SPATIAL 2

Spatial Data Methods for Environmental and Ecological Processes - 2nd Edition

PROCEEDINGS

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Preface

This book collects the proceedings of the International Conference "Spatial Data Methods for Environmental and Ecological Processes - 2nd Edition", the 2011 European Regional Conference of The International Environmetrics Society, satellite of the 58th World Statistics Congress of the International Statistical Institute (ISI).

The main scope of the conference is exchanging past results and new ideas among researchers with different scientific backgrounds, all working on spatial and spatio-temporal environmental problems.

The conference is structured into five plenary sessions, twelve specialized sessions and a poster session, as follows:

Plenary sessions:

- Climatology and Meteorology
- Ecology and Water Analysis
- Ensemble Forecasts
- Sampling and Accurate Predictions for Environmental Management
- Spatial Functional Data

Specialized sessions:

- Air Quality
- Animal and Plant Ecology
- Climatology and Meteorology
- Disease mapping and Environmental Exposure
- Environmental Data Analysis
- GIS and Soil Sciences
- Landscape Ecology and Natural Resource Management
- Methods and Environmental Modelling
- Proximal and Remote Sensing in Precision Agriculture
- Sampling Designs for Natural Studies
- Space-time Surveillance for Public Health
- Space-time Surveillance of Natural Assets

Main themes of the poster session

- Agriculture, Biodiversity, Groundwater Pollution and Hydrogeology
- Air Quality and Disease Mapping
- Climatology and Meteorology and Sampling design
- Ecology, Conservation and Natural Resources Management
- Environmental Risk Assessment

The poster discussion was held during a "Spatial Café"

The Spatial Café was organized in five discussion tables. For each table two facilitators were chosen to stimulate and organize the posters discussion.

The Conference's Scientific Committee tailored the program to provide fruitful interactions among various research fields, under the common heading of “spatial analysis”. This was very clear during the course of the conference, as communication among participants both from Italy and abroad, from universities and research centers, and most importantly, among statisticians and researchers from other subject areas, was facilitated by a charming, very friendly atmosphere.

This Volume of Proceedings contains 110 short papers and abstracts that were presented during the conference and is articulated in three parts, each corresponding to a session held in the conference. All published papers were submitted to a refereeing process. The refereeing process has been attended by the Scientific and Organizing Committees.

The Scientific and Organizing Committees are very grateful to the University of Foggia, the University of Bari, the Fondazione Cassa di Risparmio di Puglia, The International Environmetrics Society, the International Statistical Institute, the Società Italiana di Statistica, the CRA-CSA of Bari, the Agenzia Regionale per la Prevenzione e la Protezione dell’Ambiente - Puglia - and the GRASPA research group for supporting the organization of the conference and allowing us to publish this volume.

In quality of Scientific Committee and Organizing Committee Presidents, we would like to thank the members of the Scientific Committee (Liliane Bel, Annamaria Castrignanò, Corrado Crocetta, Alessandro Fassò, Giovanna Jona Lasinio, Alessio Pollice and Marian Scott) and of the Organizing Committee (Barbara Angelillis, Francesca Bruno, Rosalba Ignaccolo, Giovanna Jona Lasinio, Alessio Pollice and Alessia Spada) for their outstanding work and all the participants to the conference for their contributions.

Daniela Cocchi, President of the Scientific Committee
Barbara Cafarelli, President of the Organizing Committee

Geoadditive modeling for extreme rainfall data

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Abstract: Extreme value models and techniques are widely applied in environmental studies to define protection systems against the effects of extreme levels of environmental processes. Regarding the matter related to the climate change science, a certain importance is cover by the implication of changes in the hydrological cycle. Among all hydrologic processes, rainfall is a very important variable as it is a fundamental component of flood risk mitigation and drought assessment, as well as water resources availability and management. We implement a geoadditive mixed model for extremes with a temporal random effect assuming that the observations follow generalized extreme value distribution with spatially dependent location. The analyzed territory is the catchment area of Arno River in Tuscany in Central Italy.

Keywords: GEV distribution, geoadditive mixed model, hydrologic processes

1 Introduction

Environmental extreme events such as floods, earthquakes, hurricanes, may have a massive impact on everyday life for the consequences and damage that they cause. For this reason there is considerable attention in studying, understanding and predicting the nature of such phenomena and the problems caused by them, not least because of the possible link between extreme climate events and climate change. A number of theoretical modeling and empirical analyses have also suggested that notable changes in the frequency and intensity of extreme events, including intense rainfall and floods, may occur even when there are only small changes in climate (Katz and Brown, 1992).

In this framework, in the past two decades there has been an increasing interest for statistical methods that model rare events (Coles, 2001). The Generalized Extreme Value distribution (GEV) is widely adopted model for extreme events in the univariate context. For modeling extremes of non-stationary sequences it is commonplace to use the GEV as a basic model, and to handle the issue of non-stationarity by regression modeling of the GEV parameters.

