Benthic species as mud patrol-modelled effects of bioturbators and biofilms on large-scale estuarine mud and morphology

Muriel Z.M. Brückner, Christian Schwarz, Giovanni Coco, Anne Baar, Márcio Boechat Albernaz, Maarten G. Kleinhans

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Explanatory notes for the eco-morphodynamic model

Introduction

This file provides more detailed information on the technical aspects of the dynamic benthos model, including the structure, pre-processing of files and the usage. All files and the model code are provided on GitHub.

In order to use the dynamic benthos model, the interface between MATLAB and Delft3D, provided by Deltares and further described in their Delft3D-MATLAB manual, needs to be saved on the computer and pathed to MATLAB. This toolbox contains the functions that are required to import Delft3D FLOW output data into MATLAB and can be specified in the *Start_model.mat* line 23.

The species parameters are imported into MATLAB from text-files. These files contain information on the critical bed shear stress and erosion parameter of the abiotic and inhabited sediment, the settling and growth period of the species, habitat parameters and random establishment. The files that include the macrobenthos species parameters Bioturbator1.txt and Bioturbator2.txt are subsequently called into the model with the second one automatically the recessive species. The microphytobenthos file Phyto1.txt contains the parameters of the biofilms. There is only one microphytobenthos species possible. Depending on the scenario, the species can be used separately or in combination in the model (defined in *Start_model.mat* under the keywords 'bioturbation' and 'phyto'). Moreover, the user can specify if morphology is computed ('mor' keyword).

All files required to run the Delft3D simulation and MATLAB code need to be located in the same folder (saved under 'directory_head' with the Delft3D model files located at the path 'Delft3D model\initial files'). Throughout the simulation additional folders will be created that contain the current simulation ('work'-folder) and the results per year ('results_*year*').

Coupling of the Delft3D and the MATLAB-model

To facilitate usability, the MATLAB model is started once and calls the Delft3D-model via a batch-file. As a result, at the end of the hydro-morphodynamic computations, the code automatically computes the required benthos parameters, saves the output and restarts Delft3D. This process is repeated over the entire simulation period, leading to online coupling at time intervals of 1 ETS.

The model structure

The dynamic benthos model consists of several code modules to allow for benthos colonization as well as for generation of the in- and output-files required to communicate between Delft3D FLOW and the dynamic benthos model:

The initialization module (*inid3d*) reads the parameters defined in Delft3D by reading the main definition file (*mdf*-file). Then, a first hydromorphodynamic computation (ETS 0) is launched (*iniwork*) to generate the output data necessary to compute the first benthos distribution.

The output-data from Delft3D is imported into MATLAB to compute the benthos distribution (*Extract_parameters*). The hydro-morphodynamic results are processed to determine spatial variation of the water levels, velocities, mud distribution, salinity and erosion and deposition throughout the ETS. A sufficient number of saved time-steps within each ETS is crucial to cover the variability in the hydrodynamics over one ETS (here 20). This data is used both in the bioturbator and microphytobenthos modules. All data is stored and saved in a matrix for post-processing of the results in each result-folder (*d3dparameters.mat*).

Establishment of the benthos is computed based on the habitat of the benthic species that depends on the inundation period, mud fraction and flow velocity (*Colonization_benthos* & *Colonization_MPB*). The suitable cells are then colonized by a relative fraction, which is the minimum fraction that can live under the above parameters. For this fraction, a relative change in critical bed shear stress and erosion parameter are defined for each individual cell. These spatially varying parameters are saved as the *.tce-file and *.ero-file that is called by Delft3D, leading to spatially varying erosion properties of the mud fraction.

List of files

Start_model.mat: this is the administration file where the parameters and paths need to be set and the start file to run the model

Benthos_model.mat: is the main model file that calls the various modules

Inid3d.mat: initializes the parameters necessary to run the Delft3D suite, including time-scales and read parameters from the Delft3D-files that are necessary to compute the benthos computations

Ini_work.mat: initializes the first run in Delft3D to create the first output to run the benthos computations

D3dadmin.mat: handles the time-steps in Delft3D; updates start and stop time of the next computational time-step in the mdf-file for the Delft3D computations

Colonization_benthos.mat: macrobenthos module; reads the bioturbator.txt-files, extracts the environmental parameters from the Delft3D output-files and computes the macrobenthos distribution including the export of matrices of critical bed shear stress and erosion parameter for Delft3D.

