Workshop on Recent Advances in Modelling Spatio-Temporal Data.

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> > > Edited by Sujit K. Sahu





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1. Programme

Wednesday 25 May

8:30-9:15	REGISTRATION
9:15-9:20	Welcome
9:20-9:30	Prof W Wakeham (Vice Chancellor)
	SESSION I
	Chair: Peter Diggle
9:30-10:30	Multivariate spatial process modelling
	Alan Gelfand
10:30-11:00	Spatio-temporal modelling of ocean temperature and salinity
	Peter Challenor and Sujit Sahu
11:00-11:30	COFFEE
	SESSION II
	Chair: Alan Gelfand
11:30-12:00	Multivariate analysis of spatial-temporal variation in cancer mortality
	in Greece
	Nicky Best
12:00-12:30	Bayesian modelling of spatially correlated survival data
	Dipak Dey
12:30-1:00	Modelling the UK 2001 foot-and-mouth epidemic
	Rob Deardon
1:00-2:00	LUNCH
	SESSION III
	Chair: Dipak Dey
2:00-2:30	Seeking solutions to problems that exhibit uncertainty in both time and
	space
	Caitlin Buck
2:30-3:00	Bayesian palaeoclimate reconstruction
2 0 0 1 0 0	John Haslett
3:00-4:00	Roundtable meetings with TEA
	SESSION IV
4 00 4 80	Chair: Chris Glasbey
4:00-4:30	Bayesian radio-tracking: inference for diffusions in heterogeneous envi-
	ronments
4 20 5 00	
4:30-5:00	Interence for state-space models for wild animal populations
5.00 7.00	SESSION V. Postora
5.00-7:00 7.00	Workshop Dinner
1.00-	

Thursday 26 May

SESSION VI

	Chair: Nicky Best
9:00-10:00	Spatio-temporal point processes: methods and applications
	Peter Diggle
10:00-10:30	Space-time modelling of soil moisture
	Valerie Isham
10:30-11:00	Space-time multitype log Gaussian Cox processes with a view to mod-
	elling weeds
	Jesper Moller
11:00-11:30	COFFEE
	SESSION VII
	Chair: Ron Smith
11:30-12:00	A STARMA model for solar radiation in a microclimate
	Chris Glasbey
12:00-12:30	Non-stationary spatio-temporal analysis of karst water levels
	Ian Dryden
12:30-1:00	Applications of independence estimating equations to large space-time
	datasets
	Richard Chandler
1:00-2:00	LUNCH
2:00-2:30	Roundtable Meetings
	SESSION VIII
	Chair: Valerie Isham
2:30-3:00	A common framework for constructing non-stationary covariance func-
	tions
	Chris Holmes
3:00-3:30	Modelling rainfall data from rain seeding experiments
	Giovanna Jona Lasinio
3:30-4:00	Applying generalised additive mixed models to the estimation of spatial
	and temporal trends in tree defoliation
	Nicole Augustin
4:00-4:30	TEA
	SESSION IX
4:30-5:30	Report from the Roundtable meetings and closing remarks including
	comments from:
	Peter Diggle, Alan Gelfand and Kanti Mardia.

2. Abstracts

2.1 Wednesday morning

1. Multivariate spatial process modelling

Alan Gelfand, Duke University

Models for the analysis of multivariate spatial data are receiving increased attention these days. In many applications it will be preferable to work with multivariate spatial processes to specify such models. A critical specification in providing these models is the cross covariance function. Constructive approaches for developing valid cross-covariance functions offer the most practical strategy for doing this. These approaches include separability, kernel convolution or moving average methods, and convolution of covariance functions. We review these approaches but take as our main focus the computationally manageable class referred to as the linear model of coregionalization (LMC). We introduce a fully Bayesian development of the LMC. We offer clarification of the connection between joint and conditional approaches to fitting such models including prior specifications. However, to substantially enhance the usefulness of such modelling we propose the notion of a spatially varying LMC (SVLMC) providing a very rich class of multivariate nonstationary processes with simple interpretation. We illustrate the use of our proposed SVLMC with application to more than 600 commercial property transactions in three quite different real estate markets, Chicago, Dallas and San Diego. Bivariate nonstationary process models are developed for income from and selling price of the property.

2. Spatio-temporal modelling of ocean temperature and salinity

Peter Challenor and Sujit Sahu, University of Southampton

The world's climate is to a large extent driven by the transport of heat and fresh water in the oceans. Regular monitoring, studying, understanding and forecasting of temperature and salinity at different depths of the oceans are a great scientific challenge. Temperature at the ocean surface can be measured from space. However salinity cannot yet be measured by satellites, although systems are being developed, and space-based measurements can only ever give us surface values. Until recently temperature and salinity measurements within the ocean have had to come from expensive research ships. The ARGO float programme, described below, has been funded by various governments around the world to collect actual measurements and rectify this problem.

The primary objective of this paper is to model data obtained from ARGO floats in the North Atlantic Ocean during the year 2003. The purpose is to build a model and develop methodology for constructing annual prediction maps at three different depths following Sahu *et al.* (2004). In so doing we tackle various modelling and computational issues. The statio-temporal data sets are completely misaligned: no two measurements are recorded at the same location because of the moving floats. Moreover, there is no temporal regularity in the data. As a result many current strategies for modelling time series data from fixed monitoring sites are not appropriate here. In addition it can be expected that the underlying processes are non-stationary and anisotropic in space and time due to variations arising from different sources e.g. latitude and time of the year. Lastly, typical data sets are quite large adding to the computational burden.

