# SAMSI 2007-08 Program on Risk Analysis, Extreme Events and Decision Theory

# Final Report

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Program Leaders

## 1 Introduction

Over the past several years, there has been a wealth of scientific progress on risk analysis. As the set of underlying problems has become increasingly diverse, drawing from areas ranging from national defense and homeland security to genetically modified organisms to animal disease epidemics and public health to critical infrastructure, much research has become narrowly focused on a single area. It has also become clear, however, that the need is urgent and compelling for research on risk analysis, extreme events (such as major hurricanes) and decision theory in a broader context. Availability of past information, expert opinion, complex system models, and financial or other cost implications as well as the space of possible decisions may be used to characterize the risks in different settings. Integration of expertise developed by researchers in different scientific communities on each of these facets is the objective of this SAMSI program. Risk analysis and extreme events also carry a significant public policy component, which is driven in part by the increasing stakes and the multiplicity of stakeholders. In particular, policy concerns direct attention not only to the dramatic risks for huge numbers of people associated, for example, with events of the magnitude of Hurricane Katrina or bioterrorism, but also to "small-scale" risks such as drug interactions driven by rare combinations of genetic factors.

From the Opening Workshop in the publication by Wiley of *Bayesian Analysis for Stochastic Process Models* (anticipated in August 2009) and also a volume (as yet untitled) for the ASA-SIAM book series, the SAMSI program on Risk has encompassed four principal workshop, three dedicated sessions at JSM 2008 and an invited session at ISI 2009 as well as many individual presentations at professional meetings here and abroad. In all, 11 SAMSI postdoctoral fellows and postdoctoral associates, 12 graduate students (5 from outside the local universities), 22 new researchers and 44 other visitors to SAMSI have been engaged in 7 Working Groups. Total participation in Working Groups (local and remote) has been 89 and the total participation in the program through one or more activites is 167. As of April 2009, research articles submitted for publication total 41 (see bibliographic listing).

Highlights following the program year include an invited session at the Internation Statistical Institute 2009 meeting in Durban, South Africa and several grants awarded for continuing collaboration among SAMSI program researchers with still others pending as of April 2009. Major grants include a Fulbright award for risk analysis modeling in information and communication technologies (Dipak Dey, University of Connecticut and Javier Cano) and two awarded grants from the Spanish government plus pending applications to support continuing international collaborations involving Risk program researchers in Spain (Universidad Rey Juan Carlos) and in the the US (variously Cornell University, University of Connecticut, Duke University and IBM).

### 1.1 Research Foci

The aim of this full-year program was to address fundamental issues in risk analysis and the linked problems associated with extreme events and decision theory. By engaging researchers from the statistical sciences, applied mathematical sciences including actuarial science, and the decision sciences, including operations research, the goal was to set research agendas that can produce genuine impact on the practice of risk analysis and assessment as well as on theory and methodology for extreme events and decision theory. Interdisciplinary working groups were formed around both kinds of events and critical research tasks in theory and methodology, following the already identified interests and the existing momentum. Critical research tasks for this program included theoretical development of extreme value theory, implementations of methodologies that integrate expert opinion with data and with models, risk assessment and prediction with applications to high-impact events.

## 2 Program Organization

The program leaders were Dipak Dey (Univ. of Connecticut), David Ríos Insua (Universidad Rey Juan Carlos), Richard L. Smith (Univ. of North Carolina, Chapel Hill) and Nell Sedransk (SAMSI Associate Director).

The following Scientific Committee provided advice as needed on specific components: David Banks (Duke), Vickie Bier (Univ. of Wisconsin), James Broffitt (Univ. of Iowa), Alicia Carriquiry (Iowa State), Robert Clemen (Duke), Susan Ellenberg (Univ. of Pennsylvania), Herbert Hethcote (Univ. of Iowa), Wolfgang Kliemann (Iowa State), Robert Winkler (Duke), Stan Young (NISS).

## 3 Workshops

The workshops organized in connection with this program were:

1. Opening Workshop, September 16–19, 2007. Held at the Radisson RTP.
2. RISK: Perception, Policy and Practice, October 3–4, 2007. Held at the Radisson RTP.

3. EXTREMES: Events, Models and Mathematical Theory, January 22-24, 2008 Held at the Radisson RTP.

4. RISK Revisited: Progress and Challenges, May 21, 2008. Held at the Marriott Durham in association with the 2008 Interface.

In addition to workshops organized as part of the SAMSI program, three sessions at the Joint Statistical Meetings in August 2008 were organized around the research accomplished during this SAMSI program: "Risk Analysis for Industry and the Environment," "Bayesian Modeling of Extreme Events" and "SAMSI Program on Data Analysis, Extreme Events and Decision Theory." The full programs for these workshops have been documented elsewhere.

# 4 Research Goals and Activities

## 4.1 Adversarial Risk Analysis Group

### 4.1.1 Summary

Game theory has long been considered of little relevance for practical risk management decision-making. This viewpoint has recently become less dogmatic because:

- High-profile terrorist attacks have demanded significant national investment in protective responses, and there is public concern that not all of these investments are prudent and/or effective.
- Key business sectors (especially finance, e-commerce, and software) have become much more mathematically sophisticated, and are now using this expertise to shape corporate strategy for auction bidding, timing of product release, lobbying efforts, and other decisions.
- Regulatory legislation must balance competing interests (for growth, environmental impact, safety) in a way that is credible and transparent.
- The on-going arms race in cybersecurity means that the financial penalties for myopic protection are large and random.

