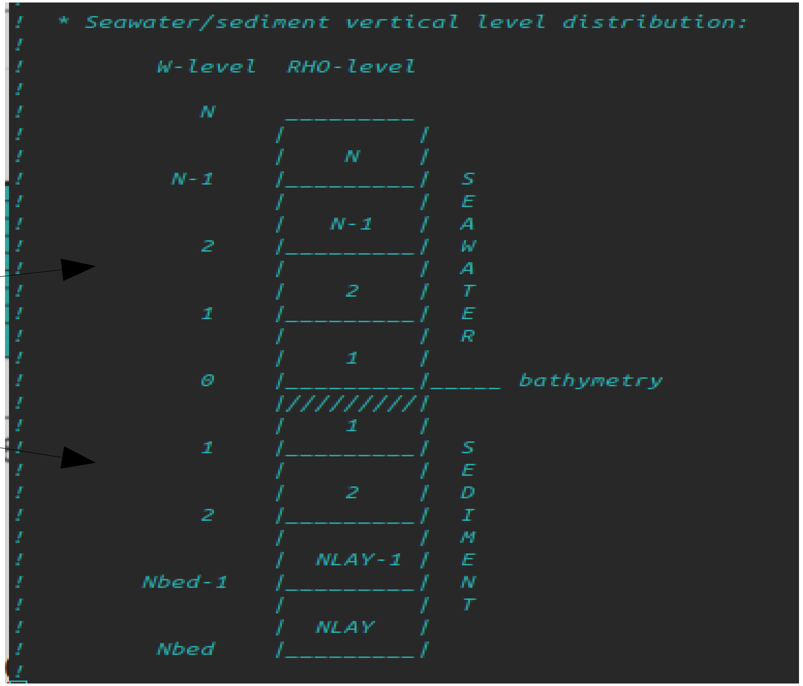


Grid :

- Length of the channel : 100m / Resolution : 2m
- Analytical and gaussian centred at the middle (50m)
  Amplitude dune : 2m

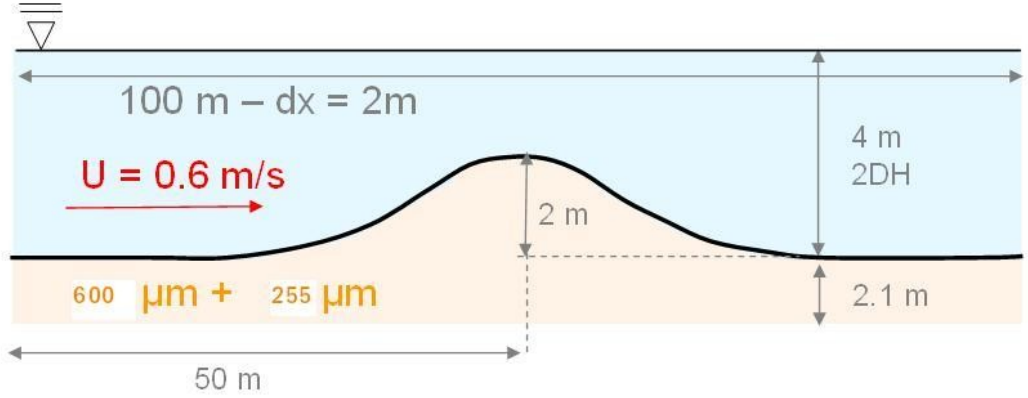
Model discretization :

- 50 x-horizontal grid point (LLm0)
- Seawater : 20 Layers (**N**)
- Sediments : 10 Layers (**NLAY**)
- first level on sediment is at bed
  and then decrease at the bottom
- *Note : mustang model use a reverse index management on the sediment*



```
!   * Seawater/sediment vertical level distribution:
!
!         W-level   RHO-level
!
!            N      __________
!                  |          |
!                  |    N     |
!           N-1    |__________|  S
!                  |          |  E
!                  |   N-1    |  A
!            2     |__________|  W
!                  |          |  A
!                  |    2     |  T
!            1     |__________|  E
!                  |          |  R
!                  |    1     |
!            0     |__________|_____ bathymetry
!                  |//////////|
!                  |    1     |
!            1     |__________|  S
!                  |          |  E
!                  |    2     |  D
!            2     |__________|  I
!                  |          |  M
!                  |  NLAY-1  |  E
!        Nbed-1    |__________|  N
!                  |          |  T
!                  |   NLAY   |
!         Nbed     |__________|
!
```

DUNE (default)



Dynamics :

- Periodic O-E barotropic flow (periodic case which generate a constant barotropic flow (0.6m/s)
- Vertical Mixing Parameterization GLS (Generic Length Scale)
- Morphodynamics (feedback to currents)
- Bottom roughness Length (Zob) (many ways to estimate this term => $Sd_{50}/12$ ...)

Croco.in :

```
bottom_drag:      RDRG(m/s),      RDRG2,   Zob [m],  Cdb_min, Cdb_max
                  0.              0.       1.e-4       1.d-4    1.d-1
```

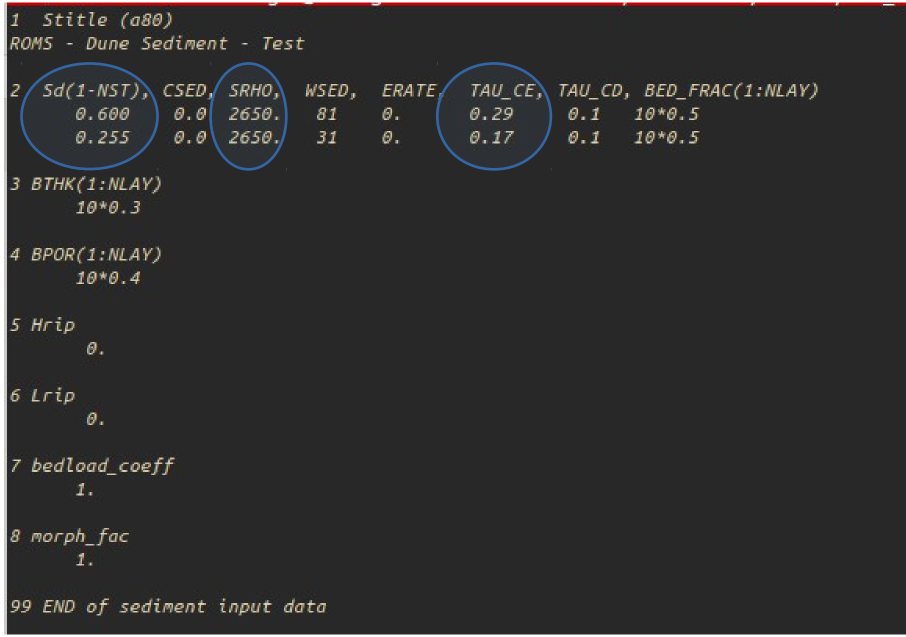
Zob → u* → bottom stress τ_b

DUNE (default)

sediment_dune.in :

Sediments :

- **non-cohesive sediment two classes (NST): Diameters (Sd) (mm) : 600 µm and 255 µm , Density (SRHO) 2650 kg/m³ each**
- **τ_c : critical shear stress for erosion (TAU_CE) i.e., the threshold for initiation of sediment motion (Pa)**



```
1  Stitle (a80)
ROMS - Dune Sediment - Test

2  Sd(1-NST), CSED, SRHO,  WSED,  ERATE,  TAU_CE, TAU_CD, BED_FRAC(1:NLAY)
      0.600    0.0  2650.   81     0.      0.29     0.1   10*0.5
      0.255    0.0  2650.   31     0.      0.17     0.1   10*0.5

3 BTHK(1:NLAY)
      10*0.3

4 BPOR(1:NLAY)
      10*0.4

5 Hrip
       0.

6 Lrip
       0.

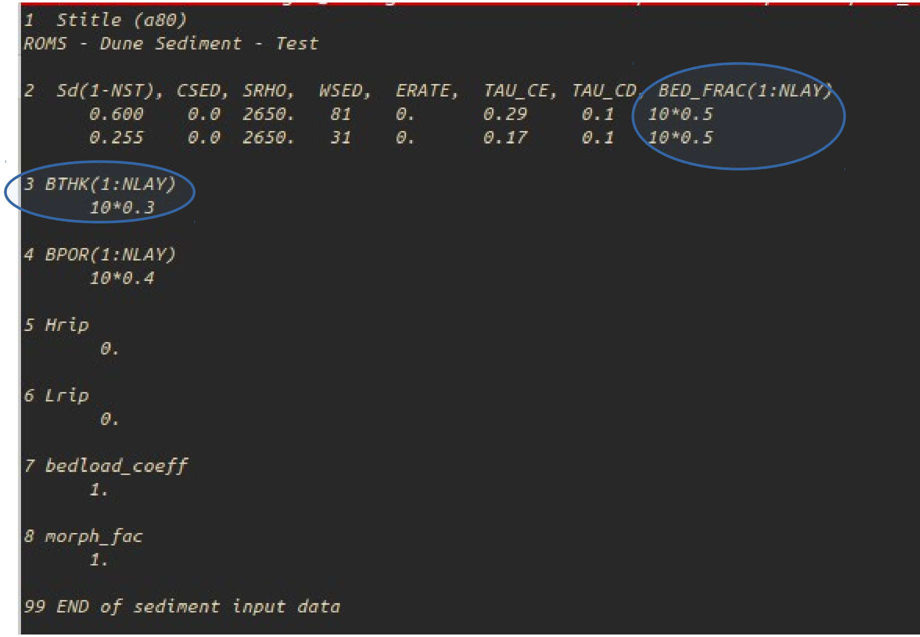
7 bedload_coeff
      1.

8 morph_fac
      1.

99 END of sediment input data
```

DUNE (default)

sediment_dune.in :



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     0.600    0.0  2650.   81     0.       0.29     0.1   10*0.5
     0.255    0.0  2650.   31     0.       0.17     0.1   10*0.5

3 BTHK(1:NLAY)
     10*0.3

4 BPOR(1:NLAY)
     10*0.4

5 Hrip
      0.

6 Lrip
      0.

7 bedload_coeff
     1.

8 morph_fac
     1.

99 END of sediment input data
```

Sediments :

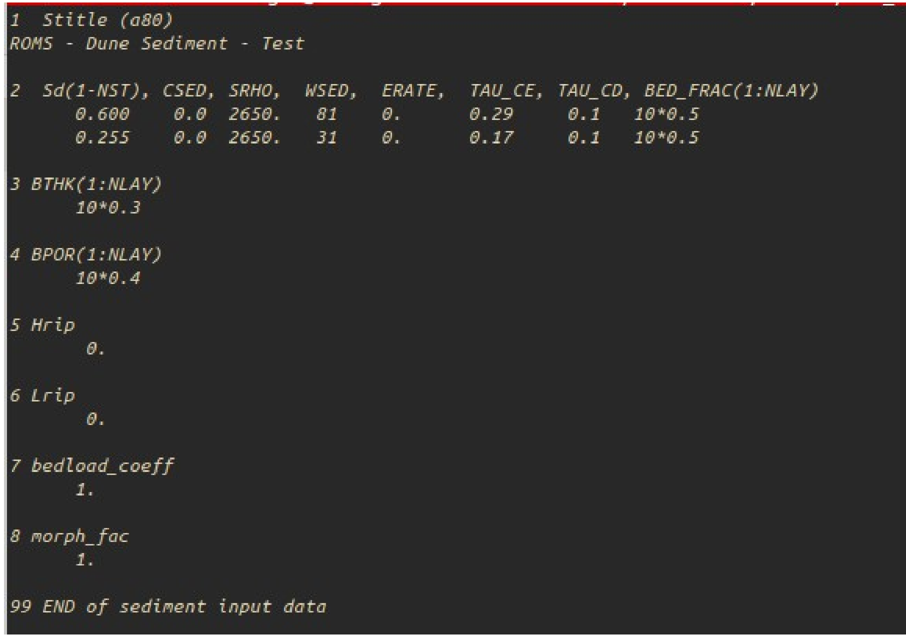
- non-cohesive sediment two classes (NST) : Diameters Sd (mm) : 600 µm and 255 µm , Density (SRHO) 2650 kg/m³
- τ_c : critical shear stress for erosion (TAU_CE) i.e., the threshold for initiation of sediment motion (Pa)
- **3 meters of sediment (10 layers with layer thickness = 0.3 m for each)**
- **fraction of sediment for each grain size class 50% for each layers**

DUNE (default)

Sediments :

- non-cohesive sediment two classes (NST) : Diameters Sd (mm) : 600 µm and 255 µm , Density (SRHO) 2650 kg/m³
- τ_c : critical shear stress for erosion (TAU_CE) i.e., the threshold for initiation of sediment motion (Pa)
- 3 meters of sediment (10 layers with layer thickness = 0.3 m for each)
- fraction of sediment for each grain size class 50%

sediment_dune.in :



```
1  Stitle (a80)
ROMS - Dune Sediment - Test

2  Sd(1-NST), CSED, SRHO,  WSED,  ERATE,  TAU_CE, TAU_CD, BED_FRAC(1:NLAY)
      0.600    0.0  2650.   81    0.      0.29     0.1   10*0.5
      0.255    0.0  2650.   31    0.      0.17     0.1   10*0.5

3 BTHK(1:NLAY)
      10*0.3

4 BPOR(1:NLAY)
      10*0.4

5 Hrip
       0.

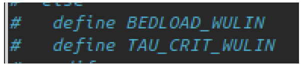
6 Lrip
       0.

7 bedload_coeff
      1.

8 morph_fac
      1.