Here we implement a geoadditive mixed model for extremes with a temporal random effect. We assume that the observations follow a generalized extreme value distribution whose locations are spatially dependent where the dependence is captured using the geoadditive model. The analyzed territory is the catchment area of Arno River in Tuscany in Central Italy.

2 Materials and Methods

The investigation is developed on the catchment area of Arno River almost entirely situated within Tuscany, Central Italy. The time series of annual maxima of daily rainfall recorded in 415 rain gauges are analyzed. In order to have enough rain gauges observations to estimate both the spatial component and the year specific effect, we reduce the time series length to the post Second World War period and we consider only stations with at least 30 hydrologic years of data, even not consecutive. The final dataset is composed by the data recorded from 1951 to 2000 at 118 rain gauges for a total of 4903 observations.

Recently to handle the issue of non-stationarity of the GEV parameters, Padoan and Wand (2008) discuss how generalized additive models (GAM) with penalized splines can be carried out in a mixed model framework for the GEV family.

Geoadditive models, introduced by Kammand and Wand (2003), are a particular specification of GAM that models the spatial distribution of y with a bivariate penalized spline on the spatial coordinates. Suppose to observe n sample maxima y_{ij} at spatial location $\mathbf{s}_{ij}$, $\mathbf{s} \in \mathbb{R}^2$, $j = 1, \ldots, p$ and at time $i = 1, \ldots, t$. In order to model both the spatial and the temporal influence on the annual rainfall maxima, we consider a geoadditive mixed model for extremes with a temporal random effect:

$$\begin{cases} y_{ij}|s_{ij} \sim \mathrm{GEV}(\mu\left(s_{ij}\right), \psi, \xi) \\ \mu\left(\mathbf{s}_{ij}\right) = \beta_0 + \mathbf{s}_{ij}^T \boldsymbol{\beta}_s + \sum_{k=1}^{K} u_k b_{tps}(\mathbf{s}_{ij}, \boldsymbol{\kappa}_k) + \gamma_i, \end{cases} \tag{1}$$

where μ, ψ and ξ are respectively location, scale and shape parameters of the GEV distribution, b_{tps} are the low-rank thin plate spline basis functions with K knots and γ_i is the time specific random effect. The model (1) can be written as a mixed model

$$\mathbf{y}|\left(\mathbf{u}, \boldsymbol{\gamma}\right) \sim \mathrm{GEV}(\mathbf{X}\boldsymbol{\beta} + \mathbf{Z}\mathbf{u} + \mathbf{D}\boldsymbol{\gamma}, \psi, \xi). \tag{2}$$

with

$$\mathrm{E}\begin{bmatrix}\mathbf{u}\\ \boldsymbol{\gamma}\end{bmatrix} = \begin{bmatrix}0\\0\end{bmatrix}, \qquad \mathrm{Cov}\begin{bmatrix}\mathbf{u}\\ \boldsymbol{\gamma}\end{bmatrix} = \begin{bmatrix}\sigma_u^2\mathbf{I}_K & 0\\ 0 & \sigma_\gamma^2\mathbf{I}_t\end{bmatrix}.$$

where

$$\boldsymbol{\beta} = \left[\beta_0, \boldsymbol{\beta}_s^T\right] \qquad \mathbf{u} = \left[u_1, ..., u_K\right] \qquad \boldsymbol{\gamma} = \left[\gamma_1, ..., \gamma_t\right]$$
$$\mathbf{X} = \left[1, \mathbf{s}_{ij}^T\right]_{1 \le ij \le n} \qquad \mathbf{D} = \left[d_{ij}\right]_{1 \le ij \le n}$$

with d_{ij} an indicator taking value 1 if we observe a rainfall maxima at rain gauge j in year i and 0 otherwise, and $\mathbf{Z}$ the matrix containing the spline basis functions, that is

$$\mathbf{Z} = [b_{tps}(\mathbf{s}_{ij}, \boldsymbol{\kappa}_k)]_{1\le ij\le n, 1\le k\le K} = [C(\mathbf{s}_{ij} - \boldsymbol{\kappa}_k)]_{1\le ij\le n, 1\le k\le K} \cdot [C(\boldsymbol{\kappa}_h - \boldsymbol{\kappa}_k)]^{-1/2}_{1\le h,k\le K},$$

where $C(\mathbf{v}) = \|\mathbf{v}\|^2 \log \|\mathbf{v}\|$ and $\boldsymbol{\kappa}_1, ..., \boldsymbol{\kappa}_K$ are the spline knots locations.

