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Editorial: Spatio-temporal dynamics of Covid

Covid-19 has rapidly spread to become a global pandemic. In response, much research has focused on the development and application of spatial–statistical models to predict variables like cases and deaths through time, based on data from national or international institutions. These models are largely based on the dynamics of data on numbers of individuals who are classified into various categories such as susceptible, exposed, infectious, recovered, or dead in specific geographical areas of interest.

Different such geographical areas differ from each other, for instance at economic, social and health services levels. Hence it is expected that there are spatio-temporally varying effects of the Covid-19 disease, while spatio-temporal statistical models capturing these effects have the potential to be of great use to decision-makers to intervene on local public health systems. The focus of this special issue is to present novelties in the domain of spatio-temporal models that are appropriate for modelling Covid-19 pandemic spread based on relevant data sets, or that are inspired by its development.

This special issue of *Spatial Statistics* called for papers on subjects including, but not limited to:

- Spatio-temporal statistical models to identify, quantify and predict variables of interest in Covid data modelling.
- Identification and appropriate modelling of the nature of spatio-temporal dependence in Covid data.
- Identification of the relevant variables that affect outcomes of interest (variable selection) at different levels of scale.
- Identification of spatio-temporal trends.
- Spatio-temporal clustering of Covid-19 territorial spread.
- Spatio-temporal modelling for big Covid-19 data.
- Identifying complex structures of Covid-19 data.
- Prediction methods to reveal correlation and patterns of Covid-19 disease outbreak.
- Spatial composite indicators for monitoring the Covid-19 territorial spread.

The call for papers for this special issue received more than 50 submissions of which quite a few had to be rejected at the peer review stage because of their un-suitability for the journal. These rejections were mainly due to a lack of novelty either in the application or the methodological development. This high rate of rejection is perhaps due to the shortness of the time scale allowed to prepare and submit the manuscripts. What remained is a collection of papers on which we are really and deeply proud: they show a wealth of information, novelty and depth, inspired by the devastating and lethal behaviour of the pandemic. The collection of papers in this issue is impressive and may have hastened the development of new methodologies which can potentially be of interest

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in a wider scientific context. In the end, we – the editors – are delighted to accept and publish nineteen high quality papers on a range of methodological and applied developments. These papers will help us to better understand the pandemic, and to improve decision making while fighting it.

The accepted papers are briefly introduced below.

D'Urso, De Giovanni and Vitale identify a clustering structure for the 20 Italian regions according to the main variables related to Covid-19 pandemic. Data are observed over time, spanning from the last week of February 2020 to the first week of February 2021. Dealing with geographical units observed at several time occasions, their proposed fuzzy clustering model embedded both space and time information.

Sahu and Böhning develop an adaptive model for the weekly Covid-19 death rates in England as part of a joint bivariate model for number of cases and deaths. The joint model is used to evaluate the effects of several socioeconomic and environmental covariates on the rates of cases and deaths. An adaptive version of their model was able to detect possible step changes in death rates in neighbouring areas.

Bartolucci and Farcomeni propose a spatio-temporal model based on discrete latent variables for the analysis of Covid-19 incidence. They assume that for each area the sequence of latent variables across time follows a Markov chain with initial and transition probabilities that also depend on latent variables in neighbouring areas.

Lee, Robertson and Marques suggest a model to estimate the small-area spatio-temporal dynamics of the Covid-19 pandemic in Scotland during a period with limited Covid-19 testing capacity. The proposed model is able to estimate the proportions of calls classified as either relating to Covid-19 directly or having related symptoms.

Feng presents a spatial–temporal generalized additive model for modelling geo-referenced Covid-19 mortality data in Toronto, Canada. A range of factors and spatial–temporal terms are incorporated into the model. The non-linear and interactive effects of the neighbourhood-level factors are modelled as a two-dimensional spline smoother and the change of spatial pattern over time is modelled as a three-dimensional tensor product smoother.

Vitale, D'Urso and De Giovanni model the spatial epidemic dynamics of COVID-19 outbreak in Italy by means of an Object-Oriented Bayesian Network in order to explore the dependence relationships, in a static and a dynamic way, among the weekly incidence rate, the intensive care units occupancy rate and that of deaths. Following an autoregressive approach, both spatial and time components have been embedded in the model by means of spatial and time lagged variables.

Celani and Giudici propose an endemic–epidemic model based on a negative binomial space–time autoregression, which can be employed to monitor the contagion dynamics of the Covid-19 pandemic, both in time and in space.