99 END of sediment input data
```

- **No suspended load, bedload only**
- **Bedload formulation Wu et Lin, 2014 with slope effects (Lesser 2009)**

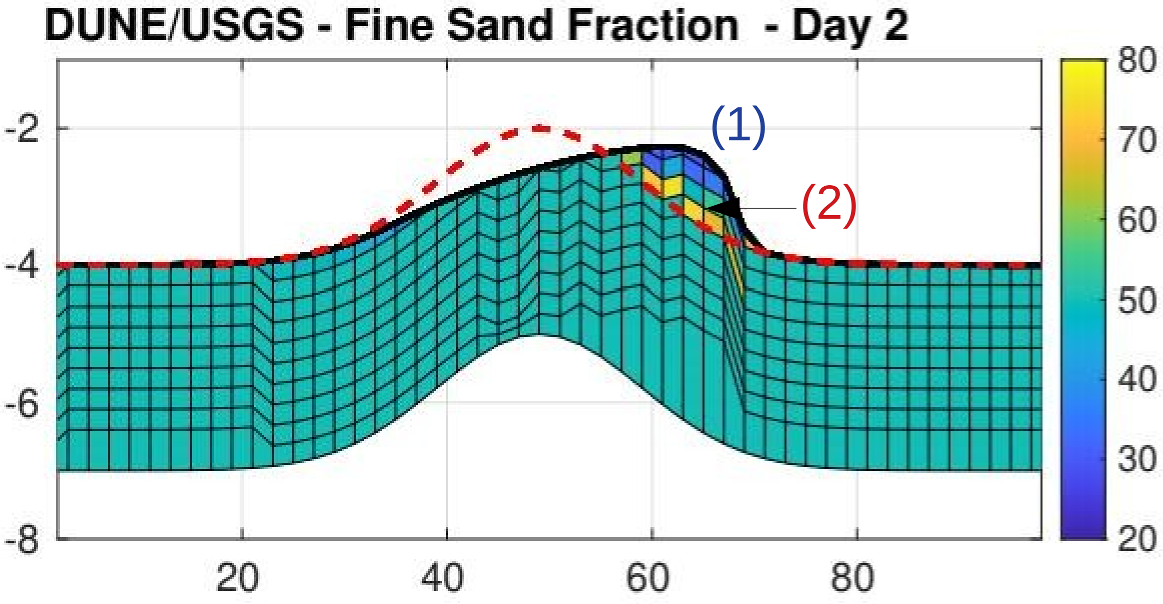


```
#   define BEDLOAD_WULIN
#   define TAU_CRIT_WULIN
```

DUNE (default)

Native position

10 layers



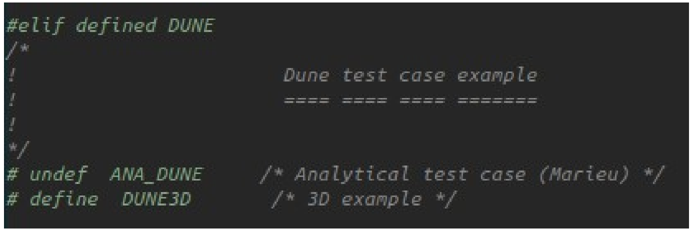
Finer sediment (600 µm< 255 µm)

Coarser sediment (600 µm> 255 µm)

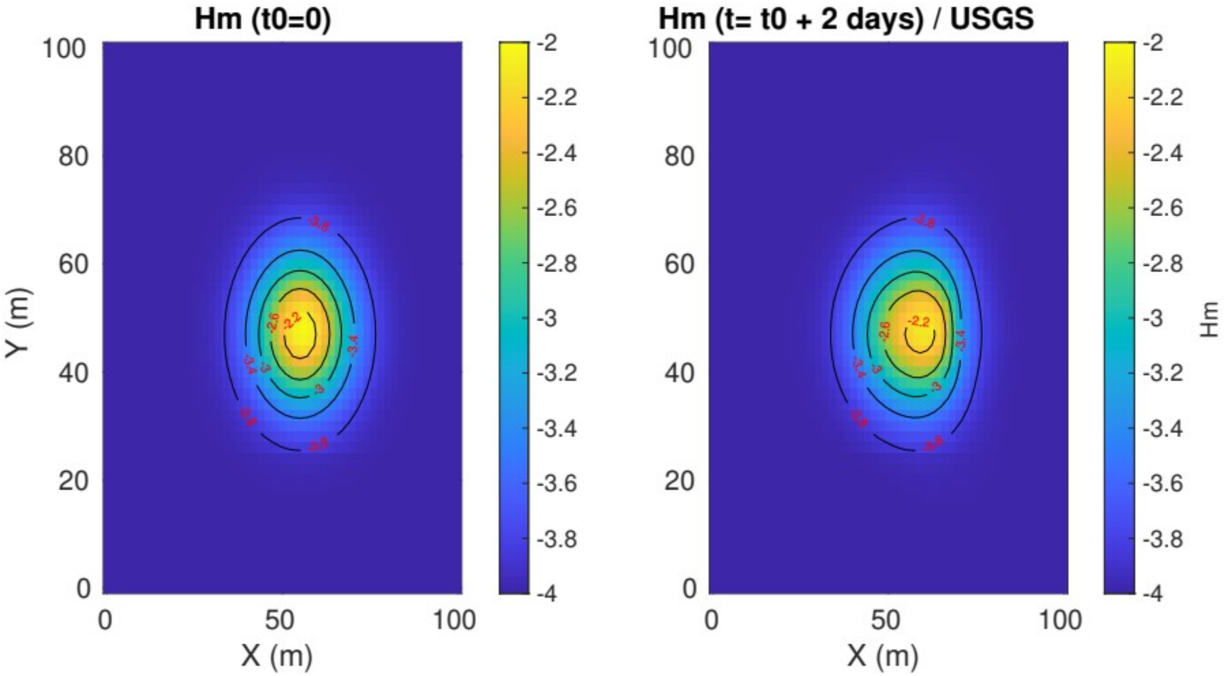
Next to 2 days :

* the front moves forward ~10m
* coarser sand is in the majority on the top of bed (1)
* layer of finer sand just below it (2)

DUNE (3D)

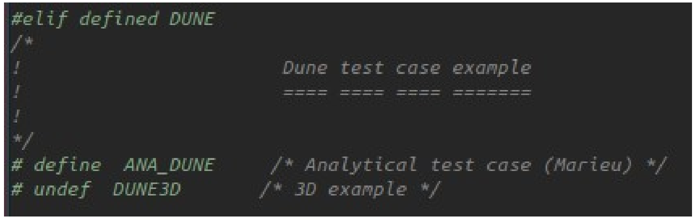


```
#elif defined DUNE
/*
!                       Dune test case example
!                       ==== ==== ==== =======
!
*/
# undef  ANA_DUNE     /* Analytical test case (Marieu) */
# define  DUNE3D       /* 3D example */
```



→ Migration of a Sand bump forced by a barotropic constant flow
→ Evolution (Hm) Morphodynamics next 2 days

DUNE (Analytical)



```
#elif defined DUNE
/*
!                          Dune test case example
!                          ==== ==== ==== =======
!
*/
# define  ANA_DUNE      /* Analytical test case (Marieu) */
# undef  DUNE3D        /* 3D example */
```

<u>Goal</u> :

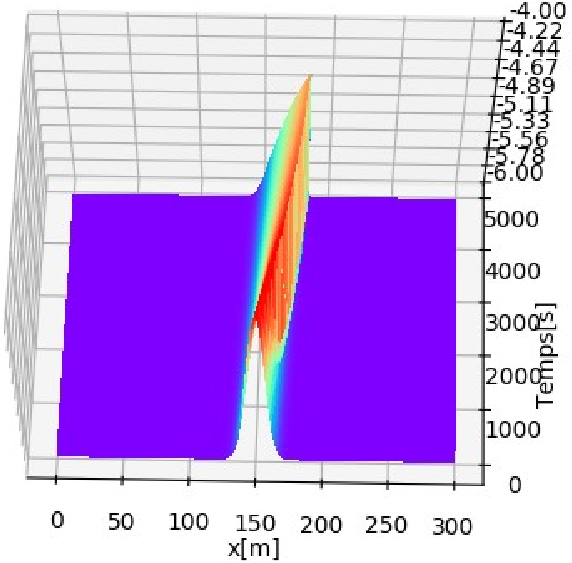
- Compare here, numerics (Croco) with analytical solutions (Marieu et al 2007)
- Test some flux interpolations methods when remain analytical steep slopes

<u>Grid</u> :

- Length of the channel : 300m / Resolution : 2m
- Analytical and gaussian centred at the middle (150m)
Amplitude : 2m

<u>Dynamics</u> :

- Periodic O-E barotropic flow (u = 1.67 m.s^{-1})
- Morphodynamics (feedback to currents)
- Bottom roughness Length (Zob) : 1e^{-4} m



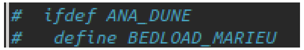
Marieu et al., 2007
Long et al, 2008

DUNE (Analytical)

Sediments :

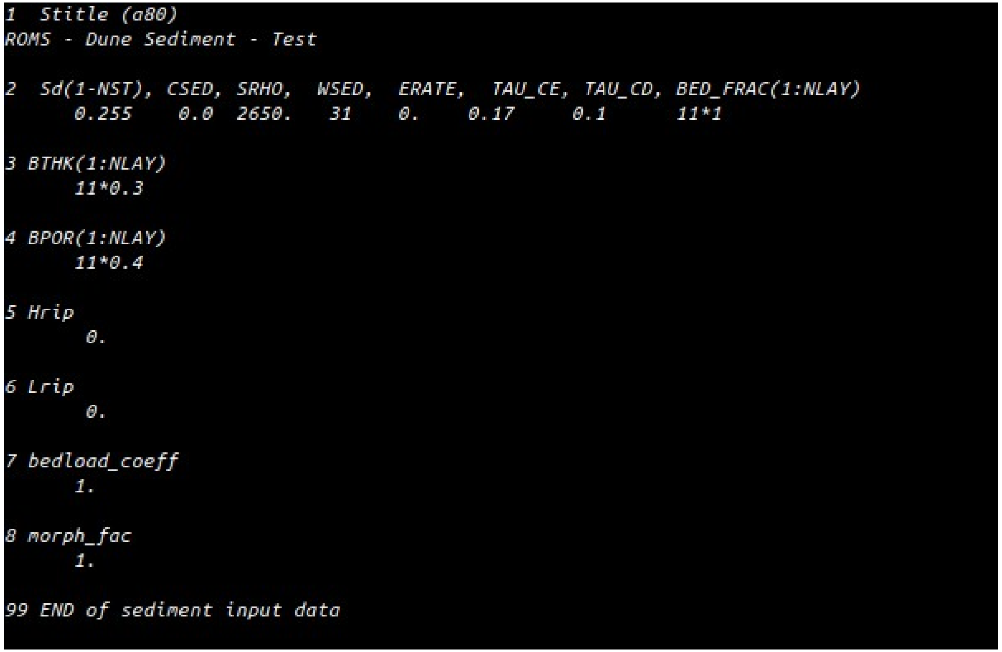
- Non-cohesive sediment one class , Diameter (**Sd**) : 255 µm
- 3 meters of sediment (11 layers with layer thickness = 0.3 m for each)

- **Bedload formulation:** Marieu et al 2007



```
#  ifdef ANA_DUNE
#   define BEDLOAD_MARIEU
```

sediment_ana_dune.in :



```
1  Stitle (a80)
ROMS - Dune Sediment - Test

2  Sd(1-NST), CSED, SRHO,  WSED,  ERATE,  TAU_CE, TAU_CD, BED_FRAC(1:NLAY)
      0.255    0.0  2650.   31    0.    0.17    0.1     11*1

3 BTHK(1:NLAY)
      11*0.3

4 BPOR(1:NLAY)
      11*0.4

5 Hrip
       0.

6 Lrip
       0.

7 bedload_coeff
      1.

8 morph_fac
      1.

99 END of sediment input data
```

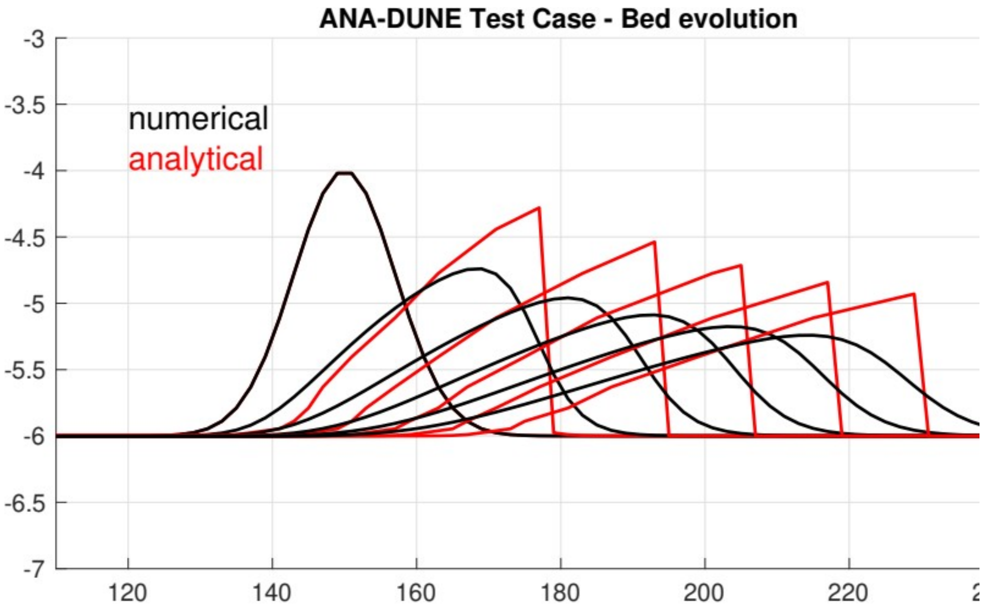
→ $q(x) = \alpha u(x)^{\beta}$ with $\alpha = 0.001 s^2/m$, $\beta = 3.0$

u(x) : barotropic u-current (m/s) **(for numerical solution)**

u(x) : Q/h (m/s) (channel flow=Q=10.m^2/s / h depth) (for analytical solution)

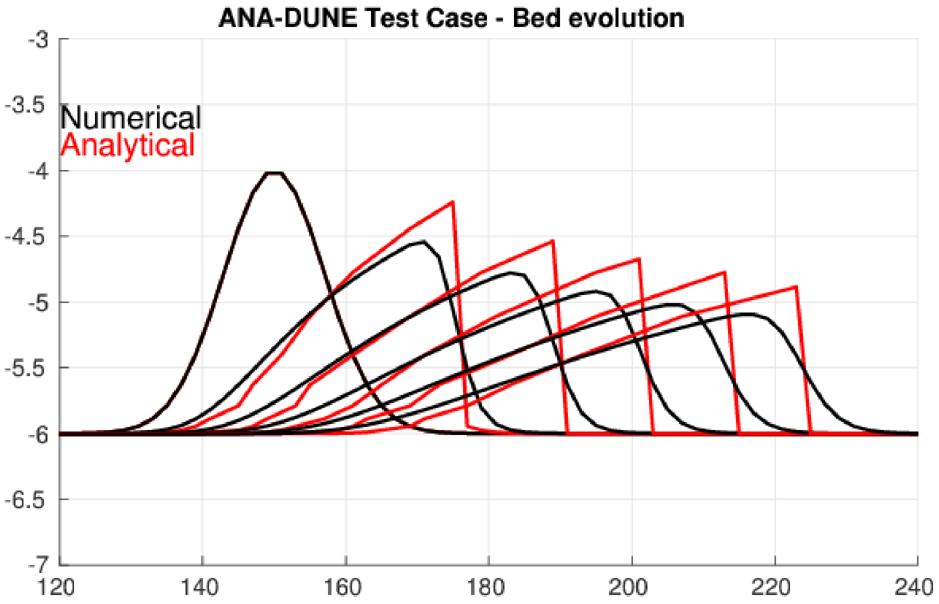
DUNE (Analytical)

Upwind first order interpolation flux **UP1**



Fifth order interpolation flux **WENO5**

