Spatio-temporal stochastic modelling of environmental hazards

Available online at www.sciencedirect.com

ScienceDirect

Spatial Statistics 00 (2015) 1–4

Spatial Statistics

Spatio-temporal stochastic modelling of environmental hazards

Jorge Mateu[a,*], Rosalba Ignaccolo[b]

[a]*Department of Mathematics, University Jaume I, Campus Riu Sec, E-12071 Castellón, Spain*
[b]*Department of Economics and Statistics, University of Torino, Campus Luigi Einaudi, Torino, Italy*

Abstract

This is the editorial letter for the Special Issue dedicated to the joint VII International Workshop on Spatio-temporal Modelling (METMAVII) and the 2014 meeting of the research group for Statistical Applications to Environmental Problems (GRASPA14), which took place in Turin (Italy) from 10 to 12 September 2014. This SI summarises a selection of the main contributions presented at this workshop, related to spatial and spatio-temporal methodology, mainly based on point processes, and illustrated with environmental applications on earthquakes, tornadoes, and radioactive particles.

Keywords: Changepoint analysis, Entropy, Environmental applications, ETAS model, Multifractality, Non-extensivity, Radioactive particle data, Residual analysis, Seismology, Spatio-temporal point processes, Spatio-temporal statistics, Superthinning, Tectonics, Thinned residuals, Tornadoes, Weighted likelihood estimator

1. Introduction

In recent years, spatio-temporal modelling has become one of the most interesting and, at the same time, challenging research areas of natural sciences. This has been largely fueled by the increased availability of inexpensive, high-speed computing. Such availability has enabled the collection of large spatial and spatio-temporal datasets across many fields, has facilitated the widespread usage of sophisticated geographic information systems (GIS) software to create attractive displays, and has endowed the ability to investigate challenging, evermore appropriate and realistic models (Gelfand *et al.*, 2010). The relevant literature is growing fast and along directions that range from theoretical works to methodological developments to real world applications. Spatio-temporal systems modelling involves the synthesis of a rich interdisciplinary body of knowledge for which it is necessary to establish a solid theoretical foundation and a science-based methodology with both researchers and practitioners in mind.

This special issue is dedicated to the VII International Workshop on Spatio-temporal Modelling - METMAVII - and the 2014 meeting of the research group for Statistical Applications to Environmental Problems (www.graspa.org) - GRASPA14 - which took place in Turin (Italy) from 10 to 12 September 2014. The purpose of this workshop was to promote the development and application of spatial, temporal, and mainly spatio-temporal statistical methods to different fields related to the environment. The joint meeting METMAVII-GRASPA14 was an opportunity to bring

*Corresponding author
Email addresses: mateu@uji.es (Jorge Mateu), rosaria.ignaccolo@unito.it (Rosalba Ignaccolo)

together two communities with common research interests, such as the development and use of statistical methods in the environmental sciences. These research aims are at the cornerstone of *The International Environmetrics Society* (TIES), indeed the meeting was a TIES regional conference.

The conference topics included: (a) development and application of spatial and spatio-temporal statistical methods in different fields related to environmental and health sciences; (b) environmental quality; (c) safety and sustainability including air and water quality; (d) epidemiology; (e) earth science and ecology; (f) functional data analysis; (g) spatial and spatio-temporal sampling and extreme values.

The complete list of papers presented at the workshop and any particular information are posted at:

`http://meetings.sis-statistica.org/index.php/graspametma14/metma7graspa14.`

And the proceedings can be found at:

`https://aisberg.unibg.it/handle/10446/30963#.VcKS5_ntlHw.`

In light of the above considerations, the articles of this special issue have been carefully selected to present a variety of conceptual frameworks, powerful methods and comprehensive techniques that address a number of interesting problems in environmental and health sciences. In particular, the selected papers present contributions related to spatial and spatio-temporal methodology, mainly based on point processes, and illustrated with environmental applications on earthquakes, tornadoes, and radioactive particles. For example, and as a direct connection between point process methodology and earthquakes, significant changes in the spatio-temporal dynamics of the seismic activity are observed previous to the volcanic eruption.

