Sediment modeling

Implementation and use within CROCO
MUSTANG module

solene.le.gac@ifremer.fr

https://croco-ocean.gitlabpages.inria.fr/croco_doc

Outline

Introduction

Implementation in CROCO

- Main formulations
- Code structure

Model options

- Parameters and input files, user guide

Examples

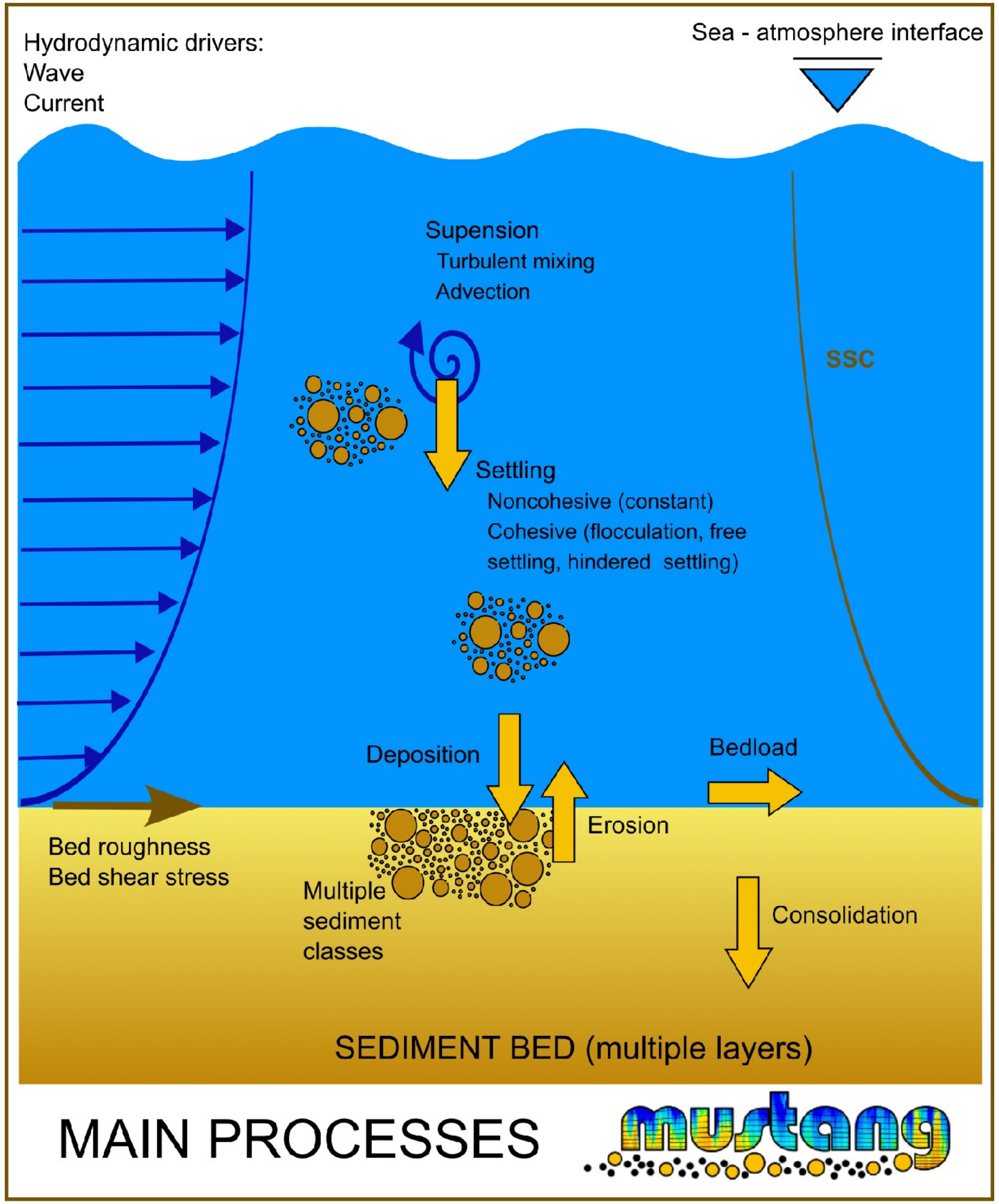
INTRODUCTION

= **MU**d and **S**and **T**r**AN**sport modelli**NG**
Developed at IFREMER by P.Le Hir, in SiAM, then MARS3D and now CROCO

Activated by cppkey **#MUSTANG**

2 main options for this module :

- one equivalent to the previous module “mixsed” (Le Hir et al, 2011) - **default**
- one developed by Mengual & Le Hir (2018), which includes bedload processes (Rivier et al, 2017) - **activated by cppkey #key_MUSTANG_V2**



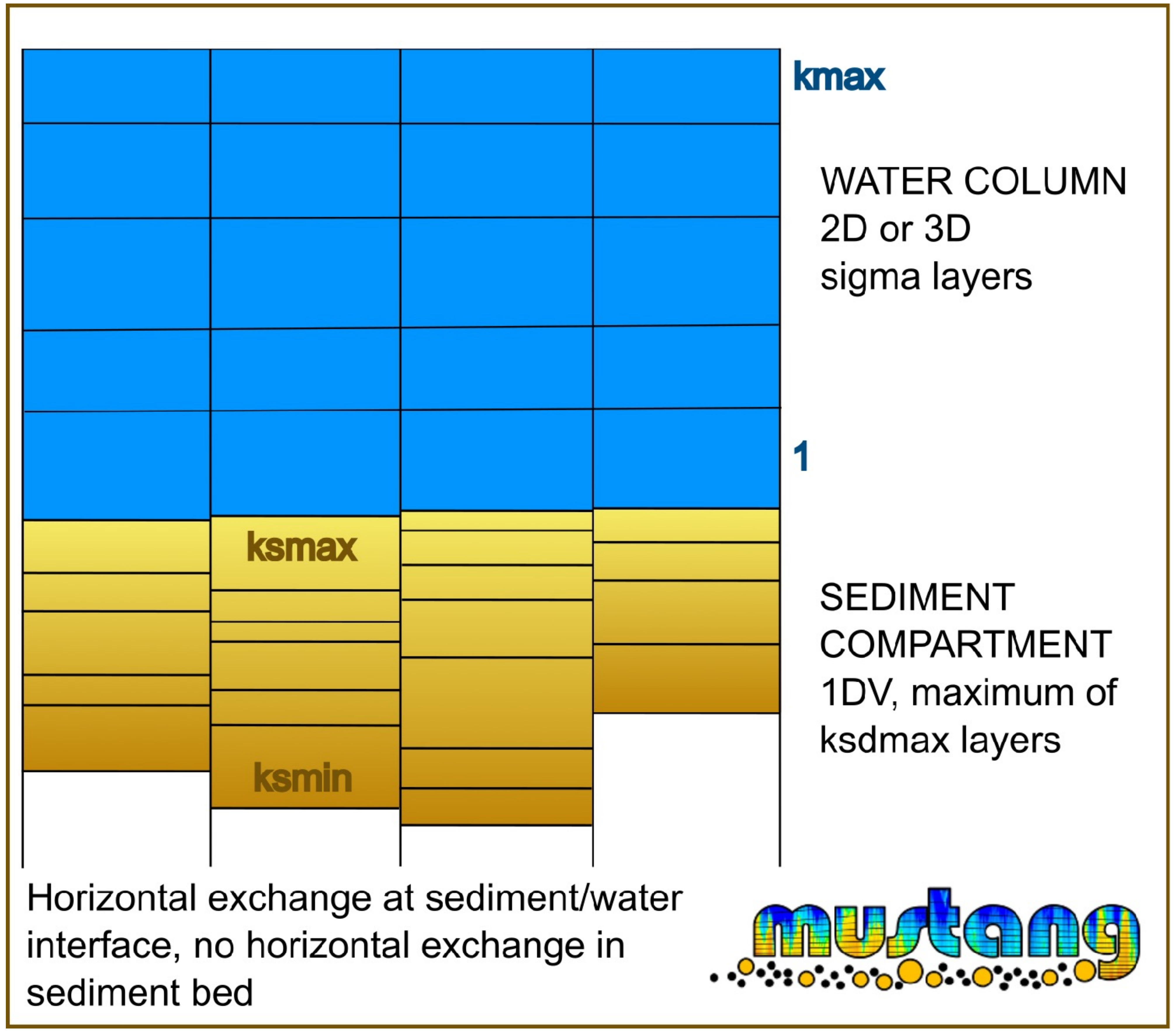
INTRODUCTION

Use sediment classes

Combined with SUBSTANCE module (from MARS too)

3 types of sediment

Type	Bedload transport	Suspended load	Flocculation
MUD	NO	YES	YES
SAND	YES	YES	NO
GRAVEL	YES	NO	NO



No limitation on the number of sediment classes

Implementation

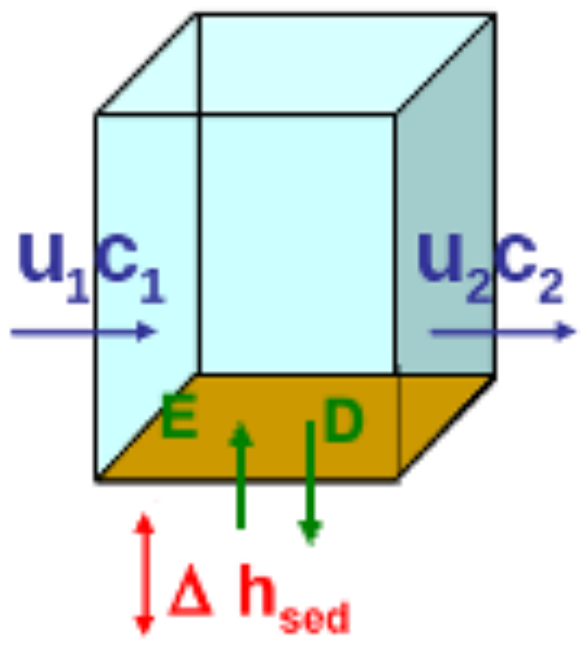
For each class of sediment :

$$\underbrace{\frac{\partial C}{\partial t}}_{RATE} = - \underbrace{\vec{\nabla}.\vec{\mathbf{v}}C}_{ADVECTION} + \underbrace{\mathcal{D}_C}_{MIXING} - \underbrace{\frac{\partial w_s C}{\partial z}}_{SETTLING} + \underbrace{\frac{E}{\delta z_b}\bigg|_{z=z_b}}_{EROSION}$$

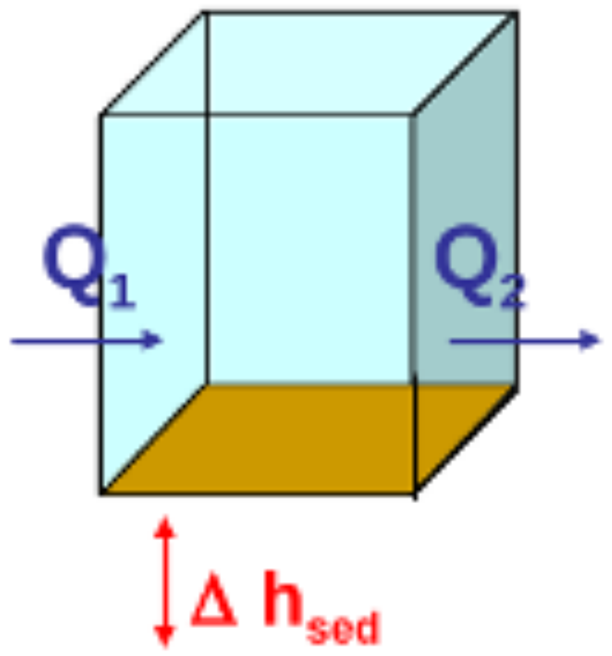
Erosion = f(τ_s,τ_e,bed composition)
Deposit = Ws . f(τ_s,τ_d) . Cbot_extrap
Ws = f(C, turbulence, salinity)
τ_e = f(consolidation)