These challenges cross many fields (Statistics, Economics, Operations Research, Engineering, etc.) and are characterized by the fact that there are two or more intelligent opponents who make decisions for which the outcome is uncertain. Collectively, we call this problem area Adversarial Risk Analysis (ARA) and represent a combination of statistical risk analysis and classical game theory.

Traditional statistical risk analysis grew in the context of nuclear reactor safety, insurance, and other applications in which loss was governed by chance rather than the malicious (or self-interested) actions of intelligent actors. But in ARA, one needs to have some model for the decision-making of

all the participants. This model might be classically game-theoretic, with (non-cooperative) Nash equilibria as core concept or it might be more psychological, reflecting either a Bayesian formulation or empirical studies of game behavior.

#### 4.1.2 Research Foci

The group addressed both fundamental and applied issues within this new field of adversarial risk analysis. At a fundamental level, the primary objective was to provide a unified approach and new solution concepts, ways to model the beliefs of the adversaries, algorithms to compute the new solutions, together with integration with negotiation analysis methodologies. At an applied level, research focused on the fields of auctions, antiterrorism modeling and cybersecurity.

#### 4.1.3 Main Participants

David Banks, Duke University
Betsy Enstrom, Duke University
Jesus Ríos, Concordia University
David Ríos Insua, Universidad Rey Juan Carlos
Lea Deleris, IBM
Mike Porter, NCSU
Matt Heaton, Duke University
Justin Shows, NCSU
Huiyan Sang, Duke University
Nabendu Pal, Louisiana State University
Javier Cano, Universidad Rey Juan Carlos
Jose Antonio Rubio, Universidad Rey Juan Carlos

#### 4.1.4 Activities

Meetings: The group met regularly on Thursday from 11.30 till 13:00 to discuss research progress, and propose new topics.

#### 4.1.5 Research output

The research output of this group is summarized here under a number of headings.

1. Foundations of adversarial risk analysis

   Topics in foundations of adversarial risk analysis covered both theorectical and computational aprroaches. Work generated the following papers.

   - Title: Adversarial risk analysis. (ARA) Authors: D. Ríos Insua, J. Ríos, D. Banks.

In this paper, we describe several formulations of adversarial risk problems, providing a unified framework for analysis. We also discuss the research challenges that arise when dealing with these models, illustrate the ideas with examples from sealed auctions, and point out relevance to national defense. The key contribution is a way to build a rational probabilistic model of the actions of the adversary, which is then used to feed a decision analytic model.

- Balanced increment and concession methods for arbitration and negotiation support, (BIM-BIC) J. Ríos, D. Ríos Insua.

  In this paper, we study arbitration schemes and develop negotiation support methods from the perspective of cooperative bargaining theory. We discuss Raiffa's solution of balanced increments and, based on that idea, propose another solution based on balanced concessions. We also consider negotiation support processes based on the application of these solution concepts. The most notable feature of the proposed schemes is that they allow the consideration of non-convex utility sets for problems with more than two agents, a topic not sufficiently considered in the bargaining theory literature. A risk sharing negotiation problem illustrates the discussion.

- Commutativity of Nash equilibria and expected utilities, J. Ros, David Banks.

  In our discussions, we observed that expected utility and Nash equilibria operators do not commute; this creates conceptual difficulties to simulation based approaches in this area. We are identifying appropriate ways to integrate both operations; and both structured and numerical experiments provide examples.

2. Other Modeling

   - Discrete choice models in adversarial risk analysis. Mike Porter.

     In this paper an alternative model for rationally choosing a probabilistic model of the actions of the adversary has been proposed based on discrete choice models. Since the assumptions introduced prevent an analytic solution, results are obtained via simulation based approaches.

3. Computations in adversarial risk analysis

   - Negotiations over influence diagrams, J. Ríos, D: Ríos Insua.

     We discuss issues concerning negotiations over influence diagrams. We base our discussion on a modification of the balanced increment method. As in standard decision analysis texts, we deal first with negotiation tables, then with negotiation trees and, finally, with (negotiation) influence diagrams. We show by example that a naive application of the balanced increment method may lead to an inferior solution. Our strategy proposes therefore computing first the nondominated alternatives and then negotiating over such set.

- Computations for adversarial risk analysis.

  As basic modelling and communication tools we are using influence diagrams. Here we extend these to a new class of adversarial IDs; the solution concepts appear in the ARA and BIM-BIC papers, and are implemented here using MCMC and other simulation methods.

4. Auctions

- Adversarial risk analysis. D. Ríos Insua, J. Ríos, D. Banks.

  The key application in the ARA paper is auctions; and the results there derive from this research.

- Bayesian methods for auction participation support.

  We believe we have been very successful in proposing a novel Bayesian approach to first price sealed bid auctions leading to, on one hand implementations for a realistic case and on the other, to extensions to other types of auctions.

5. Terrorism

- Adversarial risk analysis for terrorism prevention.

  Having already applied our ARA approach to the so called Defend-Attack, Attack-Defend and Defend-Attack-Defend models, we then extended it to more general problems, modeled as adversarial IDs. TO be successful this required application of computations also developed as part of this adversarial risk analysis project. We would also like to sketch solutions with continuous time asynchronous conflicting interactions, possibly with stochastic adversarial differential equations.

6. Cybersecurity

- An adversarial risk analysis framework for cybersecurity.

  This line of research was proposed by Lea Deleris with a qualitative description of the issues involved. The key issue here is that n (members of an interconnected network) versus m (cyberattackers), with possible cooperation among both sides. We extended original ARA model, 1 vs 1, to 1 vs m and then used the ideas in the BIC-BIM paper to consider cooperation in n vs m.