In this paper we consider a Bayesian hierarchical model describing the spatio-temporal behaviour of the joint distribution of temperature and salinity levels. The space-time model is obtained as a kernel-convolution effect of a single latent spatio-temporal process. Additional terms in the mean describe non-stationarity arising in time and space. We use predictive Bayesian model selection criteria to choose and validate the models. We obtain annual prediction surfaces and the associated uncertainty maps. We develop different models for three different depths of the north Atlantic ocean. The Markov chain Monte Carlo methods are used throughout in our implementation. More work is needed to unify the three models at different depths into a single hierarchical model.

References

Sahu, S. K., Gelfand, A. E. and Holland, D. M. (2004) Spatio-temporal modeling of fine particulate matter.

3. Multivariate analysis of spatial-temporal variation in cancer mortality in Greece

Nicky Best and Evangelia Tzala, Imperial College, London

In recent years there has been particular interest in the joint spatial analysis of area-specific rates of several potentially related diseases (Gelfand and Vounatsou 2003; Held et al. 2005; Hogan and Tchernis 2004; Knorr-Held and Best, 2001; Sun et al., 2000; Wang and Wall 2003) with a view to detecting common spatial patterns in the underlying disease-specific risk surfaces. Models have either been based on a multivariate extension of the widely used conditional autoregressive model or on spatial generalisations of a factor analysis type model. We extend the factor analysis approach to consider the joint analysis of spatial-temporal variations in area-specific rates of several diseases over time. We adopt a Bayesian hierarchical modelling framework, and consider various prior formulations for the latent spatial and temporal factors reflecting the shared pattern of risk. The model is motivated by an analysis of age standardised annual mortality rates of 17 cancer sites

across the 51 administrative districts in Greece for the years 1981 to 1999.

References

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- Hogan J and Tchernis R. Bayesian factor analysis for spatially-correlated data, with application to summarising area-level deprivation from Census data. Journal of the American Statistical Association 2004; 99: 314-24.
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4. Bayesian modeling of spatially correlated survival data

Dipak K. Dey, University of Connecticut

The last decade has witnessed major developments in Geographical Information Systems (GIS) technology resulting in the need for Statisticians to develop models that account for spatial clustering and variation. In public health settings, epidemiologists and health care professionals are interested in discerning spatial patterns in survival data that might exist among the counties. This talk develops Bayesian hierarchical model for capturing spatial heterogeneity within the framework of proportional odds. This is deemed more appropriate when a substantial percentage of subjects enjoy prolonged survival. We discuss the implementation issues of our models, perform comparisons among competing models and illustrate with data from the SEER (Surveillance Epidemiology and End Results) database of the National Cancer Institute, paying particular attention to the underlying spatial story.

5. Modelling the UK 2001 Foot-and-Mouth Epidemic

Rob Deardon, Statistical Laboratory, University of Cambridge.

Foot-and-Mouth disease (FMD) entered the UK in the beginning of February 2001. By the time it had been eradicated it had exerted terrible effects upon both the farming and tourism industries of the UK. The control policies that were put in place by the UK government have been the subject of much controversy, both at the time and since. Vital to ensuring that any future outbreak is controlled efficiently is that we have a full understanding of the spatio-temporal dynamics of the disease as possible.

To this end, we present work undertaken to model these dynamics using a Bayesian MCMC approach to parameterisation. Two areas of importance arise. One is the form of the model itself. Here we use as our starting point the model of Keeling *et al.* (2001) which has been extended to better capture the characteristics of the epidemic. The second area of importance is how the model and MCMC updates can be formulated in such a way that the computation time is not prohibitive. **References**

Keeling, M. J., Woolhouse, M. E. J., Shaw, D. J., Matthews, L., Chase-Topping, M., Haydon, D. T., Cornell, S. J., Kappey, J., Wilesmith, J., and Grenfell, B. T. (2001) Dynamics of the 2001 UK foot and mouth epidemic - dispersal in a heterogeneous landscape. *Science*, 294, 813–817.

2.2 Wednesday afternoon

6. Seeking solutions to problems that exhibit uncertainty in both time and space

Caitlin E. Buck, P.G. Blackwell and A.J. Howard University of Sheffield

Spatio-temporal problems in archaeology and palaeo-environmental research (including climate change) cannot be tackled readily using standard models because of the presence of uncertainty on both the temporal and the spatial scales. Typically, the temporal information arises from chronometric dating methods, such as radiocarbon or uranium-series dating, which lead to estimated rather than exactly known calendar dates. Alongsde this, past landscapes were often very different from modern ones in important and poorly understood ways. This means that in order to reliably make inferences on either or both of the space and time scales, we need carefully devised models that take account of the uncertainty and provide probabilistic solutions to the questions posed.

Until recently, researchers working on such problems have taken one of two approaches. Some, like the famous work by Ammerman and Cavalli-Sforza (1973), use deterministic models to represent

the spread of populations across landscapes without formally fitting them to real data. Others use stochastic models, but have not attempted to represent changes in space and time in the same model. Blackwell and Buck (2003), for example, illustrated the use of a fully Bayesian model in which the uncertainties arising from the radiocarbon dating evidence are formally accounted for, but the spatial information is not explicitly modelled at all.

In this paper we will look at on-going work in palaeo-spatio-temporal modelling, articulate why such problems are so hard to tackle and talk about some plans for future work that might benefit from input from other delegates at the workshop.

References

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- Blackwell, P.G. and Buck, C.E. (2003) The Late Glacial human reoccupation of north western Europe: new approaches to space-time modelling, *Antiquity*, **296**(77), 232–240.