Evolution of sediment height :

$$\frac{\partial h_{sed}}{\partial t} = \frac{1}{C_{sed}}(D - E)$$



$$(1-p)\frac{\partial h_{sed}}{\partial t} = \frac{\partial Q}{\partial x}$$



- Exchange water-sediment + advection
- Erosion fluxes from sediment bed
- Multiclass interactions

- Wu & Lin 2014 formulation
- Slope effect from Lesser 2004
- Multiclass interactions

Implementation

4 main phases during one time-step

```
call prestep3D_thread()
call step2d_thread()
call step3D_uv_thread()
call step3D_t_thread()
----> call mustang_update_main()
----> call step3d_t
-----------------> # include "t3dmix_tridiagonal_settling.h"
----> CALL mustang_deposition_main
----> CALL mustang_morpho_main
```

Erosion phase :

- Update roughness length
- Update bottom shear stress
- Compute erosion fluxes
- Compute bedload fluxes
- Erosion bed layer management
- Trend of deposit fluxes

Exchange water/sediment including E/D fluxes

Deposit phase :

- Update deposit fluxes
- Deposit bed layer management

Morphodynamic coupling

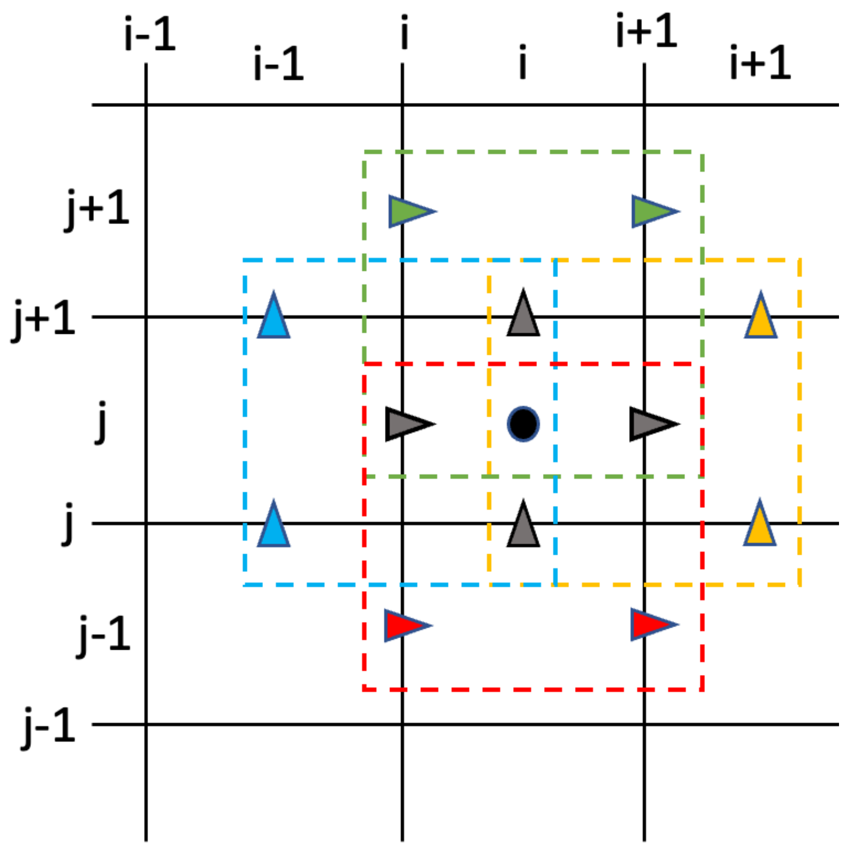
Implementation

Roughness length & Bed shear stress

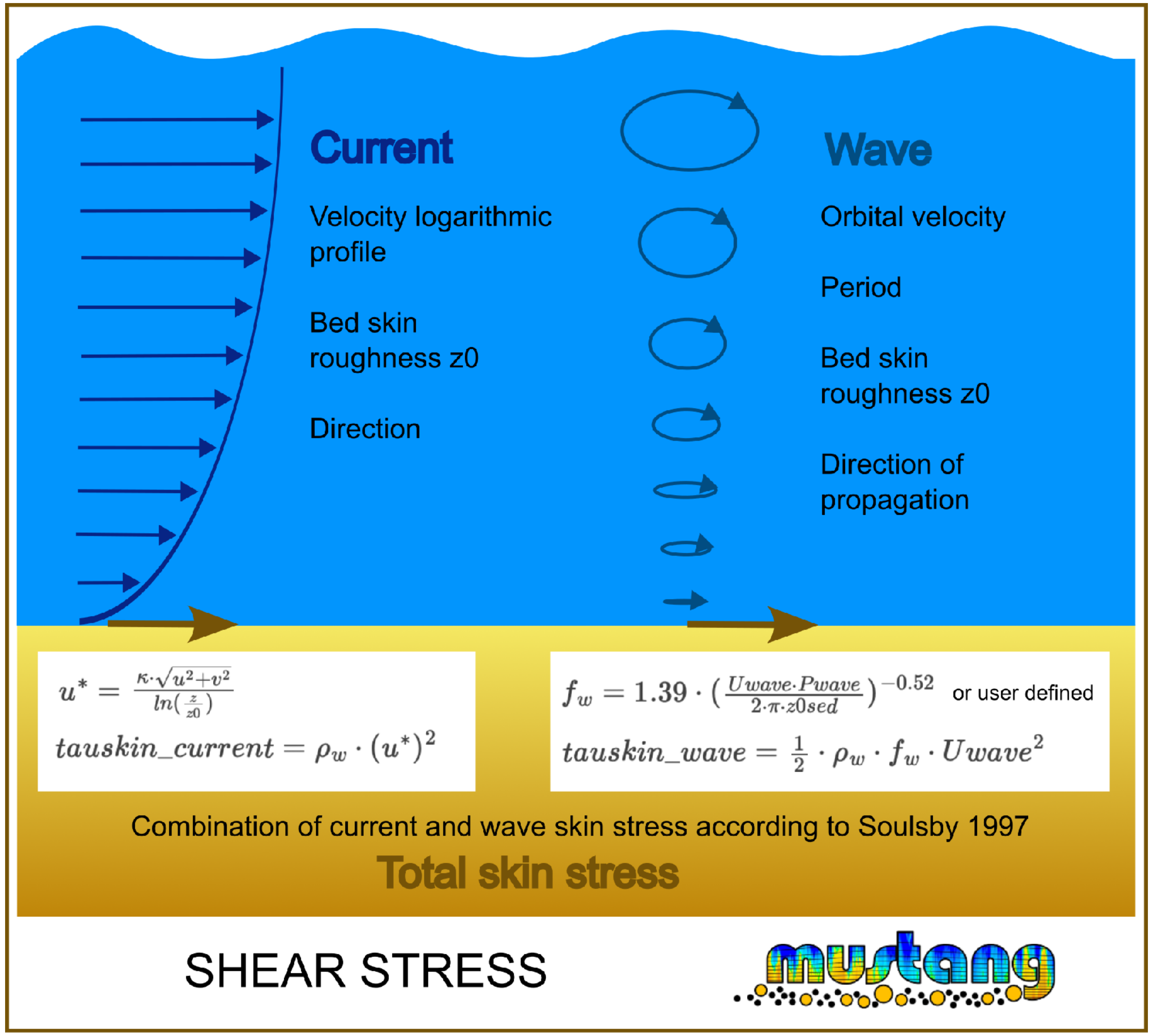
Z0sed : constant (**l_z0seduni** = .TRUE.) ,or diam/12 with diam function of bed composition
Z0hydro : possibility to compute roughness length from bed composition for coupling with roughness in hydrodynamic part

Skin friction :
- Current part (with options to compute current at the center of the cell)
- Wave part if #WAVE_OFFLINE
- Combination (Soulsby 1997)

default : 12 u,v points to compute



If cppkey #WAVE_OFFLINE



Implementation

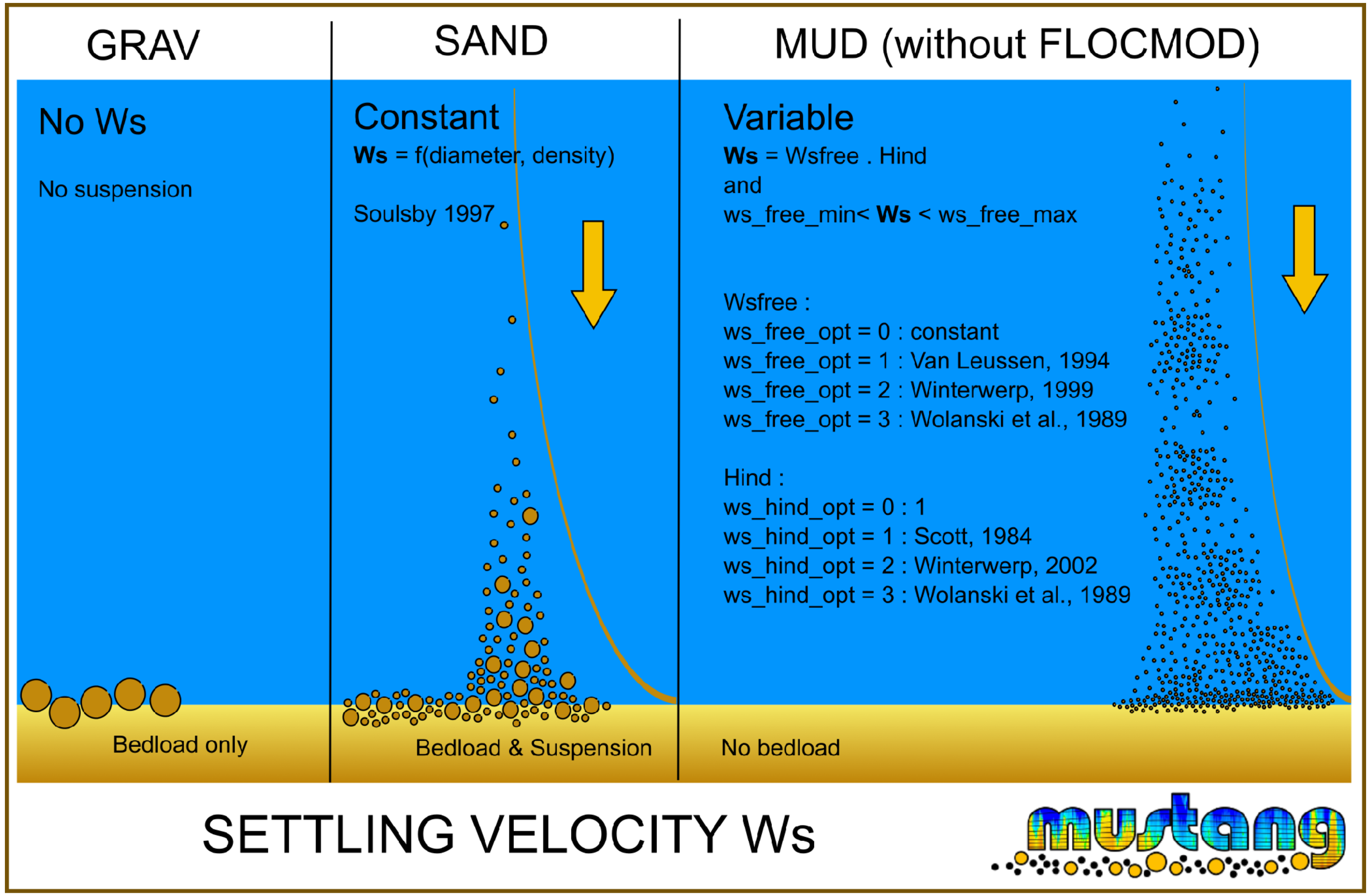
Settling

$$\underbrace{\frac{\partial C}{\partial t}}_{RATE} = -\underbrace{\vec{\nabla}.\vec{v}C}_{ADVECTION} + \underbrace{\mathcal{D}_C}_{MIXING} - \underbrace{\frac{\partial w_s C}{\partial z}}_{SETTLING} + \underbrace{\frac{E}{\delta z_b}\Big|_{z=z_b}}_{EROSION}$$

=> settling velocity w_s

- sink term
- constant or variable (depends of sediment type and input parameters)

horizontal advection : #define TS_HADV_WENO5,
+ sub time step to treat settling *(explicit upwind scheme order 1)*