```
# define BEDLOAD_WENO5
```



→ test some methods to interpolate flux
→ fifth order schemes allow to get closer to the steep slopes

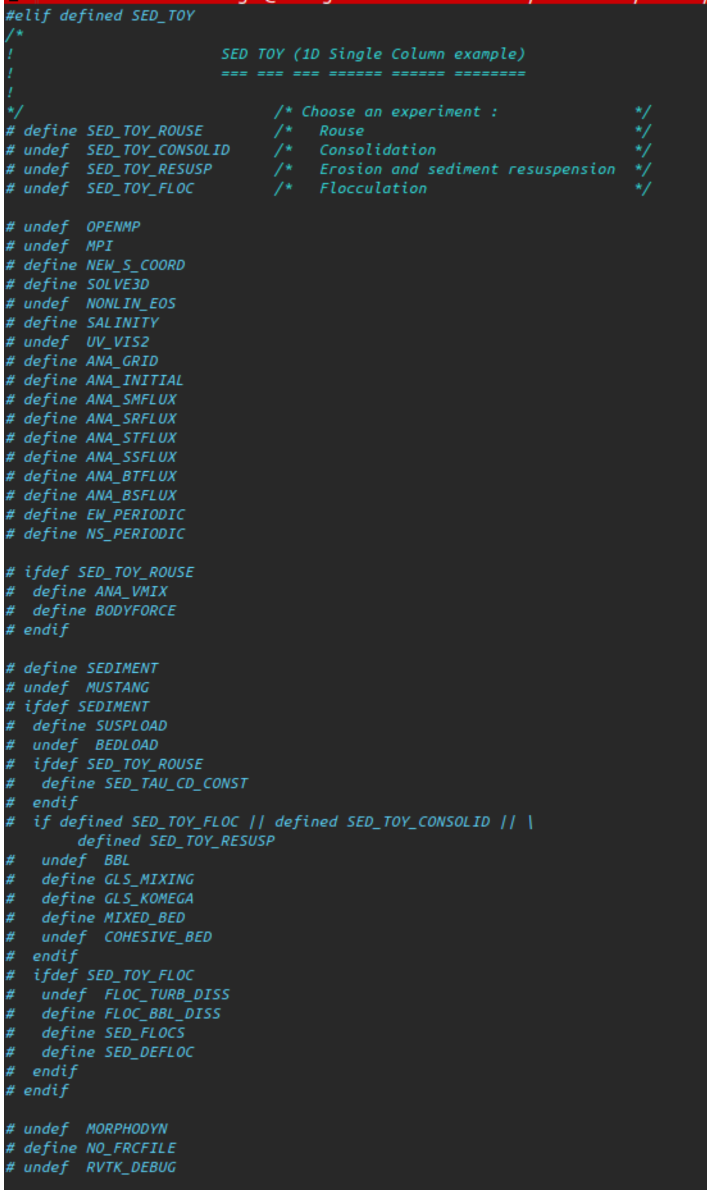
Sed toy (1DV) test cases

* Purpose ?

  * cheap cases (one water column / flat bottom)
  * periodic lateral boundary conditions on all sides
  * suspended load only
  * to isolate some processes with non-cohesive/cohesive sediments (erosion/ deposition/consolidation/flocculation)

* Sub cases :
  * SED_TOY_ROUSE : from Ifremer/Dhysed
  * SED_TOY_RESUSP : from COAWST*
  * SED_TOY_CONSOLID : from COAWST*

*(Coupled Ocean Atmosphere Wave Sediment System) , Sherwood & al, 2018



```
#elif defined SED_TOY
/*
!                           SED TOY (1D Single Column example)
!                           === === === ====== ====== ========
!
*/                                /* Choose an experiment :                */
# define SED_TOY_ROUSE             /*   Rouse                                */
# undef  SED_TOY_CONSOLID          /*   Consolidation                        */
# undef  SED_TOY_RESUSP            /*   Erosion and sediment resuspension   */
# undef  SED_TOY_FLOC              /*   Flocculation                         */

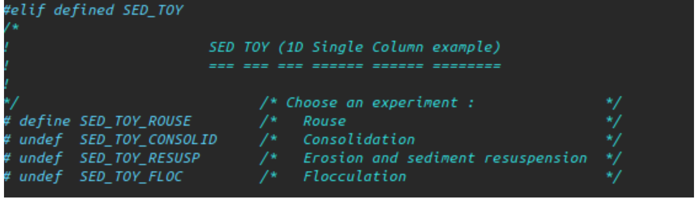
# undef  OPENMP
# undef  MPI
# define NEW_S_COORD
# define SOLVE3D
# undef  NONLIN_EOS
# define SALINITY
# undef  UV_VIS2
# define ANA_GRID
# define ANA_INITIAL
# define ANA_SMFLUX
# define ANA_SRFLUX
# define ANA_STFLUX
# define ANA_SSFLUX
# define ANA_BTFLUX
# define ANA_BSFLUX
# define EW_PERIODIC
# define NS_PERIODIC

# ifdef SED_TOY_ROUSE
#  define ANA_VMIX
#  define BODYFORCE
# endif

# define SEDIMENT
# undef  MUSTANG
# ifdef SEDIMENT
#  define SUSPLOAD
#  undef  BEDLOAD
#  ifdef SED_TOY_ROUSE
#   define SED_TAU_CD_CONST
#  endif
#  if defined SED_TOY_FLOC || defined SED_TOY_CONSOLID || \
        defined SED_TOY_RESUSP
#   undef  BBL
#   define GLS_MIXING
#   define GLS_KOMEGA
#   define MIXED_BED
#   undef  COHESIVE_BED
#  endif
#  ifdef SED_TOY_FLOC
#   undef  FLOC_TURB_DISS
#   define FLOC_BBL_DISS
#   define SED_FLOCS
#   define SED_DEFLOC
#  endif
# endif

# undef  MORPHODYN
# define NO_FRCFILE
# undef  RVTK_DEBUG
```

Sed toy (Rouse)



```
#elif defined SED_TOY
/*
!                          SED TOY (1D Single Column example)
!                          === === === ====== ====== ========
!
*/                                /* Choose an experiment :                 */
# define SED_TOY_ROUSE             /*   Rouse                                 */
# undef  SED_TOY_CONSOLID          /*   Consolidation                         */
# undef  SED_TOY_RESUSP            /*   Erosion and sediment resuspension     */
# undef  SED_TOY_FLOC              /*   Flocculation                          */
```

Model discretization :

- Seawater : 100 Layers (**N**) / 5m depth (resolution : 5cm)
- Sediments : 1 Layer (**NLAY**) / 10cm depth

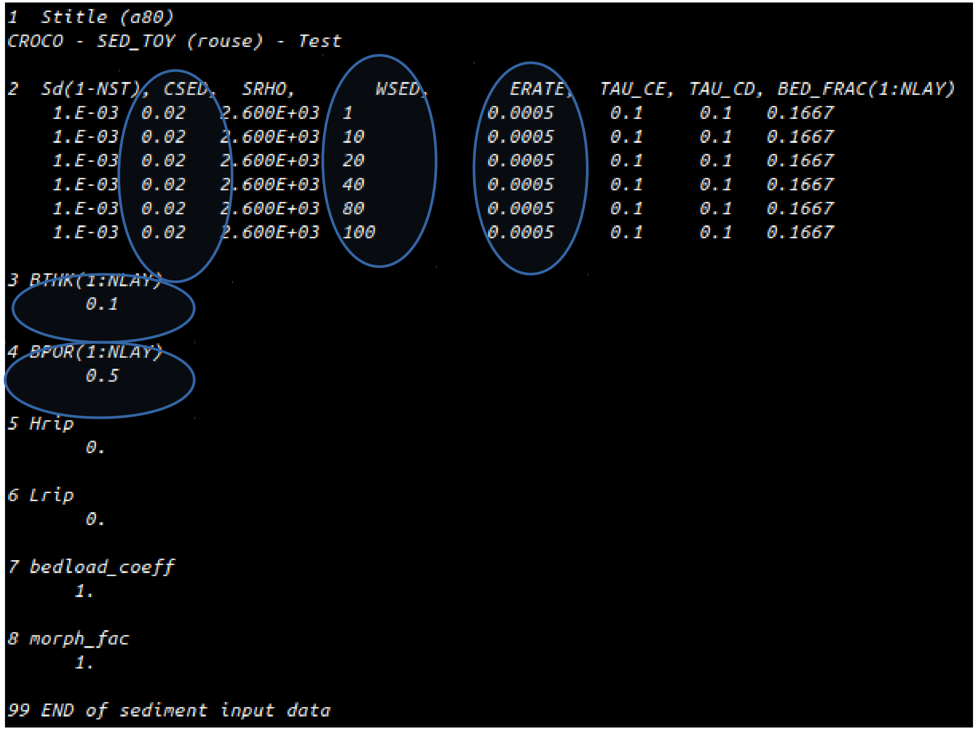
Dynamics :

- Only vertical movement
- Vertical mixing : Background vertical viscosity (1e^{-4}m^2/s)

Sediments :

- cohesive sediment six classes (**NST**)
- C_0 : 0,02Kg/m³ (**CSED**)
- W_s : 0,001 / 0,01 / 0,02 / 0,04 / 0,08 / 0,1 m/s (**WSED**)
- E_0 : 5e^{-4} (**ERATE**)

sediment_sed_toy_rouse.in :



```
1  Stitle (a80)
CROCO - SED_TOY (rouse) - Test

2  Sd(1-NST), CSED,  SRHO,         WSED,        ERATE,  TAU_CE, TAU_CD, BED_FRAC(1:NLAY)
    1.E-03  0.02    2.600E+03  1             0.0005     0.1      0.1    0.1667
    1.E-03  0.02    2.600E+03  10            0.0005     0.1      0.1    0.1667
    1.E-03  0.02    2.600E+03  20            0.0005     0.1      0.1    0.1667
    1.E-03  0.02    2.600E+03  40            0.0005     0.1      0.1    0.1667
    1.E-03  0.02    2.600E+03  80            0.0005     0.1      0.1    0.1667
    1.E-03  0.02    2.600E+03  100           0.0005     0.1      0.1    0.1667

3 BTHK(1:NLAY)
       0.1

4 BPOR(1:NLAY)
       0.5

5 Hrip
       0.

6 Lrip
       0.

7 bedload_coeff
      1.

8 morph_fac
      1.

99 END of sediment input data
```

Sed toy (Rouse)

Criterion for suspension:

- Suspended sediment behaves like tracers , and can be treated as diffusion problem, with higher concentration at bed, and lower concentration close to the surface.
- Rouse theory : $C = C_0 (1 – z/h)$ linear in depth (C$_0$: Concentration at bed / h : depth)
- Rouse number : W_s/ku_* with W$_s$: settling velocity / u$_*$: shear stress velocity / k : von Karman (0,41)

- Concentration at any depth z : $C_{rouse}(z) = C_0 [((h-z)/z) * (a/h-a)]^{\text{Rouse number}}$ with a= z$_0$ (at surface)

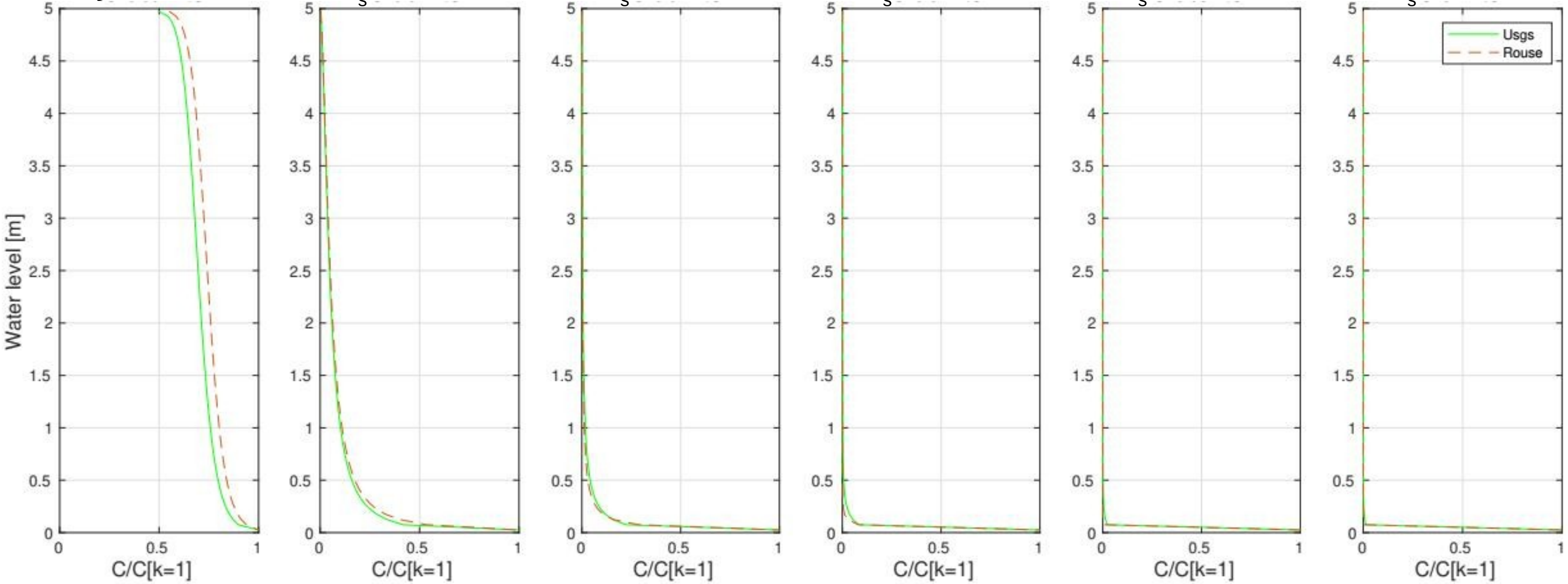
Goal :

- To Know how my numerics experiment fitted the Rouse theory → $C_{usgs}(z)$ vs $C_{rouse}(z)$

Sed toy (Rouse)

$C_{usgs}(z)$ vs *$C_{rouse}(z)$*

W_s= 0,001 m/s | W_s= 0,01 m/s | W_s= 0,02 m/s | W_s= 0,04 m/s | W_s= 0,08 m/s | W_s= 0,1 m/s



- * W_s < u*
- * lower Rouse number

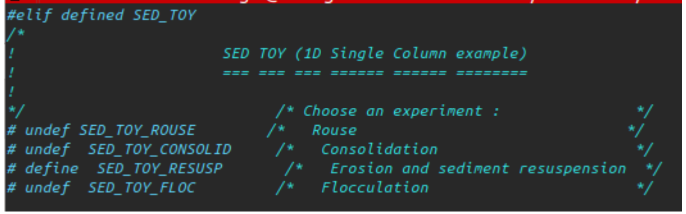
- * Higher suspended sediment concentration

→ *W_s/ku_** ←

- * W_s >> u*
- * higher Rouse number

- * Lower suspended sediment concentration

Sed toy (resusp)



```
#elif defined SED_TOY
/*
!                        SED TOY (1D Single Column example)
!                        === === === ====== ====== ========
!
*/                            /* Choose an experiment :                 */
# undef SED_TOY_ROUSE        /*   Rouse                                */
# undef  SED_TOY_CONSOLID     /*   Consolidation                        */
# define  SED_TOY_RESUSP       /*   Erosion and sediment resuspension  */
# undef  SED_TOY_FLOC         /*   Flocculation                         */
```

Goal :

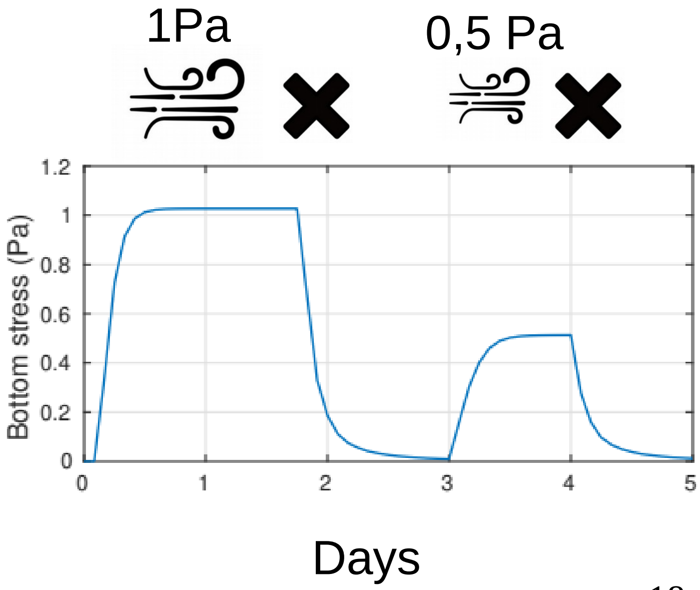
- Demonstrate the evolution of stratigraphy caused by resuspension and subsequent settling of sediment during time-dependent bottom shear stress event

Model discretization :

- Seawater : 20 Layers (**N**) / 20m depth (resolution : 1m)
- Sediments : 41 Layers (**NLAY**) / 4,1cm depth

Dynamics :

- Time-varying surface wind stress applied that generated time-dependent horizontal velocities and bottom stress
- Vertical mixing parametrization GLS

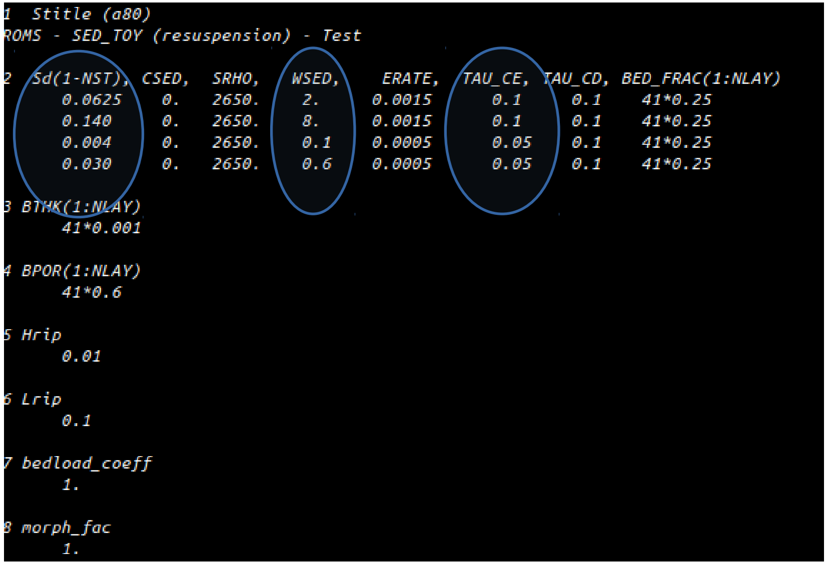


Sed toy (Resusp)

Sediments :

- Non cohesive / cohesive sediment 4 classes (**NST**)
- Sand : 140µm / 62,5µm   Mud : 30µm / 4µm (**Sd**)
- W_s : 8 / 2 / 0,6 / 0,1 mm/s (**WSED**)
- τ_c : 0,1 / 0,1 / 0,05 / 0,05 Pa (**TAU_CE**)

sediment_sed_toy_resusp.in :