A spatial point process is a stochastic process each of whose realisations consists of a finite or countably infinite set of points in the plane. Spatio-temporal point processes are considered as being a hybrid of the spatial and temporal components, by extending the definition of spatial point processes to include time. Because the spatial location can always be considered as one component of a multi-dimensional mark, the evolution of spatial features with time is often of special interest. Despite such considerations, studies of spatio-temporal models have lagged well behind those of simple temporal models, and even those of purely spatial models. No doubt the reasons have been largely practical, notably the difficulty of compiling good spatio-temporal datasets and the heavy computations needed to analyse them. One way to observe these processes is to consider the spatial location itself viewed as a mark for a simple point process in time, thereby providing one route to likelihood analyses of spatio-temporal models. Further characteristics, such as magnitude, spatial extent, or even duration, can be added as additional marks. Thus, the study of spatio-temporal point processes leads almost inevitably to the more general study of evolving spatial fields, although practical modelling in this direction is still limited and very subject-specific. In this context, principled statistical modelling and residual analysis are at the core of many outstanding research works. Indeed, for gridded forecasts, deviance residuals seem ideally suited for model comparison. And for replicated spatial or spatio-temporal point patterns, looking for methods of assessing whether all spatial point patterns share a common spatial distribution or there are specific features is of primary interest.

This special issue comprises papers mainly dealing with point processes and earthquake modelling (Adelfio and Chiodi, 2015; Gordon *et al.*, 2015; Nicolis *et al.*, 2015; Zhuang, 2015), one paper dealing with point processes and tornadoes (Gomez-Rubio *et al.*, 2015), one paper dealing with point processes and radioactive particles (Altieri *et al.*, 2015), and finally one paper dealing with entropy measures applied to earthquake modelling (Esquivel and Angulo, 2015).

The conditional intensity function of a space-time branching model is defined by the sum of two main components: the long-run term intensity and short-run term one. Their simultaneous estimation is a complex issue that usually requires the use of hard computational techniques. Adelfio and Chiodi (2015) present a new mixed estimation approach for a particular space-time branching model, the Epidemic Type Aftershock Sequence (ETAS) model. This approach uses a simultaneous estimation of the different model components, alternating a parametric step for estimating the induced component by maximum likelihood and a non-parametric estimation step, for the background intensity, by FLP (Forward Predictive Likelihood). Adelfio and Chiodi (2015) further develop graphical tools for diagnostics, presenting an `R` package named `etasFLP`.

Voronoi residuals, deviance residuals, super-thinning, and some other residual analysis methods are applied to a selection of earthquake forecast models in Gordon *et al.* (2015). Unlike simple numerical summaries such as the N-test, L-test, or R-test, graphical residual methods are proposed which can be useful for comparing multiple models and for highlighting when and where a given model does not agree closely with the observed seismicity. For gridded forecasts, deviance residuals seem ideally suited for model comparison, and Voronoi residuals seem preferable to simple grid-based residuals for assessing one model individually. For models outputting an estimated conditional rate at any particular space-time location, Voronoi residuals and super-thinning can be especially useful at identifying departures from the data.

The seismicity in Chile is estimated using an ETAS space-time point process through a semi-parametric technique to account for the estimation of parametric and nonparametric components simultaneously in Nicolis *et al.* (2015). The two components account for triggered and background seismicity respectively, and are estimated by alternating a maximum likelihood estimation for the parametric part and a forward predictive likelihood technique for the nonparametric one. Given the geographic and seismological characteristics of Chile, the sensitivity of the technique with respect to different geographical areas is examined in overlapping successive windows with varying latitude. A different behaviour of background and triggered seismicity in the different windows is observed and analysed.

Based on the technique of residual analysis, the weighted likelihood estimator for temporal and spatio-temporal point processes is proposed in Zhuang (2015), as well as weighted Poisson likelihood estimators and weighted pseudo-likelihood estimators for spatial point processes. The weighted likelihood estimator is applied to the spatio-temporal ETAS model to study the spatial variations of seismicity characteristics in the Japan region.