7. Bayesian palaeoclimate reconstruction

John Haslett, Trinity College, Dublin, Ireland.

We consider the problem of reconstructing pre-historic climates using fossil data extracted from lake sediment cores. A hierarchical Bayesian modelling approach is presented and its use demonstrated in a relatively small but statistically challenging exercise, the reconstruction of pre-historic climate at Glendalough in Ireland using fossil pollen data. This computationally intensive method extends current approaches by (a) explicitly modelling uncertainty at all stages and (b) reconstructing entire climate histories. The statistical issues raised relate to the use of compositional data (pollen) with covariates (climate) which are available at many modern sites but are missing for the fossil data. The compositional data arise as mixtures and the missing covariates have a temporal structure. Novel aspects of the method include non-parametric modelling of two dimensional response surfaces, the exploitation of parallel processing and the use of a random walk with long tailed increments. We present some details of the study, contrasting its reconstructions with those generated by a method in use in the palaeoclimatology literature. We suggest that the method provides a basis for resolving important challenging issues in palaeoclimate research but draw attention to several challenging statistical issues that need to be overcome.

8. Bayesian radio-tracking: inference for diffusions in heterogeneous environments

P. G. Blackwell and K. J. Harris, University of Sheffield

In ecology and zoology, the radio tracking of animals is an increasingly important source of data on movement, behaviour and habitat use. Observations consist of locations in space, perhaps supplemented by behavioural or physiological information, and are indexed by time. Dependence between successive observations on an individual needs to be allowed for in any statistical analysis; since observations are not necessarily made at equal time intervals, a natural approach is to regard the true underlying movement as a diffusion process.

In this talk, I will discuss a range of fully-parametric diffusion models that capture key features of realistic patterns of animal movement, and ways of making inferences about such models. The original work in this area made use of the two-dimensional Ornstein-Uhlenbeck process (Dunn and Gipson, 1977, *Biometrics* 33:85-101). More recent work allows for diffusions driven by an underlying Markov chain representing behaviour (Blackwell 2003, *Biometrika* 90:613-627), with fully Bayesian inference being carried out using a Markov Chain Monte Carlo approach. Our current work considers diffusions with different properties in different discrete regions of space as an extension of continuous-time threshold auto-regressive processes to two (or more) dimensions. I will also talk about the prospects of linking this approach to very general models for partitioning space (e.g. Blackwell and Moeller 2003, *Adv. Appl. Prob.*, 35:4-26).

9. Inference for state-space models for wild animal populations

Carmen Fernandez, Lancaster University

State-space models (SSM) are a natural framework for simultaneously describing the evolution of animal population abundances and the periodic observations made of the population (see, e.g., Newman et al., 2005). The components of a SSM are the state process and the observation process, and for many real animal populations both processes are nonlinear, non-Gaussian, and high dimensional. A somewhat unique feature of animal populations is that the evolution of the state process often involves several sub-processes, such as movement and birth, that occur sequentially and on a periodic basis, for which no observations are taken until the processes are complete. The primary inference objectives are to make statements about the state process and about the parameters which characterize the state-space model conditional on the observations.

Recent developments in sequential Monte Carlo procedures (such as those described in, e.g., Doucet et al., 2001) allow such inferences to be made for complicated SSMs. In this work we demonstrate the application of these recent developments in sequential Monte Carlo procedures for carrying out such inferences and draw attention to the problem of sub-processes. A parallel analysis using Markov chain Monte Carlo (see, e.g., Gilks et al., 1996) is performed and the relative advantages and disadvantages of each of these computational methodologies are discussed, with a

view towards providing guidelines concerning computational approaches to SSMs for wildlife animal populations.

The methods are applied to population dynamics models for salmon and for seals, where several seal colonies are considered and movement between colonies is an issue. For the salmon dataset we perform a temporal analysis, whereas for the seals data model we consider both temporal and spatial aspects.

This is joint work with Ken Newman, Steve Buckland and Len Thomas, from the University of St Andrews, UK.

References

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- Newman, K.B., Buckland, S.T., Lindley, S.T., Thomas, L. and Fernandez, C. (2005). Hidden process models for animal population dynamics", *Ecological Applications*, forthcoming.

2.3 Thursday morning

10. Spatio-temporal point processes: methods and applications

Peter Diggle, Lancaster University and Johns Hopkins University

Spatio-temporal point process data arise naturally in a number of disciplines, including (human or veterinary) epidemiology where extensive data-sets are also becoming more common. One important distinction in practice is between processes defined as a discrete-time sequence of spatial point processes, or as a spatially and temporally continuous point process.

In this talk, I will describe three approaches to the analysis of spatio-temporal point process data, each motivated by a particular application as follows:

- discrete-time modelling, exemplified by annual records of the spatial distribution of bovine tuberculosis cases in Cornwall;
- empirical modelling, exemplified by a log-Gaussian Cox process model for real-time monitoring of gastro-enteric disease in Hampshire;
- mechanistic modelling, exemplified by a model due to Matt Keeling (Warwick University) for the 2001 UK foot-and-mouth epidemic.

I will compare different approaches to inference, including non-parametric smoothing, Monte Carlo maximum likelihood and a computationally simple partial likelihood.

11. Space-time modelling of soil moisture

Valerie Isham, University College London

Soil moisture provides the physical link between soil, climate and vegetation. It increases via the infiltration of rainfall and decreases through evapotranspiration, run- off and leakage, all these effects being dependent on the existing soil moisture level. During wet periods, soil moisture tends largely to be driven by the topography, while in dry periods evapotranspiration has more influence. Many processes including plant growth, flooding, hill-slope instability and atmospheric phenomena are affected by soil moisture over a range of spatial and temporal scales.

