Chapter 19

Sediment transport module

In this chapter, the setup for the sediment transport module is described. The following usrdef_ routines, located in *Usrdef_Sediment.f90*, are available for setup, provided the sediment module has been activated with iopt_sed=1:

- usrdef_sed_params: switches and model parameters for the sediment module
- usrdef_sedics: initial conditions for sediments
- usrdef_sed_spec: particle attributes for each fraction

Note that these routine are only called if the sediment module is activated with the general switch iopt_sed.

In the listings below the value inside parentheses indicates the default value.

19.1 Sediment switches and parameters

The switches and parameters, which can be set by the user for the sediment module, are defined in the the routine usrdef_sed_params. The routines is not called if the CIF for sediments has been activated by setting ciffiles(icif_sed)%status='R', either in usrdef_mod_params or through the model CIF.

19.1.1 Sediment switches

Besides the two "generic" switches iopt_sed (for activating the sediment module) and iopt_obc_sed (enabling non-default open boundary conditions for sediments), a total of 22 switches have been implemented in the sediment module.

iopt_sed_bbc	Type of boundary condition at the sea bed (1). 0: no bed boundary conditions (no flux to and from the bed) 1: using the reference concentration (7.124) from Smith & McLean (1977) 2: using the reference concentration (7.125) from Van Rijn (1984a) 3: deposition taken as an advective flux at the bottom, erosion parameterised using equation (7.126) from Partheniades (1965)
iopt_sed_bbc_type	Selects the method to transpose the near bed boundary condition to the computational grid (see Section 7.7.1.1). It is strongly recommended not to change the default value (3). 1: EFDC method applied to lowest cell (not recommended) 2: EFDC method applied to the first the cell above the bottom (not recommended) 3: using the Rouse profile
iopt_sed_bedeq	Type of formulation for bed load transport (1). 1: Meyer-Peter & Müller (1948) 2: Engelund & Fredsøe (1976) 3: Van Rijn (1984b) 4: Wu *et al.* (2000) 5: Soulsby (1997). This equation includes wave effects. 6: Van Rijn (2003). This formula includes wave effects. 7: Van Rijn (2007a). This method includes wave effects.
iopt_sed_beta	The type of equation used for β, the ratio between the eddy viscosity and eddy diffusivity (1). 1: $\beta = 1$ 2: β is defined by the user (parameter beta_cst). 3: Van Rijn (1984b) formulation (7.136)
iopt_sed_ceqeq	The type of model for determining the equilibrium sediment concentration used to evaluate the erosion minus deposition rate for 2-D sand transport (1).

	1: numerical integration of the Rouse profile. 2: using q_t/U determined with the equation of Engelund & Hansen (1967). The precise form is also determined by the switch iopt_sed_eha. 3: using q_t/U using the formulation by Ackers & White (1973). 4: using q_s/U using the formulation by Van Rijn (2003). This formulation is very similar to Van Rijn (1984b), but takes wave stresses into account. 5: using q_s/U and the method of Wu *et al.* (2000).
iopt_sed_dens	Disables (0) or enables (1) sediment contributions in the equation of state and for the calculation of the buoyancy frequency and baroclinic pressure gradient (0).
iopt_sed_eha	Switch to select the type of formulation in the Engelund & Hansen (1967) total load formula (7.86) (1). 1: original form 2: Chollet & Cunge (1979) form (7.87) as function of θ_*
iopt_sed_filter	The type of filter used to prevent the occurrence of negative concentrations (0). 0: no filter 1: Bartnicki (1989) filter.
iopt_sed_floc	Type of flocculation factor for the settling velocity (0). 0: flocculation effect disabled 1: Van Leussen (1994) equation (7.46) 2: Van Rijn (2007b) equation (7.48) 3: combination of the two previous methods
iopt_sed_hiding	Type of formulation for the hiding factor (0). 0: hiding disabled 1: Wu *et al.* (2000) equation (7.36) 2: Ashida & Michiue (1972) equation (7.37)
iopt_sed_hindset	Type of formulation for hindered settling (0). 0: hindered settling disabled