- Formalisation of risk approaches in ICT. D. Ríos Insua, J.A. Rubio.

  This actually started from a class discussion at the SAMSI course. In it, we concluded that most approaches to ICT Risk analysis are not well founded and we are trying to formalize one of the most successful approaches. This requires the development of some novel reliability modeling approaches as described in the next two papers.

- Bayesian reliability analysis for hardware/software systems, J. Cano, D. Ríos Insua

  We provide a class of models to evaluate and forecast the reliability of complex hardware/software systems, described through Reliability Block Diagrams. Blocks referring to hardware components are modelled through 'pending' continuous time Markov chain models, whereas blocks referring to software components are modelled through a mixture of software reliability growth models. Inference and forecasting tasks with such models are described, and illustrated with an example.

- Bayesian reliability, repairability and availability for hardware systems through continuous Markov chain models, J. Cano, D. Ríos Insua

  Hardware systems are present in many fields of human activity. Markov models are sometimes used in hardware reliability, availability and maintainability (RAM) modeling. They are specially useful in situations in which the system we want to analyze may be modeled with several states through which the system evolves, some of them corresponding to ON states, the rest to OFF states. We provide here RAM analyses of such systems within a Bayesian framework. But the computations are too involved and we are devising new computational strategies as in

- Reduced order models for Bayesian risk analysis, M. Grigoriu, D. Ríos Insua, J. Ríos, H. Shen

  Standard approaches to risk analysis based on estimating parameters and performing the corresponding risk analysis computations will typically underestimate uncertainty. An alternative Bayesian approach computes posterior distributions for the parameters and then performs a posterior predictive risk analysis computation. This may be extremely involved computationally requiring some type of approximation. Reduced order models have been recently proposed to approximate given distributions and then perform predictive computations. In this paper we explore the relevance of reduced order models for Bayesian predictive computations, especially in a Bayesian risk analysis context. We consider a simple application in queueing models and a complex application in continuous time Markov chain based reliability models. General conclusions are drawn suggesting the effectiveness of this methodology.

  NOTE: This work was done in collaboration with the Service Risk group as part of a broader effort to expand Bayesian discrete event simulation.

#### 4.1.6 Horizontal topics

1. Basic concepts in stochastic processes
2. Basic concepts in Bayesian Analysis
3. Discrete time Markov chains and extensions
4. Continuous time Markov chains and extensions
5. Poisson processes and extensions

6. Continuous time processes
7. Queueing analysis
8. Reliability and maintenance
9. Discrete event simulation
10. Risk Analysis

#### 4.1.7 Other Activities

Research has been invited from multiple working group members fro presentation at meetings of national and international professional societies.

- Interface meeting 2008
- Joint Statistical Meetings 2008
- Group Decision and Negotiation 2008
- INFORMS 2008
- Probabilistic Graphical Models 2008
- International Statistical Institute 2009

### 4.2 Bayes Risk Group

#### 4.2.1 Organization and Membership

Kobi Abayomi, Duke University
David Banks, Duke University
Susie Bayarri, University of Valencia/SAMSI
Jim Berger, SAMSI
Sourish Das, Univ. of Connecticut
Dipak Dey , Univ. of Connecticut
Ian Dinwoodie, Duke University
Betsy Enstrom, Duke University
Elijah Gaioni, Univ. of Connecticut
Mircea Grigoriu, Cornell University
Feng Guo, Virginia Tech
James Hammitt, Harvard University
Huitian Lu, South Dakota State University
Christian Macaro
Vered Madar, SAMSI
Cuirong Ren, South Dakota State University
Abel Rodriguez, Duke University

Fabrizio Ruggeri, CNR-IMATI
Richard Smith, UNC-Chapel Hill
Gentry White, N.C. State University
Dabao Zhang, Purdue University
Iris(Xiaoyan) Lin, University of Missouri-Columbia

### 4.2.2 Description of Activities

Workshops: The Opening Workshop was held on September 16, 2007 - September 19, 2007. Its principal goal was to engage a broadly representative segment of the statistical, applied mathematical and decision analysis/operations research communities in formulation and pursuit of specific research activities to be undertaken by the Program Working Groups, discussed above. Mid-program workshops focused on specific topics, the first of these took place in October: Risk: Perception, Policy and Practice. A workshop on Extreme Events: Theory, Prediction and Cost was held in late January. Other workshops were organized by the working groups; and a Transition Workshop, at the end of the program, disseminated program results to chart a path for future research in the area.

Courses: Team-taught courses were taught at the NISS/SAMSI building during the fall semesters. The fall semester course began with an introduction to decision theory as a foundation for risk assessment and management; it was continued with a systematic approach to risk analysis, and then concluded with an introduction to expert opinion elicitation and modeling.

Working Groups: The working groups met regularly thoughout the program to pursue particular research topics identified during the Opening Workshop and during the January workshop. Each working group consisted of SAMSI visitors, postdoctoral fellows, graduate students and local faculty and scientists. In addition the working group meetings were continued remotely from University of Connecticut.

Presentations: The following presentations were made at the working group meetings;
Sep 27 First planning meeting
Oct 11 Huiyan Sang presented her work on "Hierarchical Modeling for Extreme Values Observed over Space and Time"
Oct 15 Mircea Grigoriu: Large Scale Stochastic Equations - A special lecture
Oct 18 Discussion on river flow data (Elijah Gaioni); discussion and some modeling issues on Hurricane data (Sourish Das); some thoughts on Bayesian modeling of Multivariate extremes (Dipak Dey)
Oct 25 Short introduction to dynamic linear models (Gentry White); Large Scale Stochastic Equations - Bayesian Framework (Mircea Grigoriu).
Nov 8 Kobi Abayomi: Fitting multivariate extreme value dist to multi-'hazard' environmental data.
Nov 15 Sourish Das: Some modeling issues on Hurricane data.
Nov 29 Elijah Gaioni: Modeling River Flow: Flash Floods and Mixture Distributions.
Dec 6 Vered Madar: Some Thoughts on Bayesian Modeling of Bivariate Extremes.

