Technical Information for

A bio-morphodynamic numerical model involving mangrove dynamics and profile changes

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1. Overview

This Technical Information offers a general explanation on the use of bio-morphodynamic numerical model applied in recent studies by Xie et al. (2020) and Xie et al. (2022). The model was developed specifically to simulate the fate of mangrove forests under the effects of sea-level rise in various coastal conditions, including tidal ranges, sediment availability, waves and coastal slope. Regarding the basic principles and equations used in this model please refer to our research papers (https://doi.org/10.1088/1748-9326/abc122) and (https://doi.org/10.1029/2021JF006301), here we focus on the installation and the usage of our model.

The bio-morphodynamic model contains two parts which interact with each other. The hydro-dynamic model, Delft3D (Deltares, 2014) interacts at given time-step with a dynamic vegetation model realized in Matlab. Tidal flow, sediment transport and bathymetric changes are calculated by the Delft3D model suite, while vegetation responses to the changing environment are calculated in Matlab so as to offer an extra flow resistance in Delft3D hydrodynamic calculations. By implementing the morphological acceleration factor (morfac), long-term profile changes and vegetation behaviors can be obtained by simulating a short-term period of hydrodynamic calculations (Roelvink, 2006).

Note: Results with a slightly different behavior will be obtained if different versions of Delt3D and Matlab are used. Our current research outputs are based on the versions of Delft3D open-source-tag: 7545 and Matlab R2017a. (One compatibility test was carried out with Delft3d open-source-tag: 65936, compiled with Intel Fortran on Windows 10, Matlab 2019b).

2. Time scale of the models

Time defined in this model could be different from each inner model and we use 3 different time scales to describe different process. First, the time that relates to tides/waves applying in seaward boundary is called hydrodynamic time, which can be regarded as the real hydrodynamic time. Second, morphological evolution is accelerated by applying morfac and the corresponding time is called morphological time. For instance, a morfac of 30, allow us to predict the evolution of 30 morphological-years profile evolution by simulating only 1-year in hydrodynamic time. Last, we use ecological time to describe the vegetation dynamics and this time scale is equal to morphological time due to the similarity of their time scales. Assuming every ecological year has 12 ecological months with the same number of days per month (currently set to 30 days/ eco. month), we define 360 ecological days as 1 ecological year.

In the current model, we apply a semidiurnal tidal cycle in seaward boundary with hydrological time period of 12 hours, so there will be exactly 2 full tidal cycles within one hydrological day. Under the settings of morfac to 30 and duration of tidal cycles to 100 hydrological years, we will obtain both morphological updates and vegetation dynamics over 300 years.

3. Model compositions

To help understand the process and compositions of dynamic vegetation model, we use a flow chart to show the connections between each module (Fig. 1). The whole dynamic vegetation model contains 12 modules coded in Matlab. In this section, readers can find a brief explanation on each module, and for more detailed explanations please refer to the papers (Xie et al., 2020; Xie et al., 2022).

1) general_input

This module defines the path of simulation, key parameters of vegetation (with/without vegetation, with/without roots), hydrodynamics (with/without waves), storing method (Delft3D default/manually designated) and how the model starts (cold/hot start).

2) inid3d

This module is used to import data from *.mdf file, including domain scales, morfac and time information.

3) iniveg

This module is initialized if the effects of vegetation are taken into account, which in our cases it is always needed to run this module because we study mangroves. Its main work is to read vegetation information defined in vegetation files (i.e., veg[No.].txt). In our mangrove models, parameters in terms of inundation stress, competition stress, growth function and initial vegetation sizes are defined in the vegetation files and will be imported through this module.

4) ini_work

This module creates the work folder where all initial files will be copied. By modifying the time slots in *.mdf file, the simulation period will be changed to cover 1 ecological time step. Generally, the very first simulation regarding the hydro-morphodynamic process without vegetation information will be started here based on initial settings. However, if the model is asked to make a hot start from previous run for all kinds of reason (such as model debug and power failure), then last stored vegetation information will be imported to supplement files needed before simulation starts.