	1: Richardson & Zaki (1954) equation (7.43) 2: Winterwerp & van Kesteren (2004) formula (7.44)
iopt_sed_median	Method for calculating the median size d_{50} at the sea bed (1). 1: no interpolation 2: linear interpolation (not recommended, especially for a low number of fractions)
iopt_sed_mode	Type of mode for sediment transport (2). 1: bedload transport only computed by a formula, determined by iopt_sed_bedeq 2: suspended load transport only (computed with the advection-diffusion equation) 3: bedload and suspended transport (i.e. option 1 and 2 together) 4: total load transport computed with a formula, determined by iopt_sed_toteq
iopt_sed_nodim	Type of grid mode for the sediment transport (3). 2: depth averaged transport[1] 3: 3-D sediment transport.
iopt_sed_slope	Bed slope effects for bed load transport and critical shear stress formulations (0). 0: bed slope effects disabled 1: bed slope effect effects enabled and using the Koch & Flokstra (1981) formulation for bed load transport
iopt_sed_tau	Type of roughness length formulation for sediments (1). 1: the same as for the hydrodynamics 2: used-defined constant roughness length zrough_sed_cst 3: user-defined spatially non-uniform value
iopt_sed_taucr	Selects type of method for the critical shear stress (1). 1: user-defined value for each fraction

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[1] Note that iopt_sed_nodim is always set to 2 if iopt_grid_nodim = 2.

	2: Brownlie (1981) equation (7.31) 3: Soulsby & Whitehouse (1997) equation (7.32) 4: Wu *et al.* (2000) equation (7.33)
iopt_sed_toteq	Type of method for total load transport (1). 1: Engelund & Hansen (1967). The precise form is also determined by the switch iopt_sed_eha. 2: Ackers & White (1973) 3: Madsen & Grant (1976). This equation includes wave effects. 4: Wu *et al.* (2000). Total load is calculated as the sum of suspended and bed load. 5: Van Rijn (2003). This equation includes wave effects and total load is the sum of suspended and bed load. 6: Van Rijn (2007a). This equation includes wave effects and total load is the sum of suspended and bed load.
iopt_sed_type	Type of sediment (2). 1: sand (non-cohesive) 2: mud (cohesive)
iopt_sed_vadv	Disables (0), enables (>0) vertical settling of sediments and selects the type of numerical advection scheme if >0 and vertical advection for (non-sediment) scalars is disabled (iopt_adv_scal=0). If iopt_adv_scal>0, then either iopt_sed_vadv=0 or equal to the value of iopt_adv_scal (3).
iopt_sed_wave_diff	Selects the turbulent diffusion coefficient due to waves (0). 0: No diffusion coefficient 1: According to Van Rijn (2007b)
iopt_sed_ws	Type of method for the settling velocity (1). 1: user-defined value for each fraction 2: Camenen (2007) formulation (7.39) for sand 3: Camenen (2007) formulation (7.39) for mud 4: Stokes formula (7.40) 5: Soulsby (1997) formula (7.41)

6: Zhang & Xie (1993) equation (7.42)

Remarks

- The EFDC method (iopt_sed_bbc_type = 1 or 2) has the advantage that somewhat better results are obtained in theoretical test cases with a high number of vertical layers (typically 100 to 200) than with the default method. However, for a low number of layers such as typically encountered in a real simulation, the results are worse (sometimes even much worse) than the default. Moreover, in case iopt_sed_bbc_type = 1, the results may worsen with an ever higher number of layers. Moreover, in case iopt_sed_bbc_type = 2, some problems with the volume balance may occur, and unphysical result may be obtained in the lowest cells. Because of the greater robustness of the default method (iopt_sed_bbc_type = 3), it is strongly recommended to use only this method.

- The option iopt_sed_tau gives the user the opportunity to calibrate the sediment model. Further, it enables the user to use for example grain-related (skin) shear stresses excluding the effect of bed forms.

19.1.2 Sediment parameters

The following parameters can be defined in usrdef_sed_params. The default values of parameters marked with a "*" can be generally applied and should, in principle, not be changed by the user.

19.1.2.1 Integer parameters

maxitbartnicki	Maximum number of iterations used by the bartnicki filter (100).
nf	Number of sediment fractions (1).
nrquad_sed	Number of vertical locations used by the Gauss-Legendre numerical integration scheme for depth averaging of sediment (equilibrium) sediment profiles (7).
nrquad_wav	Number of time steps used by the Gauss-Legendre numerical integration scheme for phase-averaging over a wave period (10).

