SECTION ON STATISTICS AND THE ENVIRONMENT

STATISTICAL ISSUES IN MONITORING THE ENVIRONMENT

A WORKSHOP ON ENVIRONMETRICS

October 22-24, 2008

National Center of Atmospheric Research, Boulder, CO
Sponsored by the Section on Statistics and Environment of the American Statistical Association with Support from NCAR and Purdue University

Program Committee

Marc Genton
Doug Nychka
Anthony Olsen
Steve Sain
Eric Smith
Michael Stein
Melanie Wall
Lance Waller
Hao Zhang (Chair)
Jun Zhu

Schedule

Wednesday, October 22, ML Main Seminar Room

Short Course Title: **Estimating Curves and Surfaces from Environmental Data**
Instructors: *Doug Nychka, Stephan Sain and Reinhard Furrer*

7:45 **Bus at the Millennium Hotel**

8:30-10:00 Curves and functions
10:00-10:30 Break and refreshments
10:30-12:00 Examples in R and fields

12:00-1:30 **Lunch on your own**

1:30-3:00 Multivariate models
3:00-5:00 Sparse matrices and large data issues

5:15 **Bus transportation to Millennium Hotel**

Thursday, October 23, ML Main Seminar Room

7:45 **Bus at the Millennium Hotel**

8:15-8:50 Registration
8:50-9:00 Welcome

Session 1 **Climate Change and Impact**
Organizer and Chair: *Stephen Sain*
9:00-9:30 Attributing Sources of Variability in Regional Climate Model Experiments
Cari Kaufman
9:30-10:00 Learning, Negative Learning, and Climate Change
Brian O'Neill
10:00-10:30 Hidden Climate Variability in Complex Terrain: Challenges For Monitoring
Christopher Daly

10:30-11:00 **Break and Refreshments**

Session 2 **Monitoring Aquatic Resources: Design And Modeling Issues**
Organizer and Chair: *Jun Zhu*
11:00-11:30 Nonparametric Small Area Estimation Using Penalized Spline Regression
Jean D. Opsomer
11:30-12:00 Prediction Of Index Of Biotic Integrity (IBI) Using Clipped Latent-Variable Spatial Models

Megan Dailey Higgs

12:00-12:30 Design- vs. Model-based Estimation of Trend in Areal Coverage of Sea Grass in Florida Bay
Mary C. Christman, Paul Kubilis, and Penny Hall

12:30-2:00 Lunch on your own

Session 3 Statistical Methods for Environmental Data
Organizer and Chair: Hao Zhang

2:00-2:30 Identifying Pollution Source Directions for Air Quality Monitoring
William F. Christensen, Basil Williams, C. Shane Reese

2:30-3:00 Hierarchical Spatial Modeling of Additive And Dominance Genetic Variance For Large Spatial Trial Datasets
Banerjee Sudipto; Andrew Finley;
Patrick Waldmann; Tore Ericsson

3:00-3:30 Distribution-free Comparison of Multiple Spatial Point Patterns
Jennifer A. Hoeting and Andrew A. Merton

3:30-4:00 Multiscale Spatial Modeling of Topsoil Geochemistry
Catherine Calder, Peter Craigmile, Jian Zhang

5:00-7:00 Poster Session and Reception, Cafeteria

7:15 Bus transportation to Millennium Hotel

Friday, October 24, CG Auditorium

7:45 Bus at the Millennium Hotel

Session 4 Monitoring Sensor Networks in Ecology
Organizer and Chair: Lance Waller

8:30-9:00 The Roles of Compression and Coding in Inference on Wireless Sensor Networks
Paul Flikkema

9:00-9:30 Median Polish Algorithms for Automated Anomaly Detection in Environmental Sensor Networks
Ernst Linder

9:30-10:00 A Correlation Process Prior For Anomaly Detection of Functional Data
Yongku Kim, Long Nguyen, and Scott Holan

10:00-10:30 Optimal Design of the Sensor Network under Energy Budget Constraints
Zhengyuan Zhu