```
1  Stitle (a80)
ROMS - SED_TOY (resuspension) - Test

2  Sd(1-NST), CSED,  SRHO,   WSED,    ERATE,  TAU_CE, TAU_CD, BED_FRAC(1:NLAY)
      0.0625    0.   2650.    2.     0.0015     0.1    0.1     41*0.25
      0.140     0.   2650.    8.     0.0015     0.1    0.1     41*0.25
      0.004     0.   2650.    0.1    0.0005     0.05   0.1     41*0.25
      0.030     0.   2650.    0.6    0.0005     0.05   0.1     41*0.25

3 BTHK(1:NLAY)
      41*0.001

4 BPOR(1:NLAY)
      41*0.6

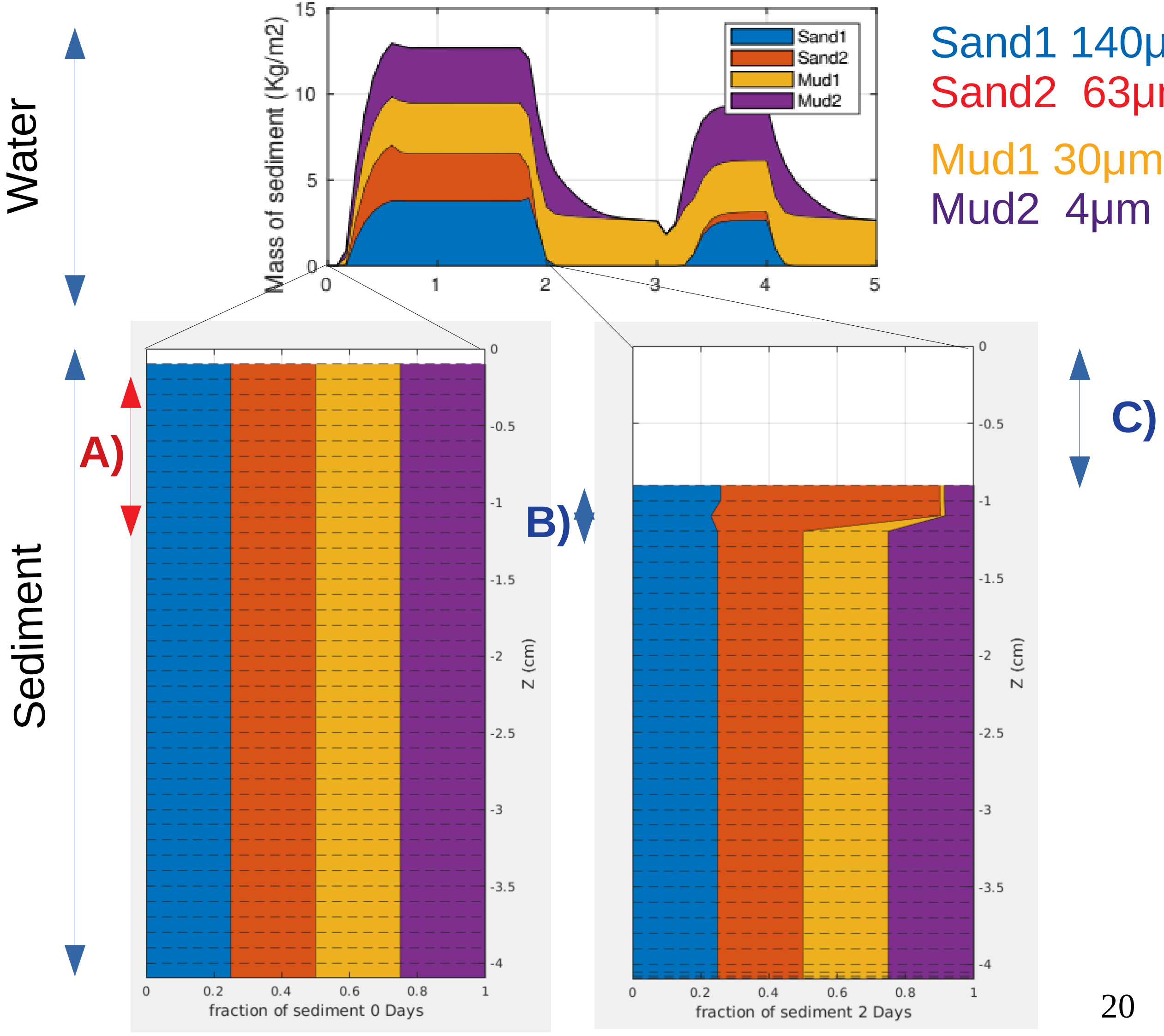
5 Hrip
      0.01

6 Lrip
      0.1

7 bedload_coeff
      1.

8 morph_fac
      1.
```

Sed toy (resusp)



0 days

2 days

Sand1 140µm
Sand2 63µm

Mud1 30µm
Mud2 4µm

<u>0 days - 2days :</u>

* first stress event → 1Pa

* 1,1 cm moves by erosion on the fluid **A)**

* Mud classes more dominant than sand

<u>At 2 days :</u>

B) When the stress subsided, coarser sediment deposited first (0,3 cm), while finer material remained suspended

C) Net erosion of 0,8 cm

Sed toy (resusp)

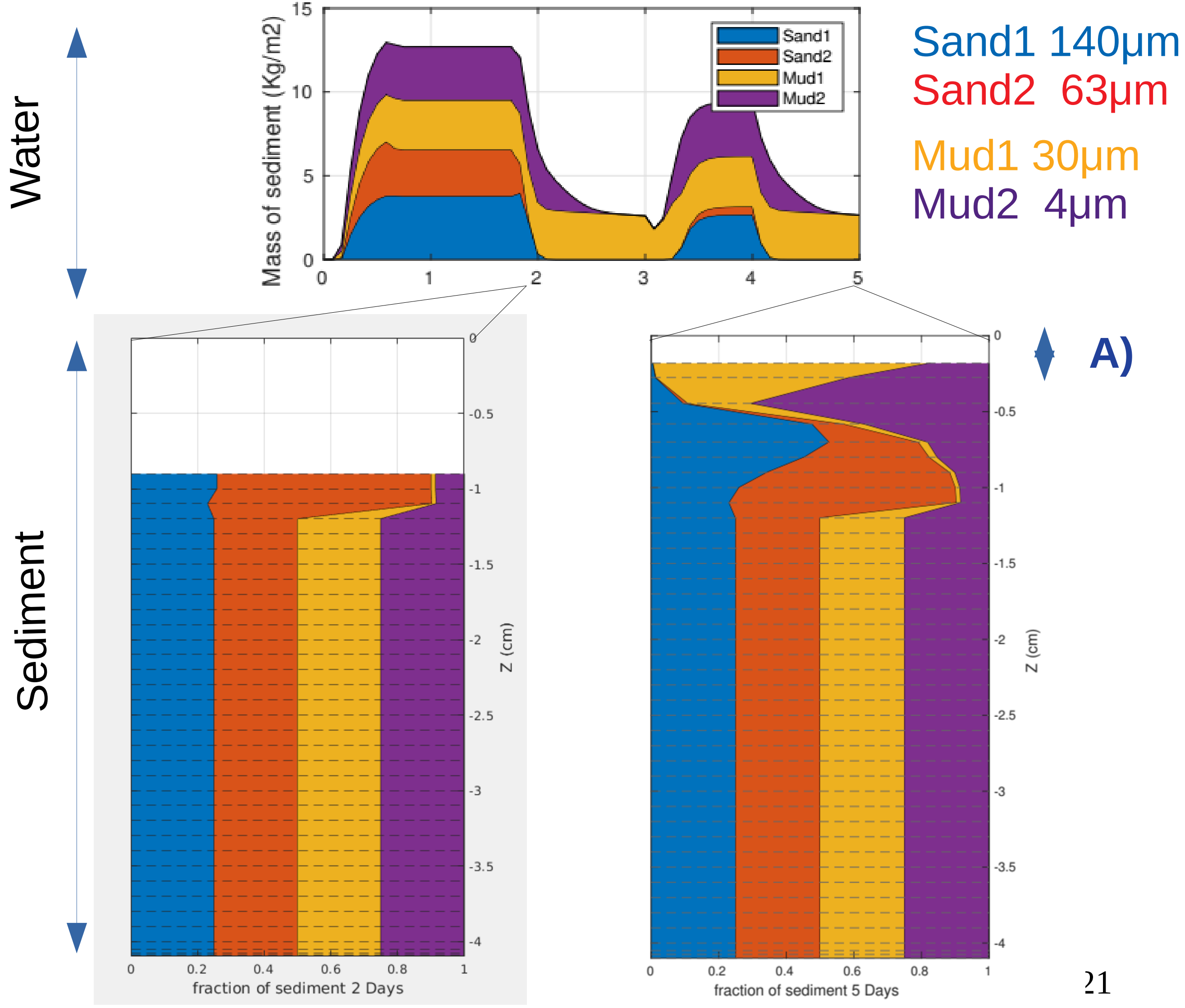
<u>3 days - 4days :</u>

* 2nd stress event → 0,5Pa

<u>At 5 days :</u>

* Then, all sand classes are deposited, mud begin to deposit

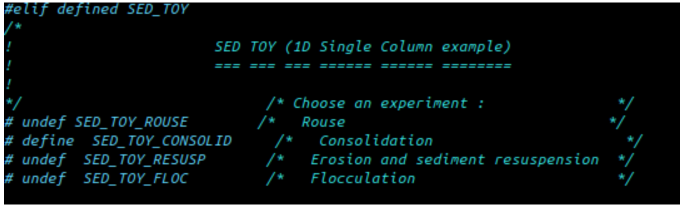
* Then some muds remains in the fluid (30µm dominant) and leave a net erosion 0,2cm **A)**



Sand1 140µm
Sand2 63µm
Mud1 30µm
Mud2 4µm

2 days **5 days**

Sed toy (consolidation)



```
#elif defined SED_TOY
/*
!                       SED TOY (1D Single Column example)
!                       === === === ====== ====== ========
!
*/                              /* Choose an experiment :              */
# undef SED_TOY_ROUSE          /*   Rouse                             */
# define  SED_TOY_CONSOLID       /*   Consolidation                      */
# undef  SED_TOY_RESUSP         /*   Erosion and sediment resuspension  */
# undef  SED_TOY_FLOC           /*   Flocculation                       */
```

Goal :

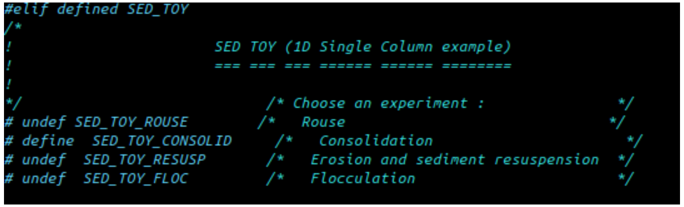
- Stratigraphic responses of cohesive behavior due to a single bottom-stress event
- Show the response of mixed bed with newer deposits
- Show consolidation / swelling processes on sediment layers

Erodibility with Cohesive sediments :

- Sediments do not erode in the same way depending on whether they are cohesive or not
- Erodibility becomes a property of the bed layer and not only given for each sediment class
- You have a critical shear stress for the erosion for each layer, which is increasing with depth

→ It is managed by a cohesive bed module within Usgs

Sed toy (consolidation)