Gomez-Rubio *et al.* (2015) describe a novel approach to modelling marked point patterns based on recent computational development for Bayesian inference. They use the flexible class of log-Gaussian Cox Processes to model the intensity of the different observed point patterns. The authors propose several types of models to account for spatial variability and provide a modelling framework that allows for a common spatial component to all point processes (regardless of the mark) and also for mark-specific spatial components. In this way, they provide a method of assessing whether all processes share a common spatial distribution or there are specific features. In order to fit these models, Gomez-Rubio *et al.* (2015) have resorted to the Integrated Nested Laplace Approximation (INLA) method and the Stochastic Partial Differential Equation (SPDE) approach. This defines a connection between point processes and geostatistics, as they model a point pattern by means of a continuous spatial process. This approach to spatial modelling is applied to a massive dataset on the occurrence of tornadoes in the United States.

Altieri *et al.* (2015) introduce a Bayesian approach to detecting multiple unknown changepoints over time in the inhomogeneous intensity of a spatio-temporal point process with spatial and temporal dependence within segments. The authors propose a new method for detecting changes by fitting a spatio-temporal log-Gaussian Cox process model using the computational efficiency and flexibility of Integrated Nested Laplace Approximation, and by studying the posterior distribution of the potential changepoint positions. A simulation study assesses the validity and properties of the proposed method. Lastly, questions are addressed concerning potential unknown changepoints in the intensity of radioactive particles found on Sandside beach, Dounreay, Scotland.

Esquivel and Angulo (2015) focus on the assessment of possible relational elements of the submarine volcanic eruption occurred during 2011 in El Hierro (Canary Islands, Spain) with both the spatio-temporal evolutionary behaviour and the scaling properties of seismic activity before, during and after it. They adopt the non-extensive frequency-magnitude distribution (FMD) model (Silva *et al.*, 2006) to fit the observed data, by introducing a weighting function based on the relation between magnitude and energy. Moreover, an extension of the dependence coefficients in terms of Tsallis entropy to the multifractal domain is proposed to study the dimensional interaction in terms of the Tsallis generalised dimension formulation as introduced in Angulo and Esquivel (2014). The study shows significant changes in the spatio-temporal dynamics of the seismic activity previous to the volcanic eruption. The combination of these techniques can be seen as a suitable tool in the continuous monitoring of volcanic activity.

To conclude we would like to express our gratitude to the set of reviewers that collaborated in the edition of this special issue. We are specially grateful to the Editor-in-Chief Alfred Stein and the Editorial Board of Spatial Statistics for their support. We hope that these contributions will further enhance the current interest in statistical methods in a spatial and a spatio-temporal framework.

References

[1] Adelfio, G. and Chiodi, M. (2015). FLP estimation of semi-parametric models for space-time point processes and diagnostic tools. *Spatial Statistics*. In press.

[2] Altieri, L., Scott, E.M., Cocchi, D. and Illian, J.B. (2015). A changepoint analysis of spatio-temporal point processes. *Spatial Statistics*. In press.
[3] Angulo, J.M. and Esquivel, F.J. (2014). Structural complexity in space-time seismic event data. *Stochastic Environmental Research and Risk Assessment*, **28**, 1187-1206.
[4] Esquivel, F.J. and Angulo, J.M. (2015). Non-extensive analysis of the seismic activity involving the 2011 volcanic eruption in El Hierro. *Spatial Statistics*. In press.
[5] Gelfand, A.E., Diggle, P.J., Fuentes, M. and Guttorp, P. (2010). *Handbook of Spatial Statistics*. Chapman and Hall/CRC Press, Boca Raton.
[6] Gomez-Rubio, V., Cameletti, M. and Finazzi, F. (2015). Analysis of massive marked point patterns with stochastic partial differential equations. *Spatial Statistics*. In press.
[7] Gordon, J.S., Clements, R.A., Schoenberg, F.P. and Schorlemmer, D. (2015). Voronoi residuals and other residual analyses applied to CSEP earthquake forecasts. *Spatial Statistics*. In press.
[8] Nicolis, O., Chiodi, M. and Adelfio, G. (2015). Windowed ETAS models with application to the Chilean seismic catalogs. *Spatial Statistics*. In press.
[9] Silva, R., Franca, G.S., Vilar, C.S., Alcaniz, J.S. (2006). Nonextensive models for earthquakes. *Physical Review E*, **73**, 026102.
[10] Zhuang, J. (2015). Weighted likelihood estimators for point processes. *Spatial Statistics*. In press.