‘spup’ – an R package for uncertainty propagation in spatial environmental modelling

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Introduction

Presently, advances in uncertainty propagation analysis have been paralleled by a growing number of software tools for uncertainty analysis, but none has gained recognition for a universal applicability, including case studies with spatial models and spatial model inputs.

Due to the growing popularity and applicability of the open source R programming language we undertook a project to develop an R package that facilitates uncertainty propagation analysis in spatial environmental modelling.

The ‘spup’ package implements the Monte Carlo approach and provides functions for examining the uncertainty propagation starting from input data and model parameters, via the environmental model onto model predictions (Fig. 1).

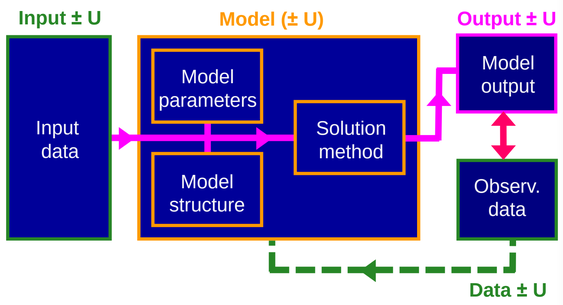


Figure 1. Uncertainty propagation overview.

Monte Carlo approach principle

Monte Carlo simulation uses statistical modelling and random sampling to analyse uncertainty propagation through a model:

1. characterise uncertain model inputs with probability distribution functions (PDFs)
2. repeatedly sample from (spatial) PDFs
3. run model with sampled inputs and store model outputs
4. compute summary statistics of model outputs

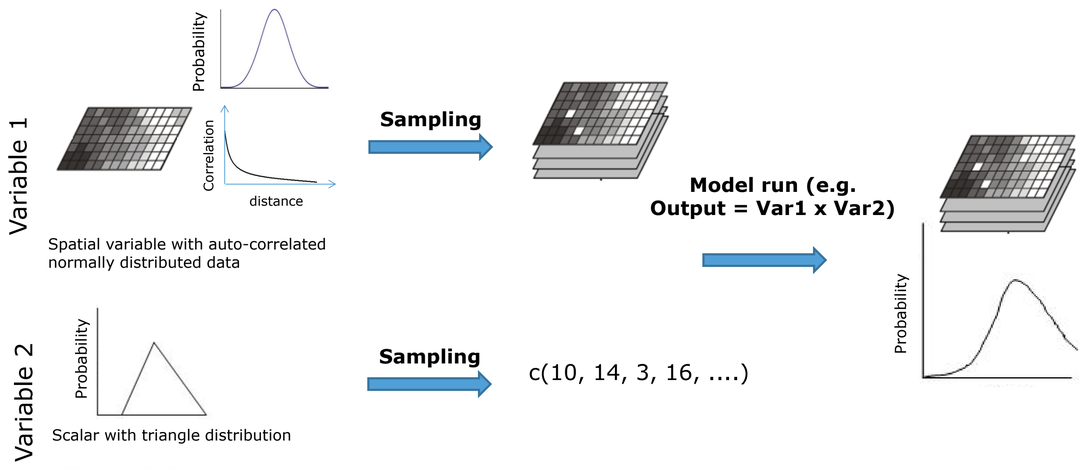


Figure 3. Example of the Monte Carlo algorithm including a spatial variable.

The ‘spup’ package overview

Functions that allow user to **define uncertainty model (UM)**:

- **Input variables and environmental model parameters**
  - Import data and objects with attributes
  - Define UM – parameters and model structure

Functions that **quantify uncertainty propagation** by sampling from uncertain inputs and running the model with sampled realizations:

- **Uncertainty propagation algorithms**
  - Monte Carlo sampling techniques
    - Simple random sampling (including unconditional Gaussian simulation using the *gstat* package)
    - Stratified random sampling
    - Latin hypercube sampling
- **Environmental Model**
  - As a function in R
  - Outside R call
  - Model used externally

Functions that allow user to **save output in a format of data or images**:

- **Output**
  - Storing solution for samples
  - Calculating contributions
  - Various plots options

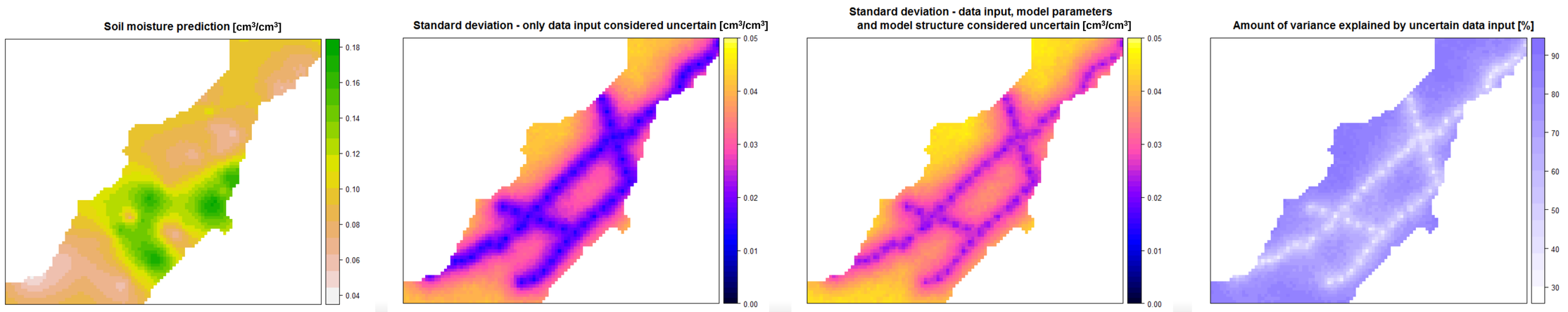
Figure 2. The ‘spup’ package design.

The package assets

- both numerical and categorical data types are handled
- spatial auto-correlation within an attribute and cross-correlation between attributes is accommodated for
- Monte Carlo approach with efficient sampling algorithms, i.e. stratified random sampling and Latin hypercube sampling
- facilitates parallel computing to speed up MC computation
- environmental models can be called from R, or externally
- selected static and interactive visualization methods that are understandable by non-experts

Application example

Predicting soil moisture (M) along the Allier river in the Limagne rift valley, central France: $M = \beta_0 + \beta_1 \cdot FC + \beta_2 \cdot SP + \varepsilon$, where: FC is field capacity, SP is soil porosity, $\beta_0, \beta_1, \beta_2$ are model parameters and ε denotes a stochastic residual attributed to lack of model fit and measurement error



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