```
#elif defined SED_TOY
/*
!                       SED TOY (1D Single Column example)
!                       === === === ====== ====== ========
!
*/                            /* Choose an experiment :               */
# undef SED_TOY_ROUSE        /*   Rouse                              */
# define  SED_TOY_CONSOLID     /*   Consolidation                      */
# undef  SED_TOY_RESUSP       /*   Erosion and sediment resuspension  */
# undef  SED_TOY_FLOC         /*   Flocculation                       */
```

Initialization :

* Initialization of the cohesive bed module with a global critical shear stress profile at equilibrium for erosion (τ_{cbeq})

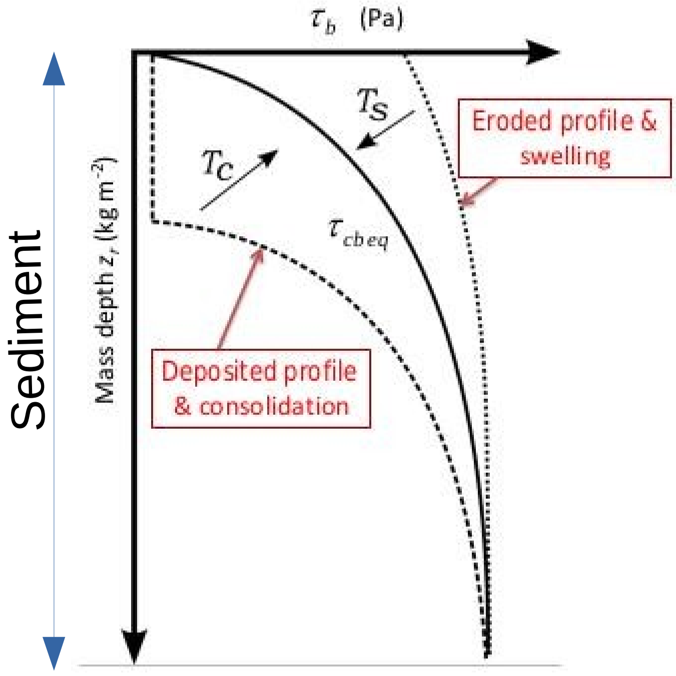
* You give some parameters like timescale (s) T_c : for consolidation / T_s : for swelling to accelerate or not each process

Run module :

* Applying a Bottom Stress event

* Then, differences appears, between τ_{cbeq} and the critical shear stress for the erosion profile (τ_b) in each layer

* τ_b profile is varying in time and then will be nudged by the model over timescale T_c or T_s toward the equilibrium profile during this period



Sherwood & al 2018

Sed toy (consolidation)

Model discretization :

- Seawater : 20 Layers (**N**) / 20m depth (resolution : 1m)
- Sediments : 41 Layers (**NLAY**) / 4cm depth

Dynamics :

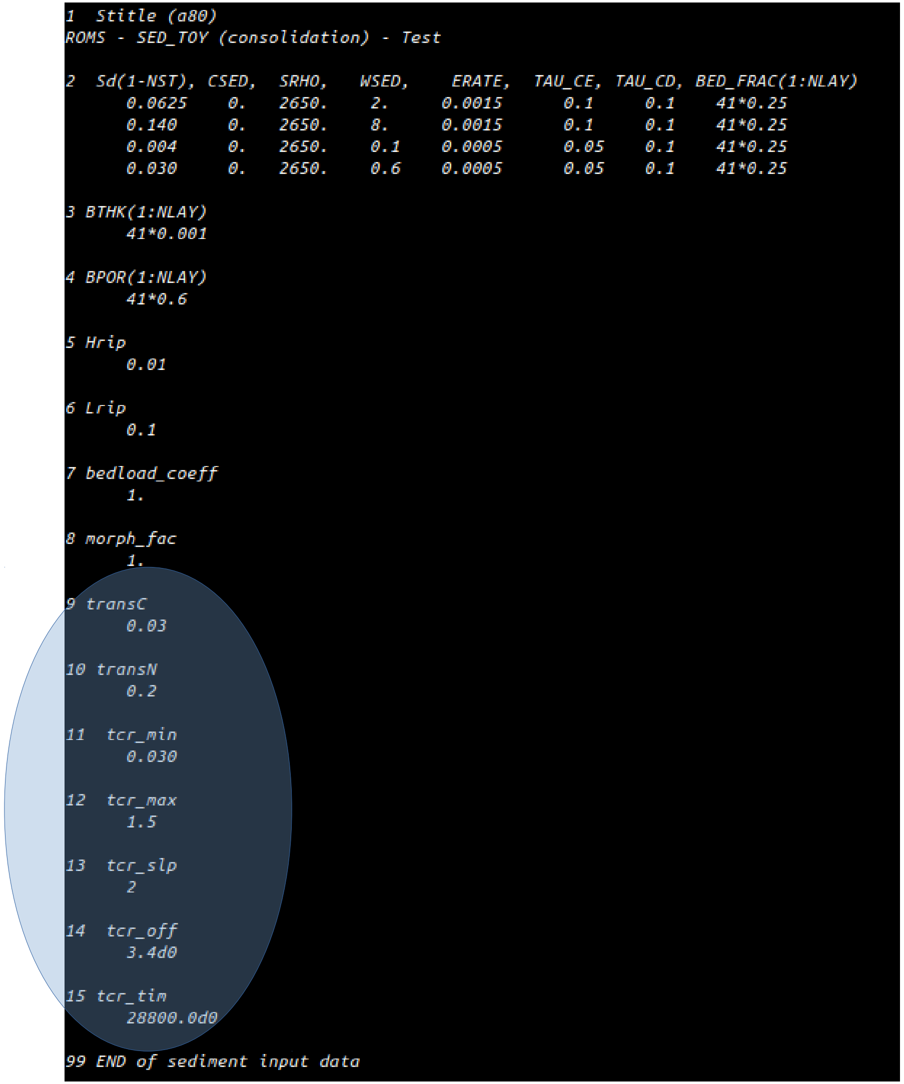
- one surface wind stress event applied that generated time-dependent horizontal velocities and bottom stress (1Pa) during 37 days
- Vertical mixing parameterization GLS

Sediments :

- Cohesive behaviour given by threshold value (**transN**)
- Parameters 13-14 (**tcr_slp/tcr_off**) : to compute τ_{cbeq}
- Consolidation rate T_c (**tcr_tim)** (8h in seconds)

  Swelling rate → T_s =100*T_c= 33 days

sediment_sed_toy_consolid.in :



```
1  Stitle (a80)
ROMS - SED_TOY (consolidation) - Test

2  Sd(1-NST), CSED,  SRHO,   WSED,    ERATE,  TAU_CE, TAU_CD, BED_FRAC(1:NLAY)
      0.0625    0.   2650.    2.     0.0015      0.1     0.1    41*0.25
      0.140     0.   2650.    8.     0.0015      0.1     0.1    41*0.25
      0.004     0.   2650.    0.1    0.0005      0.05    0.1    41*0.25
      0.030     0.   2650.    0.6    0.0005      0.05    0.1    41*0.25

3 BTHK(1:NLAY)
      41*0.001

4 BPOR(1:NLAY)
      41*0.6

5 Hrip
      0.01

6 Lrip
      0.1

7 bedload_coeff
      1.

8 morph_fac
      1.

9 transC
      0.03

10 transN
      0.2

11  tcr_min
      0.030

12  tcr_max
      1.5

13  tcr_slp
      2

14  tcr_off
      3.4d0

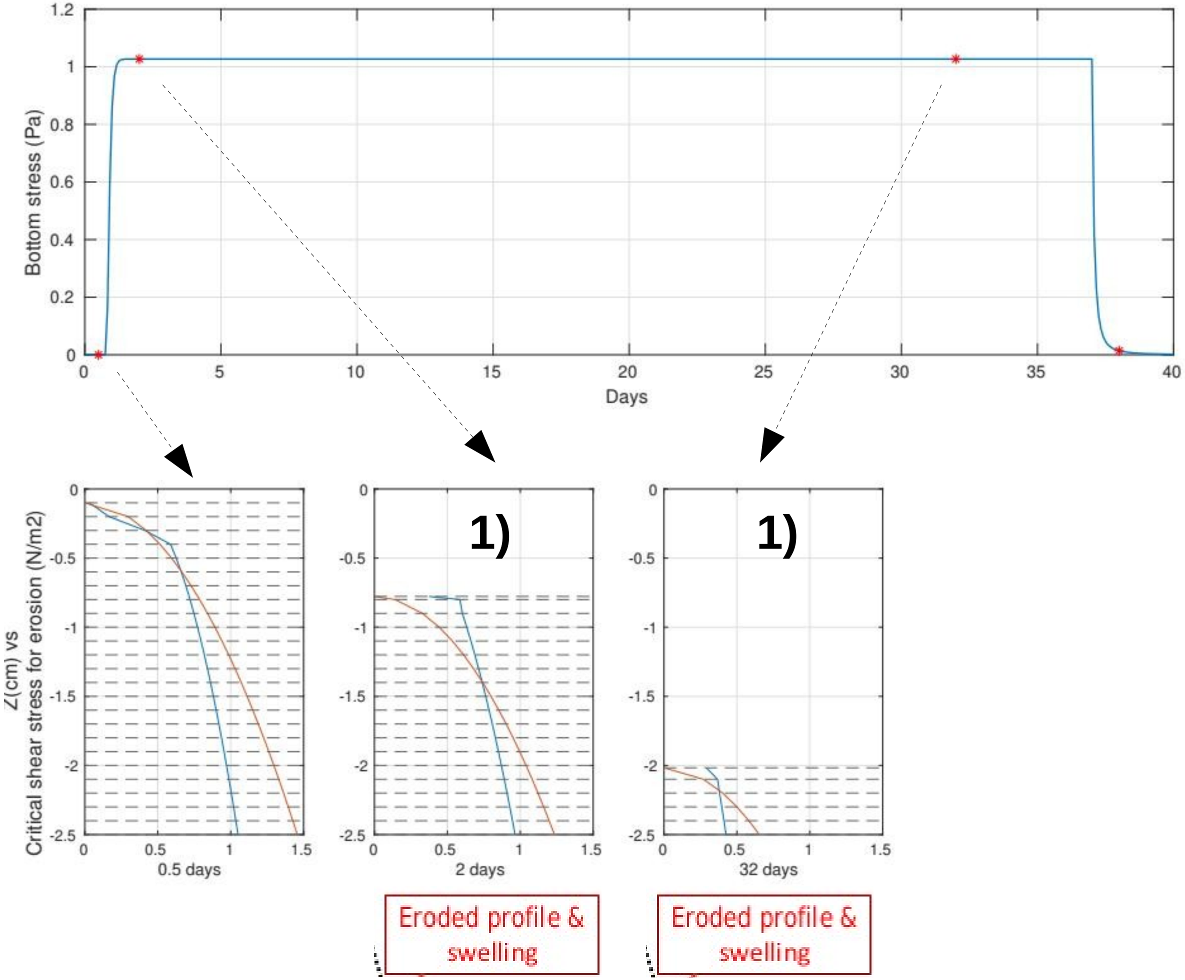
15 tcr_tim
      28800.0d0

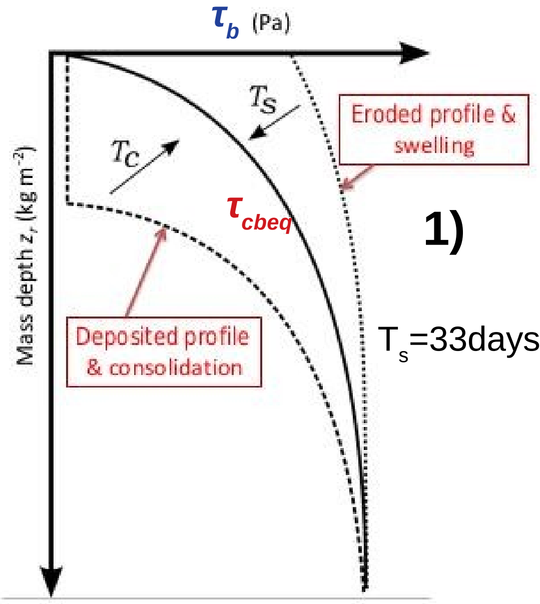
99 END of sediment input data
```

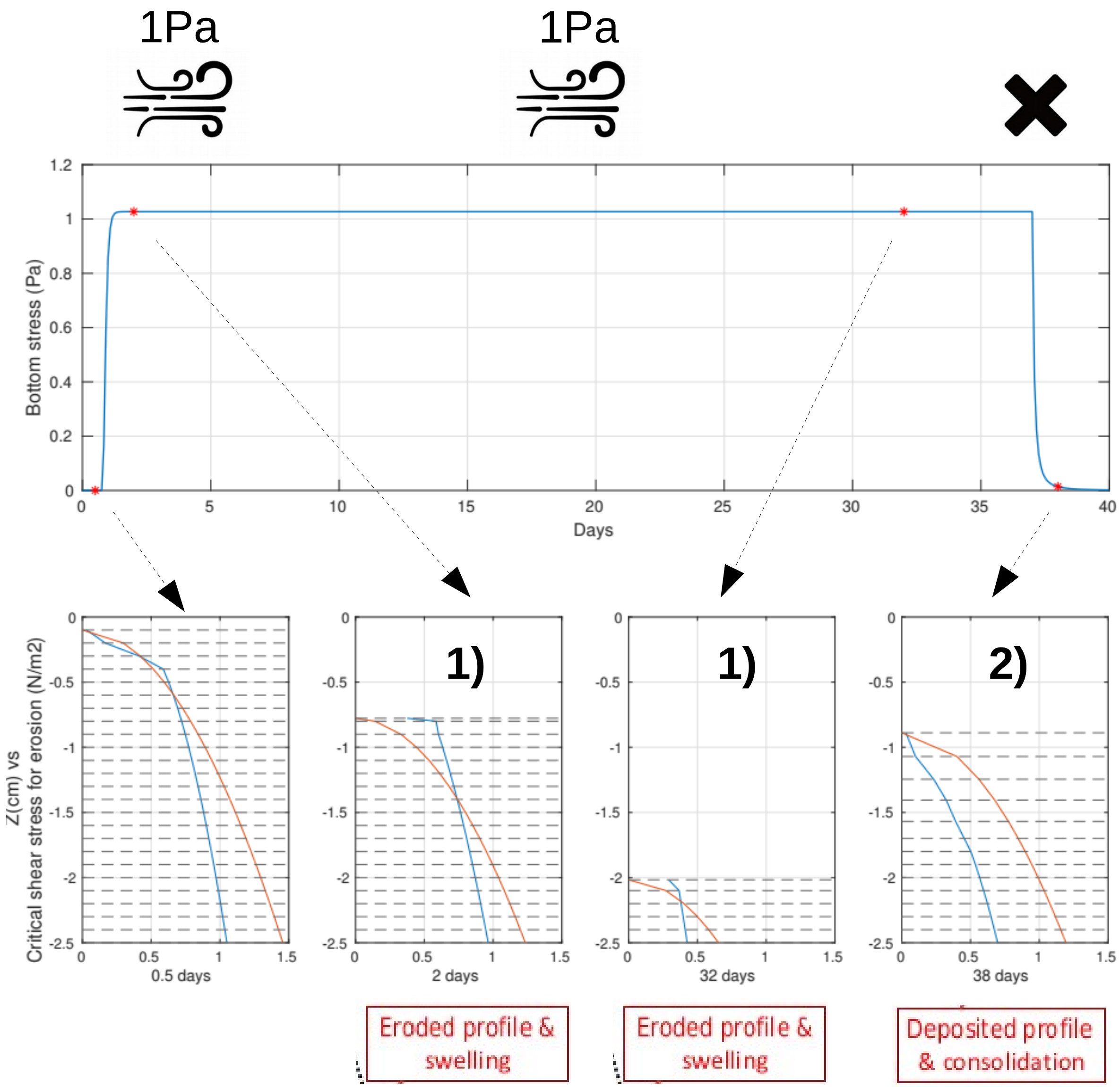
1Pa 1Pa

We Apply here a Bottom Stress event during a period of nearly 37 days :

1) cause erosion , resusp. of material process of swelling made more erodible layers and profile tend to τ_{cbeq}





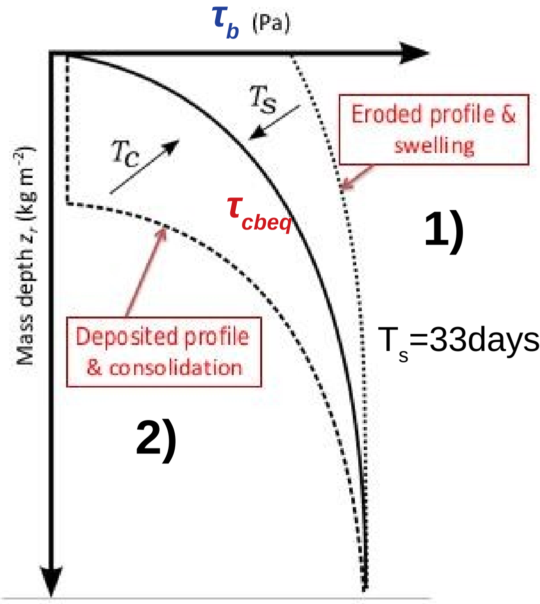


We Apply here a Bottom Stress event during a period of nearly 37 days :

1) cause erosion , resusp. of material process of swelling made more erodible layers and profile tend to τ_{cbeq}

2) then happens new deposits process of consolidation made less erodible

Layers consolidated next 38 days



Sandbar

Goal :

- We initialize a linear beach slope → to see waves forcing effects on sediment bed
- To predict onshore and offshore sandbar migrations

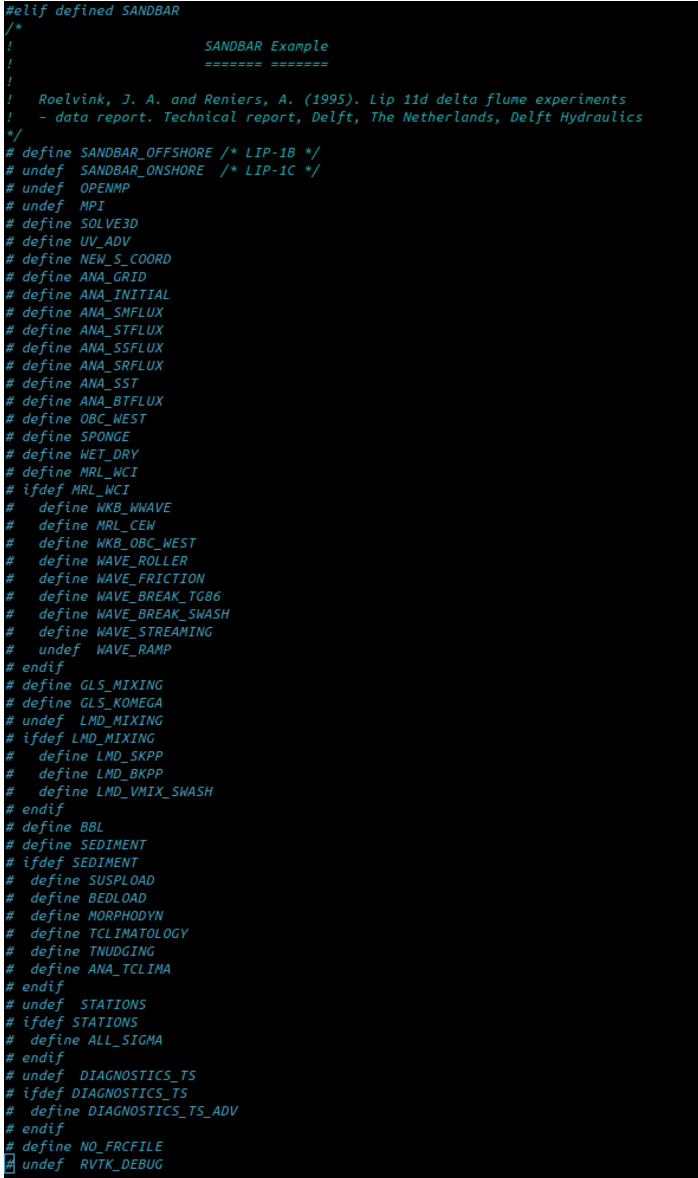
- To Fit well with sandbar experiment data from European Large Installation Plan (LIP) :

  * LIP-1B (characterizing erosion of sandbar) **SANDBAR_OFFSHORE**
  * LIP-1C (accretion) **SANDBAR_ONSHORE**

Different Wave Forcing methods :

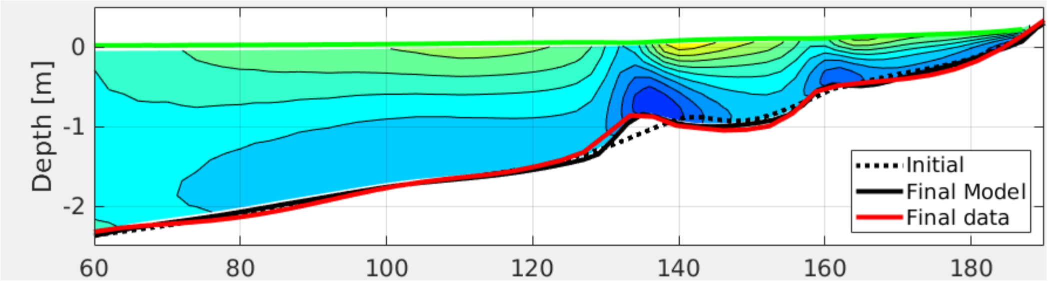
- Wave statistics from WKB wave model that will initialize a Bottom Boundary Layer and process then wave current interactions

- Use of Wave maker for wave-resolving simulations in Non hydrostatic mode (NBQ) (need high resolution at the bottom)