Feb 4 Elijah Gaioni: Semiparametric functional estimation using quantile based prior elicitation
Feb 11 Jose Bernardo, University of Valencia
Mar 3 Fabrizio Ruggeri: Model-based prior elicitation: a possible approach?
Mar 24 Susie Bayarri, University of Valencia/SAMSI
Mar 31 Sourish Das

#### 4.2.3 Research Outcomes

Expert opinion. Data inadequacies were perhaps the most clearly identified theme for modeling extreme data. For some rare events whose risk must be assessed, there are no data; more often there are data of mixed degrees of relevance and reliance on experts' opinions is needed to avoid rigid specifications of parameters and/or functional forms within risk models that cannot be documented. Various Bayesian methodological techniques were implemented using prior elicitation and models incorporating expert opinion to produce accurate estimates of parameters of interest. Examples include modeling hurricane intensity and floods.

### 4.3 Extreme Values

Extreme Value Theory has its origins in papers by Fréchet (1927), Fisher and Tippett (1928) and Gnedenko (1943), who established the existence of special families of extreme value distributions, defined as limiting distributions of maxima and minima in independent, identically distributed sequences of random variables. The theory immediately found applications in practical risk assessment, for example through the work of Gumbel on hydrological extremes or Weibull on strength of materials. During the last thirty years, the scope of both the theory and applications have greatly expanded. The earlier statistical methods that were based on directly fitting the extreme value distributions to data have for many applications been replaced by methods based on threshold exceedances, which have in turn focused attention on new families of distributions (in particular, the generalized Pareto distribution). There is an ever expanding theory of extremes in stochastic processes, which has found particular application in the field of finance. Statistical methods for extremes have become increasingly elaborate, for example using second-order approximations for threshold selection or bias reduction, using robustness concepts, and (especially) a rapidly increasing interest in the use of Bayesian methods. Applications have ranged over many areas, including finance and insurance, meteorology, hydrology and oceanography.

A particularly significant development of the last thirty years has been the development of a whole field of multivariate extreme value theory. The original papers were concerned with extending the classification of extreme value distributions to cover joint distributions of maxima in dependent processes  for example, a landmark paper of de Haan and Resnick (1977) established domain of attraction conditions for multivariate extremes and the connection with multivariate regular variation. The earliest papers on statistical inference for multivariate extremes started at around the same time, but this research greatly expanded in the late 80s and early 90s. During the last 15 years, two new formulations of multivariate extremes have been proposed. The first originated in papers

of Ledford and Tawn (1996, 1997), and was concerned with dependence measures for bivariate extremes that are more sensitive to different kinds of asymptotic behavior than the traditional bivariate extreme value distributions. For instance, bivariate normal variables with correlation in (0,1) are asymptotically independent under the traditional formulation, but the Ledford-Tawn approach captures the hidden dependence that still exists at very high threshold levels. However, this approach has so far been limited to the case of bivariate extremes. A second approach due to Heffernan and Tawn (2004) was based on classes of conditioned limit theorems as one component (but typically not all components) become extreme. However at the moment, this approach is still too new and too poorly understood for its full implications to be appreciated.

The SAMSI program on Risk Analysis, Extreme Events and Decision Theory allowed many of these issues to be analyzed in depth. Talks at the Opening Workshop ranged across the spectrum from theory to applications, from such topics as the role of multivariate regular variation in determining theoretical properties of GARCH and stochastic volatility process in finance, through to a very applied discussion of the role of extreme events in the current mortgage crisis. At the end of this workshop, it was agreed to make multivariate extreme value theory the primary focus of two working groups, one oriented towards new methodological developments and the underlying mathematical theory, the other focused on applications. These topics were further cemented at the January workshop entitled Extremes: Events, Models and Mathematical Theory. At this workshop, talks were given by a number of the worlds top experts in extreme value theory and its applications.

#### 4.3.1 Theoretical Developments

1. **Classical Univariate EVT**. Two talks at the January workshop highlighted recent developments in the estimation of the tail-index parameter, that determines the rate of growth of extremes. **Chen Zhou** discussed second-order tail conditions and their implications for asymptotic properties of estimators of the tail index, including non-regular cases where classical maximum likelihood theory breaks down. In contrast, **Debbie Dupuis** focussed on robustness, highlighting a "weighted prediction error" criterion for reconstructing the upper tail of a distribution.

   From a different perspective, **John Nolan** gave a talk about estimation of stable distributions, which in some contexts are an alternative to fitting an extreme value distribution to long-tailed data.

2. **Extremes in Stochastic Processes**. Three talks at the January workshop discussed particular topics in extreme value theory for (univariate) stochastic processes. **Vicky Fasen** discussed the extreme value theory of "threshold autoregressive" processes, which are a widely used class of nonlinear time series models that have recently found application in the field of financial time series. **Ross Leadbetter** gave a talk about the "capsize risk" problem for ships, used to illustrate the general principle that a naïve approach to extreme value theory may be inadequate for characterizing upcrossings and other significant properties of random

processes. **Gennady Samorodnitsky** strarted his talk with the observation that regular variation of the upper tail of a distribution is preserved under linear filters, and discussed the *inverse problem* of determining when regular variation of the output of a linear filter implies regular variation of the input.