A marked Poisson process will be used to model the temporal process of rainfall input to the soil moisture dynamics, first at a fixed location and then over a spatial region. Under dry conditions, when soil saturation is not an issue and the upper bound that it imposes on soil moisture can be ignored, a generalisation of the Takács virtual waiting time process (well-known from queueing theory) can be used to model soil moisture at a fixed location. The model can be further developed to allow for the saturation upper bound. In these models, precipitation input is instantaneous and in a spatial-temporal analogue, rain storms have a spatial extent but no temporal duration. A further generalisation is to allow storms to have both spatial and temporal extents. Evapotranspiration is dependent on vegetation cover and in the spatial-temporal model, random-radius circular tree canopies are located in a homogeneous Poisson process over the region. Under arid/semi-arid conditions, many transient and equilibrium properties of these models can be determined analytically and used for comparison with data on soil moisture dynamics.

12. Spatio-temporal models for red pine decline

Jesper Moller, Aalborg University, Denmark

Red pine decline is characterized by expanding pockets of dead and chlorotic trees in plantations throughout the Great Lakes Region. Elucidation of exact mechanisms of pocket development and expansion remain elusive since a single site has never been observed over more than two years. In the present study, we fit a space-time model to a seven-year data set of annual censes of all trees in a plantation. Each year, each of the 2,715 trees was examined for presence/absence of Ips spp. and borers, and tree condition (live/dead) was recorded. The number of pitch tubes, each of which signifies colonization by a turpentine beetle, was also recorded. A subsample of trees was sampled for the presence/absence of root weevils. We attempt to answer the following questions: Do root weevils or turpentine beetles predispose trees to attack by Ips spp.? Do Ips spp. kill the trees? How does the spatial arrangement of turpentine beetle- and Ips-colonized trees affect the progression of the pocket decline?

This is an ongoing research project together with Kenneth F. Raffa and Brian Aukema, Department of Entomology, University of Wisconsin, Jun Zhu, Department of Statistics, University of Wisconsin, and my Ph.D.-student Jakob G. Rasmussen, Department of Mathematical Sciences, University of Aalborg. In the talk I'll compare two different approaches based on a discrete-time model and a continuous-time model. In the discrete-time model the likelihood function depends on unknown normalising constants, which need to be estimated when finding maximum likelihood estimates. Moreover, an unknown ratio of normalising constants appears in the Hastings ratio when doing straightforward MCMC posterior simulations, and I'll show how a new auxiliary variable technique eliminates this problem. In the continuous-time model the full likelihood is tractable, but for the marginal likelihood we need to account for missing data, using again MCMC methods.

13. A STARMA model for solar radiation in a microclimate

Chris Glasbey and Dave Allcroft, Biomathematics and Statistics, Scotland

Knowledge of the statistical characteristics of solar radiation over space and time are needed for the design and evaluation of solar energy systems. In an EU-funded project, solar radiation was recorded at a pair of sites in Edinburgh every 30 seconds for two years, with the sites changed each month (Glasbey *et al*, 2001). From these data, which are much richer in time than in space, our aim is to develop a spatio-temporal model of the solar radiation microclimate in Edinburgh.

Solar radiation has a bimodal marginal distribution: one mode is due to direct radiation and the other is when the sun is obscured by clouds. Rainfall is another non-Gaussian weather variable, in this case with a singularity at zero and a long upper tail. However, by applying a monotonic transformation, marginal normality is achieved, with zero rainfall corresponding to censored values below a threshold (Allcroft and Glasbey, 2003). Initial attempts to transform solar radiation to a Gaussian distribution were unsuccessful because the resulting process was clearly not multivariate normal. Therefore, instead we proposed a new form of nonlinear autoregressive time series for single-site data, by specifying joint marginal distributions at low lags to be multivariate Gaussian mixtures (Glasbey, 2001). Unfortunately we know of no way of generalising this model to include a spatial dimension.

We have now found a way to improve the agreement between transformed solar radiation and multivariate normality, by adding an independent noise term with signal dependent variance. We use a spatio-temporal auto-regressive moving average (STARMA) model in preference to the Markov random field we used to model rainfall, because it is more suited to the task of forward simulation in time. Although STARMA models can be computationally expensive, we show that by working on a torus in space, the order of dimension of calculations can be substantially reduced. We overcome the spatial sparsity of the data by assuming that space and time are interchangeable, and consider issues of model identification, estimation and validation.

References

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14. Non-stationary spatio-temporal analysis of karst water levels

Ian L. Dryden¹, L. Márkus², C. C. Taylor³ and J. Kovács² ¹University of Nottingham, ² Eötvös Loránd University, Hungary, and ³ University of Leeds.

We consider non-stationary spatio-temporal modelling in an investigation into karst water levels in western Hungary. A strong feature of the dataset is the extraction of large amounts of water from mines, which caused the water levels to reduce until about 1990 when the mining ceased, and then the levels increased quickly. We discuss some traditional hydrogeological models which might be considered appropriate for this situation, and various alternative stochastic models. In particular, a separable space-time covariance model is proposed which is then deformed in time to account for the non-stationary nature of the lagged correlations between sites. Suitable covariance functions are investigated and then the models are fitted using weighted least squares and crossvalidation. Forecasting and prediction is carried out using spatio-temporal kriging. We assess the performance of the method with one step ahead forecasting and make comparisons with naive estimators. We also consider spatio-temporal prediction at a set of new sites. The new model performs favourably to the deterministic model and the naive estimators, and the deformation by time-shifting is worthwhile.