```
#elif defined SANDBAR
/*
!                        SANDBAR Example
!                        ======= =======
!
!   Roelvink, J. A. and Reniers, A. (1995). Lip 11d delta flume experiments
!   - data report. Technical report, Delft, The Netherlands, Delft Hydraulics
*/
# define SANDBAR_OFFSHORE /* LIP-1B */
# undef  SANDBAR_ONSHORE  /* LIP-1C */
# undef  OPENMP
# undef  MPI
# define SOLVE3D
# define UV_ADV
# define NEW_S_COORD
# define ANA_GRID
# define ANA_INITIAL
# define ANA_SMFLUX
# define ANA_STFLUX
# define ANA_SSFLUX
# define ANA_SRFLUX
# define ANA_SST
# define ANA_BTFLUX
# define OBC_WEST
# define SPONGE
# define WET_DRY
# define MRL_WCI
# ifdef MRL_WCI
#   define WKB_WWAVE
#   define MRL_CEW
#   define WKB_OBC_WEST
#   define WAVE_ROLLER
#   define WAVE_FRICTION
#   define WAVE_BREAK_TG86
#   define WAVE_BREAK_SWASH
#   define WAVE_STREAMING
#   undef  WAVE_RAMP
# endif
# define GLS_MIXING
# define GLS_KOMEGA
# undef  LMD_MIXING
# ifdef LMD_MIXING
#   define LMD_SKPP
#   define LMD_BKPP
#   define LMD_VMIX_SWASH
# endif
# define BBL
# define SEDIMENT
# ifdef SEDIMENT
#  define SUSPLOAD
#  define BEDLOAD
#  define MORPHODYN
#  define TCLIMATOLOGY
#  define TNUDGING
#  define ANA_TCLIMA
# endif
# undef  STATIONS
# ifdef STATIONS
#  define ALL_SIGMA
# endif
# undef  DIAGNOSTICS_TS
# ifdef DIAGNOSTICS_TS
#  define DIAGNOSTICS_TS_ADV
# endif
# define NO_FRCFILE
# undef  RVTK_DEBUG
```

Sandbar



Model discretization :

- 720 x-horizontal grid point (LLm0) (200m) (resolution 0,25m)
- Seawater : 10 Layers (**N**) / 4,1m depth
- Sediments : 2 Layers (**NLAY**) / 10m depth

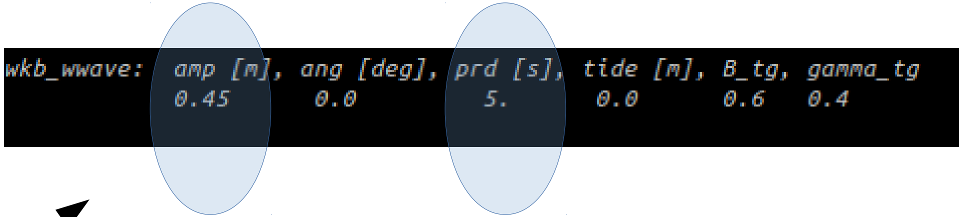
Dynamics :

- Morphodynamics
- Vertical mixing parameterization GLS

- WKB Wave propagation model (monochromatic): initialization
- WKB pass then his variables to *MRL_WCI*/*BBL* routines

- Interaction Wave Current (*MRL_WCI*)
- Bottom Boundary Layer (*BBL*) model compute his own bed roughness (depending of grain sediment and waves)

Croco.in.Sandbar_1B :

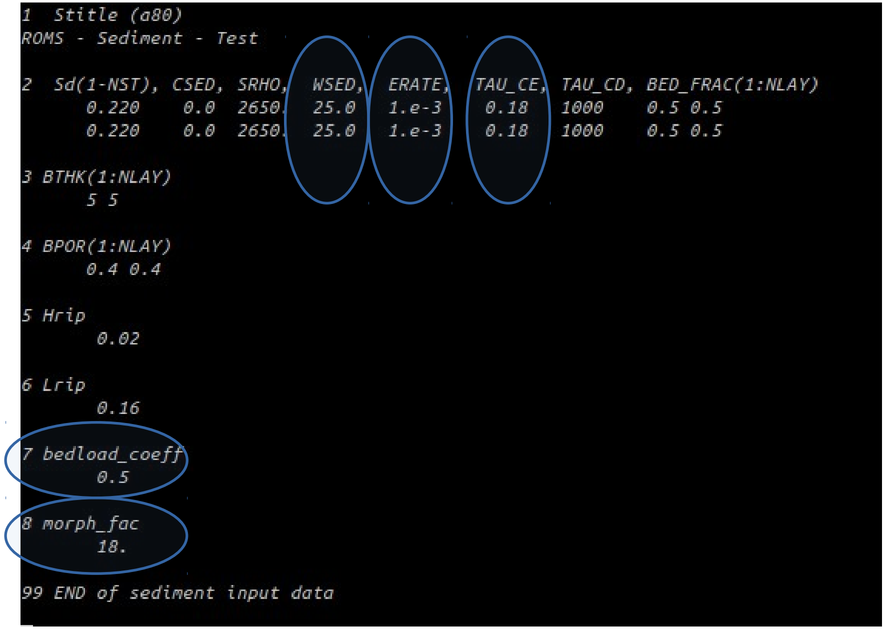


```
wkb_wwave:  amp [m], ang [deg], prd [s], tide [m], B_tg, gamma_tg
            0.45      0.0         5.       0.0       0.6   0.4
```

Waves parameters :
* amp : wave amplitude
* prd : wave period

Sandbar

sediment_sandbar_(1B/1C).in :



```
1  Stitle (a80)
ROMS - Sediment - Test

2  Sd(1-NST), CSED, SRHO,  WSED,  ERATE,  TAU_CE, TAU_CD, BED_FRAC(1:NLAY)
     0.220     0.0  2650.  25.0   1.e-3   0.18   1000    0.5 0.5
     0.220     0.0  2650.  25.0   1.e-3   0.18   1000    0.5 0.5

3 BTHK(1:NLAY)
     5 5

4 BPOR(1:NLAY)
     0.4 0.4

5 Hrip
      0.02

6 Lrip
      0.16

7 bedload_coeff
      0.5

8 morph_fac
      18.