The theory of extremes in *random fields* is still much less well developed than that of one-parameter stochastic processes, but in the special case of continuous Gaussian processes, a rich theory now exists. **Yimin Xiao** gave an excellent overview of this topic in one of the working group meetings.

3. **Multivariate Regular Variation**. **Richard Davis's** talk at the Opening Workshop covered several aspects of extreme value theory as applied to commonly used models for financial time series, such as the popular GARCH(1,1) model, and as an alternative, a stochastic volatility (SV) model. His starting point was the question "Do fitted models actually capture the desired characteristics of the real data?" He then presented a number of real financial time series, focussing on clustering properties of the extreme values and on the behavior of the sample autocorrelation functions (ACFs) of the log returns and their squares and absolute values. He then surveyed recent developments in multivariate extreme value theory, focussing on the property that regular variation is preserved when forming linear combinations of the data, and discussing a result of Basrak, Davis and Mikosch on conditions for the converse statement to be true. He then discussed applications of this result to GARCH and SV processes, including the theoretical properties of sample ACFs and clustering properties of extremes — for example, a GARCH process typically has extremal index in (0,1), which implies clustering of extreme values, whereas a SV process has extremal index 1, which implies no local clustering. He then returned to some of the real-data time series, discussing how their empirical properties match up with theoretical properties of GARCH and SV processes. Although he did not commit himself to a firm statement about which model fits better, the implication was that in many cases these considerations favor the SV model.

   The theme of multivariate regular variation was continued in **Thomas Mikosch's** talk at the January workshop. In a wide-ranging talk he also discussed the preservation of regular variation under formation of linear combinations, and generalizations of the result to processes in $\mathbb{D}[0,1]$, including results for the Ornstein-Uhlenbeck and Lévy processes. He went on to discuss max-stable and stable random fields, models for spatial and spatio-temporal processes, and large deviations theory for stochastic processes. The final part of the talk covered ruin processes and their multivariate generalization.

4. **Classical Multivariate Extreme Value Theory.** In the Opening Workshop, **Holger Rootzén** discussed the bivariate generalized Pareto distribution, a recent development in threshold-exceedance methods for bivariate extremes. He gave an example based on insurance claims for windstorm damage to buildings and forest, comparing an analysis in which the two types of claims are conisdered separately with one in which they are treated as a bivariate

pair. He concluded "bivariate analysis may give the most correct evaluation of the real uncertainties".

Another development presented by Holger was the use of stable laws as a mixture distribution to generate new classes of multivariate extreme value distributions. This was based on joint work with **John Nolan** and Anne-Laure Fougères. As an application, he discussed a problem about pitting corrosion, where the object of interest is maximum pit depth, where the possible presence of common environmental factors means that depth of different pits are not necessarily independent. To solve this problem, he proposed a flexible class of "logistic" models with Gumbel marginal distributions, where the distribution of maxima of all kinds of sets are also Gumbel.

The question of *bivariate measures of extremal dependence* was discussed by **Ishay Weissman** in the January workshop. In this talk he discussed two measures of dependence that have been proposed in previous literature, denoted $\tau_1$ and $\tau_2$, and presented a number of new identities and bounds.

The field of *multivariate stable distributions* was also discussed by Nolan in one of the working group meetings. Although this leads to different distributions from the traditional multivariate EVT distributions, for many practical applications they may be a suitable alternative.

5. **Max-Stable Processes**. Max-stable processes are the generalization of multivariate extreme value theory to infinite dimensions. In a working group presentation following the January workshop, the originator of the whole concept, **Laurens de Haan**, surveyed the current state of the theory as it appears in his 2006 book with Ana Ferreira. Theoretical developments were presented by **Zhengjun Zhang** and **Stilian Stoev** in the opening workshop. Applications to spatial statistics were presented by **Tailen Hsing** in a discussion, and **Dan Cooley** gave a talk on prediction theory for max-stable processes, in effect the analog of kriging in traditional spatial processes.

6. **Alternative Models for Multivariate Extremes**. As noted in the introduction, two alternative formulations of multivariate extremes have been proposed during the past decade, one initially developed in two papers by Ledford and Tawn (1996, 1997), the other stemming from Heffernan and Tawn (2004). These papers and some recent extensions formed the topic of **Sid Resnick's** talk at the January workshop, and several working group discussions.

   **Anthony Ledford** gave one working group presentation remotely from Oxford, based on recent work by him and **Alexandra Ramos**. This work contains a reformulation of the original Ledford-Tawn work, with more clearly defined statistical properties, and the potential for extensions to multivariate cases, most of the existing theory being for bivariate models. Other working group talks by **Xiao Qin** and **Richard Smith**, and an opening workshop presentation by **Jonathan Hill**, discussed other aspects of the theory of these models and their relation with classical bivariate extreme value theory.

The more recent model of Heffernan and Tawn leads to a class of *conditioned limit theorems*, in which one component becomes extreme but the objective is to establish conditional limit theorems for the other component(s). This theory is still two recent to have been subjected to many practical tests, but two talks by **Luis Pericchi** presented joint work with Beatriz Mendes that discussed an application to flooding in Puerto Rico.