10:30-11:00 Break and Refreshments

Session 5	**Methods for Spatial Massive Data**
	Organizer and Chair, *Marc Genton*
11:00-11:30	Prediction for Large Multivariate Spatial Datasets *Reinhard Furrer*
11:30-12:00	Gaussian Markov Random Fields in Large Spatial Models: Modelling and Bayesian Inference *Havard Rue*
12:00-12:30	Estimation of Semiparametric Space-time Models with Regular Monitoring Data *Michael Stein*
12:45	**Bus transportation to the Millennium Hotel**

ABSTRACTS OF INVITED TALKS

Thursday, October 23 ML Main Seminar Room

Session 1 Climate Change and Impact
Organizer and Chair: Stephan R. Sain [ssain@ucar.edu], NCAR

Attributing Sources of Variability in Regional Climate Model Experiments

Cari Kaufman, University of Berkeley

Variability in regional climate model (RCM) projections may be due to a number of factors, including the choice of RCM itself, the boundary conditions provided by a driving general circulation model (GCM), and the choice of emission scenario. We describe a new statistical methodology, Gaussian Process ANOVA, which allows us to decompose these sources of variability while also taking account of correlations in the output across space. Our hierarchical Bayesian framework easily allows joint inference about high probability envelopes for the functions, as well as decompositions of total variance that vary over the domain of the functions. These may be used to create maps illustrating the magnitude of each source of variability across the domain of the regional model. We use this method to analyze temperature and precipitation data from the Prudence Project, an RCM intercomparison project in which RCMs were crossed with GCM forcings and scenarios in a designed experiment.

Learning, Negative Learning, and Climate Change

Brian O'Neill, NCAR

Learning – i.e., the acquisition of new information that leads to changes in our assessment of uncertainty – plays a prominent role in the international climate policy debate. For example, the view that we should postpone actions until we know more continues to be influential. One aspect of learning that is greatly under-appreciated is that new technical information may lead to scientific beliefs that diverge over time from the a posteriori right answer. We call this phenomenon, which is particularly problematic in the global change arena, negative learning. Negative learning may have affected policy in important cases, including stratospheric ozone depletion, dynamics of the West Antarctic ice sheet, and population and energy projections. We illustrate how it could affect current climate change analysis by simulating negative learning in the context of climate change with a formal model that embeds the concept within the Bayesian framework. Based on these cases, we suggest approaches to scientific assessment and decision making that could mitigate the problem.

Hidden Climate Variability in Complex Terrain: Challenges for Monitoring

Christopher Daly, Oregon State University

It is generally recognized that long-term mean climate varies spatially over complex terrain, responding to factors such as elevation, aspect, and coastal proximity. It is also generally assumed that climatic variations in time respond less strongly to these factors, and are fairly consistent on a regional basis. For example, when one location has a warmer than normal winter, other nearby locations are expected to have had a similarly warm winter. The assumption of temporal synchrony of climate is made in every field study for which data from an off-site meteorological station are used to represent conditions at the location of interest. Commonly-used methods for downscaling climate change projections from coarse-grid general circulation models do so, as well.

This paper refutes the assumption of regional climatic synchrony in complex terrain, using temperature data collected from several stations at various elevations and topographic positions in the HJ Andrews Experimental Forest, Oregon. Even at the monthly time step, temperature trends and variations at sites just a few km or less apart can be completely different. A main cause is the presence of cold air drainage and pooling in valley bottoms and other local depressions. In areas free from cold air drainage, such as hill slopes and ridge tops, temperatures respond strongly to changes in synoptic flow pattern, but low-lying areas dominated by cold air drainage do not. This creates steep temperature response gradients among topographically different sites that ebb and flow with variations in flow pattern over time.

This is a “sleeper” issue that significantly complicates the estimation of biotic and abiotic responses to climate change and variability. The good news is that our simple first efforts to model the effects statistically were reasonably successful, at least in our study area. We hope that alerting the community to this issue will help spark new research and measurement programs designed to understand the complexities of climatic asynchrony in mountainous terrain. This, in turn, will reduce a potentially large source of error in scientific conclusions and management decisions regarding ecological and hydrological responses to climate change and variability. Recommendations for a data collection strategy are discussed.