15. Applications of independence estimating equations to large space-time datasets

Richard E. Chandler, University College London

Large space-time datasets arise frequently in applications such as climatology. For routine analyses of such datasets, computationally efficient methods for model fitting and inference are desirable. In such settings we consider the use of independence estimating equations (IEEs), obtained as though the data were a collection of independent time series from different spatial locations. A comparison of IEEs with Generalized Estimating Equations (GEEs), in which an attempt is made to model the dependence structure, suggests that the IEEs may be considerably more robust in a space-time context. We also propose an adjustment to the "independence" likelihood ratio test, to account for inter-site dependence. The ideas are illustrated using an example involving the fitting of Generalized Linear Models to European wind speeds.

2.4 Thursday afternoon

16. A common framework for constructing non-stationary covariance functions

Chris Holmes and A. Pintore, Oxford University

There is a growing literature on methods for constructing non-stationary covariance functions that are useful for modelling geostatistical processes. In recent work, we have highlighted the spectral domain as an efficient and interpretable framework for comparing and contrasting many of these methods, including the deformation approach, kernel convolutions, spatially varying anisotropic kernels and spatially adaptive spectra. In this talk, we will review these methods and show how they relate to one another. We will also point to generalisations which result in spatially adaptive covariance functions with standard forms, such as the Gaussian or the Matèrn, but now with "localised" parameters. We illustrate our approach with an analysis of rainfall measurements in Scotland.

17. A Comparison of spatio-temporal Bayesian models for reconstruction of rainfall fields in a cloud seeding experiment

Giovanna Jona Lasinio (University of Rome "La Sapienza"), Kanti Mardia (University of Leeds), Arianna Orasi (APAT) and Sujit Sahu (University of Southampton)

In response to the drought experienced in Southern Italy a rain seeding project has been setup and developed during the years 1989–1994. The initiative was taken with the purpose of applying existing methods of rain enhancement technology to regions of South Italy starting with Puglia. The aim of this talk is to provide statistical support for the evaluation of the experimental part of the project. In particular our aim is to reconstruct rainfall fields by combining two data sources: rainfall intensity as measured by ground raingauges (rain mm to the nearest 10th of one millimeter) and radar reflectivity. Radar raingauges are increasingly used to reconstruct rainfall fields since they are able to provide spatially continuous images of precipitation for short and regular time intervals; ground raingauges, on the other hand, provide more accurate and direct estimates of rainfall intensity. Here we consider a rainfall seeding operation conducted in April 11, 1992 when 44 out of total 80 ground raingauges recorded amount of rainfall in 10 minutes interval; in addition data from a C-band digital weather radar, scanning the whole area every five minutes, were available.

In this talk we present several hierarchical Bayesian modelling approaches to investigate the above described problem, based on Mardia and Sahu (2005) and Sahu *et al.* (2004). As a first approach we consider a hierarchical Bayesian kriged-Kalman filtering (BKKF) model introduced by Sahu and Mardia (2005), see also Mardia *et al.* (1998). The spatial prediction surface of the BKKF model is built using the well known method of kriging for optimum spatial prediction and the temporal effects are analyzed using the models underlying the Kalman filtering method. As an alternative we consider a random effects model in the form of a separable and stationary Gaussian spatio-temporal process described in Sahu *et al.* (2004) for monitoring some air pollution levels. The latter has been modified introducing a censoring procedure in order to account for the discreteness introduced by the raingauges measurement mechanism. The full Bayesian models are implemented using MCMC techniques which enable us to obtain the optimal Bayesian forecasts in time and space. We compare the two modelling approaches using different Bayesian model selection criteria. Using the mean-square error of predictions we are also able to compare these new methods with our previously adopted approaches described in Orasi and Jona Lasinio (2004a) and (2004b).

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18. Applying generalised additive mixed models to the estimation of spatial and temporal trends in tree defoliation

Nicole Augustin¹, Monica Musio², Simon N. Wood¹ Edgar Kublin ³, Klaus von Wilpert³, and Martin Schumacher⁴

¹University of Glasgow, ²University of Cagliari, Italy ³Forest Research Centre Baden-Württemberg, Germany, and ⁴Universitätsklinikum Freiburg, Germany

Yearly data on percentage tree defoliation are available from a monitoring survey carried out in Baden-Württemberg, Germany since 1983. On a regular grid, with changing levels of coarseness, needle loss and other site specific variables such as soil type or altitude, tree specific information such as age, are recorded. The main purpose of the survey is monitoring the trend of needle loss over time and space, so that forest management decisions can be made promptly and targeted at specifically affected areas. The method currently in place for trend estimation does not take any spatial or temporal correlation of the data into account and thus does not allow statistically sound trend estimation. We propose a model for trend estimation which takes temporal and spatial correlation of data into account. We use (generalised) additive mixed models for this task Kamman and Wand (2003). We use the general methodology of Wood (2004) for constructing scale invariant tensor product smooths of the space-time dimension.