Implementation

SAND type : High settling velocities

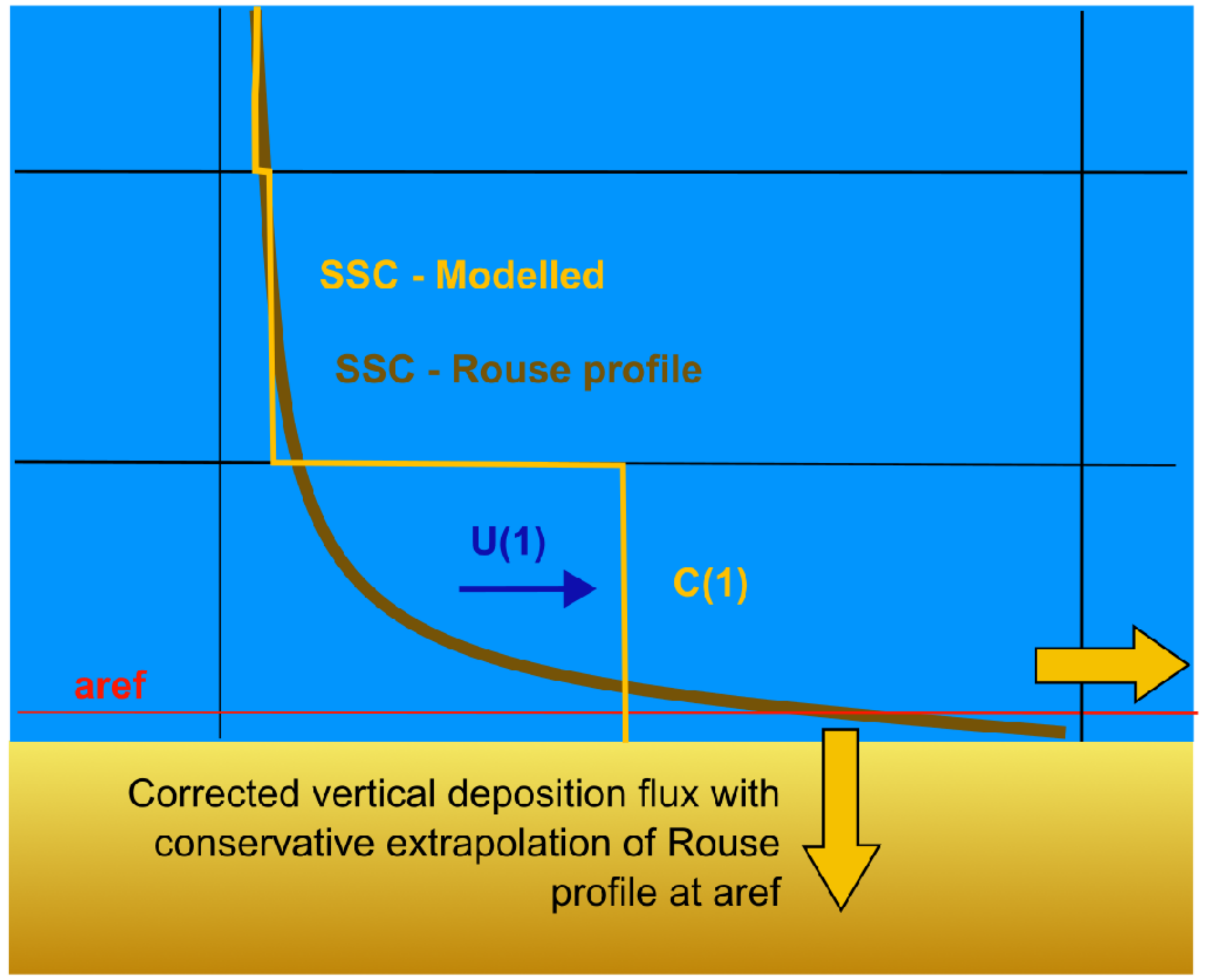
Corrections added :

- deposit from an extrapolated concentration at aref location
- horizontal fluxes corrected in the bottom layer to take into account both velocity and concentration gradients close to the bottom => only if **#MUSTANG_CORFLUX**

$$\underbrace{\frac{\partial C}{\partial t}}_{RATE} = -\underbrace{\vec{\nabla}.\vec{\mathbf{v}}C}_{ADVECTION} + \underbrace{\mathcal{D}_C}_{MIXING} - \underbrace{\frac{\partial w_s C}{\partial z}}_{SETTLING} + \underbrace{\frac{E}{\delta z_b}\Big|_{z=z_b}}_{EROSION}$$

\+

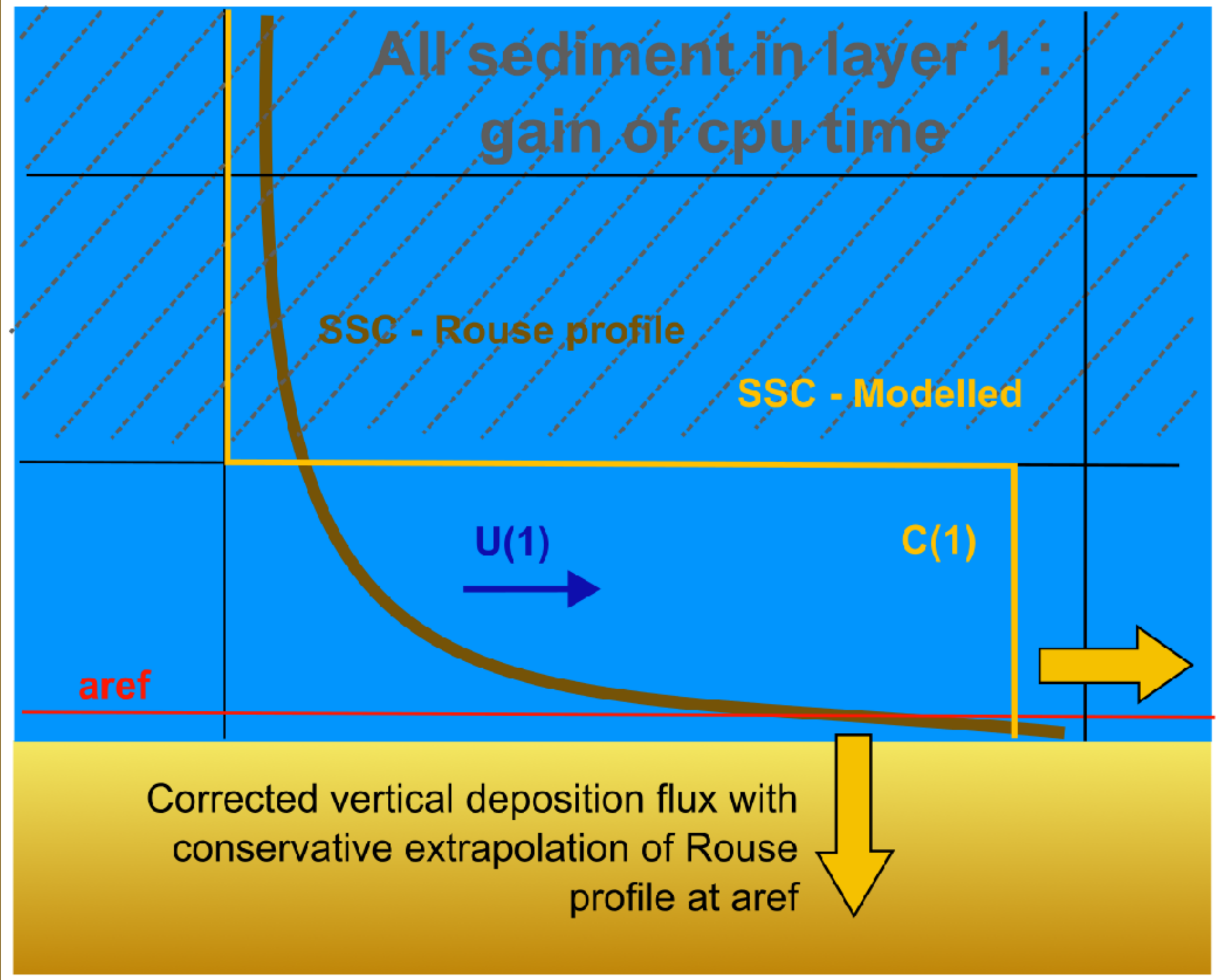
Compute SAND sediment in 2D with cppkey **#key_sand2D** to gain CPU time



SAND suspension corrections in 3D

#MUSTANG_CORFLUX
Horizontal advection fluxes correction factor considering a Rouse profile of concentration and a logarithmic profile of current :

$$\text{corflux} = \frac{\int_{aref}^{zw(1)} C_{rouse}\, u_{log}\, dz}{u(1)C(1)\Delta z(1)}$$



SAND suspension corrections with **#key_sand2D**

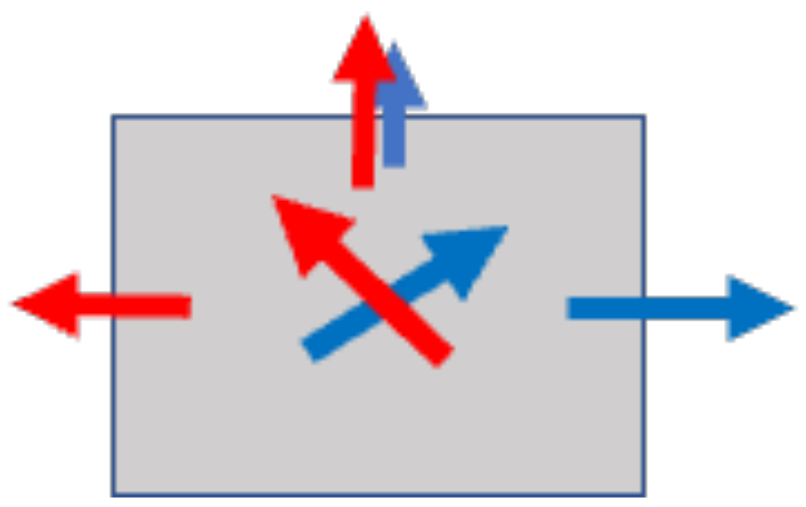
#MUSTANG_CORFLUX
Horizontal advection fluxes correction factor considering a Rouse profile of concentration and a logarithmic profile of current :

$$\text{corflux} = \frac{\int_{aref}^{zw(1)} C_{rouse}\, u_{log}\, dz}{u(1)C(1)\Delta z(1)}$$

Implementation

Bedload (#key_MUSTANG_V2) : Wu & Lin formulation

- Horizontal fluxes are computed on the direction of shear stress evaluated at center of cell
- Both composants (u,v) are extracted during erosion phase
- Fluxes from adjacent cells are then treated like additional deposit fluxes
- Fluxes are limited with available sediment



Slope effect : Lesser et al.