Session 2 Monitoring Aquatic Resources: Design and Modeling Issues

Organizer and Chair: Jun Zhu, Department of Statistics, University of Wisconsin-Madison

Nonparametric Small Area Estimation Using Penalized Spline Regression

Jean D. Opsme, Colorado State University

We propose a small area estimation approach that combines small area random effects with a smooth, nonparametrically specified trend. By using penalized splines as the representation for the nonparametric trend, it is possible to express the nonparametric small area estimation problem as a mixed effect model regression. The resulting model is readily fitted using existing model fitting approaches such as restricted maximum likelihood. We present theoretical results on the prediction mean squared error of the proposed estimator, including a second order consistent estimator of the prediction mean squared error, and on likelihood ratio tests for random effects. For practical applications, we propose a simple nonparametric bootstrap approach for model inference and mean squared error estimation. We apply the small area estimation and bootstrap inference approach on a survey of lakes in the Northeastern US.

This is joint work with G. Claeskens (Katholieke Universiteit Leuven), M.G. Ranalli (Universita' degli Studi di Perugia), G. Kauermann (Universitaet Bielefeld) and F.J. Breidt (Colorado State University).

Prediction of Index of Biotic Integrity (IBI) Using Clipped Latent-Variable Spatial Models

Megan Dailey Higgs, Montana State University

Environmental monitoring may result in ordered categorical data collected at point-referenced spatial locations. An example of such data is the use of an Index of Biotic Integrity (IBI) to construct an overall descriptor of stream health. Historically, models dealing with both the categorical and spatial nature of such data are scarce. We combine and extend previous methods to develop models for point-referenced ordered categorical data under two conceptual frameworks. Both approaches rely on the use of an underlying latent Gaussian random field and the idea of clipping an underlying continuous distribution. The models are fit in the Bayesian paradigm using Gibbs sampling and Markov chain Monte Carlo (MCMC) methods. We assess and compare the models through analytical, graphical, and simulation-based methods, focusing on prediction at new locations. The models are applied to predict stream health in Montgomery County, Maryland based on point-referenced IBI data.

Design- vs. Model-based Estimation of Trend in Areal Coverage of Sea Grass in Florida Bay

Mary C. Christman[1], Paul Kubilis[1], and Penny Hall[2]

[1] Department of Statistics IFAS, University of Florida; [2] Florida Fish and Wildlife Research Institute

The Florida Fish and Wildlife Conservation Commission (FWCC) has been monitoring several species of sea grass in several basins within Florida Bay since 1998. Of interest is whether the areal coverage and extent of individual species have increased over that time due to recent efforts at restoring the Everglades. We review the advantages and disadvantages of the monitoring design and measurement variables used by FWCC. Sampling is based on a stratified design with restricted randomization of sampling locations within strata. The restricted randomization is designed to obtain good spatial distribution of sampling locations within each stratum. At each location, four subsamples are taken and presence/absence of a species is recorded. If present, the Braun-Blanquet (BB) score, an unequally spaced ordinal categorical variable describing the observed percent cover of the particular species of grass of interest, is also recorded. We describe both design and model based estimation methods that allow for assessment of both status and trend of sea grass cover in the Bay. The model-based approach assumes an underlying Beta distribution for the true proportion of cover within a quadrant.

Session 3 **Statistical Methods for Environmental Data**
Organizer and Chair: Hao Zhang, Purdue University

Identifying Pollution Source Directions for Air Quality Monitoring

William F. Christensen, Basil Williams, C. Shane Reese; Department of Statistics, Brigham Young University

The identification of pollution source directions is an important part of the source apportionment problem. Estimated source directions are used both as inputs to a source apportionment analysis, and as part of a post-analysis check to associate identified pollution factors with potential pollution sources. We consider two approaches for source location identification that can be used in different settings. The first requires wind direction data measured at the air quality receptor and makes use of statistical and/or deterministic (AERMOD) models for chemical transport of particulate matter from source to receptor. The second makes use of HYSPLIT back-trajectory estimates and a kriging estimator which filters heterogeneous measurement errors.