In his talk at the January workshop and a series of subsequent presentations to the working group, **Sid Resnick** discussed the mathematical relationship among classical bivariate extreme value theory, the Ledford-Tawn approach, and conditioned limit theorems. We have already noted that classical bivariate (or multivariate) extreme value may be characterized in terms of multivariate regular variation. In a series of papers over the last 6 years, Sid and co-authors have shown that the key mathematical condition for the Ledford-Tawn approach is *hidden regular variation*, which is equivalent to regular variation on a cone. In recent papers with Janet Heffernan and Bikramjit Das, Sid has extended this work to cover also the case of conditioned limit theorems. Some key statistical questions remain, however. For example, a key step in all of these limit theorems is standardization of the marginal distribution to unit Fréchet. The traditional approach is through a semiparametric estimator of the index of regular variation (Hill's estimator is the best known of many proposals for this), but Heffernan and Resnick (2005) preferred a nonparametric "rank transform" approach. It remains an open question which of the two is better.

These issues were the centerpiece of an invited session on multivariate extremes at the May 2008 Interface, when **Janet Heffernan** was one of the invited speakers.

### 4.3.2 Applications of Extreme Value Theory

Some applications have been interwoven into the above theoretical discussion, for example, **Holger Rootzén's** work on pitting corrosion, and **Luis Pericchi's** application of the Heffernan-Tawn method to floods. However, a number of applications received extensive examination in their own right during the course of the program.

1. **Finance.** In recent years, many of the liveliest applications of extreme value theory have been in the area of finance, and the SAMSI program reflected that. As already noted, **Richard Davis's** talk at the opening workshop was motivated by the problem of distinguishing between GARCH and stochastic volatility models for financial time series. Other workshop presentations touching on financial extremes included **Yacov Haimes's** talk on the Partitioned Multiobjective Risk Method (PMRM) to portfolio selection; **Zhengjun Zhang's** talk on testing and modeling extreme dependence in the financial markets; and **Bas Werker's** talk at the January workshop, on integer-value time series models for financial data. In the January workshop, **Dominik Lambrigger** discussed new measures of *Value at Risk*, focussing on subadditivity and superadditivity properties.

2. **Insurance.** In the Opening Workshop, **Dougal Goodman** presented a broad-ranging review of how risk analysts approach extreme events, from the contrasting points of view of government, industry and regulators. On a much more technical level, **Shyamal Kumar** talked about phase-type distributions in actuarial science, and their application to ruin theory and related problems.

3. **Energy Pricing.** In the January workshop, **Pilar Muñoz** discussed volatility modeling and risk assessment in electricity markets. Her main approach was a stochastic volatility model for prices, using a state space approach, combined with extreme value theory to model the probability of extreme jumps, conditional on the volatility process. Fitting this model was tried using a particle filter algorithm, and also a modification of the sampling-importance-resampling method that she called SIRJ. The possibility of using multivariate extreme value theory to improve the analysis was posed as an open question.

4. **Meteorology and Hydrology.** Some of the oldest applications of extreme value theory have concerned assessing probabilities of extreme floods or extreme meteorological events, so it was not surprising that these themes emerged several times during the SAMSI program. In a provocative talk at the January workshop, **Jery Stedinger** touched on several key points of the application of extreme value theory to hydrological extremes, including the relationship among maximum likelihood, L-moment and Bayesian approaches to the estimation of extreme value parameters; the relationship between the threshold exceedance approach and older methods based on annual maxima; and a new approach to the regionalization problem (combining data from multiple stations in a region to improve the estimation of extreme value parameters) using a new Bayesian GLS approach. Applications to meteorology included **Laurens de Haan's** presentation at the January workshop about spatial modeling of precipitation extremes in the Netherlands; **Huiyan Sang's** presentation to one of the working group meetings about a spatial hierachical model for precipitation extremes; and **Elizabeth Shamseldin's** poster presentation on the change of scale problem for precipitation extremes. In the January workshop, **Francis Zwiers** presented a broad overview of how extremes are viewed by climate scientists, focussing on the very wide range of spatial and temporal scales that must be considered; the use of "simple" indices of extremes and some of the pitfalls that can occur with them; the difficulty of reconciling observations and climate models; and finally, the growing problem of "operational attribution", which refers to the extent to which extreme events can be attributed to external forcing factors, in particular greenhouse gases versus natural causes such as solar fluctations

5. **Volcanoes.** In a presentation at the January workshop, **Elaine Spiller** discussed the work of a large group of SAMSI researchers on pyrostatic flows. The work combined an elaborate differential equation model for flows, the GASP technique for statistically interpolating parameters of the flow model, and extreme value theory to extend the model to encompass the possibility of extremely large eruptions.

6. **Hurricanes.** Although this does not involve extreme value theory as usually defined, several discussions during the program included statistical modeling of hurricane or tropical storm count data. At the opening workshop, **Tom Knutson** reviewed the difficulties of inferring a trend from long-term time series of tropical storms and hurricanes, and also presented some of the conflicting evidence on whether climate models predict an increase in the frequency of hirricanes as greenhouse gases continue to rise. This gave rise to several statistical projects. Sourish Das's work is discussed in more detail in the Bayes Risk section of this report. **Yongku Kim** has been working on determining the optimal relationship between hurricane and tropical storm counts and the spatial distribution of sea-surface temperatures (SSTs). Since hurricane counts are discrete, there is really a need for discrete-data time series models, and **Vangelis Evangelou** suggested an approach to this based on models for Poisson time series in rceent papers of Davis, Dunsmuir and Streett. He and **Richard Smith** are working on bivariate time series models for the joint evolution of storm counts and SSTs.

