Geostatistics for Environmental Applications

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This Special Issue is dedicated to geostatistics applied to environmental applications through a set of selected papers that were originally presented at geoENV 2016, the 11th International Conference on Geostatistics for Environmental Applications, held in Lisbon in July, 2016.

The conference featured sessions dedicated to theory, meteorology and climate, surface and sub-surface hydrology, health, soil contamination and pedology and air quality. From these sessions, six papers were selected to comprise this issue of *Mathematical Geosciences*. CERENA, The paper by Stelios Liokadis, Phaedon Kyriakidis and Petros Gaganis, addresses an important issue related to the uncertainty analysis of the outputs of complex models whose parameters are spatially distributed. As it requires a large number of simulated attribute realizations of the model inputs, uncertainty analysis is often hindered due to the computational expense of evaluating complex environmental models. This paper proposes an alternative stratified sampling (including Latin hypercube sampling) for the purpose of efficient conditional simulation of Gaussian random fields. To illustrate the proposed methodology, the paper features the example of saturated hydraulic conductivity that is used as an input to physically-based simulators of flow and transport to evaluate the associated uncertainty in the spatial distribution of solute concentration in an aquifer.

Alessandro Comunian and Mauro Giuici propose coupling a stochastic simulation of an aquifer's properties with a deterministic inversion method to integrate the high

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heterogeneity of the aquifer's properties (transmissivity) and its hydraulic behavior. A hybrid approach is proposed to join a direct inversion method (the comparison model method, CMM) and multiple-point statistics (MPS) simulation to determine a hydraulic transmissivity field from a map of a reference hydraulic head and a training image of the transmissivity.

The paper of Marco D' Oria, Andrea Zanini and Fausto Cupola addresses the same problem, but with a different approach; specifically, the authors employ a Bayesian Geostatistical inversion method. In this Bayesian formalism, the a posteriori distribution is solved based on a linearization between the parameters (transmissivity) and the state variables, the observed hydraulic heads. This method is illustrated with a set of pumping tests performed in a real aquifer.

In some environmental applications, such as pollutant concentration, the monitoring data often shows a small proportion of very high concentration values. As these high values are spatially dispersed, it produces a non-robust estimation of second-order statistics, such as the variance and the variogram. This problem is addressed in the paper of Pierre Petitgas, Mathieu Woillez, Mathieu Doray and Jacques Rivoirard for fish stocks characterization. The high fish density values are generated by aggregative fish behavior, which may vary greatly at a small scale in time and space. The high values are thus imprecisely known, both in their spatial occurrence and order of magnitude. To estimate the spatial dispersion of fish density, the authors purpose three indicator-based geostatistical methods: the top-cut model, min–max autocorrelation factors (MAF) of indicators and multiple indicator kriging. The methods are applied on a spatial dataset of anchovy densities derived from a typical fish stock acoustic survey performed in the Bay of Biscay, which shows a few high-density values distributed in small spatial patches, as well as solitary events.

Continuous Ranked Probability Score, CRPS, a known metric to evaluate the accuracy of forecasts, compares a full distribution with the observation, where both are represented as cumulative distribution functions. Michaël Zamo and Philippe Naveau apply CRPS to measure the performance of probabilistic forecasts of a scalar observation. While they apply CRPS to meteorological forecasts, the problem they approach can be found in many other environmental applications. When the CDF forecast is not fully known and is represented only as an ensemble of values, then CRPS can be estimated with some bias. Thus, using the CRPS to compare different probabilistic forecast models with ensemble forecasts may be misleading due to the unknown error of the estimated CRPS for the ensemble. The authors evaluate the impact of CRPS with simulated ensemble data. Recommendations about the use of the most accurate CRPS according the ensemble are illustrated with real ensemble weather forecasts.

Based on an extensive soil sampling campaign undertaken in Northern Ireland, the work of Jennifer M. McKinley, Eric Grunsky and Ute Mueller determines the influence of underlying regional geology on the soil geochemistry signature by using compositional multivariate techniques. The approach was explored for environmental monitoring of peat and to measure the ability to predict fragile ecosystems.

The research presented in this Special Issue holds the potential for broad applications and impact. Indeed, the featured geostatistical methodologies, although applied

to the environmental sciences specifically, can be generalized to many other applications in the Earth Sciences, and it is hoped that these works will spur further paths of inquiry and discovery.