EGU25-7198, updated on 13 Nov 2025
https://doi.org/10.5194/egusphere-egu25-7198
EGU General Assembly 2025

A Novel Framework for Stochastic Simulation of Multivariate Non-Gaussian Random Fields in Environmental and Geological Studies

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Many environmental and geological phenomena are inherently complex, shaped by the interplay of physical, chemical, biological, and anthropogenic factors. These interactions often result in spatial asymmetries, where high and low values exhibit distinct statistical behaviors. For instance, a contaminant field may simultaneously reflect natural and anthropogenic sources, producing unique spatial patterns that challenge conventional analysis.

Despite significant advancements in geostatistics, multivariate spatial models remain limited. The linear model of coregionalization (LCM) dominates the field but assumes symmetrical dependencies and Gaussian behavior. These assumptions restrict its ability to capture the structural complexity of multivariate spatial data, potentially obscuring meaningful relationships or introducing misleading correlations.

This presentation introduces a stochastic methodology for simulating non-Gaussian multivariate random fields using a non-linear model of coregionalization (N-LCM). The proposed approach accounts for rank asymmetry (differing spatial dependencies for low and high values) and directional asymmetry (variations in spatial dependence across directions). It supports multiple dependencies between variables, allowing some to exhibit Gaussian behavior while others display non-Gaussian characteristics. Pseudo-admissible N-LCMs are approximated through spectral decomposition, with negative eigenvalues replaced by zero.

The methodology leverages an adapted Generalized Fast Fourier Transform Moving Average (G-FFTMA) algorithm for multivariate non-Gaussian geostatistical simulations, offering a flexible and efficient framework for analyzing and simulating complex datasets. Synthetic examples demonstrate the method's ability to uncover meaningful spatial patterns. Additionally, a real-world case study highlights the duality between natural contamination and anthropogenic emissions from a smelter in Quebec, Canada. This case study emphasizes the methodology's capability to analyze geochemical processes influenced by human activities and environmental interactions.

This research advances geostatistics and multivariate analysis, providing new insights into geological and environmental processes at the Earth's surface.