#### 4.3.3 Working Group on Multivariate Extremes — Methodology

Participants:

Susie Bayarri, University of Valencia and SAMSI
Jaya Bishwal, UNC-Charlotte
Michela Cameletti, SAMSI
Guang Cheng, SAMSI and Duke University
Dan Cooley, Colorado State University
Sourish Das, University of Connecticut
Dipak Dey, University of Connecticut
Ian Dinwoodie, Duke University
Evangelos Evangelou, UNC-Chapel Hill
Elijah Gaioni, University of Connecticut
Eric Gilleland, NCAR
Dougal Goodman, The Foundation for Science and Technology (UK)
Laurens de Haan, Erasmus University Rotterdam (Netherlands) and University of Lisbon (Portugal)
Jonathan Hosking, IBM
Rosalba Ignaccolo, SAMSI
Huijing Jiang, Georgia Institute of Technology
Myron Katzoff, Centers for Disease Control
Yongku Kim, SAMSI
Lada Kyj, Rice University
Anthony Ledford, Man Investments (UK)
Huitian Lu, South Dakota State University
Wenbin Lu, N.C. State University
Vered Madar, SAMSI

Pilar Munoz, Technical University of Catalonia
XuanLong Nguyen, SAMSI
John Nolan, American University
Jayanta Pal, DUKE Univ. and SAMSI
Luis Pericchi, University of Puerto Rico, Rio Piedras
Xiao Qin, University of North Carolina, Chapel Hill
Cuirong Ren, South Dakota State University
Abel Rodriguez, Duke University
Paul Schuette, Meredith College
Nicoleta Serban, Georgia Institute of Technology
Kazuhiko Shinki, UW-Madison
Richard Smith, UNC-Chapel Hill
Neil Shephard, Oxford (UK)
Huixia Wang, N.C. State University
Ishay Weissman, Technion (Israel)
Gentry White, N.C. State University
Robert Wolpert, DUKE University
Yimin Xiao, Michigan State University
Fei Xu, Renmin University of China
Saeid Yasamin, Indiana University
Dabao Zhang, Purdue University

Schedule of meetings:

Sept 27: Initial group discussion
Oct 11: Richard Smith gave a tutorial on multivariate extreme value theory
Oct 18: Dan Cooley on Spatial Extremes
Oct 25: Jaya Bishwal (remotely from Charlotte) on Financial Extremes
Nov 8: Group discussion, primarily to agree on an outline program for future meetings
Nov 15: Vered Madar on multiple comparisons and possible links with extreme value theory
Nov 29: Nicoleta Serban on high-dimensional wavelets and extremes
Dec 6: Xiao Qin on Dependence Modelling in Multivariate Extremes
Dec 13: Richard Smith on possibilities for extending the Ledford-Tawn models to higher dimensions
Jan 14 2008: Vangelis Evangelou presented an overview of Davis, Dunsmuir and Streett (2003) Biometrika paper
Jan 22–24: Workshop on EXTREMES: Events, Models and Mathematical Theory, January 22-24, 2008
Jan 28: Laurens de Haan on Extremal Processes
Feb 4: Group discussion
Feb 11: Richard Smith on statistical models for hurricane counts
Feb 25: Sidney Resnick on Regular Variation, Extreme Value Theory, Hidden Regular Variation

and Conditioned Limit Laws (part I of a multi-part talk)
March 3: Anthony Ledford (remotely from Oxford) on "A new class of models for bivariate joint tails" (joint work with Alexandra Ramos)
March 17: John Nolan (remotely from Washington) on Multivariate Stable Laws.
March 24: Resnick presentation part II
March 31: Yimin Xiao on Extreme Value Theory of Gaussian Random Fields
April 14: Resnick presentation part III

#### 4.3.4 Working Group on Multivariate Extremes — Applications

Participants:

Kobi Abayomi, Duke University
Michela Cameletti, SAMSI
Guang Cheng, SAMSI/Duke University
Dan Cooley, Colorado State
Evangelos Evangelou, UNC-Chapel Hill
Eric Gilleland, NCAR
Rosalba Ignaccolo, SAMSI
Yongku Kim, SAMSI /Duke
Wenbin Lu, N.C. State University
Vered Madar, SAMSI
Pilar Munoz, Technical University of Catalonia, Spain
XuanLong Nguyen, SAMSI/ Duke
John Nolan, American University
Nabendu Pal, University of Louisiana
Xiao Qin, UNC-Chapel Hill
Huiyan Sang, Duke University
Paul Schuette, Meredith College
Richard Smith, UNC-Chapel Hill
Nikita Tuzov, Purdue Univ
Huixia Wang, N.C. State University
Robert Wolpert, Duke University
Fei Xu
Zhengjun Zhang, University of Wisconsin

Schedule of meetings:

Sep 27: Organizational meeting. Aims of the working group were discussed and a list of references compiled.
Oct 11: Paul Schuette on "Power laws and extreme values".
Oct 18: Pal Nabendu on estimation and testing with (univariate) EVD.

Oct. 25: Discussion of the papers by S. Poon, M. Rockinger and J. Tawn (2004), Extreme value dependence in financial markets: Diagnostics, models and financial implications. *Review of Financial Studies* **17**, 581–610; and J.L. Geluk, L. de Haan, and C. G. de Vries (2007), Weak and Strong Financial Frailty, Tinbergen Institute Discussion Paper TI 2007-023/2.
Nov 8: Kobi Abayomi on EVD-multiple environment hazard: World Bank hostpots report; Zhengjun Zhang on Testing and modeling extreme dependencies in financial markets
Jan 28: Kobi Abayomi discussed *Multivariate Models and Dependence Concepts*, by Harry Joe (1997).
Feb 25: Pilar Muñoz on Daily Spanish electricity prices and other variables associated with them: Univariate and bivariate approaches.
Mar 10: Evangelos Evangelou on Description and models for five stock prices.
Mar 24: Nikita Tuzov on Applying EVT analysis to US energy prices.
Apr 7: Jen Ting on US energy prices.

