Modelling past land use using archaeological and pollen data

Motivation

Anthropogenic land cover changes may have impacted the climate system over long time scales. Most past studies of the biogeophysical effects of vegetation and land use changes on climate were carried out on the global scale using simulations of past land cover and land use. The reconstruction of land use and land cover based on archaeological findings and fossil pollen records is an alternative, to the dynamic vegetation model simulations and anthropogenic scenarios, that may provide more realistic descriptions of past land use and land cover for climate modelling studies.

Model

Hierarchical model:

To model the spatial structure in the compositional and count data we propose a hierarchical model where the observed compositions are modelled as draws from a Dirichlet distribution and observed counts are modelled as log-Gaussian Cox process, both conditional on transformed underlying latent fields (Pirzamanbein et al. 2015. Simpson et al. 2011). The transformed function can be any \( f : \mathbb{R}^d \to \mathbb{R}^d \). \( f(q) = x, d = D - 1 \) so that \( \sum x_j = 1 \). The spatial dependence is modelled as a Gaussian Markov Random Field (GMRF) with separable covariance structure:

\[
\begin{align*}
Y_{LC}(i), \eta &= \text{Dir}(\alpha(f(\eta)), ) \\
Y_{LU}(i), \eta_{LU} &= \text{LOGC}(\lambda)
\end{align*}
\]

where \( \log \lambda = \eta_{LU} \).

\[
\eta_{all} = B\beta + X
\]

for each composition together with the corresponding changes in the other compositions.

\[
\begin{align*}
\beta &\sim \mathcal{N}(0, \mu\beta) \\
\alpha &\sim \mathcal{G}(0, \nu) \Gamma(\alpha) \\
|\beta| &\sim \text{IW}(\nu, \gamma)
\end{align*}
\]

A gamma prior is chosen for scale parameters, \( \alpha \) and \( \beta \), and an inverse Wishart (IW) conjugate prior for \( \beta \), the covariance matrix between the fields.

MCMC scheme:

A 2-block updated Markov chain Monte Carlo (MCMC) is used to estimate parameters and latent fields, \( \{X, \beta, \alpha\} \).

\[
\begin{align*}
X', \beta', \alpha' &\sim \mathcal{N} \left( X, \beta, \alpha \right) + \mathcal{N} \left( 0, \mu\beta \right) \\
\beta' &\sim \mathcal{G}(0, \nu) \Gamma(\beta) \\
|\beta'| &\sim \text{IW}(\nu, \gamma)
\end{align*}
\]

Uncertainty:

Using the MCMC samples, we construct the elliptical confidence region for approximate multivariate Gaussian distributions for each location:

\[
\begin{align*}
(\eta - \mu)^\top \Sigma^{-1} (\eta - \mu) &\leq \chi^2_{\nu, \text{prob}}
\end{align*}
\]

Thereafter, the confidence ellipse is transformed using \( f \). The new ternary region is considered as the 95% confidence region for the composition estimates.

To illustrate the changes in compositions, we choose the maximum and minimum along each component. This way, we get a joint lower bound (minimum) and upper bound (maximum) for each composition together with the corresponding changes in the other compositions (Pirzamanbein et al. 2015). The ratio between the ternary region and total area is also provided.

References


Sugita 2007 Theory of quantitative reconstruction of vegetation 1: pollen from large sites REVEALS regional vegetation composition http://gva.gu.se/lqgg/reveals

Trondman et al. 2015 Pollen-based quantitative reconstructions of Holocene regional vegetation cover (plant functional types and land-cover types) in Europe suitable for climate modelling. http://gva.gu.se/3kkluw6

Goal

To provide a statistical model that reconstructs past land use and land cover over Sweden, by combining pollen-based estimates of land-cover composition with archaeological findings of land use (KK10).

Data

Archaeological records:

The archaeological data consists of the point location and dating of several thousand artefacts. Each artefact is classified into one of several usage categories, such as, agriculture, settlements, fortifications, maritime, and burial grounds. The base idea is that a higher proportion of these artefacts in a given region would also correspond to a higher land use.

Land Use (LU): Agriculture.

Breakpoints for dating:

Time windows:

Results

Spatial reconstruction of land-cover composition:

Pollen-based land-cover composition: Given pollen records extracted from lakes and bogs, pollen-based estimates of land cover are obtained using the REVEALS model (Sugita 2007) for a limited area around each lake or bog (Trondman et al. 2015).

Land Cover (LC): Coniferous forest, Broadleaved forest, and Unforested land.

• Unforested land consists of LU and Open land

Spatial reconstruction of agricultural findings:

Spatial reconstruction of land cover and land use for 1850-1950: