

Technical Information of the Numerical Model Developed for the Research

Mangrove-saltmarsh Ecotones: Are Species Shifts Determining Eco-morphodynamic Landform Configurations?

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Model Availability Statement

The mangrove-saltmarsh ecotone model code with a representative setting is available at <https://github.com/yizhangw/Mangrove-Saltmarsh-Ecotone.git>. The mangrove model code with a representative setting can be accessed at <https://doi.org/10.1038/s41467-023-42733-1>. Delft3D is an open-source code available online at <https://oss.deltares.nl/>.

Overview

This Technical Information provides a detailed explanation of the eco-morphodynamic numerical model developed for a recent study that focuses on the feedback between tidal flow, mangrove dynamics, saltmarsh dynamics, mangrove-saltmarsh interactions, and morphological changes. Specifically, the model aims to investigate the effects of biotic interactions (i.e., competition and herbivory) on ecotone dynamics and to explore whether a change in dominant ecotone species influence sediment transport and channel networks. The basic principles and equations used in this model are detailed in the attached research paper; here, I primarily focus on the practical application of the model.

The eco-morphodynamic model comprises two interacting components (Fig. 1). The first component is the hydro-morphodynamic model implemented in Delft3D (Deltares, 2020), and the second is the dynamic vegetation model implemented in Matlab. Tidal flow, sediment transport, and bed-level changes are calculated using the Delft3D model suite, while vegetation responses to environmental changes and biotic interactions are evaluated in Matlab. This interaction provides additional flow resistance in Delft3D's hydrodynamic calculations. By applying the morphological acceleration factor (MORFAC), long-term profile changes and vegetation behaviors can be derived from short-term hydrodynamic simulations (Roelvink, 2006; Coco et al., 2013).

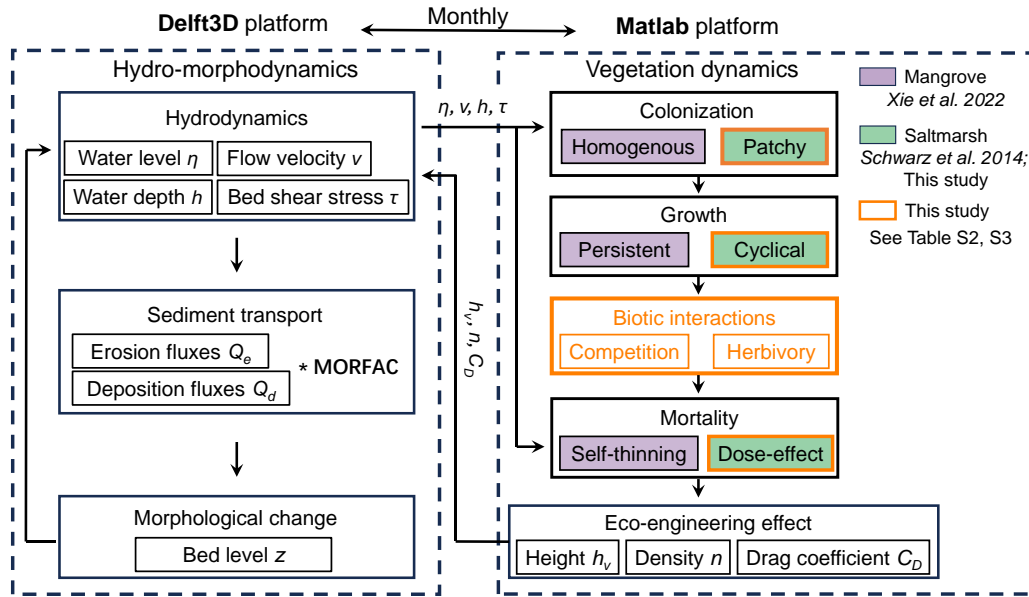


Figure 1. Overview of eco-morphodynamic interactions incorporated into the model. The modelling approach couples a hydro-morphodynamic model and a new dynamic vegetation model so that the feedback between tidal flow, sediment motion, morphological change, mangrove-saltmarsh ecotone dynamics can be investigated. The vegetation model receives information on the bed shear stress and inundation regime from the hydro-morphodynamic model and then regulates the development of mangroves and saltmarshes. The growing mangroves and saltmarshes compete for light and nutrients, leading to their mortality. Information on vegetation characteristics is in turn exchanged with the hydro-morphodynamic model which then accounts for vegetation effects on tidal flow resistance.

Time scales of the model

The time scales defined in this model vary across its components, with three distinct time references used to describe different processes.

- **Hydrodynamic Time:** This refers to the time associated with the tides applied at the seaward boundary, and it represents real time, as we experience it.
- **Morphological Time:** To enable long-term simulation, the morphological evolution is accelerated using the MORFAC, resulting in a time scale known as morphological time. In this study, a MORFAC of 30 is applied, meaning that to simulate 30 years of morphological evolution, only one-year of hydrodynamic time needs to be defined at the seaward boundary.
- **Ecological Time:** This time scale is used to describe vegetation dynamics and is aligned with morphological time. Each ecological year is divided into twelve ecological months, allowing for monthly updates to vegetation characteristics in different seasonal life stages (Fig. 2). For example, mangroves and saltmarshes are modeled to colonize only during the first seven ecological months, representing the growing season, while their growth slows or ceases during the remaining five months, representing the non-growing season. During each ecological month, vegetation characteristics are updated based on environmental conditions (e.g., inundation frequency and competition stress) and seasonal life stages.

