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Modelling soil formation at the profile scale

Sebastien Salvador-Blanes (1), Budiman Minasny (2), and Alex B. McBratney (2)

(1) UMR ISTO, Université François Rabelais, Tours, France (salvador@univ-tours.fr), (2) Faculty of Agriculture, Food and Natural Resources, The University of Sydney, Sydney, Australia

The formation of soil is a key component in the evolution of the landscape. Soil formation processes have been extensively studied in various geomorphic contexts. These processes are now well described, but works to model their evolution ab initio are scarce, and mostly focused on individual processes observed in soils or soil horizons, often at short timescales. Another approach has been in recent years to model the evolution of the regolith at the landscape scale, but it is not yet able to reproduce the soil evolution as an entity considering the evolution of its physical, chemical biological and mineralogical properties. The model that is presented here aims in a first approach at quantitatively modeling the formation of soil at the profile scale over the soil evolution duration, e.g. several thousands or tens of thousands of years.

This model consists in four modules, each aiming at representing a major soil genesis process, with a time step ranging between the decade and the century. At the current stage of development, the model attempts to reproduce four major soil genesis processes and their interactions, no lateral transfer from or to the soil profile is yet implemented. The challenge is here to model each of these processes using sufficiently simple equations that are integrative of a much more complex reality. This should ensure to keep it sufficiently generic to avoid a multiplicity of input parameters, keep its stability and to represent soil evolution as a whole entity, as seen by the pedologist.

The resulting soil profile consists in the summation of elementary layers each corresponding to a given quantity of matter released by the bedrock at each time step. This matter is then submitted to the physical fragmentation of the coarse and fine fractions of the soil - simply represented by a first order kinetics reaction - taking into account a variable resistance to fractionation according to the mineralogy, the size and the position of the rock fragments and individual mineral particles within the soil profile. Chemical weathering of the fine fraction is supposed to correspond to a congruent dissolution, with the formation of secondary minerals following predefined weathering pathways. The organic matter dynamics is simulated through its incorporation on and within the soil, based on the net primary productivity, the root/shoot ratio, and the root depth distribution. Its subsequent mineralisation applying a simple one-compartment model is as well simulated. Finally, movements of soil within the profile are approached through the particular process of bioturbation. At each time step, these processes result in the addition or loss of matter that implies a modification of the layer thicknesses. The model can thus track various key properties of soils at all depths through time, such as the evolution of particle size and mineral composition of the soil, the bulk density, the available water and the organic matter contents.

The model is run for various input parameters, and the results are discussed. This model constitutes only a first and rough attempt to integrate some key processes of soil evolution. Other processes such as leaching, secondary reactions, water dynamics should be implemented. The application of this model at the landscape scale by taking into account redistribution processes should finally contribute to landscape evolution modeling.