References

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2.5 Poster: Wednesday afternoon

19. Identifying space-time clusters in point processes

Renato Assuanção¹, Andréa Tavares¹, and Martin Kulldorff² ¹Universidade Federal de Minas Gerais, Brazil and ²Harvard Medical School, USA

Space-time interaction occurs in a point process when there are space-time clusters not explained by neither the purely spatial nor the purely temporal clustering. Knox (1964) and Diggle et al (1995) among others have proposed tests to determine if there is space-time interaction as a general phenomena in a data set. These methods have been widely used in epidemiology, ecology and other fields. Sometimes it is also of interest to know the specific location of space-time interaction clusters. Usual statistical tests for the presence of space-time interaction have in common that they are general tests evaluating whether there is space-time interaction throughout the data, without pinpointing the location of specific clusters. That is very useful if we for example want to determine whether a particular disease may be infective or not, or if one is interested in the general patterns of crime in order to understand sociological and behavioral aspects of criminal behavior. They are less useful for a police department wanting to know where and when to allocate their resources most effectively, or a public health official wanting to know the time and location of a disease outbreak, both of which requires knowledge of the space and time parameters of specific clusters.

Therefore, it is useful to differentiate two different types of alternatives to the null hypothesis of no space-time interaction. One of them focus on space-time clustering occurring throughout the map, either due to many small clusters of slightly larger than average incidence rate or many weakly interacting clusters of events. The other focus on situations where one or a few localized space-time clusters will have a substantially higher incidence rate, or where there is strong interaction between a subset of the events. For this second type of alternative, it is of interest to detect the location and time of specific clusters.

Suppose that data are available consisting of the locations and reference times of events occurring within a specified geographical region and time period. In this paper, we are interested in the second type of alternative, and we combine the use of a space-time scan statistic (Kulldorff, 1997) with a score test to generate a new statistical procedure for the detection and inference of space-time interaction clusters. The method does not require risk population information. The proposed method differs from other space-time scan statistics that use a Poisson or Bernoulli based likelihood ratio test statistic but like earlier space-time scan statistics, it is able to identify the specific space-time regions leading to rejection of the null hypothesis without prior assumptions about the cluster location and size. Since the naive algorithmic implementation of our proposed method is inefficient, preventing its use in practice, we describe an efficient algorithm and analyze its complexity.

To illustrate the method, we apply it to crime statistics from Belo Horizonte, Brazil. Four different data sets are used, investigating the space-time distribution of homicides as well as robberies of bakeries, drug stores and lottery houses. Statistically significant clusters were detected in all four data sets, and the method was successfully able to pinpoint the location and time of the clusters.

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20. Defining Spatial and Temporal hydromorphological sampling strategies for the Leigh Brook river site

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Detailed surveys of depth and velocity are undertaken to describe hydro- ecological status of rivers. Fieldwork for these surveys is time consuming and expensive, yet little work has examined the most suitable sampling strategy for effective field data collection and river representation in time and space. This poster aims to describe the methodology applied in order to determine the best depth sampling strategy at the Leigh Brook river site, Worcester, UK.

The accuracy of three different sampling strategies (i.e. regular transects, random grids and stratified grids) for predicting depth at non-measured points has been compared and the mesohabitats that better characterise depth changes due to variations in flow have been identified.

Depth, mesohabitat (e.g. pool, glide, riffle) and surface flow type (e.g. smooth, rippled) measurements were collected at 2583 points for two different flows (Q=0.517m3/s and Q=0.344 m3/s) on the Leigh Brook river site. Geostatistical techniques were applied to predict depth values at non-measured points for each flow and for each sampling strategy. Eight indicators (variogram, mean squared error, mean error, R-squared, residual plots, frequency distributions, cross-sections, mapping resolution, standard error maps) were analysed to identify the differences between sampling strategies. Effective sampling strategies were considered to be those that provide the best results for the eight indicators analysed.

The results show that depth changes due to flow changes are mainly located at shallow and deep glides habitat types. The analysis for the comparison of sampling strategies indicates that grid sampling strategies, either random or stratified, give better results than regular transects. Since the results also show that higher errors in predictions are obtained in deepest areas (pools-deep glides), higher sampling densities should be applied in these locations.

21. Spatio-temporal river monitoring network modelling

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Many environmental processes involve variability over both space and time. In general, the space-time models are temporally dynamic and spatially descriptive: they exploits the unidirectional flow of time, in an autoregressive framework, and they are spatially descriptive in that the autoregressive process is spatially coloured (Wikle and Cressie, 1999). So no causative interpretation is associated with the observed spatial correlation. These models are not appropriate for modelling the data originating from a river network. With respect to the spatial dependence structure an important distinction has to be made: the water flows only in one direction within the river reaches, so a causal interpretation can be given to the correlations. However, rivers can join or split, which implies a more general branched unidirectional structure. In Cressie's terminology,

such models have to be both spatially and temporally dynamic. We developed a state-space modelling approach in which the state variable is defined by a Directed Acyclic Graph (DAG) which is directly implied by the river network topology. In reality, however, this dependence structure might possibly be obscured by common environmental influences such as rainfall or climatological conditions in general. The rather strict structure implied by the DAG is assumed only to hold for an isolated river system. Therefore, the DAG is embedded in an observation model which enables additional spatial interactions. The spatial correlation structure is assumed to be stationary over time. For the temporal dependence structure we simply assume a first order autoregressive model. A model for the mean can be specified to capture the features of interest. For instance, the model may be used for intervention analysis, trend detection or forecasting. The parameters are estimated with an EM-like algorithm based on the recursive nature of the unobservable process modelled by the DAG. The complete model allows for making valid inference on the parameters of interest. This is illustrated on a real data case study.