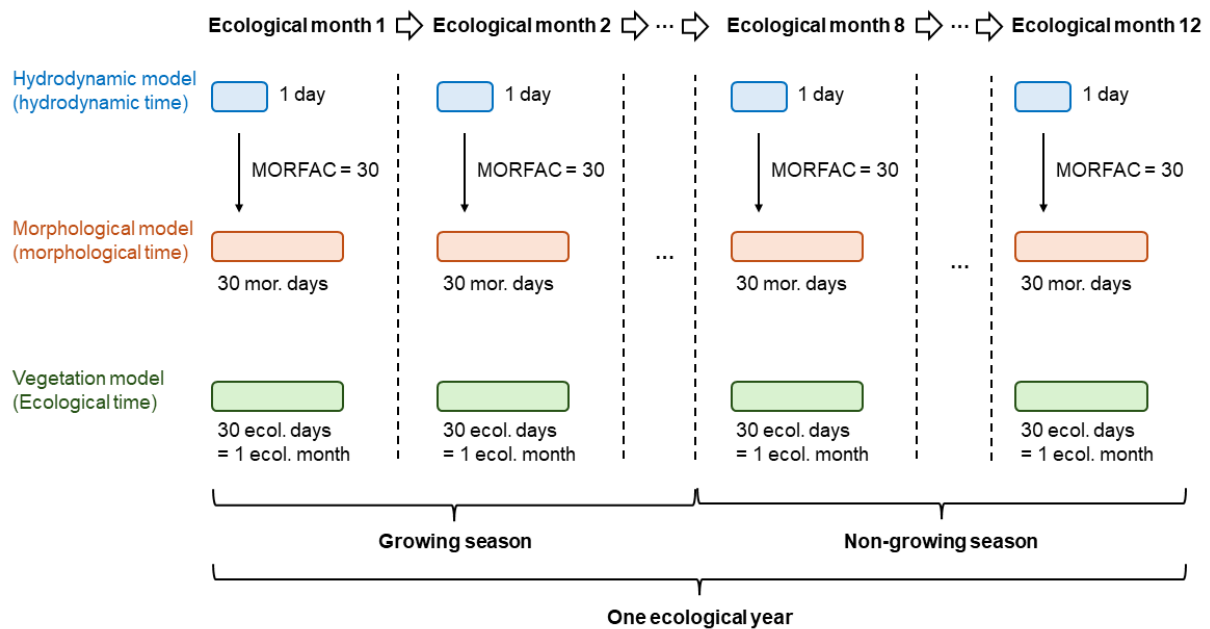


Figure 2. An example of model time scales when the MORFAC is set to 30. Morphological changes and vegetation dynamics are under the same time frame, which is driven by a much shorter time (hydrodynamic time) of hydrodynamic simulation due to the application of morphological acceleration factor. mor. = morphological, ecol. = ecological.

Preparation before model simulations

1) Install Delft3D and Matlab

When it is the first time for the users to run this model, the software including Delft3D 4 Suite and Matlab should be installed correctly. A prior test should be implemented by running Delft3D example cases in order to check the successfully set up of Delft3D.

2) Check initial files

Each modeling case is set up in a main folder. In the example provided below, the main folder is named *MfS*, within which there are three subfolders: *initial_files*, *Matlab_functions* and *Matlab_vegetation_modules*. The *initial_files* folder contains all the necessary files to run the Delft3D model, which is the hydro-morphodynamic model that should be executed directly using the Delft3D executable file. In this study, the simulation is executed on a Windows system using the ‘*Startrun.bat*’ file. The path in this file should be modified based on where Delft3D is installed on the computer. To incorporate vegetation effects on hydrodynamics during the simulation, the following keywords should be added at the end of the *mdf* file (in this case, *360x1.mdf*):

Trtrou = #Y#

Trtdef = #veg.trd#

Trtu = #veg.trv#

Trtv = #veg.trv#

The values of Trtrou determine whether or not to include the vegetation effects (“Yes” or “No”), and Trtdef and Trtu/Trtv indicate the vegetation files that will be used during the simulation. The vegetation files *veg.trd* and *veg.trv* store vegetation parameters including grid cell number, vegetation height, vegetation density, drag coefficient and bed roughness, etc. These two files will be generated and updated through the vegetation model, but the basic vegetation information should be provided beforehand in the *Veg.txt* file. Please refer to the explanation within the *Veg.txt* file to set up the basic information of the modelling vegetation, such as initial stem diameter, maximum stem diameter, shoot height, etc.