Hierarchical Spatial Modeling of Additive and Dominance Genetic Variance for Large Spatial Trial Datasets

Banerjee Sudipto; Finley Andrew O.; Waldmann Patrick; Ericsson Tore.
1 University of Minnesota; 2 Michigan State University; 3&4 Swedish Academy of Agricultural Sciences

With accessibility to geo-coded locations where scientific data are collected through Geographical Information Systems (GIS), investigators in diverse fields such as environmental sciences, ecology and forestry and public health are increasingly turning to spatial process models for modeling associations and relationships over space. Over the last decade hierarchical models implemented through Markov Chain Monte Carlo (MCMC) methods have become especially popular for spatial modeling, given their flexibility and power to estimate models (and hence address scientific hypothesis) that would be infeasible otherwise. However, estimation in hierarchical spatial models often involves expensive matrix decompositions whose computational complexity increases exponentially with the number of spatial locations, rendering them infeasible for large spatial data sets. Recently much attention has been devoted to this problem. In this talk we primarily focus upon the use of a predictive process derived from the original spatial process that projects process realizations to a lower-dimensional subspace thereby reducing the computational burden.
This approach can be looked upon as a process-based approach to reduced-rank methods for "kriging" but offers additional complexities.
We discuss attractive theoretical properties of this predictive process as well as its greater modeling flexibility compared to existing methods. In particular, we show how the predictive process seamlessly adapts to settings with non-stationary processes, with richer and more complex space-varying regression models and with multivariate spatial models. We also discuss some pitfalls of this and other reduced-rank methods and offer remedies. A computationally feasible template that encompasses these diverse settings will be presented and illustrated.

Supporting grants: NSF DMS-0706870; NIH R01-CA95995.

Distribution-free Comparison of Multiple Spatial Point Patterns

Jennifer A. Hoeting and Andrew A. Merton Colorado State University

We develop a procedure to determine whether there are significant differences between two or more realizations where (spatial) location is one of the response measures.
We generalize the multi-response permutation procedure (MRPP) to incorporate geo-referenced data for both Euclidean and non-Euclidean spaces and designate the resultant procedure as the spatial multi-response permutation procedure (SMRPP). The SMRPP inherits all of the benefits of the MRPP test: the SMRPP does not require distributional assumptions for the observed data, it is invariant with respect to the spatial domain, and it is congruent with the data space. Furthermore the test can be applied to non-Euclidean geometric spaces, e.g., the surface of the globe and stream networks. The utility of the test is illustrated through simulation as well as recovery data for Northern Pintail ducks across the contiguous United States for the years 2000 through 2002. This is joint work with Colleen T. Webb, Colorado State University.

Multiscale Spatial Modeling of Topsoil Geochemistry

Catherine Calder, Peter Craigmile, Jian, Ohio State University

Geographic information about the levels of toxics in environmental media is commonly used in regional environmental health studies when direct measurements of personal exposure is limited or unavailable.
We propose a statistical framework for analyzing the spatial distribution of topsoil geochemical properties, including the concentrations of various toxicants. Due to the small scale heterogeneity of most geochemical topsoil processes, direct measurements of the processes themselves only provide highly localized information; it is thus financially prohibitive to study the spatial patterns of these processes across a large region using traditional geostatistical analyses of point-referenced topsoil data. Instead, it is standard practice to assess geochemical patterns at a regional scale using point-referenced measurements collected in stream sediment since, unlike topsoil data, individual stream sediment geochemical measurements are representative of the surrounding area. We propose a multiscale soils (MSS) model that formally synthesizes data collected in topsoil and stream sediment and allows the richer stream sediment information to inform about the topsoil process, which in environmental health studies is typically more relevant. Our model accommodates the small scale heterogeneity of topsoil geochemical processes by modeling spatial dependence at an aggregate resolution corresponding to hydrologically-similar regions known as watersheds. We present an analysis of the levels of arsenic, a toxic heavy metal, in topsoil across the midwestern U.S. using the MSS model and show that this model has better predictive abilities than alternative approaches using more conventional statistical models for point-referenced spatial data.