19.1.2.2 Real parameters

alpha_VR	Exponent α in the flocculation equation (7.48) by Van Rijn (2007b) (2.19).
a_leussen	Coefficient a in the (7.46) flocculation equation by Van Leussen (1994) [s] (0.02).
b_leussen	Coefficient b in the (7.46) flocculation equation by Van Leussen (1994) [s^2] (0.0024).
beta_sed_cst	Constant value of the eddy diffusivity to viscosity ratio as used in equation (7.136) if iopt_sed_beta=2 (1.0).
cgel	Volumetric gelling concentration used for hindered settling of mud and flocculation [m^3/m^3] (0.0).
cmax	Volumetric maximum concentration for sand at the sea bed used in equations (7.104) and (7.114) for total load and for calculating the reference concentration in the Smith & McLean (1977) formula (7.124) [m^3/m^3] (0.65).
coef_bed_grad	Coefficient β_s used in the bed slope formula (7.83) of Koch & Flokstra (1981) (1.3).
floc_VR_max*	Maximum value for the flocculation factor ϕ_{floc} in equation (7.48) by Van Rijn (2007b) (10.0).
floc_VR_min*	Minimum value for the flocculation factor ϕ_{floc} in equation (7.48) by Van Rijn (2007b) (1.0).
height_c_cst	Constant reference height a (normalised by the water depth) if iopt_sed_bbc=0 (0.01).
maxRV*	Maximum value for the reference height a (normalised by the water depth) (0.1).
minRV*	Minimum value for the reference height a (normalised by the water depth) (1.0E-05).
n_RichZaki*	Exponent in equation (7.43) for hindered settling by Richardson & Zaki (1954) (4.6).
parth_coef	Coefficient M in the formulation (7.126) for erosion of mud by Partheniades (1965) [$m^3/m^2/s$] (1.0E-08).
parth_exp	Exponent n_p in the formulation (7.126) for erosion of mud by Partheniades (1965) (1.0).
wu_exp*	Exponent m used to calculate the hiding factor (7.36) in the Wu *et al.* (2000) formulation (-0.6).

z0_coef*	Factor by which z_0 is multiplied to determine the minimum depth for averaging used in the boundary condition at the sea bed in the EFDC method (iopt_sed_bbc_type = 2 or 3) (30.0).
zrough_sed_cst	Uniform roughness length used for obtaining the (skin) bed stress if iopt_sed_tau=2 [m].

Remarks

- In COHERENS, all concentrations are defined as volume concentrations, even for variables as cgel and parth_coef, where this is not customary in literature.
- The default value of cgel in COHERENS(0.0) is not a valid one for this variable. This is done on purpose. In this way, the user must always provide a value, as this variable is very situation dependent.Typical values in practice are normally in the range between 0.01 and 0.05.
- The non-dimensional height height_c_cst is only used for 2-D simulations with mud, in which case the Rouse profile is integrated from this elevation to the water depth (iopt_sed_nodim = 2, iopt_sed_ceqeq = 1, iopt_sed_bbc = 3).

19.1.2.3 Forcing file parameters

Forcing attributes for the sediment module are defined in routine usrdef_mod_params or by the CIF. The following forcing "files" are used for sediments

- modfiles(io_inicon,ics_sed,:): initial conditions for the sediments
- modfiles(io_sedspc,1,:): attributes of sediment particle fractions
- modfiles(io_sedobc,:,:): specifiers and open boundary data for sediments
- modfiles(io_sednst,1:nonestsets,2): sediment open boundary data for nested sub-grids (one file per sub-grid)

19.2 Initial conditions for sediments

The input type for initial conditions in the sediment transport module are defined via the variable modfiles(io_inicon,ics_sed,1)%status attribute. In order to use a COHERENS standard input file, one must set modfiles(io_inicon,ics_sed,1)%status='R'. In case the status attribute is set to 'N', the procedure usrdef_sedics is used, which is located in *Usrdef_Sediment.f90.*

The initialisation of some variables depends on the values of switches. Some arrays are defined "locally". In that case, the arrays must be given with a different shape, depending on whether the model is applied in parallel or serial mode (see Section 15.2) for details.