D'Urso, Mucciardi, Otranto and Vitale propose a robust fuzzy clustering model, the STAR-based fuzzy C-Medoids clustering model with noise cluster, to define territorial partitions of the European regions according to the workplace's mobility trends for places of work provided by Google with reference to the whole Covid-19 pandemic period. The clustering model considers both temporal and spatial information by means of the autoregressive temporal and spatial coefficients of the STAR model.

Mukhopadhyay, Singh and Bandopadhyay develop an adaptive clustering method for estimating the growth rate of infection during the early phase of a pandemic. They formulate a 'chain ratio to regression type estimator of population total' in two occasions adaptive cluster successive sampling and studied the properties of the estimator.

Kumar, Lahiri and Alvarado use multiple change point estimation methods for detecting trends in Covid-19 infections and deaths in India and compare those with other WHO regions.

Slater, Brown, Rosenthal and Mateu relate spatial structures of Covid-19 case counts with cell-phone mobility data. They investigate the efficacy of the method using Covid-19 case counts of two communities in Spain. Furthermore, they show that mobility data captures spatial variation in Covid-19 case counts much more accurately than physical adjacency alone.

Scimone, Menafoglio, Sangalli and Secchi analyse official daily data on mortality from all causes in the provinces and municipalities of Italy for the year 2020 by considering the tools and perspective

of Object Oriented Spatial Statistics. By comparison with mortality data from 2011 to 2019, they assess the local impact of the pandemic as perturbation factor of the natural spatio-temporal death process.

Li and Dey propose a spatio-temporal Conway Maxwell Poisson model for both under and over-dispersion. Their model is illustrated to have better predictive performance than ordinary spatio-temporal disease mapping models.

Bucci, Ippoliti, Valentini and Fontanella use a Bayesian nonparametric approach to investigate spatial patterns of deaths in several European countries. They use a mixture of Gaussian processes coupled with a Dirichlet process to group Covid-19 mortality curves.

Mingione, Di Loro, Farcomeni, Divino, Lovison, Maruotti and Jona Lasinio introduce an extended generalized logistic growth model for discrete outcomes, in which spatial and temporal dependence are dealt with the specification of a network structure within an auto-regressive approach in a Bayesian modelling framework.

Matuk and Guo take a functional modelling framework under the Bayesian paradigm to study and understand spatio-temporal pattern in the Covid-19 spread in the USA.

Fassò, Maranzano and Otto perform variable selection methods to assess impact of air quality and lockdown on Covid-19. They also use other relevant sources of data, e.g., meteorological data in their endeavour.

Martinez Beneito, Mateu and Botella-Rocamora propose a new spatio-temporal spline model particularly suited for COVID-19 surveillance, which allows estimation and monitoring for small areas. They illustrate their proposal on the study of the disease pandemic in two Spanish regions.

Grimée, Dunbar, Hoffmann and Held extend the endemic–epidemic modelling framework for the analysis of infectious disease data. They propose to adjust the static neighbourhood matrices over time to reflect changes in spatial connectivity between geographical units. They model the spread of Covid-19 disease between Swiss and bordering Italian regions in the first wave of the Covid-19 pandemic.

Cioban and Mare use the global and local Moran spatial autocorrelation coefficients to identify significant clustering processes in the Covid-19 infection rate during the third wave in Romania. These processes are seen to be significantly influenced by the development level of localities, proxied by unemployment rate and Local Human Development Index.

We are delighted to present such a large variety of methodological and applied papers all discussing different aspects of spatio-temporal spread of Covid-19. Looking back, the collection of the special issue papers does fulfil the aims set out in the issued call for papers. Hopefully, the articles in the special issue will inspire a generation of researchers to develop new methods and applications related to the ongoing pandemic as nature generates new data and dynamics.

We wish to speak our gratitude to those that helped to establish the special issue. First, and foremost, we thank the authors for compiling the papers from such a wide variety of points of view. They have, perhaps more than anyone else, realized that the pandemic has components that can very well be addressed with spatial statistical methods. Secondly, we would like to thank the reviewers, holding the manuscripts against the light of scientific judgement as we are very much aware that often many papers end up in depositories without proper evaluation and may lead to erroneous conclusions. Finally, we thank Pradeep Kumar at Elsevier Science who professionally handled the technical issues for the Special Issue at the highest level.

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