It is important to note Matlab will call the hydro-morphodynamic simulation through executive file and the xml-file, so the directory within the executive file should be carefully checked and the name of *.mdf file should be matched with the name in the xml-file (here, *config_d_hydro.xml*).

The *Matlab_functions* folder includes several functions supporting the process of data extraction and update. For example, the code *d3d_admin_v5.m* helps to update the time after an ecological season of simulation has been done by Delft3D.

The *Matlab_vegetation_modules* folder is an important folder containing all the key files to run the vegetation model. A detailed explanation of each module will be introduced in the following section.

Vegetation model structures

This model structure is updated from previous mangrove modeling studies by incorporating the influence of saltmarshes. A comprehensive explanation of how this model works can also be found in previous studies (Xie et al., 2020; Xie et al., 2022; Xie et al., 2023). The core components of the vegetation model, including colonization, growth, biotic interactions, and mortality. The following section provides a general explanation of each main module.

1) *general_input.m*

This is the main module defining the path of simulation, key parameters of vegetation (with/without vegetation, with/without roots, with/without biotic interactions) and how the model starts (from the beginning/a restarted file).

2) *inid3d.m*

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

3) *iniveg.m*

This module is initialized to read the mangrove information defined in the vegetation file (e.g., *veg1.txt*), including coefficients related to inundation stress, competition stress, growth functions, and initial mangrove parameters.

4) *ini_work.m*

This module creates the “*work*” folder where all initial files will be copied. By modifying the time slots in the *.mdf file, the simulation period will be changed to cover one ecological month. 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 restart from the previous run, then the last stored vegetation information will be imported to supplement files needed before the simulation starts.

As an initial setup, the codes including *general_input*, *inid3d*, *iniveg* and *ini_work* are only carried out once at the beginning of each simulation. The outcome of Delft3D results and vegetation files are temporarily calculated at the ‘*work*’ folder, both of which will be stored in a new folder under the main folder ‘*M/S*’ following with a specific name on their ecological year (e.g. ‘*results_1*’, ‘*results_2*’, ‘*results_3*’, etc.).

5) *d3dadmin.m*

This module moderates the time slots of simulation in *.mdf file for the next simulation.

6) *extract_par.m*

This module extracts and calculates data from Delft3D output, i.e. trim-*.dat file, for the coming vegetation dynamic process, such as water level, water depth and bed shear stress. These data will be stored in a specific matrix every ecological season time step.

7) mortality_fract_av.m

The mortality process for mangroves is triggered in this module when the growth rate of a mangrove remains below 0.5 for 5 consecutive years. The growth rate depends on the fitness factor and total competition stress factor (i.e., intraspecific and interspecific competition). Within a single cell, mangroves of different sizes and species can co-exist. When mortality occurs, the reduction in the number of mangroves of different species is determined by the relative value of their fitness function—species with higher fitness values will experience less vegetation loss. The young mangroves are assumed to be more vulnerable than older age groups, so they are the first to be removed until no further mortality occurs in that cell.

8) GrowthStrategy.m

This module is used to update the size of mangroves (stem height and diameter) for a new ecological month. The growth rate is dependent on the fitness function and total competition stress factor, which have been calculated in the previous module (mortality_fract_av).

9) colonization.m

This module allows new mangrove 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 the research paper) and the 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.

10) saltmarsh_development.m

This module is specifically developed for this research to simulate the colonization, growth, competition, and mortality of saltmarshes following previous saltmarsh study (Schwarz et al., 2014). Saltmarsh colonization occurs randomly by allocating saltmarshes to suitable grid cells with initial density and height. Their growth follows a logistic pattern until reaching maximum capacity, with the growth rate influenced by fitness functions and competition stress from mangroves. Saltmarshes can expand laterally into neighboring grid cells based on density gradients. Excessively strong tidal flows may wash away saltmarshes, leading to mortality as described by the dose-effect function. Unlike mangroves, saltmarshes undergo a senescence stage during the non-growing season, resulting in reduced density and height. This module integrates all developmental processes, providing parameters on density, height, distribution, and drag coefficients for the computation of hydro-morphodynamics and mangrove dynamics.

11) settlement.m

This module consolidates all vegetation information calculated by Matlab in previous processes and adds the number of pneumatophores according to the number and size of mangrove stems. Additionally, mangrove

seedlings that have been inhibited for 2 years and are shorter than the surrounding saltmarshes are removed, as these seedlings are considered to have exhausted the energy stored in their propagules and lack sufficient external resources to sustain survival. The module also incorporates predation effects by removing mangrove seedlings if predation occurs. Finally, the module generates output files detailing vegetation characteristics, including mangroves and saltmarshes, for the new hydro-morphodynamic simulation, such as *veg.trd* and *veg.trv*.

Run the vegetation model

After preparing all the files, make sure to update the paths in the following two locations: 1) the executive file ('Startrun.bat') in the *initial_files* folder and 2) the case path in the *general_input.m* code within the *Matlab_vegetation_modules* folder. Once these updates are complete, the vegetation code can be started by pressing 'RUN' on *general_input.m*.

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