The following variables can or must be initialised:

cvol	The volumetric sediment concentration for each sediment fraction. Shape is (nc-1,nr-1,nz,nf) in serial and (ncloc,nrloc,nz,nf) in parallel mode [m^3/m^3].
zroughatc_sed	Skin roughness length at C-nodes for the skin bottom stress in the sediment model if iopt_sed_tau=3. Shape is (nc-1,nr-1) in serial and (ncloc,nrloc) in parallel mode [m].
bed_fraction	The amount of material in the bed for each sediment fraction. Note that the sum over all fractions must be smaller than or equal to 1. Shape is (nc-1,nr-1,nf) in serial and (ncloc,nrloc,nf) in parallel mode.
obcsedatu(nobu,nz,nf,0:2)	sediment concentrations at U-open boundaries (iopt_obc_sed=1)
obcsedatv(nobv,nz,nf,0:2)	sediment concentrations at V-open boundaries (iopt_obc_sed=1)

The particle properties of each sediment fraction are defined in the routine usrdef_sed_spec. In this routine, the physical characteristics (such as material density and particle diameter) are set for each fraction separately. The following vector variables of size nf can be defined:

dp	Particle diameter [m] (10^{-6}).
rhos	Solid density of the particles [kg/m^3] (2650).
tau_cr_cst	Kinematic constant critical shear stress if iopt_sed_taucr = 2 [m^2/s^2] (10^{-4})
ws_cst	Constant settling velocity if iopt_sed_ws = 1 [m/s] (0.001).

Remarks

- The meaning of the arrays obcsedatu, obcsedatv is the same as the scalar arrays for the physics (e.g. obctmpatu, obctmpatv), except that the arrays are defined for each fractions. For details, see Section 15.2.

- The critical shear stress in COHERENS is defined as a kinematic shear stress (i.e. equal to $u_{*,cr}^2$), which is given as the dynamic critical shear stress divided by the fluid density $u_{*,cr}^2 = \tau_{cr}/\rho_f$.

19.3 Sediment open boundary conditions

Open boundary conditions for sediments are defined in *Usrdef_Model.f90*, rather than in the file *Usrdef_Sediment.f90*. Applying open boundary conditions in COHERENS is described in detail in Section 16.2. Open boundary specifier arrays for sediments are defined within the forcing file modfiles(io_sedobc,1,1). Open boundary data profiles of sediment concentrations are obtained from data files whose attributes are stored in modfiles(io_sedobc,2:nofiles,1) where nofiles-1 is the number of files containing sediment data. The user defined routine usrdef_profobc_spec is called if modfiles(io_sedobc,1,1)%status ='N', while the user defined routine usrdef_profobc_data is called when modfiles(io_sedobc,ifil,1)%status = 'N', where ifil is the number of the data file (between 2 and nofiles).

Each sediment fraction is considered to be a separate variable in COHERENS. Therefore, one can assign open boundary conditions for each fraction separately by prescribing different profiles of the variable psiprofdat along the first dimension. This variable is a 2-D array, with along the first dimension the number of prescribed profiles, and on the second dimension the number of vertical cells. These profiles need to be mapped at each open boundary point to the right fraction. This is done with the variables indexprof and indexvar in the subroutine usrdef_profobc_spec.

For more details see Section 16.2

19.4 Sediment nesting

It is possible to export suspended sediment concentrations for nesting in COHERENS. An overview of nesting is given in Section 17.3. In order to use sediment concentrations as open boundary data in a sub-grid model by nesting, it is necessary to set modfiles(io_sednst,ifil,2)%status = 'W', where ifil is the number of the nested sub-grid (between 1 and nonestsets).

Definitions of the grid used for nesting is done similar as for other (scalar) variables in the file *Usrdef_Nesting.f90*, except that two additional arrays need to be defined in usrdef_nstgrd_spec

```
INTEGER, DIMENSION(nonestsets) :: nosednst
INTEGER, DIMENSION(nf,nonestsets) :: instsed
```

where

nosednst	number of fractions for each sub-grid
intsed	fraction numbers for each sub-grid

19.5 Sediment output

Output for sediment is generated by the standard output routines in COHERENS, viz. time series (*Usrdef_Time_Series.f90*), time averaged (*Usrdef_Time_Averages.f90*), harmonic analysis (*Usrdef_Harmonic_Analysis.f90*) and user formatted output (*Usrdef_Output.f90*). The output in COHERENS is described in detail within Chapter 20. Important to note is that output variables may have an extra attribute numvar representing the fraction number in case the model variable has an extra last dimension of nf. This attribute, when needed, has to be stored in the tsrvars, avrvars or analvars arrays.

A list of available key ids for sediments is found in Appendix E.