3 Results

The geoadditive mixed model for extremes (2) can be naturally formulated as a hierarchical Bayesian model and estimated under the Bayesian paradigm. Following the specifications of Padoan (2008), our complete hierarchical Bayesian formulation is

1st level $\quad y_i|(\mathbf{u}, \boldsymbol{\gamma}) \overset{\text{ind}}{\sim} \text{GEV}([\mathbf{X}\boldsymbol{\beta} + \mathbf{Z}\mathbf{u} + \mathbf{D}\boldsymbol{\gamma}]_i, \psi, \xi)$

2st level $\quad \mathbf{u}|\sigma_u^2 \sim N(0, \sigma_\gamma^2 \mathbf{I}_K) \qquad \boldsymbol{\gamma}|\sigma_\gamma^2 \sim N(0, \sigma_\gamma^2 \mathbf{I}_t) \qquad \boldsymbol{\beta} \sim N(0, 10^4\mathbf{I})$
$\quad \xi \sim \text{Unif}(-5, 5) \qquad \psi \sim \text{InvGamma}(10^{-4}, 10^{-4})$

3st level $\quad \sigma_u^2 \sim \text{InvGamma}(10^{-4}, 10^{-4}) \qquad \sigma_\gamma^2 \sim \text{InvGamma}(10^{-4}, 10^{-4}).$

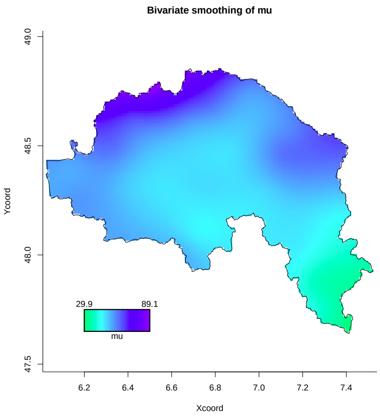
where the parameters setting of the priors distributions for ξ, ψ, $\boldsymbol{\beta}$, σ_u^2, σ_γ^2, corresponds to non-informative priors.

Given the complexity of the proposed hierarchical models, we employ `OpenBUGS` Bayesian MCMC inference package to do the model fitting. We access `OpenBUGS` using the package `BRugs` in the `R` computing environment. We implement the MCMC analysis with a burn-in period of 40000 iterations and then we retain 10000 iterations, that are thinned by a factor of 5, resulting in a sample of size 2000 collected for inference. Finally, the last setting concern the thin plate spline knots that are selected setting $K = 30$ and using the *clara* space filling algorithm of Kaufman and Rousseeuw (1990), available in the `R` package `cluster`.

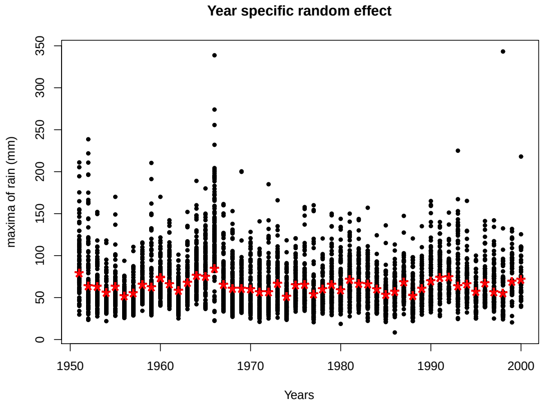
The resulting spatial smoothing component and time specific component of $\mu(s_{ij})$ are presented in Figures 1(a) and 1(b). Observing the map, it is evident the presence of a spatial trend in the rainfall extreme dynamic, even after controlling for the year effect. The spline seems to capture well the spatial dependence as it produce the same same patter of the Average Total Annual Precipitation. The time influence is pointed out by the estimated year specific random effects, that present a strong variability through years.

4 Conclusions

We have implemented a geoadditive modeling approach for explaining a collection of spatially referenced time series of extreme values. We assume that the obser-



(a)



(b)

Figure 1: Estimated spatial component (a) and year specific random effects (b) of $\mu\left(s_{ij}\right)$. Black dots indicate the observed values.

vations follow generalized extreme value distributions whose locations are spatially dependent.

The results show that this model allows us to capture both the spatial and the temporal dynamics of the rainfall extreme dynamic.

Under this approach we expect to reach a better understand of the occurrence of extreme events which are of practical interest in climate change studies particularly when related to intense rainfalls and floods, and hydraulic risk management.

References

Coles, S.G. (2001) *An Introduction to Statistical Modeling of Extreme Values*, Springer, London.

Kammann, E.E., Wand, M.P. (2003) Geoadditive models, *Applied Statistics*, 52, 1-18.

Katz R.W., Brown B.G. (1992) Extreme events in a changing climate: variability is more important than averages, *Climate Change*, 21, 289-302.

Kaufman, L., Rousseeuw, P.J. (1990) *Finding Groups in Data: An Introduction to Cluster Analysis*, Wiley, New York.

Padoan, S.A. (2008) *Computational methods for complex problems in extreme value theory*, Ph.D. thesis, Ph.D. in Statistical Science, Department of Statistical Science, University of Padova.

Padoan, S.A., Wand, M.P. (2008) Mixed model-based additive models for sample extremes, *Statistics and Probability Letters*, 78, 2850-2858.