Modules
bioturbation_CD

F. Lafolie

Content

1 Introduction

This module simulates the mixing of soil components in response to bioturbation. The module was developped from the approach proposed by *Jagercikova et al. 2014*[1] for modelling the displacement of soil components during pedogenesis.

As any module in VSOIL, this module can be duplicated for modification. In addition, note that the core of this module, i.e. the methods for creating the matrix and the second member can be easily reused in other modules.

2 Hypotheses

Transport of soil components is modeled as a convection and diffusion process. Usually bioturbation is associated with a diffusion process, while convection mimcs other transport phenomena. Equations are described below. The module is activated at a time interval chosen by the user. The module incorporates a fraction of the organic matter pools of the mulch to the first soil compartment before bioturbation occurs. Since the time step at which the module is called is chosen by the user (parameter of the module), this fraction must be adapted to account for the frequence at which the module is called and to mimic the rate at which the mulch organic matter pools are incorporated into the soil.

In this module, bioturbation modifies the following soil components :

[1] Modeling the migration of fallaout radionuclides to quantify the contemporary transfer of fine particles in Luvisol profiles under different land uses and farming practices. Soil and Tillage Research, 140, 82-97

- soil particles (sand, silt, clay)
- grains defining the soil particles
- solutes species
- water content
- temperature
- mineral species
- clay exchangeable cations
- organic carbon exchangeable cations
- organic matter pools
- 14C organic matter pools
- chemicals associated with the organic matter pools
- weathering mineral pools
- mulch organic matter pools
- chemicals associated with the mulch organic matter pools

3 Equations

The convection dispersion equation used writes :

$$\frac{\partial M}{\partial t} = \frac{\partial}{\partial z}\left(D\frac{\partial M}{\partial z} - vM\right) - \lambda M \quad (1)$$

where M is the soil component transported, D is a diffusion coefficient, v is the velocity, z is depth, λ is a decay constant, and t is time. The diffusion coefficient and the velocity depend on depth, and in the module they obey the following relationships:

$$D(z) = D_0 exp(-bz) \quad (2)$$

where b is a parameter and D_0 is the diffusion coefficient at the soil surface. Usually bioturbation is associated with the diffusion process while transport by other mechanisms is associated with the convective part. A bioturbation depth is calculated assuming that the ratio D/D_0 is less than 0.001. The bioturbation depth is then given by :

$$z_{biot} = \frac{-ln(0.001)}{b} \quad (3)$$

The velocity is assumed to be zero at the soil surface, to vary linearly between surface and a depth δ and to decrease exponentially below. The following relationships are used.

$$v(0) = 0. \tag{4}$$

$$\begin{aligned} v(z) &= V_0 + (1/\delta)(V_\delta - V_0)z \quad \forall z \leqslant \delta \\ v(z) &= V_\delta exp(-d(z-\delta)) \quad \forall z \geqslant \delta \end{aligned} \tag{5}$$

where V_0 is the velocity just below the soil surface (velocity is not continuous at the soil surface), V_δ is the velocity at depth δ and d is a parameter controling diminution with depth. Velocity parameters V_0 and V_δ can be set to zero to have diffusion only.

The equation contains a decay term as it can be used to simulate the fate of radionuclides.

4 Résolution

The finite differences technique is used to solve the equation. It uses the grid provided by the platform. The solution uses its own time step as the time characteristics of the phenomena is very different from the time characteristics of the other transport phenomena that occur within the soil, in particular the water and solute transport phenomena. Given these differences, it would be useless and time consuming to solve the diffusion equation with the time increments used for the other phenomena with which it could be coupled. The parameter *dt_eval* allows to define this time step.

Given that the module is used to displace soil components that are also subject to other phenomena, the situation at the beginning of the time step is not the situation at the end of the previous. Changes could have occur in between. This is particularly the case for the soil organic matter pools, or the soil particles that could have move due to other mechanisms such as tillage or colloids transport.

Hence this module must be seen as a mean of calculating changes resulting from bioturbation only and not as a mean of simulating long term space and time changes in soil components concentrations.

The solution obtained after a time step is used to calculate the changes induced for the soil components.

If we note M_t the situation at the beginning of the time increment, and M_{t+dt} the solution obtained after resolution of the equation, the change induced by bioturbation is calculated as :

$$\delta M = M_{t+dt} - M_t \tag{6}$$

Modules outputs are these values. Note they are not rates, the time increment is not used.

A Crank-Nicholson schema is used for time derivative. The second order space derivative is approximated by a centered finite differences approximation, while a upstream schema is used for the first order derivative (Jagercikova et al. 2014).

5 Outputs

In addition to the quantities indicates in the hypotheses section, the module provides the two following outputs that are usefull for other modules.

- **soil bioturbation depth**, [m]. This is an estimation of the bioturbation depth. It is calculated using the parameter c (see below and equation 2) with the relation given in equation .

- **soil bioturbated mass fraction yearly**, [$ratio$]. This the mass fraction of the soil surface that is redistributed by bioturbation during a year. Calculated from the bioturbation of the soil particles.

6 Parameters

The parameters description is also available in the VSOIL-MODULES application. Default values are sometimes provided. **These values are given to ease the use of the module but there is no warranty that they always fit with the simulated case. The user must check these values.**

- **Activation**, [$choice$], To activate or to by-pass the module. When bypassed, the module outputs are all set to zero, meaning that there is no modification due to bioturbation.

- **frac_mulch**, [$ratio$], The fraction of the organic matter pools of the mulch that are incorporated to the soil by bioturbation each time the module is called.

- **clay_rho** [$kg.m^{-3}$] Bulk density of the clay particles.

- **sasil_rho** [$kg.m^{-3}$] Bulk density of the sand and silt particles.

- **om_rho** [$kg.m^{-3}$] Bulk density or organic matter particles.

- **D0** [$m^2.s{-}1$] Diffusion coefficient at soil surface.

- **c** [m^{-1}] Parameter (c) in the expression used to describe diffusion coefficient decrease with depth : $D = D0 * exp(-cz)$. where $D0$ is diffusion coefficient at soil surface and z is depth (m).

- **CV0** [$m.s{-}1$] Vaue of the convection coefficient at soil surface.

- **CVM** [$m.s{-}1$] Vaue of the convection coefficient at the middle of the tilled depth. This is parameter V_δ in equation 4.

- **d** [m^{-1}] Parameter (d) in the expression used to describe convection coefficient decrease with depth (see equation 4).

- **decay** [s^{-1}] The decay constant λ in equation 1.

- **dt_eval** [s] The time lag between two solutions of the equation. When the time since the previous solution exceeds dt_eval, the equation is solved with a time step equal to the difference between the actual time and the time of the previous resolution.