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22. Novelty detection and Kernel Canonical Correlation Analysis of brain activities in fMRI images

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We have developed the statistical novelty (outlier) detection-based model for an extended primary sketch or segmentation of images obtained by a Functional Magnetic Resonance Imaging (fMRI) scanner. The method is based on the estimation of mixing parameters of the probabilistic mixture models in the small sliding window. A novelty score is defined by mixing parameter and this is utilized to recognize the corresponding class of image patch such as homogeneous regions, edge neighbourhood, outlier in the center of sliding window, neighbourhood of outliers, small objects and their neighbourhood for images obtained after spatial-temporal processing based on standard correlation and Kernel Canonical Correlation Analysis (KCCA). We use KCCA to infer brain activity in the fMRI images by learning a semantic representation of fMRI brain scans and their associated activity signal. The semantic space provides a common representation and enables a comparison between the fMRI and the activity signal. The application of KCCA on the raw fMRI enables us to "pull out" the activated voxels. The performance of spatial-temporal analysis of real and simulated fMRI images using novelty detection and KCCA methods is analysed.

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23. Optimising the utility of national malaria data for health system planning in Kenya using spatiotemporal analysis

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A critical component in the fight against malaria in sub-Saharan Africa is an increase in the availability of data to assist health decision-makers to optimise limited resources. In this study, access was obtained to a national health management information system (HMIS) database from Kenya which records monthly case counts of malaria at out-patient facilities across the country from 1996 to 2002. In common with other such databases in Africa, under-reporting has lead to less than half of the monthly records being present. This incompleteness prevents the calculation of even basic public-health statistics. This study aims to develop a methodology by which missing monthly records can be optimally predicted. This Kenyan database is unique amongst African HMISs in that most facilities have been recently georeferenced (Noor et al., 2004), introducing the potential for the application of geostatistical techniques. Whilst malaria case counts at different facilities display little spatial autocorrelation, the density of malaria defined as the proportion of malaria cases to all cases exhibits spatial autocorrelation that can be used as the basis for spatial prediction. Malaria density also exhibits temporal autocorrelation, although facility time-series data are generally complex and include multiple intra- and inter-annual cycles. A method is presented in which space-time Kriging (STK) is applied to predict malaria density values at unknown facility months (Kyriakidis and Journel, 1999). Prediction and modelling were carried out locally using an automated moving-window technique. This approach allowed the adoption of a random function model with spatial non-stationarity of the mean and variogram, which resulted in improved estimates of malaria density when compared to a global approach.

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24. Fitting and Testing Spatiotemporal Additive Models.

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A co-ordinated international programme monitoring acidifying air pollution was initiated in the 1970's as a direct response to observed acidification. Several international protocols on the reduction of acidifying emissions were agreed and the subsequent policy question of interest is whether the protocols have resulted in real improvement in environmental quality and real change in the acidifying environment.

This work presents an evaluation of the observed spatiotemporal trends of sulphur dioxide (SO_2) in Europe for the last quarter of the twentieth century, on the basis of data from EMEP (Co-operative Programme for Monitoring and Evaluation of the long Range Transmission of Air Pollutants in Europe) using additive models. Standard smoothing techniques (see for example Bowman & Azzalini, 1997) have been generalized in order to account for circular smoothers (such as weeks of the year) and correlation in the data. Model fitting procedures, based on the backfitting algorithm (Hastie & Tibshirani, 1990) and testing procedures based on approximate F tests have been adapted to account for correlation. This involves new definitions of degrees of freedom and performances have been analyzed through simulation studies.

Spatial patterns in the SO_2 field and their temporal evolution have also been analyzed. A regression surface has been fitted to each month, the spatial correlation modeled and a time series analysis of the spatial parameters carried out. At each time point, different spatial surfaces (i.e. linear models, nonparametric smoothers, etc ...) have been fitted and theoretical variograms have been fitted to the residuals (Cressie, 1991). Kriging analysis has produced estimates of the spatial distributions. Estimates of the time and spatial correlation, obtained from the time series and from the spatial analysis, have been used to fit an additive model that jointly models the space-time pattern of SO_2 . "Binned" versions of both univariate and bivariate smoothers that are able to deal with large data sets (Bowman & Azzalini, 2003) have been developed in order to fit a separable spatiotemporal model which incorporates appropriate spatiotemporal correlation. We report on our findings.

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25. Statistical Modelling and Inference for Radio-Tracking

Keith Harris, University of Sheffield

Radio-tracking is a well-established tool in ecological research for collecting data about the location over time of animals. Hence, statistical models of animal movement are needed to help us interpret data collected in this manner. There are many possible approaches to analysing such data when the observations are sufficiently separated in time that they can be regarded as statistically independent. However, when successive observations are dependent, which is usually the case with radio-tracking data, there is only one standard approach. This method models animal movement using a bivariate Ornstein-Uhlenbeck diffusion process. However, this model has been criticised for being an unrealistic description of animal movement behaviour. In particular, it fails to take into account the fact that animals may move differently in different types of habitat. My research is focussing on how this problem can be overcome, that is, how spatial heterogeneity can be incorporated into models for animal movement. The approach I am pursuing is to extend a class of models called continuous time threshold autoregressive models into two dimensions. My poster presentation will define and illustrate my proposed model for animal movement and discuss how the statistical inference for such models can be tackled in the simplest case of there being a single linear threshold.

26. Biodiversity of ecosystems - complex interactions and complex modelling

Janine Illian, University of Abertay, Dundee

Ecologists are keen to understand the mechanisms behind the functioning of intact plant communities, in particular the processes that promote and sustain biodiversity. So far not many studies have applied advanced statiscal methods in this context.