- option : correction of bedload fluxes from bed slope

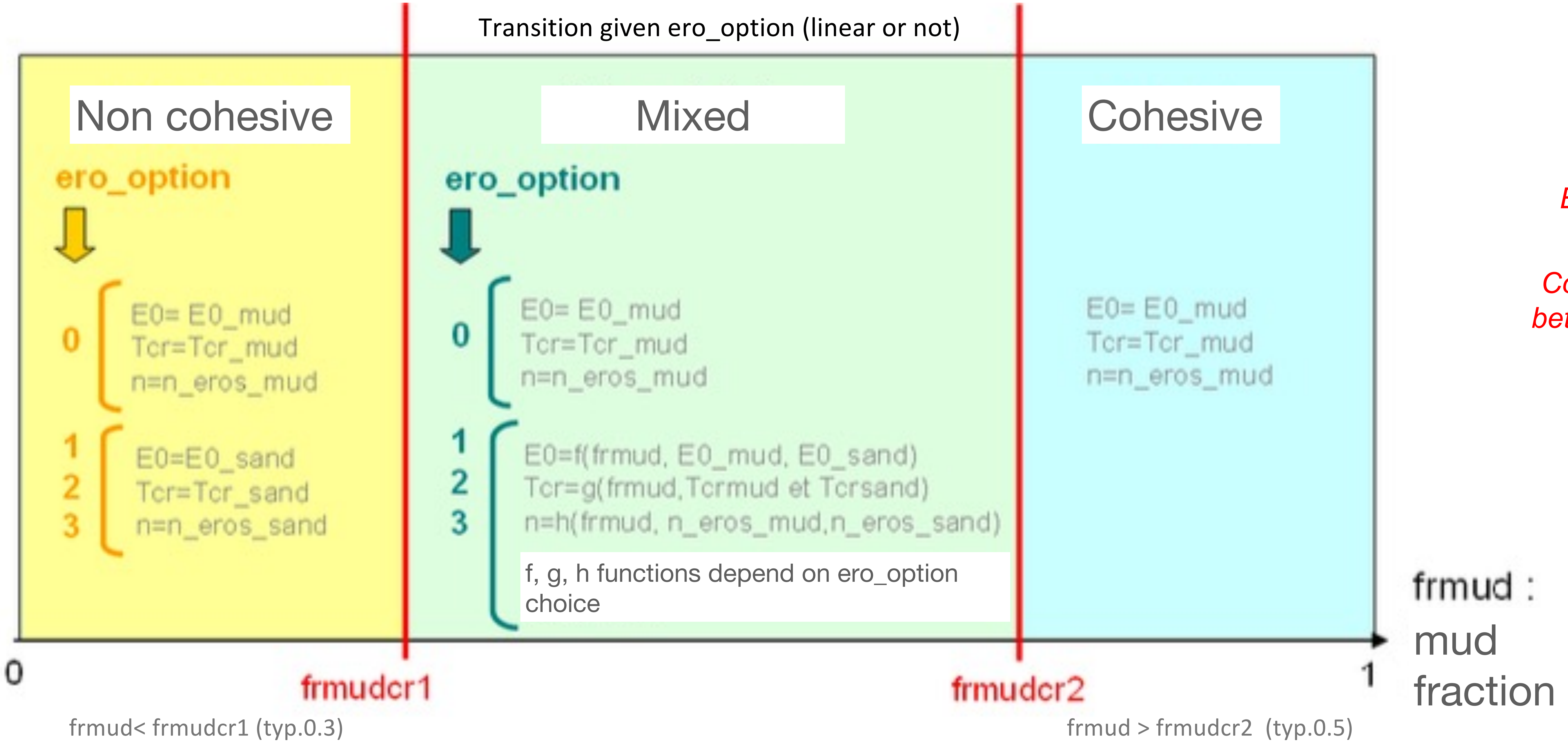
$$\alpha_s = 1 + \alpha_{bs} \cdot \left(\frac{tan(\phi)}{cos(beta\_s) \cdot (tan(\phi) - tan(beta\_s))} - 1 \right)$$
$$qx' = qx \cdot \alpha_s$$
$$qy' = qy \cdot \alpha_s$$
$$\alpha_n = \alpha_{bn} \cdot tan(beta\_n) \cdot \left(\frac{taucr}{tau}\right)^{0.5}$$
$$qx = qx' - qy' \cdot \alpha_n$$
$$qy = qy' + qx' \cdot \alpha_n$$

Implementation

Erosion fluxes in V1

$$E = E_0 \left(\frac{\tau - \tau_c}{\tau_c} \right)^n$$

Superficial sediment ?



NB :

Erosion of sand not realistic

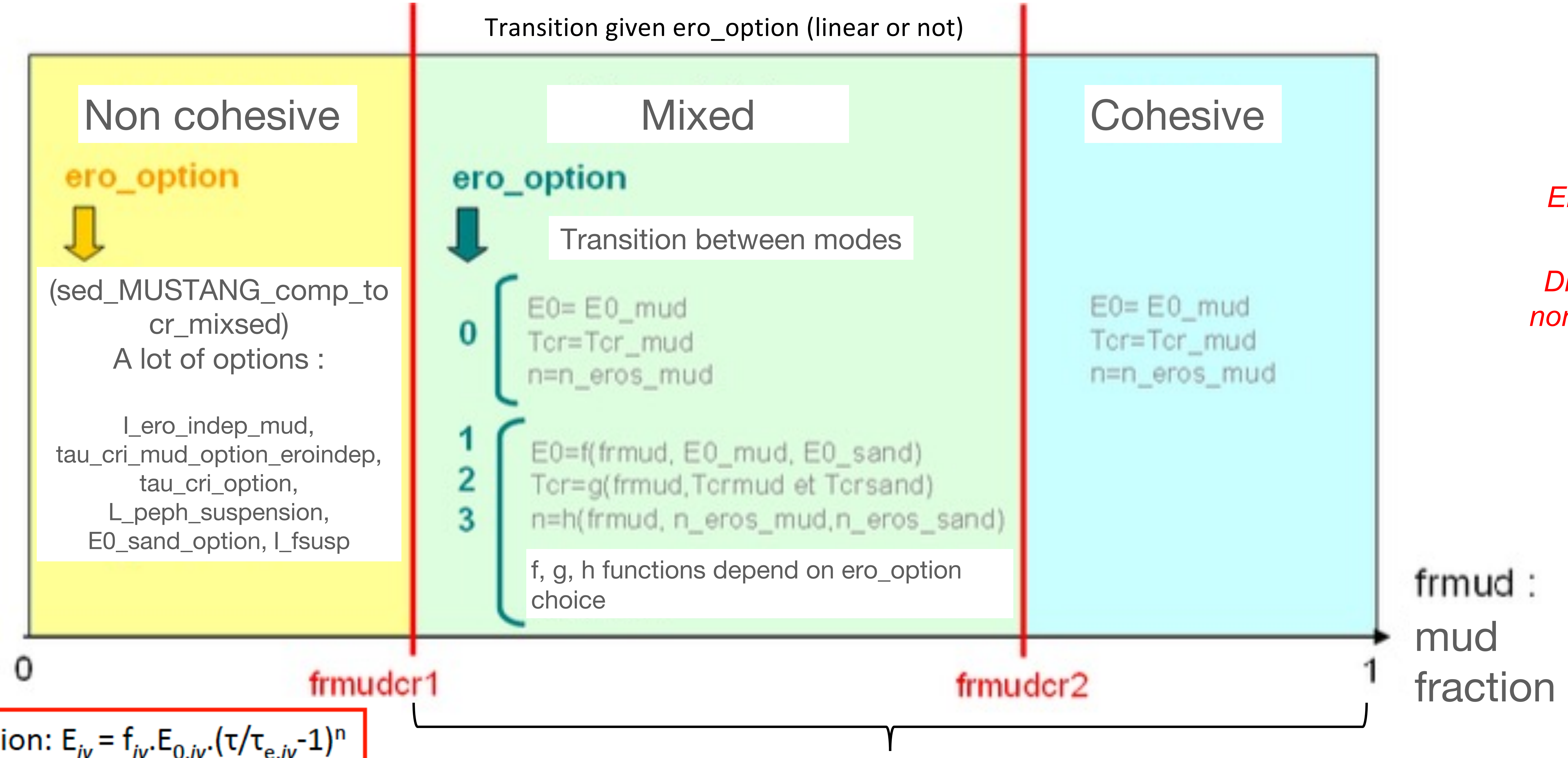
Continuity of transition between non-cohesive / cohesive / mixed regimes

Implementation

Erosion fluxes in V2 (#key_MUSTANG_V2)

$$E_i = E_{0_i}\left(\frac{\tau - \tau_{c\,i}}{\tau_{c\,i}}\right)^{n_i}$$

Superficial sediment ?



NB :

Erosion of sand more realistic

Discontinuity between non-cohesive / cohesive or mixed regimes

Si $\tau_{e,iv} > \tau$

Flux d'érosion: $E_{iv} = f_{iv}.E_{0,iv}.(\tau/\tau_{e,iv}-1)^n$

Indépendant erosion

l_eroindep_noncoh=.TRUE sinon frmudcr1=0.

Erosion of superficial sediment by class proportion

Implementation

Erosion : bed layer management

V1 No bedload

Iterative process over time step

Cohesive, mixed or non cohesive ??

*Erosion of superficial sediment by **class proportion***

update of bed layer with fusion of layer if remaining surface layer is too small

If still time and all layer eroded

V2 (**#key_MUSTANG_V2**)

Iterative process over time step

Cohesive, mixed or non cohesive ??

*Erosion of superficial sediment by **class proportion***

update of bed surface layer and porosity

Indépendant erosion

Combine erosion fluxes and bedload

- compute active layer thickness

- mixing in active layer
- potential bedload by class
- potential erosion fluxes by class

Limitation of fluxes (bedload and erosion) by availability

update of bed surface layer and porosity

If still time and all layer eroded

Implementation

Deposition fluxes

Krone law

$$D_{iv} = W_{s,iv} C_{aref} (1 - \frac{\tau_{skin}}{\tau_{d,iv}})$$

With :

MUD

C_{aref} = C (k=1)

τd = f(concentration of fresh deposit)

SAND

C_{aref} = extrapolation of $C_{k=1}$ at elevation *z=aref,* given a Rouse profile

τd infinity

Implementation

Deposition : bed layer management

V1 : Deposition from the coarsest to the finest

- Each class of gravel or sand sediment is in first put in the existing surface layer until *cvolmaxmel* is reached then the resting sediment is put in a new layer.
- For mud sediment, the deposit is made from the surface when a new layer is created by an exceeding of sand or gravel in order to avoid trapping mud sediment by mixing it in the underneath layer ksmax-1 when a new layer is created.
- Possible cases if there is deposition
  - sediment already exist (ksma > 0) :
    - if superficial sediment is not consolidated (cmudr < *cmudcr*) then mixing with superficial sediment until completion (*cvolmaxmel*) before creation of a new layer
    - else : creation of a new layer
  - no existing sediment : creation of a new layer

V2 (**#key_MUSTANG_V2**) : Simultaneous deposition of gravel, sand and mud.

- For each class , deposit is computed from bedload and settling fluxes

Deposit is different of superficial sediment ? (Density, composition, porosity)