Friday, October 24, CG Auditorium

Session 4 **Monitoring Sensor Networks in Ecology**
Organizer and Chair: Lance Waller, Emory University

The Roles of Compression and Coding in Inference on Wireless Sensor Networks

Paul Flikkema and Sheryl Howard, Northern Arizona University

Wireless sensor networks for environmental monitoring are data-gathering networks designed to provide data for inference of both the data streams themselves and the structure and state of models. In these networks, minimizing energy consumption is often critical to the network's viability, since low energy consumption can reduce the cost of battery replenishment or make energy-harvesting technologies more feasible. While the network ideally should provide perfect data, the energy cost is prohibitive due to noise inherent in wireless networking. Thus a reasonable goal is to provide a required fidelty at minimum energy cost.

Since wireless communication is a major contribution to network energy consumption, we begin with a short discussion of the fundamental principles and techniques of wireless communication that affect reliable inference. We then describe an approach to integrate these techniques---source coding, channel coding, and control of transmissions---into a Bayesian inference framework that exploits the often high data correlation of environmental datasets in time, space or both. We term this approach 'coded compressive estimation', and show that it can significantly reduce the consumption of energy for communication compared to approaches that perform separate coding, transmission control, and inference.

Median polish algorithms for automated anomaly detection in Environmental Sensor Networks

Ernst Linder, University of New Hampshire

Environmental sensors malfunction with a high likelihood due to a variety of reasons, such as power failure, temporary interference by animals and a number of other possible disturbances. Sensor networks are typically deployed for the purpose of new discovery and thus, an a-priori statistical model that reflects the underlying scientific reality is not available. Therefore it is a challenge for an investigator to decide which data represent typical behavior and which data is anomalous or extreme, indicating sensor malfunctioning. For contemporaneous sensor responses we propose to fit a two-factor ANOVA main effects model sequentially via repeated median polish estimation. The two factors of the median polish are sensor effect, and time effect. We apply two outlier rules for automated anomalous data removal: Traces whose sensor effects are extreme with respect to an overall fit are removed. Individual observations whose median polish residuals are extreme are also removed. We train this algorithm for various outlier thresholds relative to a manually cleaned data from 147 psychrometers that were utilized in an experiment on water uptake and transpiration of 21 sage plant in a semi-arid area in Utah during the summer of 2007. For this application we also examine the use of median polish algorithms for discovery of anomalous and interesting behavior of individual plants.

A Correlation Process Prior For Anomaly Detection of Functional Data

Yongku Kim, NCAR, Long Nguyen, SAMSI, and Scott Holan, University of Missouri

In this talk we consider the problem of detecting anomalous patterns in water potential data collected by a sensor network. The dataset is represented by a collection of time series curves $X_s(t)$, where s denotes covariate index corresponding to differing sensor location and other experiment treatments. We propose an anomaly detection method by studying the correlation process realizations, which can be constructed by cross-correlating multiple curves corresponding to similar experiment treatments. A nonparametric prior distribution is placed on the correlation process that allows both the spatial dependence within individual curves and information sharing across multiple curves to be taken into account. Our prior makes use of a latent labeling process, and the anomaly detection task is then posed as a labeling inference problem, which can be solved via MCMC sampling. We present an evaluation of our anomaly detection method and a comparison to data cleaning results performed independently by humans.

Optimal Design of the Sensor Network under Energy Budget Constraints

Zhengyuan Zhu, University of North Carilina---Chapel Hill

We study the design of a wireless sensor network in aspatial temporal domain for optimal parameter estimation. We consider the setting where we are given a set of potential sensor locations, a parametric model for the process being monitored, a cost constraint, and a communication protocol, and our objective is to design a sensor network to deploy at a subset of these locations, and use the data collected from the network to estimate parameters of the underlying process. The design includes the location of the sensor, the sampling plan at each location, and the routing plan. We formulate the problem as maximizing a D-optimal design criterion for parameter estimation under communication and cost constraints. Both linear and non-linear models are considered, and we provide a general framework to include a variety of practical cost consideration in the constraints. Algorithms based on semidefinite programming are developed to find the optimal design under constraints, and numerical examples are provided to illustrate the use of the proposed approach.