As an initial set up, general_input, inid3d, iniveg and ini_work are only carried out once at the beginning of each simulation (Fig. 1).

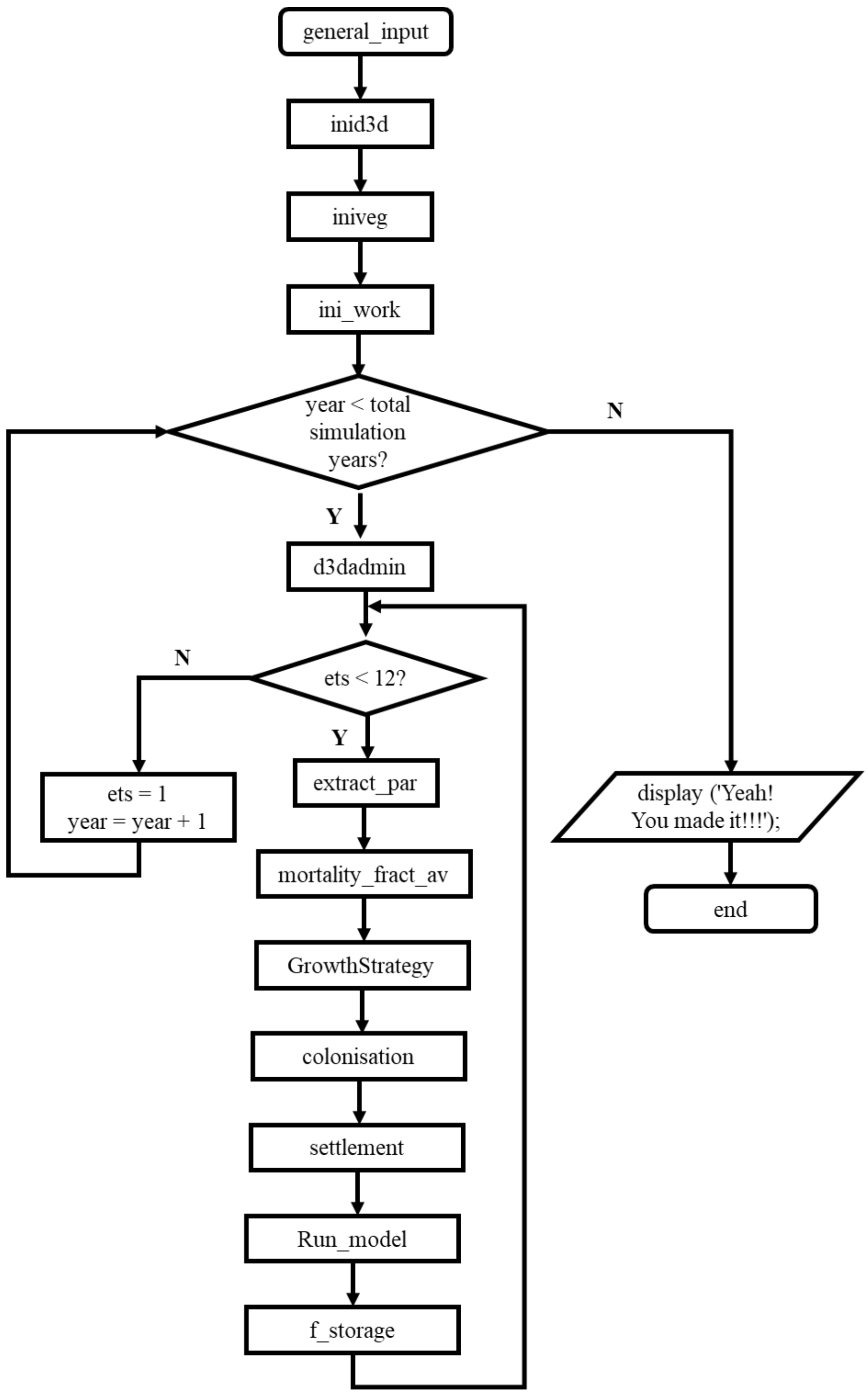

Figure 1. Flow chart of dynamic vegetation models. 'ets' is the abbreviation of ecological time step.