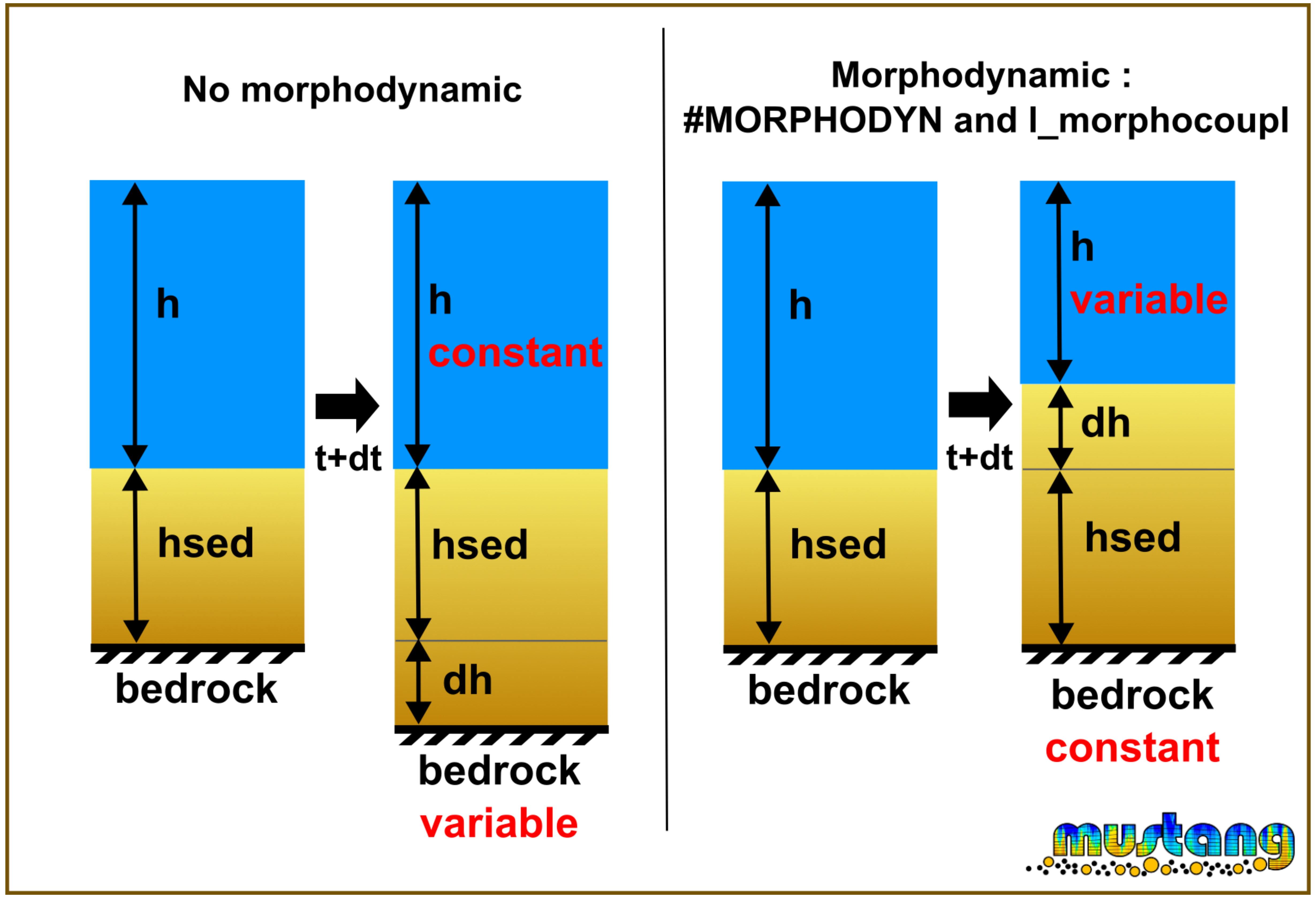
YES → Creation of a new layer

NO → Mixing with the surface layer

Update of porosity

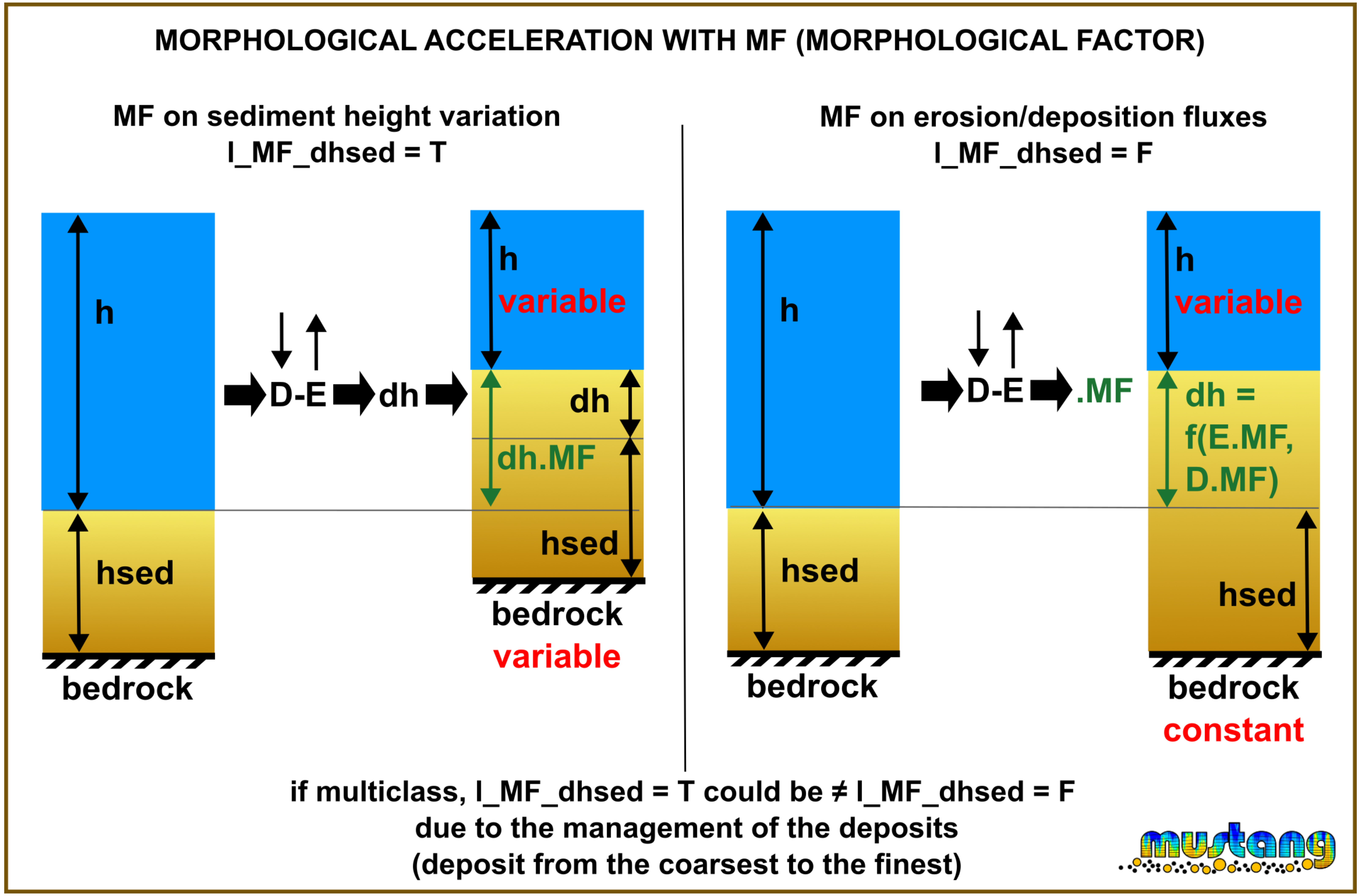
Implementation

Morphodynamic #MORPHODYN. + l_morphocoupl



Implementation

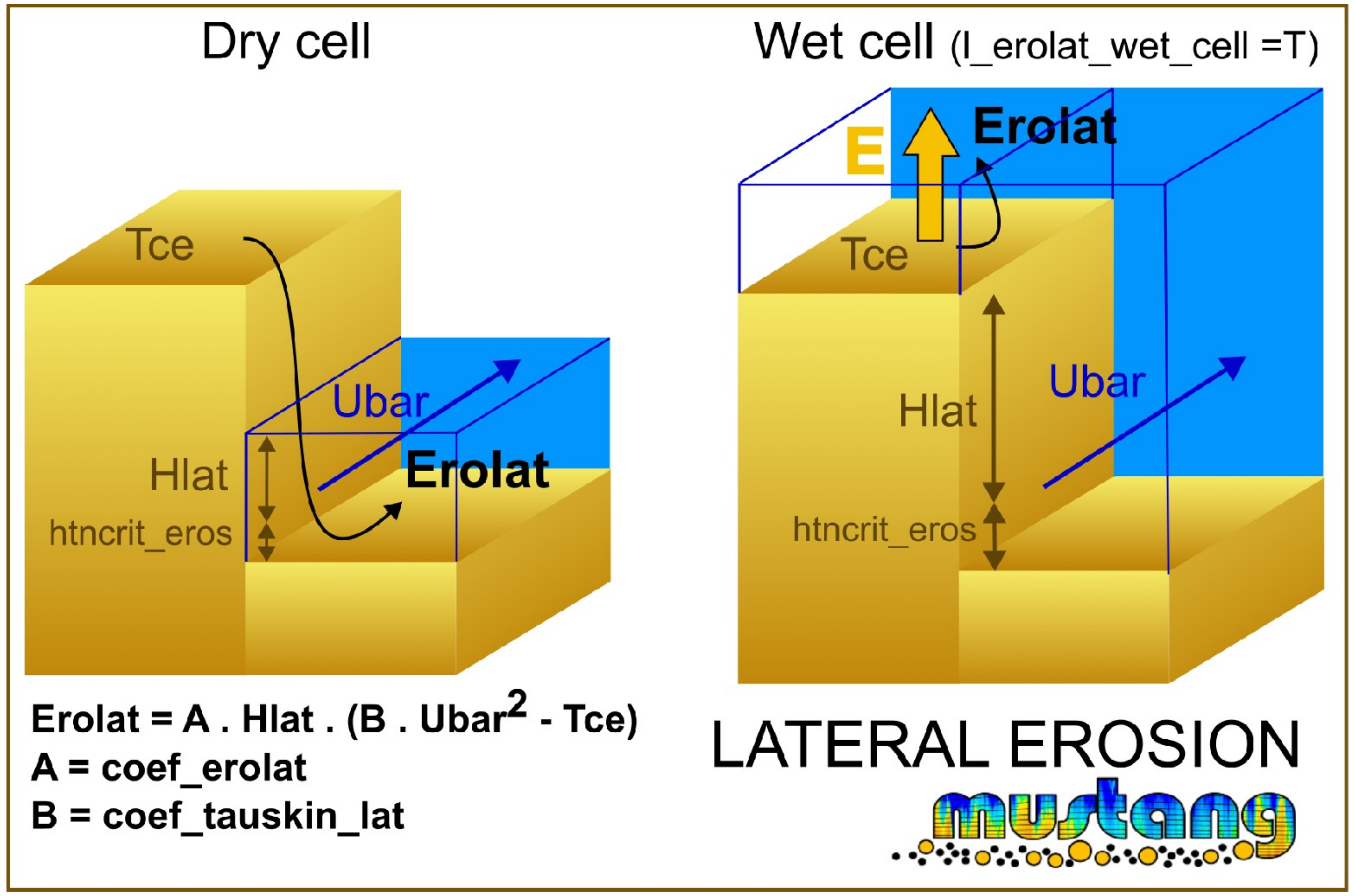
Morphodynamic - MF



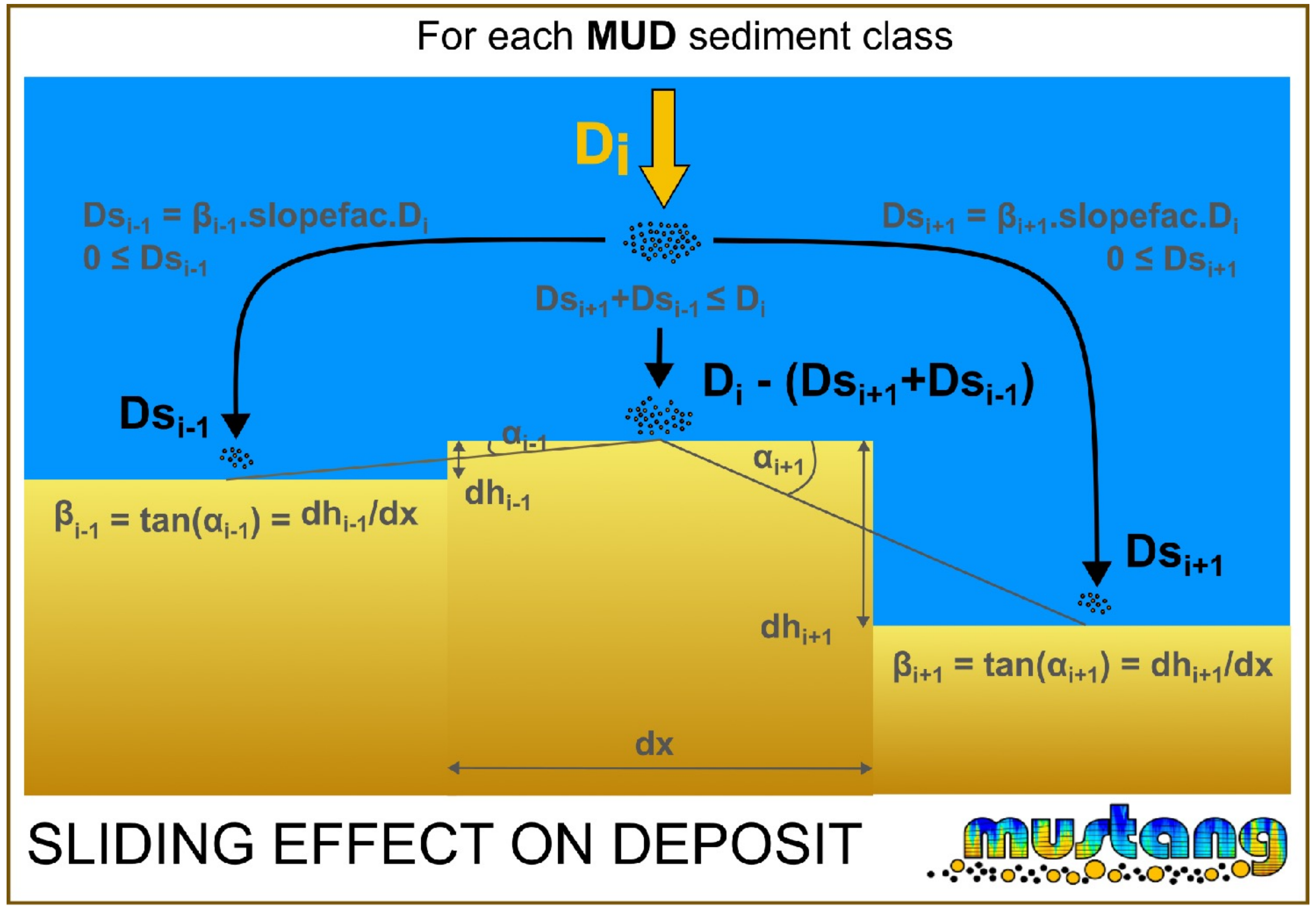
Implementation

Other sediment behaviors

#key_MUSTANG_lateralerosion



##key_MUSTANG_slipdeposit



Model options

Parameters and input file, user guide

MUSTANG is controlled through both **CPP keys** and **input files**.
For some processes it is needed to activate the options through a CPP key, and also through a flag (true or false) in the input files

