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Correlation functions for describing and reconstructing soil microstructure: the use of directional correlation functions

Marina Karsanina (1,2), Kirill Gerke (2), Elena Skvortsova (3), and Dirk Mallants (1)

(1) Institute of Geospheres Dynamics of RAS, Institute of Physics of Earth of RAS, Moscow, (2) CSIRO Land and Water, Adelaide, (3) Dokuchaev Soil Science Institute of RAS, Moscow

Structural features of porous materials define the majority of its physical properties, including water infiltration and redistribution, multi-phase flow (e.g. simultaneous water/air flow, gas exchange between biologically active soil root zone and atmosphere, etc.) and solute transport. To characterize soil microstructure, conventional soil science uses such metrics as pore size and grain-size distributions and thin section-derived morphological indicators. However, these descriptors provide only limited amount of information about the complex arrangement of soil structure and have limited capability to reconstruct structural features or predict physical properties. We introduce three different spatial correlation functions as a comprehensive tool to characterize soil microstructure: (i) two-point probability functions, (ii) linear functions, and (iii) two-point cluster functions. This novel approach was tested on thin-sections (2.21$\times$2.21 cm2) representing eight soils with different pore space configurations. The two-point probability and linear correlation functions were subsequently used as a part of simulated annealing optimization procedures to reconstruct soil structure. Comparison of original and reconstructed images was based on morphological characteristics, cluster correlation functions, total number of pores and pore-size distribution.
Results showed excellent agreement for soils with isolated pores, but relatively poor correspondence for soils exhibiting dual-porosity (i.e. superpositions of pores and microcracks). Insufficient information content in the correlation function sets used for reconstruction may have contributed to the observed discrepancies. Improved reconstructions may be obtained by adding cluster and other correlation functions into reconstruction sets. Correlation functions and the associated stochastic reconstruction algorithms introduced here are universally applicable in soil science, including for soil classification, pore-scale modelling of soil properties, soil degradation monitoring, and description of spatial dynamics of soil microbial activity.

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