This poster will present a number of spatial statistical approaches which we have applied to different types of data sets in order to analyse the community dynamics, i.e. interaction structures within plant communities. We will mainly focus on the application of spatial point process models in this context but will also mention other related approaches. Due to the high dimensionality of the data sets novel methods have been developed and we discuss their appropriateness.

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27. A Bayesian hierarchical model for local precipitation by downscaling atmospheric circulation patterns.

Jorge Mendes, ISEGI-UNL, Lisbon

Precipitation over the western part of Iberian peninsula is known to be related to the large scale sea level pressure field and thus to advection of humidity into this area. The major problem is to downscale this synoptic atmospheric information to local daily precipitation patterns. One way to handle this problem is by weather state models, where, based on the pressure field, each day is classified into a weather state and precipitation is then modelled within each weather sate via multivariate distributions. In this paper, we propose a spatio-temporal Bayesian hierarchical model for predicting precipitation. Basic objective and novelty of the paper is to capture and model the essential spatio-temporal relationships that exist between large-scale sea level pressure field and local daily precipitation.

28. Spatial interaction of crime incidents in Japan

Kazuhiko Kakamu¹, **Wolfgang Polasek**¹ and Hajime Wago² ¹Institute for Advanced Studies, Austria and ² Nagoya University, Japan.

We analyze the development of 18 types of criminal records in Japan for the period 1990 to 2001 across 47 prefectures with spatial lag and spatio-temporal heteroscedasticity. We explore the hypothesis that crime data are related to socio-demographic variables in Japan. We extend the Bayesian approach of LeSage (1997) for spatio-temporal Bayesian models. Additionally we analyze unobserved heterogeneity and heteroskedasticity in the panel model by variance factors as in Geweke (1993). Weak spatial dependencies can be found for all types of crimes and the influence of the socio-demographic variables varies over the type of crimes.

29. Bayesian extrapolation of space-time trend in cancer registry data

Volker Schmid, Imperial College, London

In 1995, Besag, Green, Higdon and Mengersen have described a Bayesian formulation of the age-period-cohort (APC) model for cancer data. The time effects are modelled with autoregressive processes. A slightly modified version of this formulation has recently being used for the prognosis of lung cancer mortality in West Germany (Knorr-Held and Rainer, 2000).

Typically such disease data from cancer registries is additionally stratified by areal districts. I will present two approaches to include spatial heterogenity within the APC model. Following ideas of Knorr-Held (2000), we added an intrinsic Markov random field prior for the spatial effects to this model. In addition, space time interactions can easily be included in the model.

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30. Spatial and temporal structure of predator-prey relationships in the Celtic Sea fish community

Verena Trenkel, IFREMER, France.

The spatial and temporal structure of predator-prey relationships in the Celtic Sea was modelled for four commercially-important predator species: cod, hake, megrim, and whiting using stomach content and bottom-trawl survey data for the period 1982 to 1995. Generalized additive models were used to visualise the relationship between the probability of a given prey species being found in a predator stomach and environmental covariables such as latitude, depth (correlated with longitude), month and predator length. Sampling year was treated as factor and spatial and temporal structures were modelled separately due to a lack of data. Model selection and estimation of the degrees of freedom for the smooth functions were carried out using the methods described in Wood and Augustin (2002). The models were fitted jointly for all predators unless the differences in the form of the functional relationships for different predator species feeding on the same prey species were significant. The results showed that blue-whiting were consumed more often during the summer months whereas mackerel and Trisopterus spp. were found more often in predator stomachs during the winter half year. On a spatial scale, blue-whiting was consumed over the shelf edge, in accordance with their higher densities in the environment, while mackerel, horse-mackerel and Trisopterus spp. were eaten more often on the continental shelf, again in agreement with their depth-related density distribution patterns. This study suggests seasonal and spatial prey switching behaviour by hake, cod and whiting. Inter-specific predator interactions are reduced by size-, space and time-dependent feeding behaviours.

31. Modelling evolution of coral reefs

Kamila Zychaluk, P. G. Blackwell, N. L. Foster and P. J. Mumby University of Sheffield

Better understanding of the relations between different species in coral colonies and their long and short term effects on each other is crucial in preservation of these endangered ecosystems.

We examine these relations in two ways: by analysis of detailed data for one of the reefs in Belize and by building a cellular automaton which mimics the behaviour of the coral reef.

The data were collected in 8 sampling periods in Belize (not evenly spaced), where the same colonies of Montastraea corals were filmed each time. From these videos, the information about location and size of coral ramets (the structure formed by the coral skeleton) and the sizes of the species present on them was retrieved.

The main species present on the reef apart form the coral are algal turf, various types of macroalgae (which compete with the coral for space), fish and urchins (which feed on the macro-algae and turf). The evolution of the reef depends on the relations between all these species but other factors, e.g. hurricanes, rugosity (unevenness) of the reef, coral bleaching, can also have great influence on the state of the colony.

In the analysis of the data from the videos, we are primarily interested in the relations between different species present on the ramet: how the changes in the sizes of the patches and extinction of some species depend on the past composition of the ramet. The data is modelled by a combination of a discrete probability model which corresponds to the probabilities of extinction and a Dirichlet distribution which corresponds to the proportions occupied by the surviving species. We use MCMC methods to examine the model.

The cellular automaton is designed to examine the relations between various types of coral and macro-algae in the presence of herbivory. This approach enables us to analyse the influence of fish on different aspects of coral-algal competition (coral recruit survival rates, changes in coral cover). In particular, we can examine the long term results of overfishing and relation between reef expansion and the amount of fish present in the reef.

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