To use MUSTANG in CROCO :

- **cppdefs.h** >> **#MUSTANG #SUBSTANCE #SALINITY #TEMPERATURE #USE_CALENDAR #key_noTSdiss_insed #key_nofluxwat_IWS** + *option cppkeys*

- **croco.in** >> MUSTANG and SUBSTANCE files

- **param.h** >> appropriate dimensions

- **options : input files** >> initialization file, wave file, source with solid discharge file

Model options

Option CPPKEYS

key_MUSTANG_V2	to use MUSTANG in V2, without this key, the version V1 is used
MORPHODYN	to activate morphodynamic
key_sand2D	to treat SAND in suspension as 2D variable
MUSTANG_CORFLUX	to correct SAND horizontal fluxes
WAVE_OFFLINE	to use wave in bed shear stress computation
key_tauskin_c_upwind	Upwind scheme for current-induced bottom shear stress (for analytical test case)
key_tauskin_c_center	Compute bottom shear stress directly at (rho) location (center of the cell)
key_tauskin_c_ubar	Shear stress computed form depth-averaged velocity
PSOURCE_NCFILE & PSOURCE_NCFILE_TS	to read solid discharge in river from netcdf files
key_MUSTANG_slipdeposit	Add sliding fluxes
key_MUSTANG_lateralerosion	Add lateral erosion process
key_MUSTANG_splitlayersurf	cutting of surface sediment layers to have regular and precise discretization at surface
key_MUSTANG_bedload	only with key_MUSTANG_V2, bedload processus included (if l_bedload activated for the sediment class)
key_MUSTANG_debug	only with key_MUSTANG_V2, not MPI compatible, to print information during E/D
key_MUSTANG_specif_outputs	Adding output variables in history file
FILLVAL	output feature to add fill value attribute in netcdf file

Model options

croco.in

```
sediments_mustang: input file
                   MUSTANG_NAMELIST/parasubstance.txt
                   MUSTANG_NAMELIST/paraMUSTANG.txt
```

param.h >>

ksdmin & ksdmax sediment variables are allocated with ksdim:ksdmax dimension
ntrc_subs number of substance corresponding to a tracer (advected)
ntfix number of fixed substance (not advected)
ntrc_substot total number of substance (= ntrc_subs + ntfix)

Substance namelist >> example MUSTANG_NAMELIST/parasubstance_MUSTANG_full_example.txt

- nmlnbvar : number of each type of substance to be defined (other than T (temperature) & S (salinity))
- nmlpartnc : characterization of Non Constitutive Particulate subtances
- nmlpartsorb : characterization of particulate susbtances sorbed on an other particule
- nmlvardiss : characterization of dissolved susbtances
- nmlvarfix :characterization of fixed susbtances (not advected)
- nmlgravels (if MUSTANG only) : characterization of GRAVEL substances
- nmlsands (if MUSTANG only) : characterization of SAND substances
- nnmlmuds (if MUSTANG only) : characterization of MUD substances
- nmlvarbent (if key_benthic only) : characterization of benthic substances

→ Class parameters : diam, Ws, Cini/obc in water, fraction in sediment …

MUSTANG namelist >> default MUSTANG_NAMELIST/paraMUSTANG_default.txt

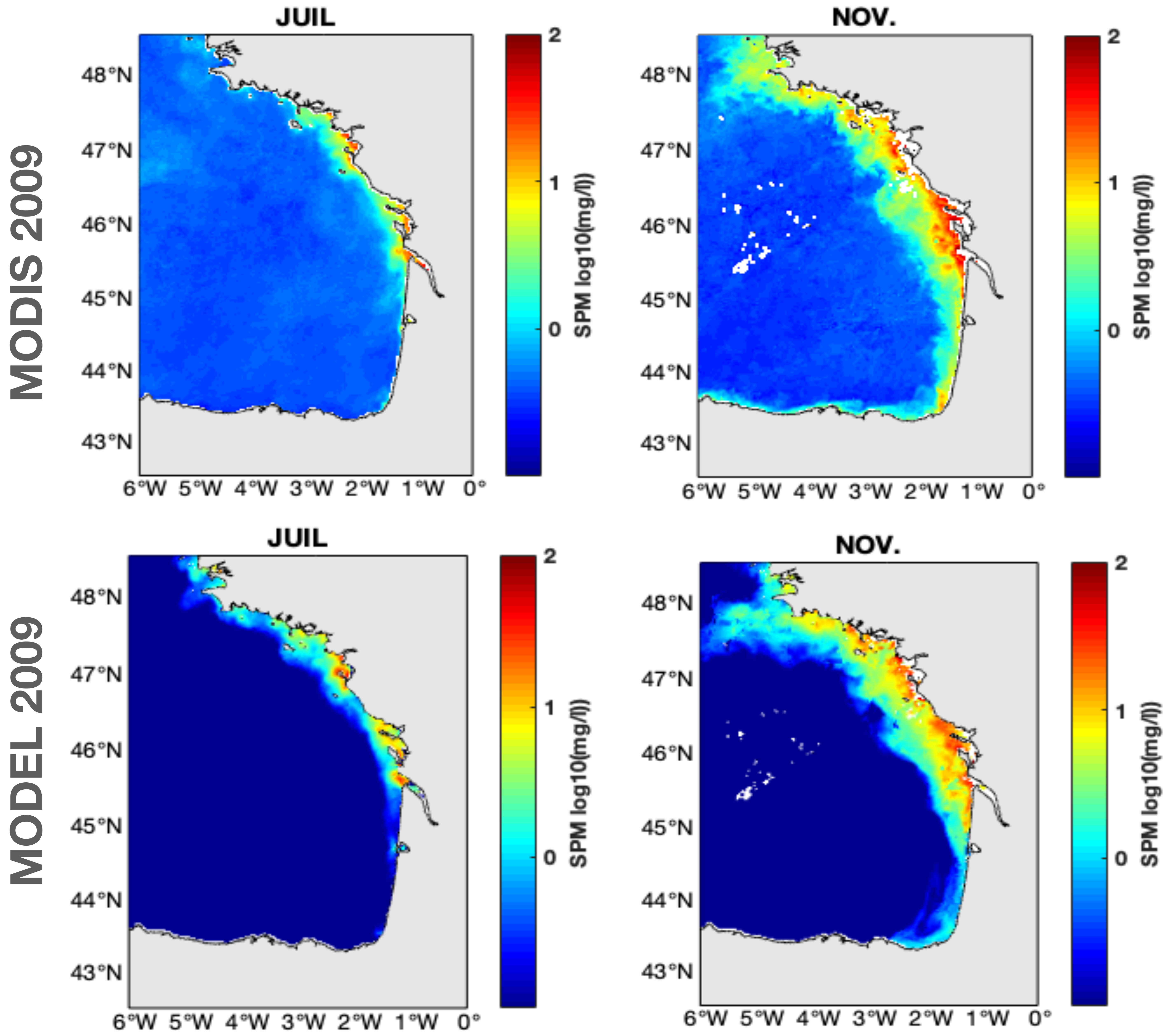
→ Process parameters

Example

Bay of Biscay configuration (dx=2.5km) CROCO-MUSTANG

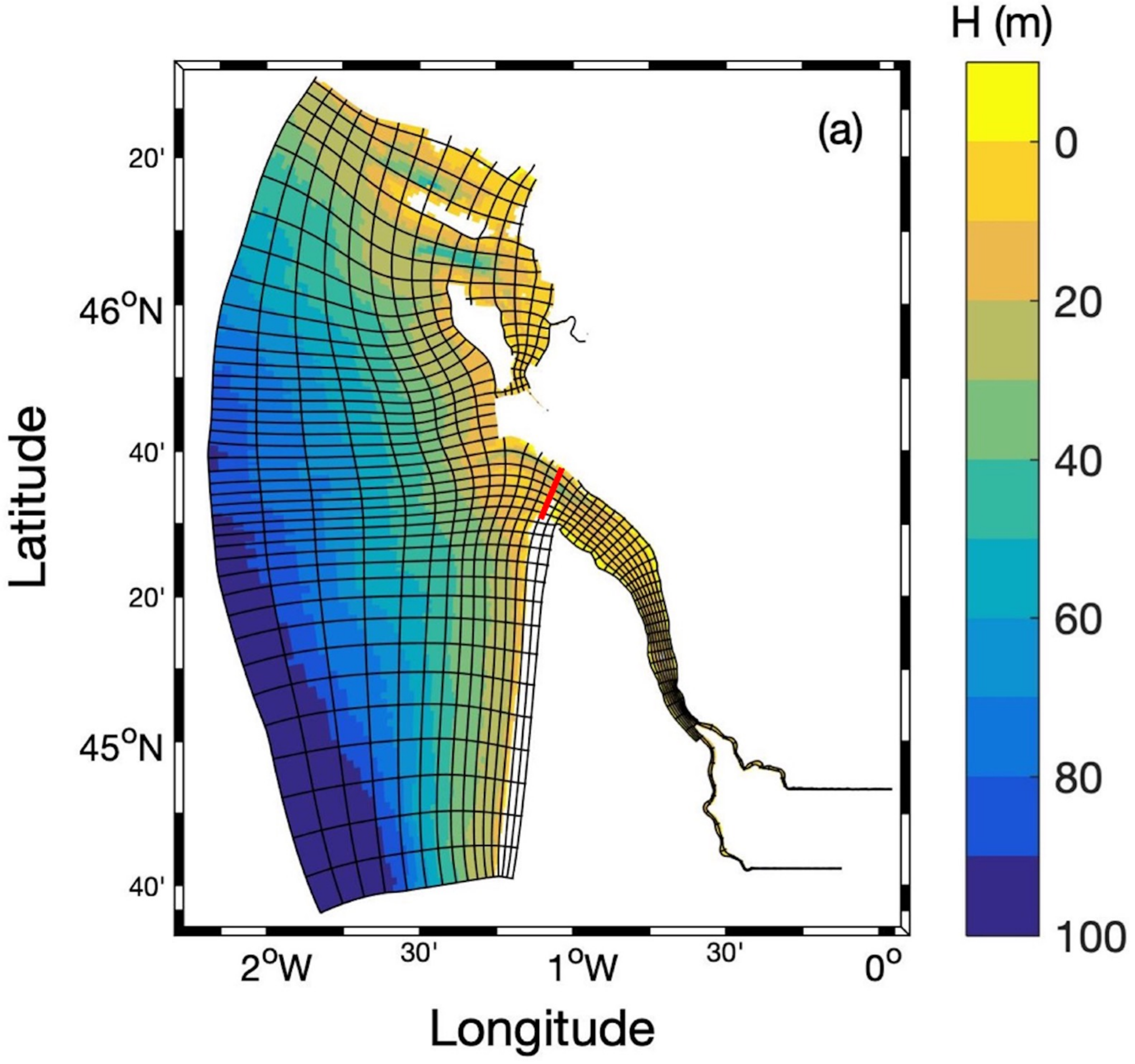
Ongoing work
(illustrations thank to Y.Fossi Fotsi)