99 END of sediment input data
```

Sediments :

- Non-cohesive sediment two classes (**NST**) : Diameters Sd : 220 µm Density (**SRHO**) 2650 kg/m³
- W_s : 25 mm/s (**WSED**)
- τ_c : 0,18 Pa (**TAU_CE**)
- E_0 : $1e^{-3}$ (**ERATE**)

- Suspload and Bedload transport
- **Bedload formulation:** SANTOSS (Van der A, 2013) with bedload flux multiplied by factor 0,5 (**bedload_coeff**)
- Acceleration of bed response (**morph_fac**) : factor of 18 (13 for LIP-1C experiment) (with one hour simulation)

t_0

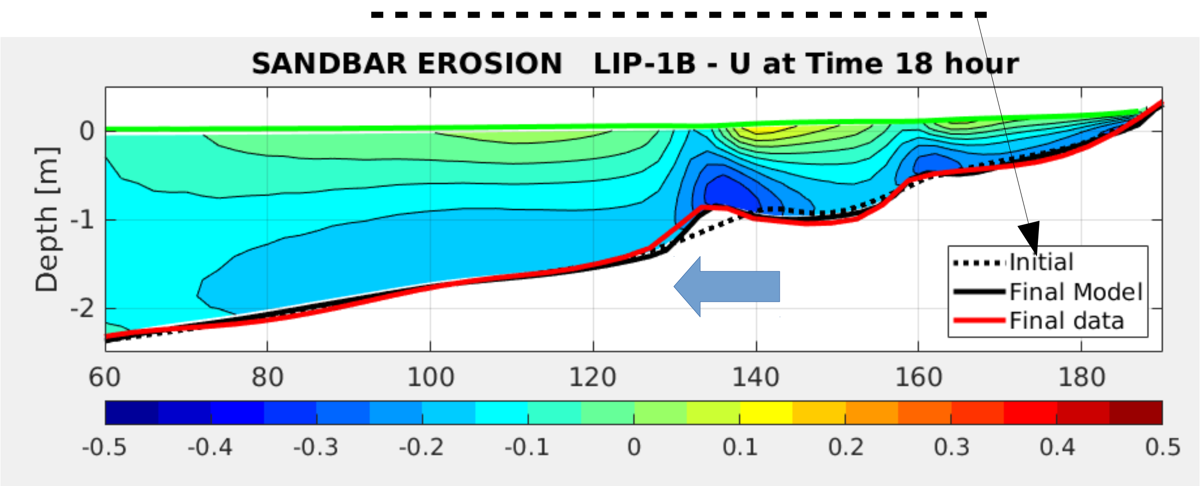
Initialize beach profile with linear slope

Dean number $De = H_s / T_p W_s$

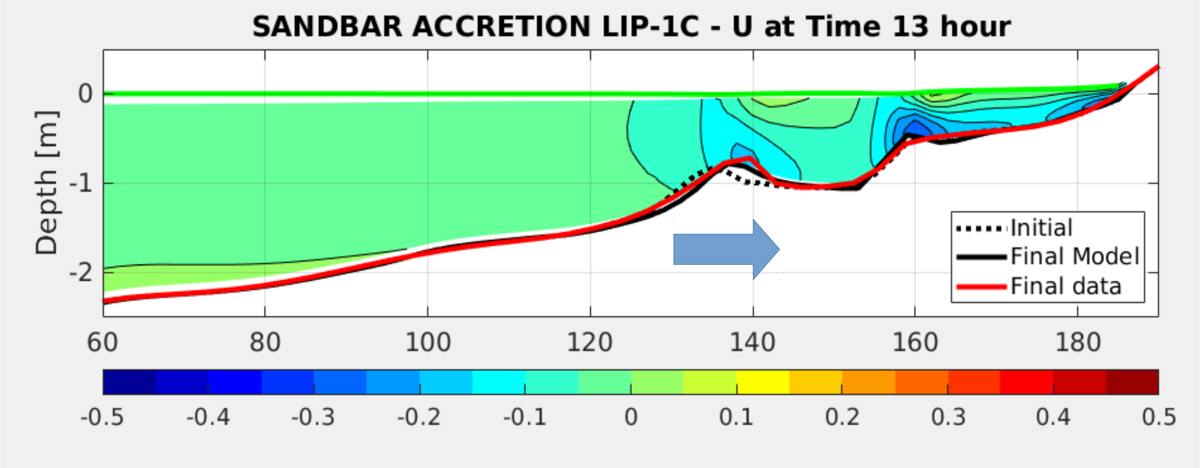
(Erosion vs Accretion)

W_s=25mm/s

t_1



$t_2 = t_1 + 18h$

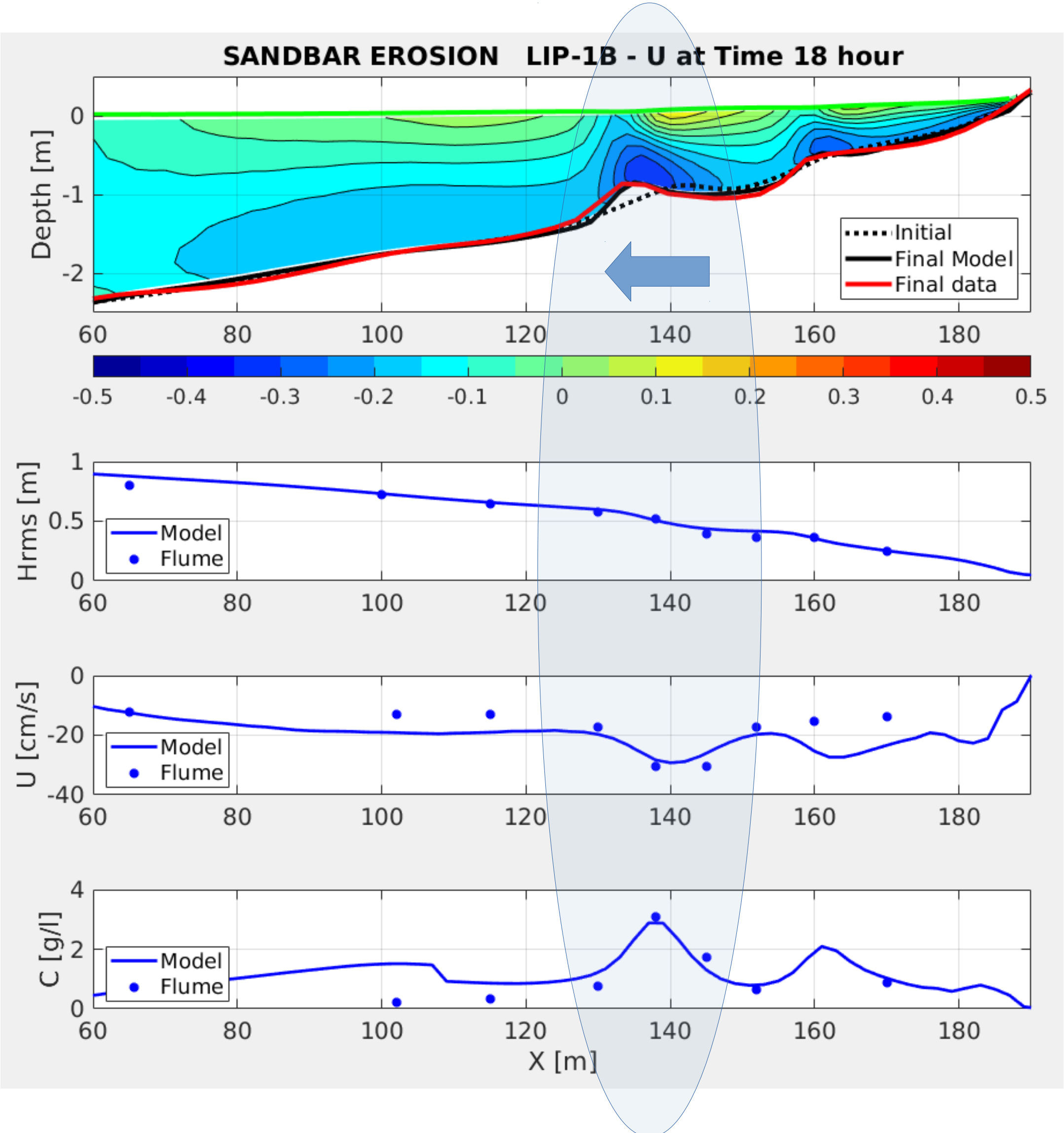


t_2+13h

Offshore Wave Forcing changes

High energy waves :
H_s=0,45m / T_p=5s De =3,6

Low energy waves :
H_s=0,18m / T_p=8s De=0,9



*Transport increase onshore to offshore

* Hrms : root-mean-square wave height (fit well with flume data)

* Undertow

* Bottom Concentration is correlated with undertow Resuspended material greater

Tidal flat2DV

Goal :

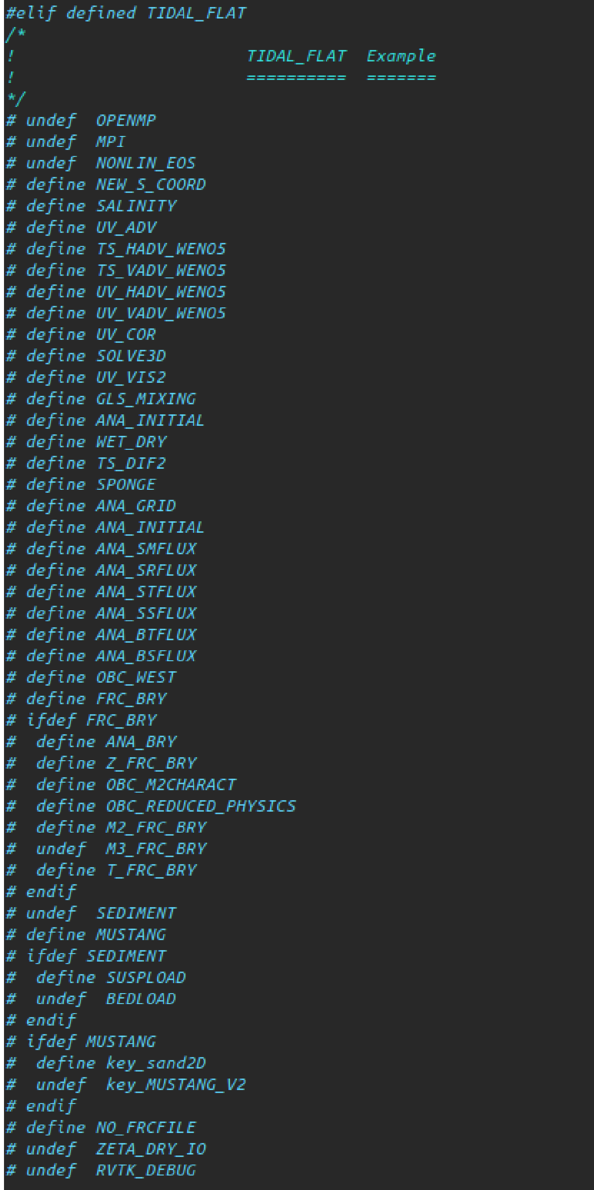
- Characterize bottom mud concentration evolution over several tidal cycles

Model discretization :

- 200 x-horizontal grid point (LLm0) (100km) (resolution 2km)
- Seawater : 10 Layers / 16m depth
- Sediments : 3 Layers / 15cm depth

Dynamics :

- Flat bottom
- At western boundary:
  SSH pulses : *zetabry_west(j)=2.*sin(2.*pi**__time__*/(12.0*3600.0))*
- Bottom roughness Length (Zob) : $1e^{-4}$ m

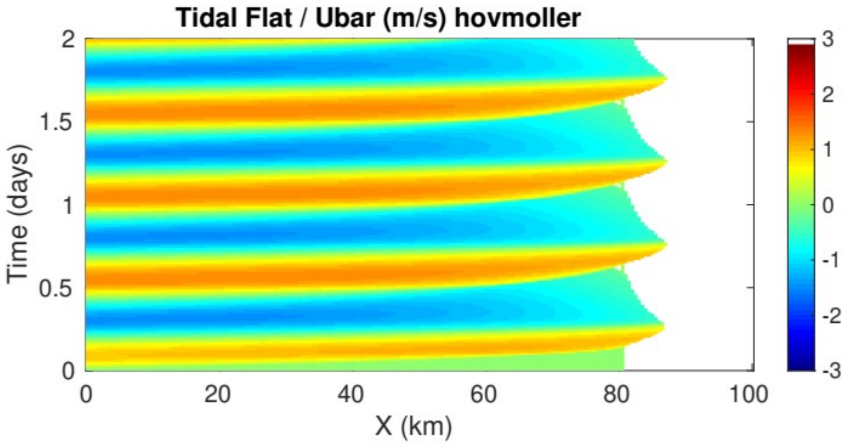