5) d3dadmin

This module moderates the time slots of simulation in *.mdf file and spin-up intervals in *.mor file for the next simulation.

6) extract_par

This module extracts and calculates data from trim-*.dat file for the coming vegetation dynamic process, including water depth and bed shear stress. These data will be stored in a specific matrix every ecological time step.

7) mortality_fract_av

The mortality process is realized in this module when the growth rate of one vegetation is continually lower than 0.5 for 5 years. The growth rate is dependent on the fitness function (*f*) and competition stress factor (*C*). In one cell, mangroves with different sizes/ species are allowed to co-exist. When the mortality occurs among different mangroves, the number of mangroves in different species be removed from that cell is dependent on the relative value of their fitness function. For example, vegetation with higher fitness values is assumed more resistant to the environmental stress and thus, less vegetation will be removed, compared to vegetation with lower fitness values. We also assume the young vegetation is more vulnerable than other age groups, so they will be a first vegetation group to be removed. The mortality process continues until the growth rate (f*C) becomes above 0.5 again or no vegetation exists in that cell.

8) GrowthStrategy

This module is used to update the size of vegetation (stem height and diameter) for a new ecological time step. The growth rate is dependent on the fitness function and competition stress factor, which have been calculated in previous module (mortality_fract_av). Different vegetation species may have different parameters for their growth function and these functions have been recognized in the previous module already, i.e. iniveg.

9) colonisation

This module allows new seedlings to settle down in a suitable location. The conditions of one specific location are evaluated based on both inundation frequency (named as 'relative hydroperiod' in our research paper) and 90th percentile bed shear stress. The number of new seedlings assigned to the cell is dependent on the existing vegetation number and the capacity of one cell can hold. When different vegetation species are all applicable to colonize in one cell, the number of seedlings for each species will be calculated based on the relative value of their fitness function. The cells where mortality process occurs in the previous module will be excluded from this module.

10) settlement

This module summarizes all vegetation information that Matlab calculates in previous processes and add roots according to the number and size of vegetation stems. At the same time, output files for the new hydro-morphodynamic simulation will be generated.

11) Run_model

This code calls the start of hydro-morphodynamic simulations based on newly set-up files.

12) f_storage

This module will start to store new model results to a specific folder.

4. Model installation and setup

When it is the first time for the reader to use this model, several processes should be done before one executives the model simulations:

1) **Installation**

   Check whether both the Delft3D and Matlab are installed correctly, both of which should be successfully run independently on their own working environment.

2) **Deltares OpenEarth Matlab Tools**

   Since the vegetation coupling relies on external MATLAB functions, it requires the installation of the OpenEarth tool box. Please install the OpenEarth Matlab Tool box through the link: https://publicwiki.deltares.nl/display/OET/MATLAB

3) **Settings of Startrun.bat**

   For D3D open-source the Startrun.bat file needs to point to d_hydro.exe, which will generate the executable: "call C:\... \Delft3D 4.01.00\win32\flow2d3d\bin\d_hydro.exe"

   (tested with Delft3D open-source-tag: 7545, compiled with Intel Fortran on Windows 10, Matlab 2017a)

4) **Directory settings in Matlab**

   Change working directory and add Deltares OpenEarth matlab Tools to Matlab environment in the lines 16 and 26 of "general_input.m", respectively.

5. References

Deltares (2014), *Simulation of multi-dimensional hydrodynamic flows and transport phenomena, including sediments - User Manual (Version: 3.15.34158)*, Deltares, Delft, the Netherlands.

Roelvink, J. A. (2006), Coastal morphodynamic evolution techniques, *Coastal Engineering*, *53*(2), 277-287.

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