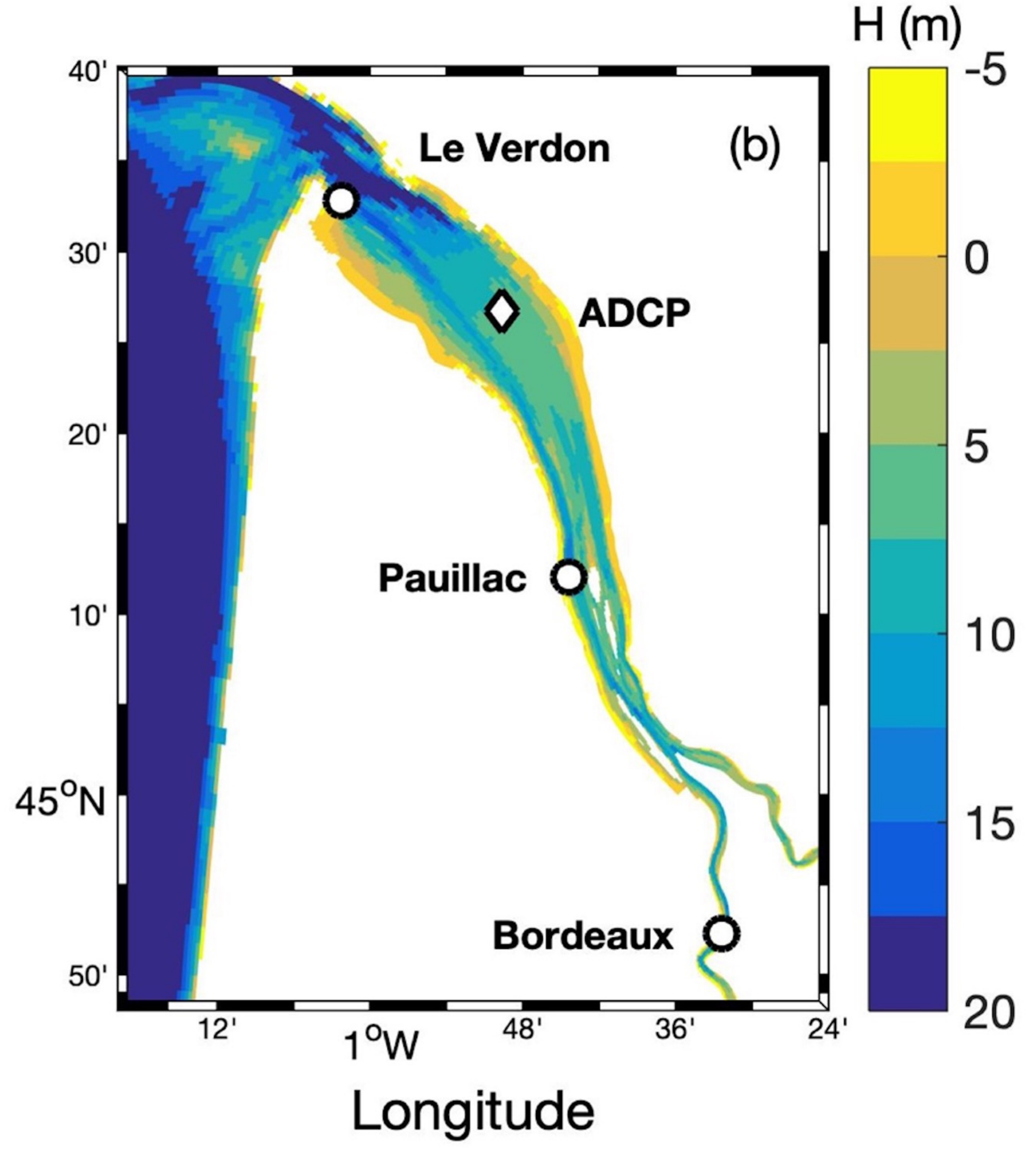
Satellite/Model comparison on surface concentration monthly mean

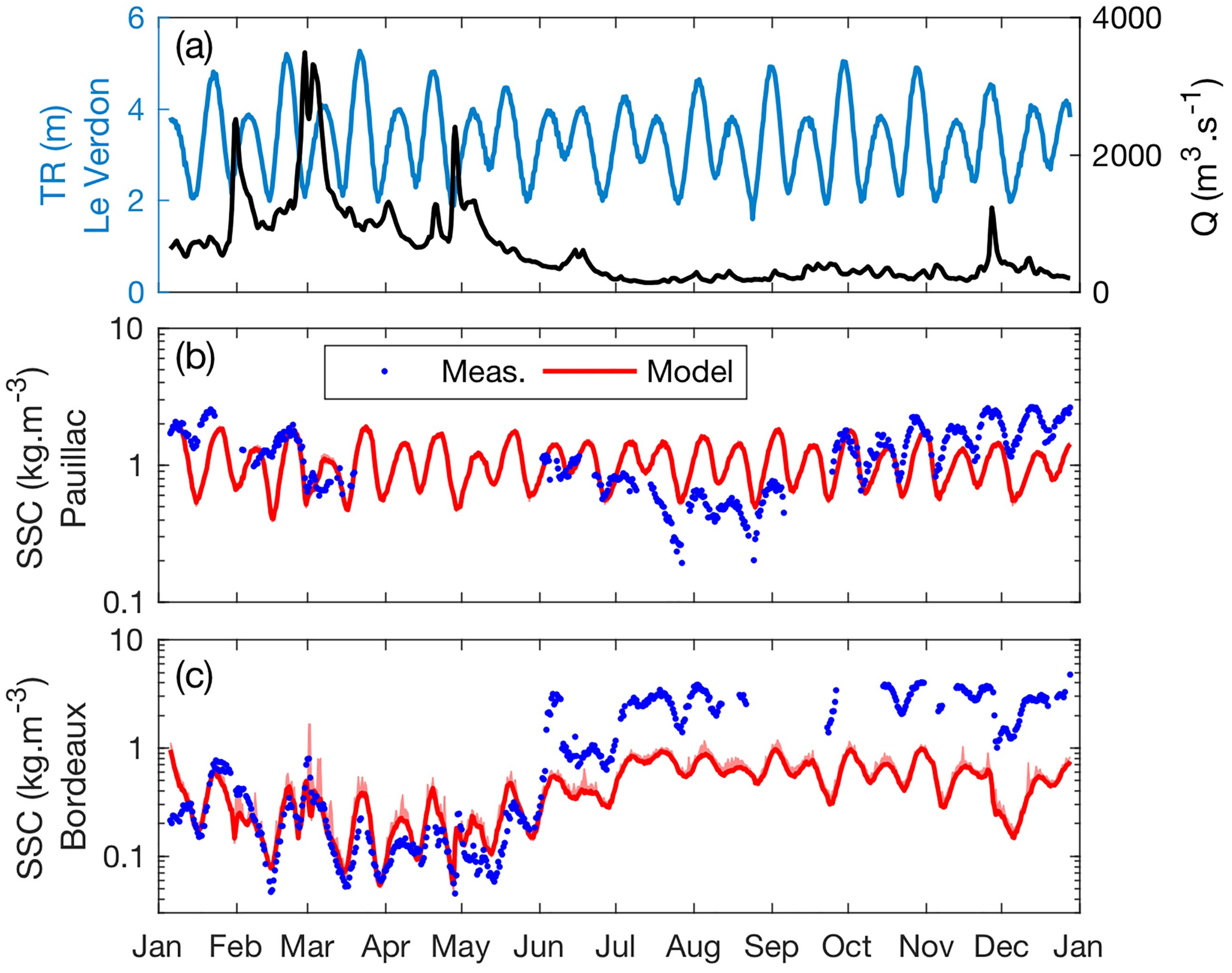


Example

Gironde estuary (MARS3D-MUSTANG)