```
#elif defined TIDAL_FLAT
/*
!                       TIDAL_FLAT  Example
!                       ==========  =======
*/
# undef  OPENMP
# undef  MPI
# undef  NONLIN_EOS
# define NEW_S_COORD
# define SALINITY
# define UV_ADV
# define TS_HADV_WENO5
# define TS_VADV_WENO5
# define UV_HADV_WENO5
# define UV_VADV_WENO5
# define UV_COR
# define SOLVE3D
# define UV_VIS2
# define GLS_MIXING
# define ANA_INITIAL
# define WET_DRY
# define TS_DIF2
# define SPONGE
# define ANA_GRID
# define ANA_INITIAL
# define ANA_SMFLUX
# define ANA_SRFLUX
# define ANA_STFLUX
# define ANA_SSFLUX
# define ANA_BTFLUX
# define ANA_BSFLUX
# define OBC_WEST
# define FRC_BRY
# ifdef FRC_BRY
#  define ANA_BRY
#  define Z_FRC_BRY
#  define OBC_M2CHARACT
#  define OBC_REDUCED_PHYSICS
#  define M2_FRC_BRY
#  undef  M3_FRC_BRY
#  define T_FRC_BRY
# endif
# undef  SEDIMENT
# define MUSTANG
# ifdef SEDIMENT
#  define SUSPLOAD
#  undef  BEDLOAD
# endif
# ifdef MUSTANG
#  define key_sand2D
#  undef  key_MUSTANG_V2
# endif
# define NO_FRCFILE
# undef  ZETA_DRY_IO
# undef  RVTK_DEBUG
```

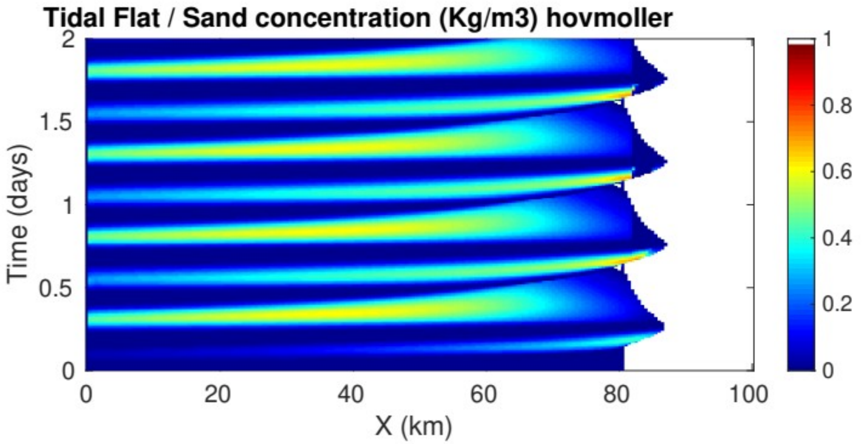
Tidal flat2DV

Sediments :

3 classes :
* 2 non cohesive sediment : 200µm (40% in each layer) / 100µm (40%)
* 1 cohesive sediment (20%) / W_s : 0,5 mm/s
* E_0 : $2e^{-4}$



Western Tide pulses give sequences of higher and lower concentrations of material on the fluid (anti-correlated with barotropic flow)



Sedim.Test cases	Cppkeys (SEDIMENT key activated by default)	Model used (to be tested)	Processes transport / scheme ?
Plannar Beach	SHOREFACE (No)	Usgs	Wave current Interaction (WCI)
Sandbar	SANDBAR (Yes)	Usgs	WCI / Bedload / Suspload / Morpho
Rip	RIP (No)	Usgs	WCI
Dune	DUNE (Yes)	Usgs/Mustang	Non cohesive sediments / Bedload / Morpho
Dune 3d	DUNE3D (Yes)	Usgs/Mustang	Non cohesive sediments / Bedload / Morpho
Analytical Dune	ANA_DUNE (Yes)	Usgs/Mustang	Non cohesive sediments / Bedload
Sed toy (Rouse)	SED_TOY_ROUSE (Yes)	Usgs/Mustang	Cohesive sediments / Suspload
Sed toy (Double Resuspension)	SED_TOY_RESUSP (Yes)	Usgs *(Mustang)*	Mixed bed / Double erosion and resuspension events / stratigraphy
Sed toy (consolidation)	SED_TOY_CONSOLID (Yes)	Usgs *(Mustang)*	Mixed bed / Consolidation / Swelling
Sed toy (flocculation)	SED_TOY_FLOC (Yes)	*(Usgs / Mustang)*	Mixed bed / Flocculation
Tidal Flat	TIDAL_FLAT (Yes)	Mustang *(Usgs)*	Mixed bed / effects from tidal cycles forcing
Vilaine (Realistic case)	COASTAL + VILAINE (Yes)	Mustang	Mixed Bed

How to build your own test case ?

* Most of test cases comes from literature

* Create your own cppkey « MYCONFIG »

 # define MYCONFIG

* Give various analytical fields / initial statement to the model when appropriate
Include it on files :
cppdefs.h / param.h
ana_grid.F / ana_initial.F / analytical.F

* Adapt namelists croco.in / sediment.in (USGS) / paraMUSTANG*.txt (Mustang)

END

Sediment Transport Components

Suspended sediment transport

$$\frac{\partial C}{\partial t}+\frac{\partial U_i C}{\partial x_i}=\frac{\partial}{\partial x_i}\left(K_H\frac{\partial C}{\partial x_{1,2}}+K_V\frac{\partial C}{\partial x_3}\right)+Sources/Sinks$$

Erosion formulation

$$Source=E_0(1-\varphi)\frac{\tau_b-\tau_{ce}}{\tau_{ce}}$$ when $t_b > t_{ce}$

Deposition formulation

$$Sink=w_s\frac{\partial C}{\partial z}$$

Bed load transport: Meyer-Peter Muller

$$\tau_{*sf}=\frac{\tau_{sf}}{(\rho_s-\rho)gD}$$ non-dimensional shear stress

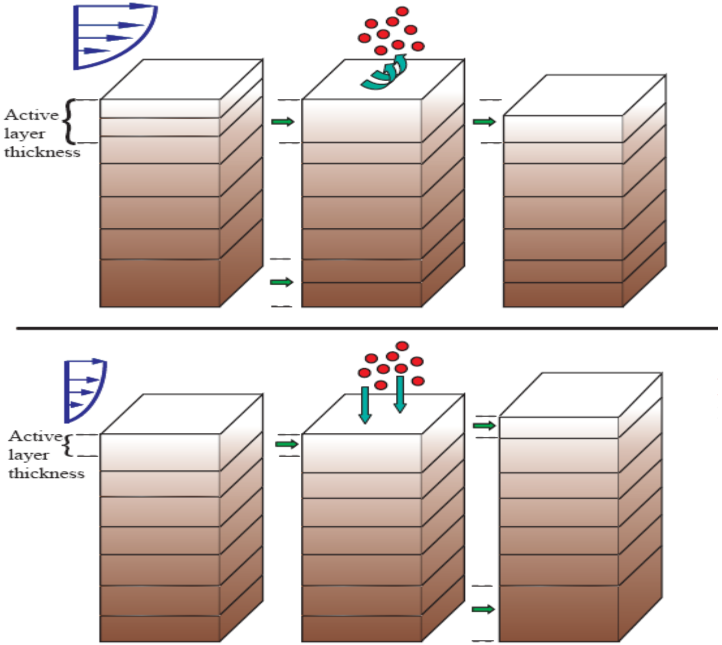
$$\Phi=8(\tau_{*sf}-0.047)^{3/2}$$ non-dimensional sediment flux

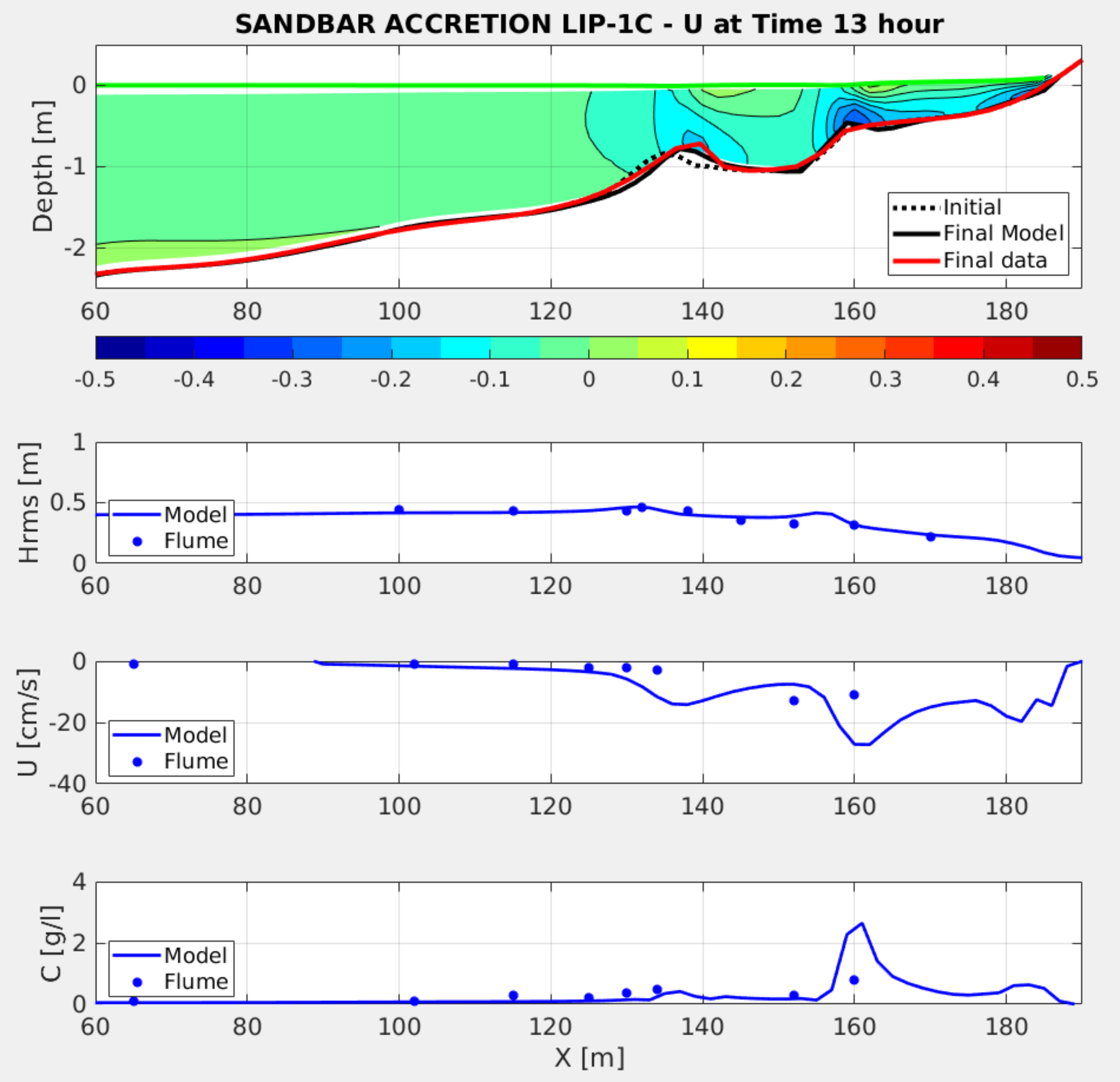
$$q_{bl}=\Phi\sqrt{\frac{\rho_s-\rho}{\rho}gD^3}$$ bed load transport rate, kg $m^{-1}s^{-1}$

Bed Model

Active layer thickness (Harris and Wiberg, 1997)

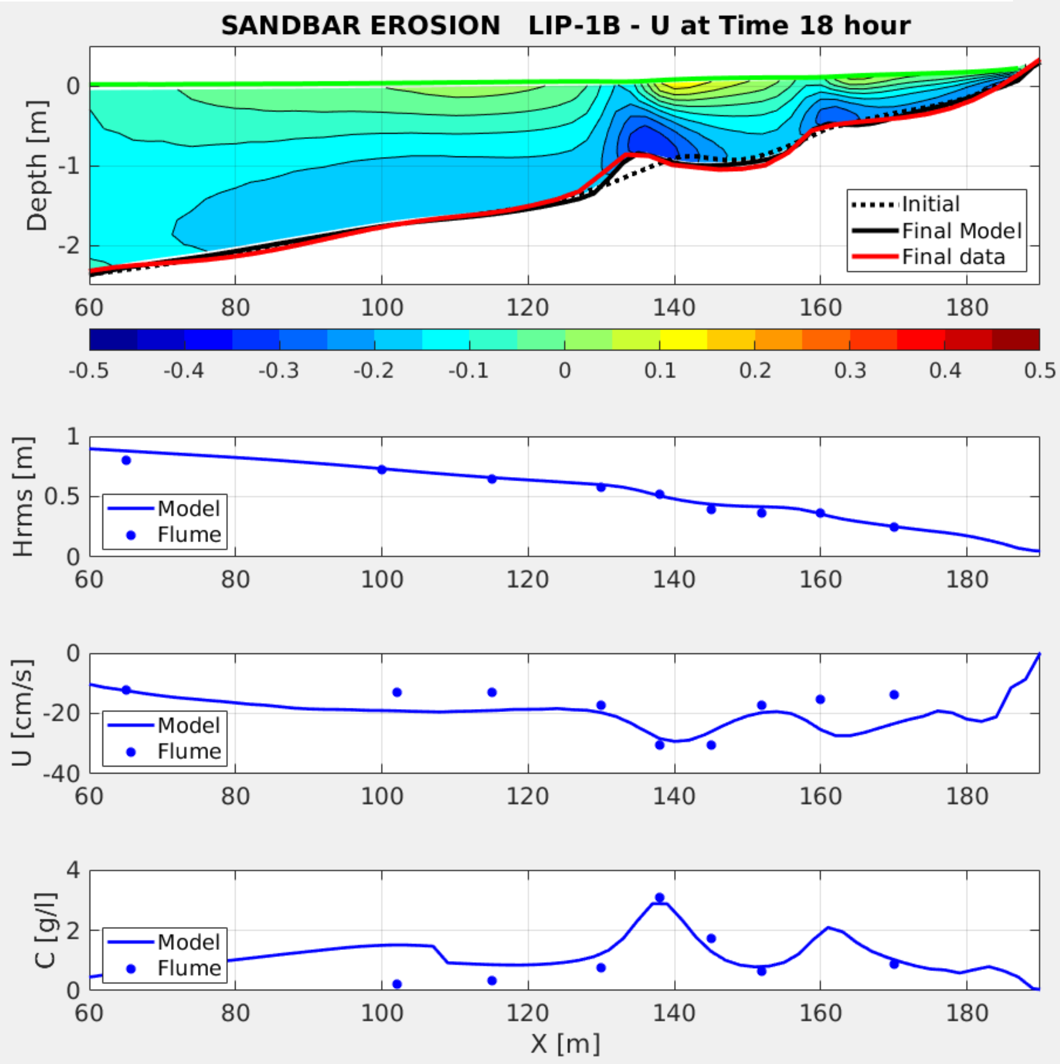
$$z_a=k_1(\tau_{sf}-\tau_c)+6D_{50}$$

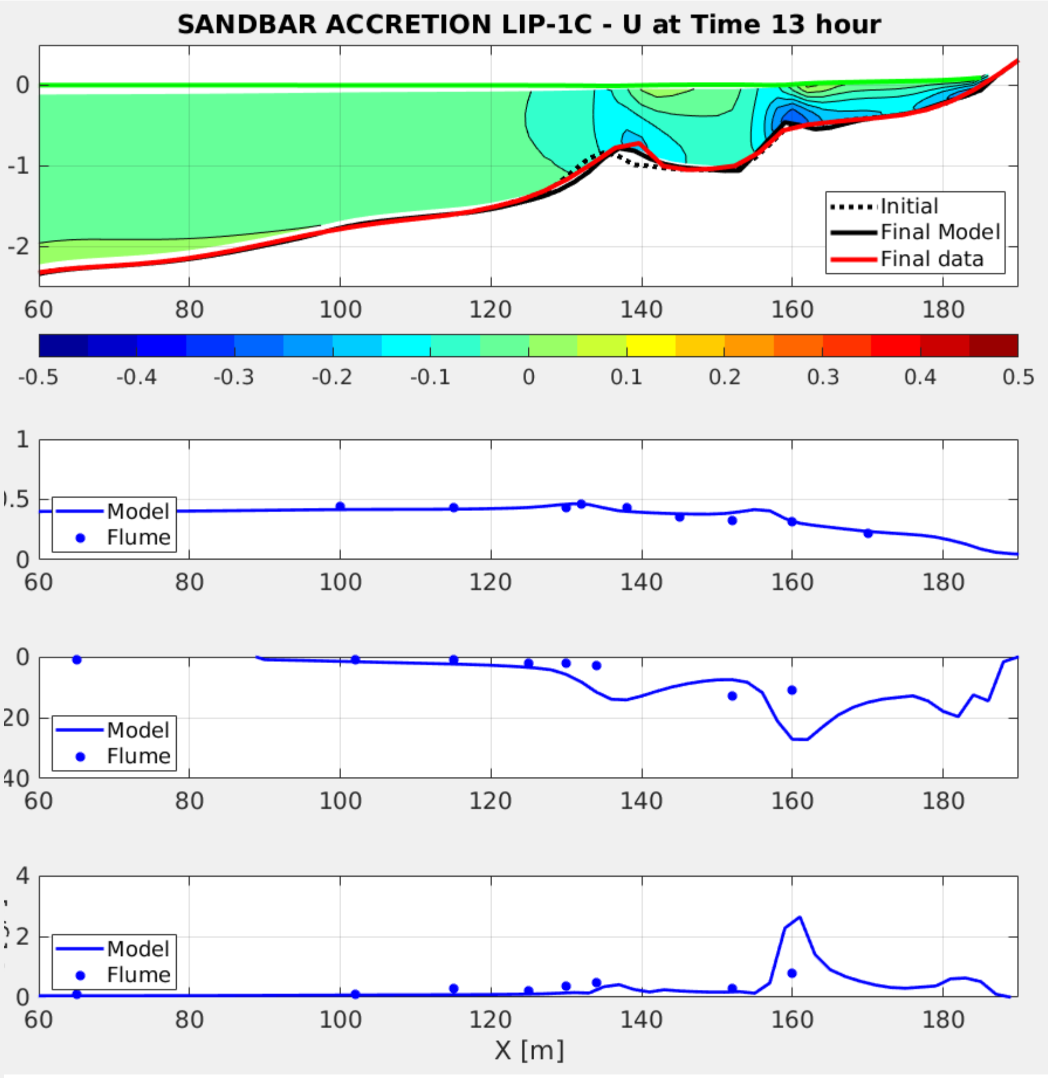



SANDBAR ACCRETION LIP-1C - U at Time 13 hour
Depth [m]
0
-1
-2
Initial
Final Model
Final data
60
80
100
120
140
160
180
-0.5
-0.4
-0.3
-0.2
-0.1
0
0.1
0.2
0.3
0.4
0.5
Hrms [m]
1
0.5
0
Model
Flume
U [cm/s]
0
-20
-40
C [g/l]
4
2
0
X [m]

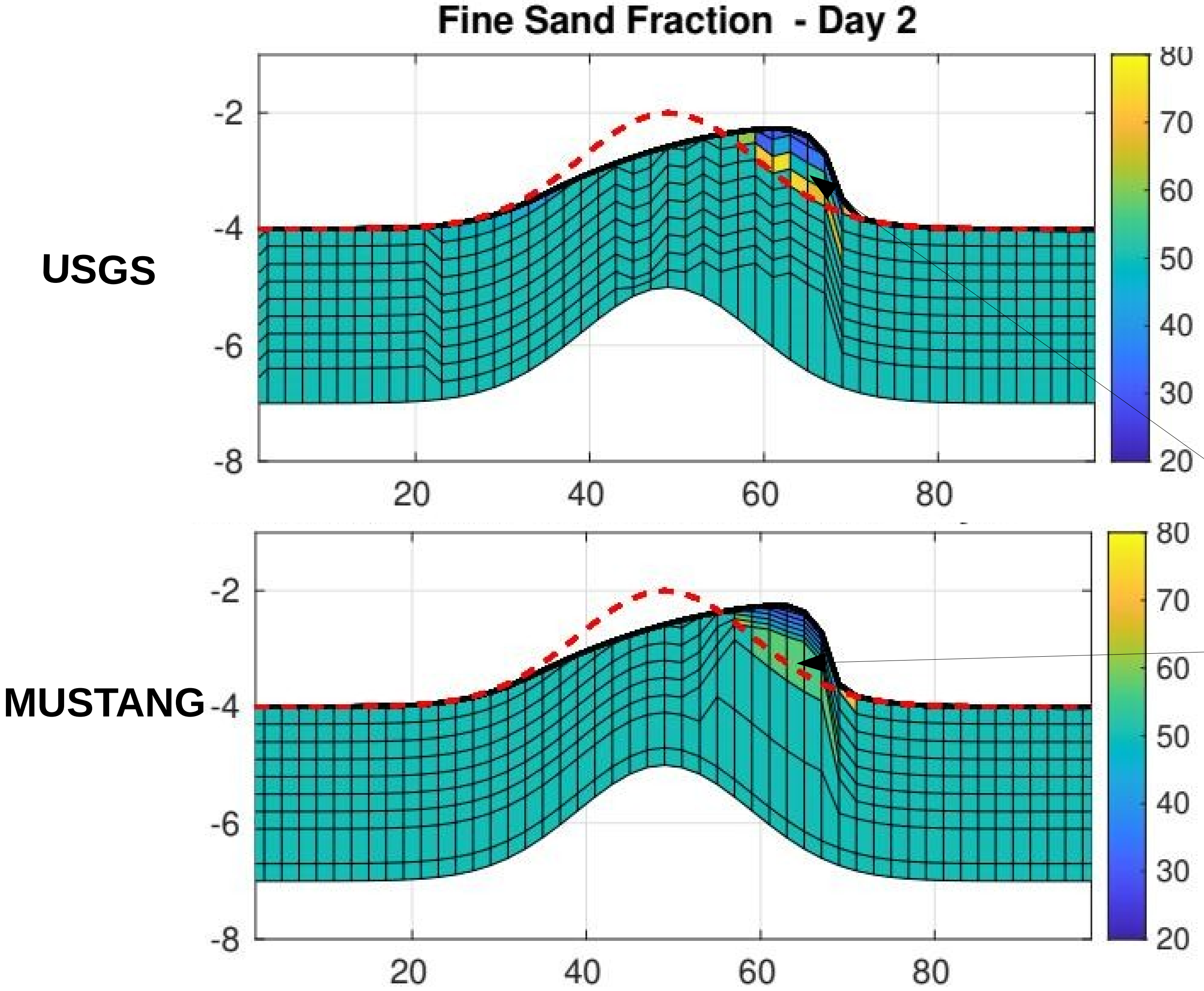
Model vs Obs

Model vs Obs


SANDBAR EROSION LIP-1B - U at Time 18 hour
Depth [m]
0
-1
-2
Initial
Final Model
Final data
60
80
100
120
140
160
180
-0.5
-0.4
-0.3
-0.2
-0.1
0
0.1
0.2
0.3
0.4
0.5
Hrms [m]
1
0.5
0
Model
Flume
U [cm/s]
0
-20
-40
Model
Flume
C [g/l]
4
2
0
Model
Flume
X [m]


SANDBAR ACCRETION LIP-1C - U at Time 13 hour
0
-1
-2
Initial
Final Model
Final data
60
80
100
120
140
160
180
-0.5
-0.4
-0.3
-0.2
-0.1
0
0.1
0.2
0.3
0.4
0.5
1
.5
0
Model
Flume
0
20
40
Model
Flume
4
2
0
Model
Flume
X [m]

Dune test case (default)



The same dynamic but bed stratigraphy have some differences between each model