CQUESST: A Bayesian Framework for Soil-Carbon Sequestration

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ABSTRACT

A statistical framework we call CQUESST (Carbon Quantification and Uncertainty from Evolutionary Soil STochastics), which models carbon sequestration and cycling in soils, is applied to a long-running agricultural experiment that controls for crop type, tillage, and season. CQUESST embeds a dynamic stochastic model of soil carbon, motivated by the deterministic RothC soil-carbon model, within a Bayesian hierarchical statistical model. CQUESST has a coherent framework that acknowledges uncertainties in soil-carbon dynamics, in physical parameters, and in observations. The long-running experiment ran from 2000-2010 and is called the Millenium Tillage Trial; here CQUESST is used to model soil carbon in six pools, across 42 agricultural plots, and on a monthly time-step for 10 years. It is implemented efficiently in the probabilistic programming language Stan using its MapReduce parallelisation. We infer the effectiveness of different experimental treatments for soil-carbon sequestration; and we show how CQUESST can be used for the analysis of designed experiments to draw statistically defensible conclusions about the dependence of soil-carbon decay rates on crop rotations and tillage treatments. These results take into account the uncertainties in the model, resulting in inferences that could inform soil-carbon-sequestration decisions and policies. This joint research is also with Jeff Baldock, David Clifford, Ryan Farquharson, Lawrence Murray, and Mike Beare.

Keywords: Bayesian hierarchical statistical model; biophysical-statistical modelling; posterior inference; soil-carbon cycling

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Modelling Count Data in the Presence of Intervention

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ABSTRACT

Analysis of count data is extremely important in environmental risk assessment particularly when developing control limits on pollutants entering the environment from point and non-point sources that harm the resident biota. Poisson and mixed Poisson models and their extensions provide the backbone of inferential methods for dealing with various complexity encountered in the analysis of count data. Here we show how to adopt these methods to deal with over and under dispersion and lack of independence in real data sets from the Canadian Effects Monitoring Program on aquatic biota, the drinking water project of the International Development Research Center to help developing countries to have safe drinking water; The ELF Ecological Monitoring Program of the U.S Navy and the 2024 Canadian wildfire on the city of Jasper.

Keywords: Toxic contaminants, Impact Assessment, Poisson regression; negative binomial, lognormal, Taylo's power low

Covariate-Dependent Spatio-Temporal Covariance Models

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ABSTRACT

Geostatistical regression models are widely used in environmental and geophysical sciences to characterize the mean and dependence structures for spatio-temporal data. Traditionally, these models account for covariates solely in the mean structure, neglecting their potential impact on the spatio-temporal covariance structure. This paper addresses a significant gap in the literature by proposing a novel covariate-dependent covariance model within the spatio-temporal random effects model framework. Our approach integrates covariates into the covariance function through a Cholesky-type decomposition, ensuring compliance with the positive-definite condition. We employ maximum likelihood for parameter estimation, complemented by an efficient expectation conditional maximization algorithm. Simulation studies demonstrate the superior performance of our method compared to conventional techniques that ignore covariates in spatial covariance. We further apply our model to a PM2.5 dataset from Taiwan, highlighting wind speed's pivotal role in influencing the spatio-temporal covariance structure. Additionally, we incorporate wind speed and sunshine duration into the covariance function for analysing Taiwan ozone data, revealing a more intricate relationship between covariance and these meteorological variables.

Keywords: Cholesky decomposition; Maximum likelihood; Nonstationary spatial covariance function; Vector autoregressive model

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