Session 5 Methods for Spatial Massive Data

Organizer and Chair:, Marc Genton, University of Geneva

Prediction for Large Multivariate Spatial Datasets

Reinhard Furrer, Colorado School of Mines

Best linear unbiased prediction of spatially correlated multivariate random processes, often called cokriging in geostatistics, requires the solution of a large linear system based on the covariance and cross-covariance matrix of the observations. For many problems of practical interest it is impossible to solve the linear system with direct methods. We propose an efficient linear unbiased prediction based on a linear aggregation of the covariables. The primary variable together with this single meta-covariable is used to perform cokriging. We discuss the optimality of the approach under different covariance structures and relate it to the recently advocated tapering technique useful in univariate settings.

Gaussian Markov Random Fields in Large Spatial Models: Modeling and Bayesian Inference

Havard Rue, NTNU, Norway

Gaussian Markov random fields (GMRFs) allows for a compact representation and fast numerical computations, of Gaussian fields on a discrete domain, but GMRFs are not that easy to model/specify as the parameters have conditional interpretation and not marginal. In this talk, I will present some new results on the connection between GMRFs and Gaussian fields with a Matern covariance function. By using this connection, we can for example, obtain an explicit parametrisation for a GMRF on a regular lattice, which defines (in a weak sense) a Gaussian field with a Martern covariance function. We do Bayesian inference with such models using Integrated nested Laplace approximations; this approach proved posterior marginals that (totally) outperform MCMC alternatives in both accuracy and speed.

Estimation of Semiparametric Space-time Models with Regular Monitoring Data

Michael Stein, University of Chicago

When a spatial-temporal process is monitored at a modest number of fixed locations, it is natural to use a spectral approach in time both to specify a class of models and fit them to the data. This naturally leads to models in which at least some of their properties can be written in terms of functions of frequency that are not specified parametrically.
This talk describes some ways for fitting these functions, including regression splines and local polynomials and discusses the good and not so good features of each. The methods are considered in the context of modeling atmospheric pressure based on high frequency measurements taken in north-central Oklahoma.

Posters

Quantifying the Spatial Variability of Airborne Surface Flux Measurements Using Data from the International H2O Project 2002

Joseph G. Alfieri

Cross-Covariance Functions for Multivariate Random Fields

Tatiyana V. Apanasovich and Marc G. Genton

Spatial characteristics of the difference between MISR and MODIS aerosol optical depth retrievals over mainland Southeast Asia

Candace Berrett

A spatio-temporal downscaler for outputs from numerical model.

Veronica J. Berrocal, Alan E. Gelfand and David M. Holland

Spatial Hierarchical Modeling of Precipitation Extremes from a Regional Climate Model

Dan Cooley

Fixed-domain Asymptotic Properties of Tapered Maximum Likelihood Estimates

Juan Du, Hao Zhang and V.S.Mandrekar

Improving the Simulation of Extreme Precipitation Events by Stochastic Weather Generators

Eva Furrer

Mapping Indices of Aggregation from Spatial Counts using Penalized Likelihood Regression

Nels Grevstad

Bayesian Inversion for Long-path Spectroscopic Data: Estimation of Vertical Profiles for Trace Gases

Radu Herbei and Catherine Calder

Comparing Accuracy of Spatial Forecasts

Mandy Hering and Marc Genton

Correcting for signal attenuation from noise: Sharpening the focus on past climate

Bo Li

Functional Zoning on corrected air quality data

R. Ignaccolo, S. Bande and S. Ghigo

Testing the covariance structure of multivariate random fields

Bo Li, Marc G. Genton and Michael Sherman

Spatial bias modeling with application to assessing remotely-sensed aerosol as a proxy for particulate matter

Christopher Paciorek

Putting Citizen Science to Work: A Synthesis of High-Performance MCMC, Likelihood Approximations, and Data Mining Methods for Approximate Bayesian Inference

Ben Shaby

MAD: a new method for inverse modeling of spatial random fields with applications in hydrogeology

Zepu Zhang and Yoram Rubin

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