Colonization_MPB.mat: microphytobenthos module; reads the phyto.txt file, extracts parameters from Delft3D and computes MPB distribution. If grazers are present, then computation of grazing on MPB. Export of matrices of critical bed shear stress for Delft3D.

data_save.mat: extracts and saves parameters from Delft3D in case no species are present for post-processing

Extract_parameters.mat: extraction and computation of environmental parameters from Delft3D output

d3d_admin_v5.mat: function to handle Delft3D time-scales
growth_distr_bioturb.mat: parabolic growth curve
struct2mat.mat: translates structures into matrices in correct dimensions

Model time-scales

As we require a synchronization between the different time-scales of the hydrodynamic, morphodynamic and ecological computations, the choice of the model time-scales requires careful consideration. The total simulation time defined in Delft3D must be the sum of all ecological couplings (ETS) carried out in the simulation including an initial run to

$$SimulationTime_{D3D} = n_{ETS,year} \times t_{ETS} \times n_{morph.years} + t_{ETS}$$

With total hydrodynamic simulation time in Delft3D left of the equal sign, $n_{ETS,year}$ the number of ETS per year, t_{ETS} the hydrodynamic time per ETS and $n_{morph.years}$ the number of morphological years. This means that for instance 50 years of morphodynamic computations with 12 ETS (meaning monthly coupling) per morphological year requires a total simulation time of $50*12*\ t_{ETS} + t_{ETS}$ in hydrodynamic time. The length of the ETS, meaning the period of the hydrodynamic forcing, can be defined by the user.

The time-scales are based on the assumption that simplified hydrodynamic boundaries represent morphodynamic computations with a morphological acceleration factor of the choice of the user. The user has to predefine the length of the ETS that is an appropriate representation of one morphodynamic/ecological computation time-step and needs to apply the morphodynamic acceleration factor (*morfac* keyword) accordingly.

Similarly, the output interval of the results written to the Delft3D output-file defines the data points used in the benthos or microphytobenthos calculations. As a result, the output must be written at intervals that are a divisor of the t_{ETS} at as dense time-scales as possible but keeping in mind the computational feasibility. For instance, for an ETS of an M2-tide of 744 minutes the output interval must be set to a divisor such as 74.4 min (1/10 ETS) or 37.2 min (1/20 ETS). Each of these data points will be considered in the calculation of the benthos and microphytobenthos distribution leading to a more accurate benthos distribution with smaller time-steps.

Preprocessing of the mdf-file

The set-up of the mdf-file is crucial.
The initial starting conditions can either be read from a restart or trim-file using the *restid*-keyword or from initial constants. Importantly, the initial conditions must be written in subsequent order starting with the water level keyword *zeta0* and ending with the initial concentration of the last sediment fraction *Cn*. This is necessary as the removal of the initial conditions is hardcoded in MATLAB between these two values, meaning that all keywords between these two values will be deleted after the initial ETS 0. When the *restid*-option is used, this step is forfeited.

Preprocessing of the *.txt-files
The txt-files contains all relevant parameters for the computations in MATLAB. It is important to not alter the number of lines and locations of the parameters as MATLAB looks up specific lines in the file to read the data.

Starting the model
After pre-processing all the files and folders, the model is started via the MATLAB-GUI running the code "*Start_model.mat*". The path to the directory has to be added as well as to the files of the interface to MATLAB ("*delft3d_matlab*"). Here, the user can specify several parameters in the model and which codes should be called.

Output for post-processing of the model

Trim-files: contain hydro-morphodynamic computations in Delft3D. Is saved for the last time-step of each year. Output interval can be increased in *Benthos_model.mat* (be careful: very large files, increases computational time; consider specifying output parameters or averaging of trim-file)

bio_type_*x.mat*: structure per *x*=ETS; saves matrices for all macrobenthic species (1-4,7: distributions based on various environmental parameters; 5: new tau crit distribution per species; 6: new erosion parameter distribution per species; 8: final tau crit distribution all species; 9: final erosion parameter distribution all species

*P*x*.mat*: structure per *x*=ETS saves microphytobenthos distribution; new tau crit distribution is saved in *d3dparameters.mat*.

d3dparameters.mat: structure per year; saves matrices of environmental parameters for post-processing for each ETS. depth: bed level, mudfract: mud fraction in top layer, salinity: salinity concentration, Flooding: inundation period, waterdepth: water depth, VelocityMax: 90%-ile of flow velocity, taucrit: critical bed shear stress for MPB presence