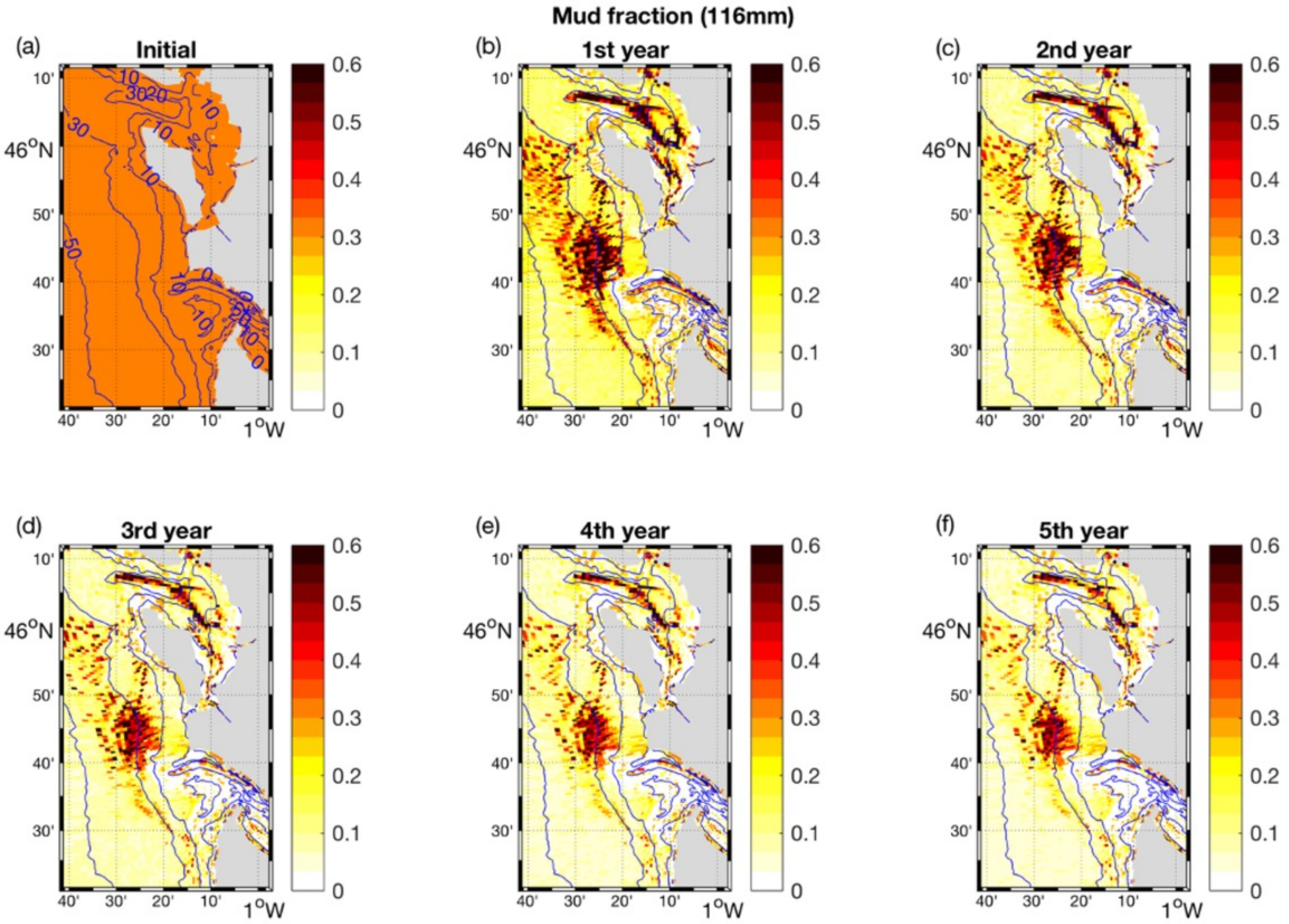






Example

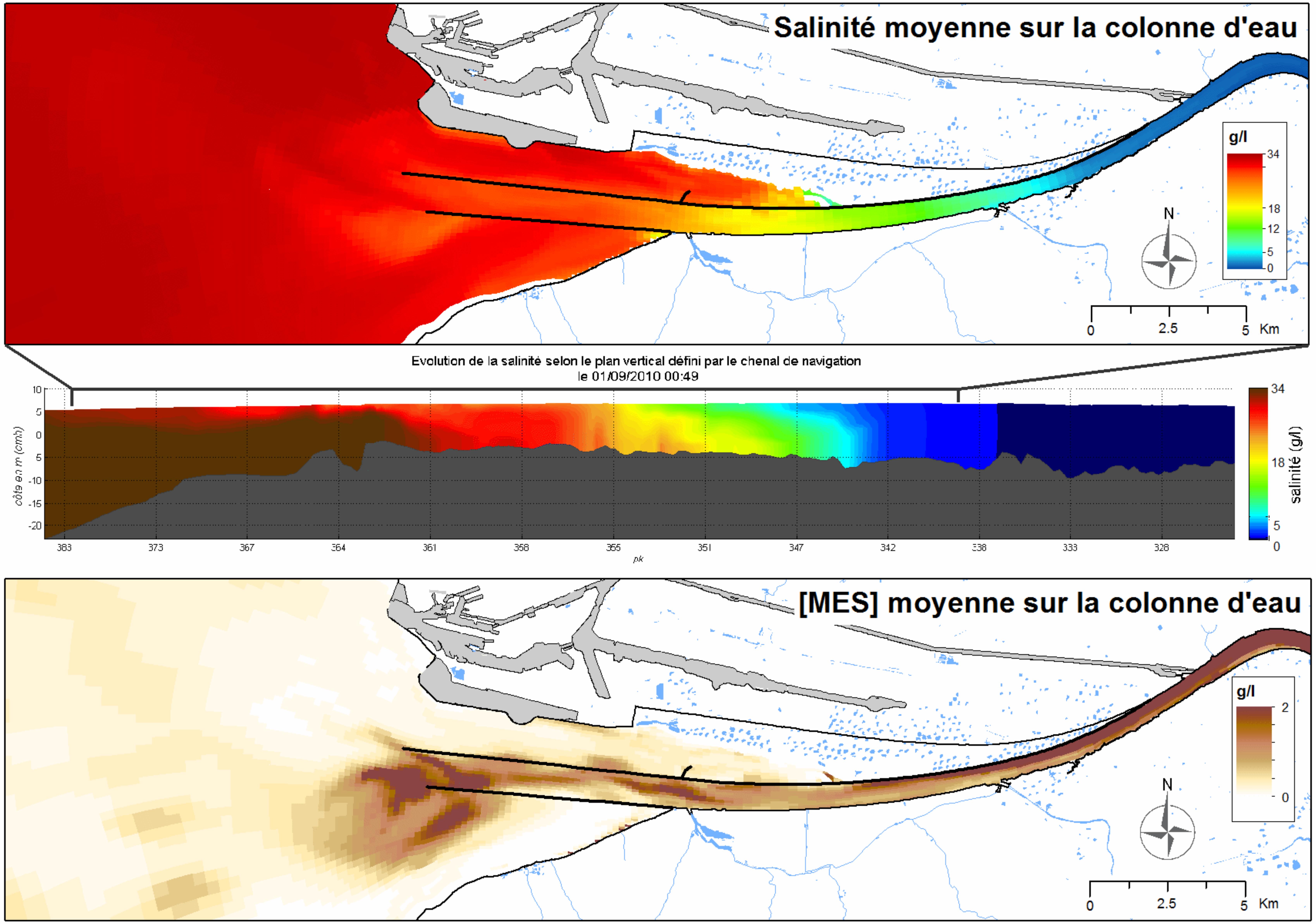
Gironde estuary (MARS3D-MUSTANG)



Numerical simulation of mud fraction within the surficial sediment bed (over 116 mm) in the continental shelf adjacent to the Gironde Estuary during 5 years. (a-f) Median over a neap-spring tidal cycle at the end of each simulated year. Figure from Diaz [2019].

Example

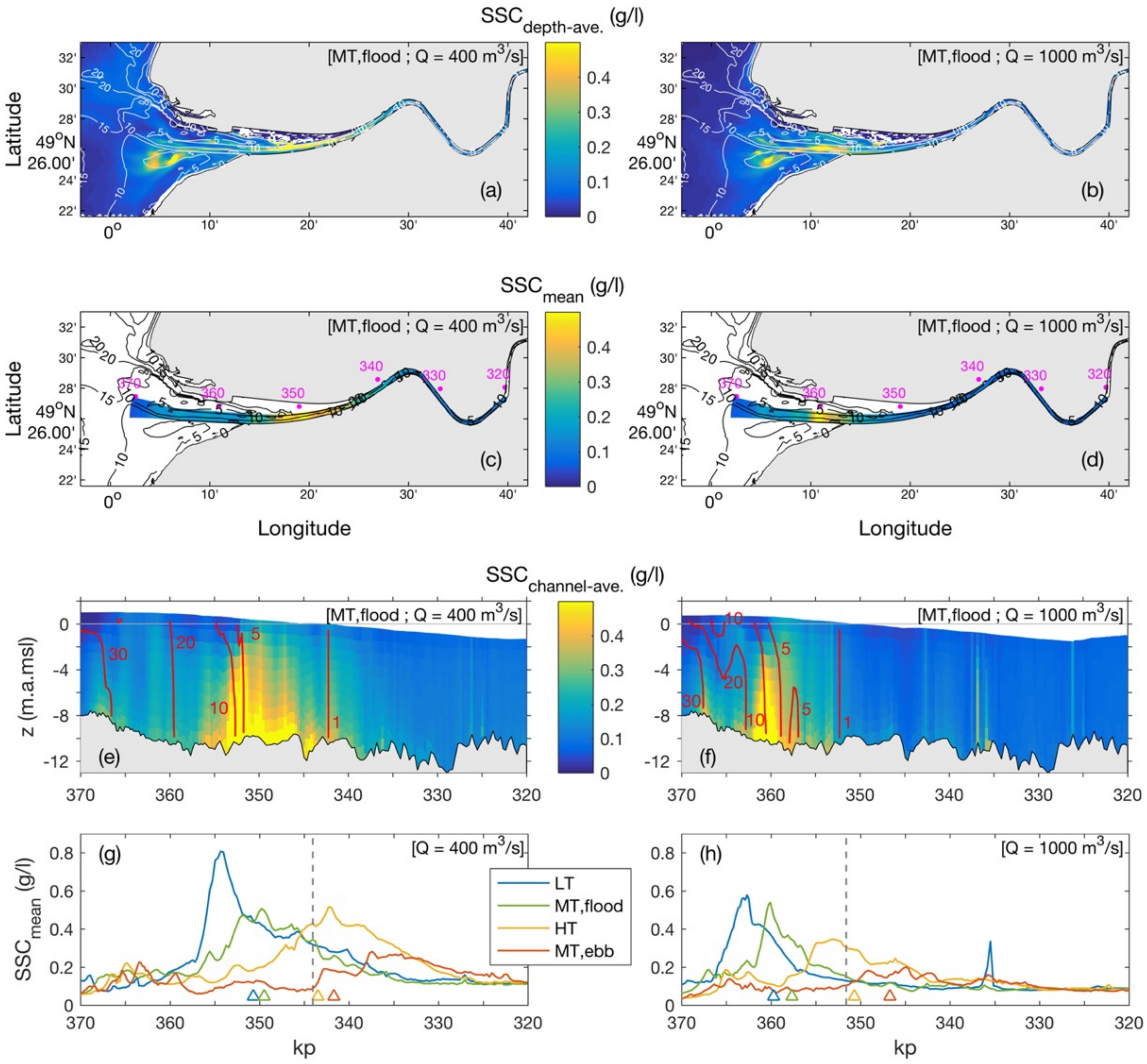
Seine estuary (MARS3D-MUSTANG)



Example

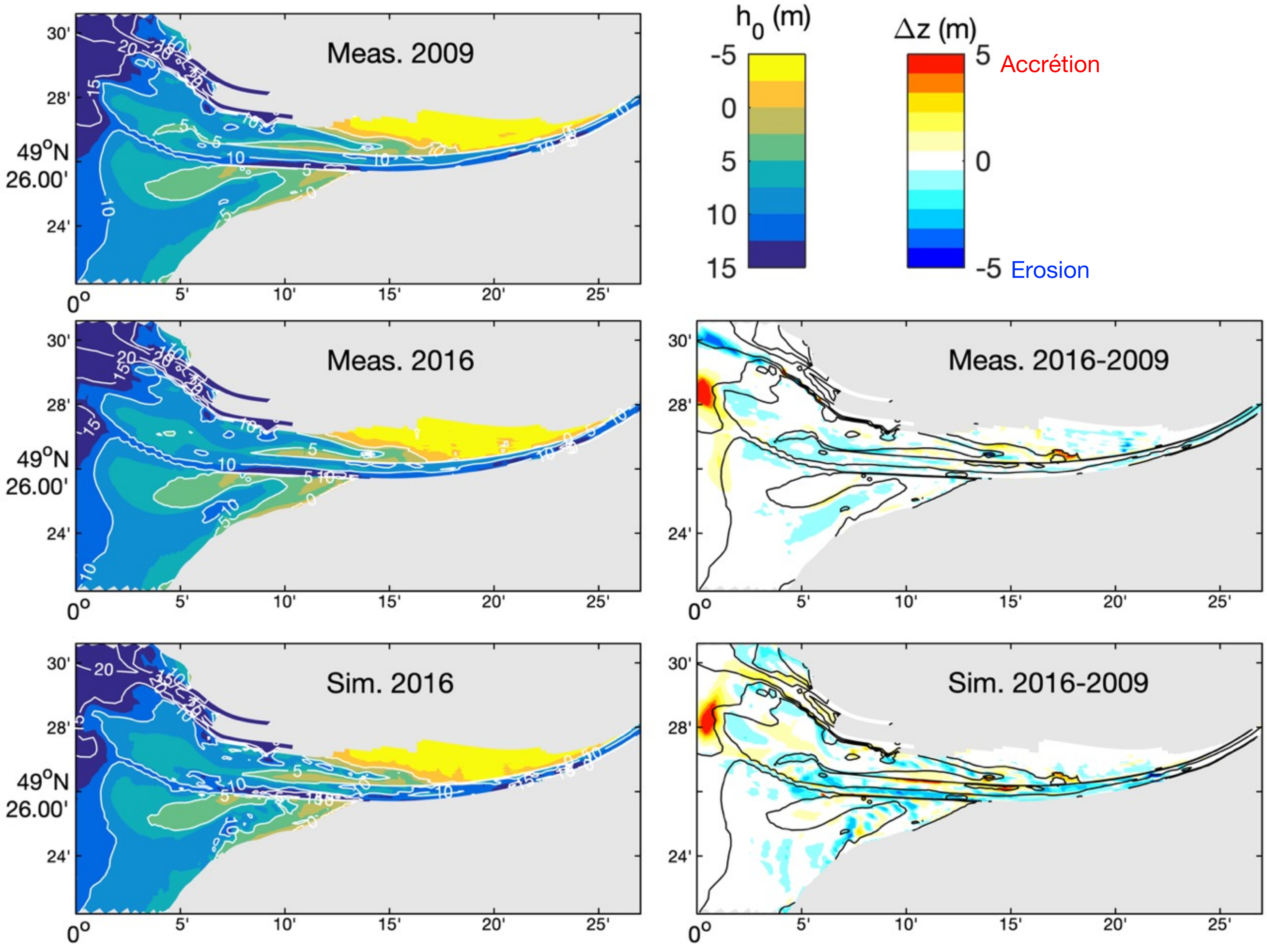
Seine estuary (MARS3D-MUSTANG)

Grasso et al., 2018



Example

Seine estuary (MARS3D-MUSTANG)



SUMMARY

Underway – still processes to test in CROCO-MUSTANG

- Testing on floculation (FLOCMOD)
- Testing on consolidation

To Be Done

- IO features : Mass balance, station
- Effect on density
- Effect of vegetation