#### 4.3.5 New Research Stimulated by the Program

At the time of writing (April 2009), research begun within the program and research stimulated by the program have been presented and continue to develop.

1. **Extreme Value Distributions.** Xiaoyan Lin (graduate student, visiting from University of Missouri) continues her work on reference priors for extreme value distributions; see Section 6.7 for a more detailed description of her work.

2. **Regular Variation and Multivariate Extremes.**

   **Sidney Resnick** (Cornell University, visiting SAMSI) is working on the connection between regular variation and different formulations of multivariate extreme value theory. Regular variation on cones can be specialized in at least 3 different directions giving (a) classical extreme value theory; (b) hidden regular variation (the Ledford-Tawn approach); and (c) limit approximations for the distribution of a random vector given one component is extreme (the Heffernan-Tawn approach). In each of the first two cases, there exists a reduction to a one dimensional criterion which allows detection of the phenomenon. For case (c), we have taken the initial steps to find a criterion that a conditioned limit law exists to a one dimensional condition that can be statistically confirmed. Done first in an important special case progress has been made on the generalization.

   **Xiao Qin** and **Richard Smith** are working to develop alternative forms of bivariate and multivariate distributions consistent with the Ledford-Tawn-Ramos approach to characterizing extremal dependence. Xiao presented a Topic Contributed Paper on this subject at the JSM in August, 2008.

3. **Max-Stable Processes**. Zhengjun Zhang (University of Wisconsin) has revised and resubmitted his paper "On Approximating Max-stable Processes and Constructing Extremal

Copula Functions."

In addition, Zhengjun has presented this work at the JSM in August 2008, and at the International Conference on Financial Econometrics, June 21-23, Chengdu, China.

**XuanLong Nguyen's** (postdoc, SAMSI and Duke) work on estimation methods in max-stable processes (e.g., M4 processes) using empirical process theory and concentration of measure techniques has been drafted into a paper.

4. **Spatial and Space-Time Processes.** Huiyan Sang (PhD student, Duke University) presented "Extreme Value Modeling for Space-time Data with Meteorological Applications" at the International Indian Statistical Association Conference (May 22-25, 2008, Storrs, CT).

   Huiyan also worked with Yongku Kim on extreme value modeling for explaining sea surface temperatures observed in space and their impact on hurricane data.

   **Zhengjun Zhang** is preparing a paper "Nonlinear and Extremal Spatial Dependencies of Precipitations in Continental USA."

   **Cuirong Ren** (Department of Plant Science, South Dakota State University, visiting SAMSI) has written two papers on objective priors in spatial statistics:

   (a) "Objective Bayesian Analysis for a Spatial Model with Nugget Effects" (Cuirong Ren, Dongchu Sun and Zhuoqiong He).

   Summary: We often need to consider geostatistical data with nugget effects. In this paper, we have systematically studied the Jeffreys priors and various reference priors, derived by both "exact" and asymptotic marginalization. Interestingly, not all Jeffreys and reference priors yield proper posterior distributions. We have found the conditions under which the corresponding posteriors are proper. Finally, we conduct a simulation study to compare the objective priors by frequentist coverage probabilities of the one-sided credible intervals.

   (b) "Objective Bayesian Analysis for a Spatial Model with Correlated Repeated Measurements" (Cuirong Ren, Dongchu Sun, Jing Zhang and Zhuoqiong He).

   Summary: Geostatistics is an important part of Spatial analysis, and has been widely used in case studies. Using the Bayesian hierarchical modeling not only facilitates to count all the variabilities of the parameters, but also helps decompose the problem into several levels, and hence makes the model more flexible and improves the estimation of parameters as well as the prediction of new locations. In this paper the reference priors and Jeffreys priors for a Spatial model with repeated measurement are developed and comparions are made based on frequentist coverage probabilities of the one-sided credible intervals.

   Cuirong also presented a paper at the IISA in May 2008 at the University of Connecticut.

5. **Extreme Values in Finance and Insurance.**

   **Dougal Goodman** (Director of the Foundation for Science and Technology, London, UK) writes: "I found it invaluable to attend the opening workshop of the programme last September. The workshop stimulated me to think of new ways in which extreme statistics can be applied to policy questions within government departments. I used as an example in my talk the sudden failure of the Northern Rock bank in the UK. The succession of further failures in the banking system particularly Bear Sterns since the workshop raise many interesting questions about how extreme statistics methods could be used to assist managers and regulators in assessing risks in the financial services sector. Multivariate methods surely have an application to these problems."

   **Xiao Qin** (PhD student from Beihang University, China, visiting UNC-Chapel Hill) has written a paper using extreme value theory for the identification of currency crises. The paper is submitted to *Journal of International Money and Finance*, and was also the subject of a poster presentation at the opening workshop.

   Xiao is also using the Ledford-Tawn-Ramos approach to bivariate extremes to model the coincidence of two specific types of financial crises, i.e., banking system crises and currency crises (the "twin crises" in economic literature). She has submitted an abstract to the 2009 Annual Meeting of the American Economic Association.

   **Zhengjun Zhang** has taught a seminar course on "Statistics for Financial Markets and Insurance" at the University of Wisconsin drawing on materials that are closely related to presentations in the SAMSI Risk program.

6. **Energy Markets. Pilar Muñoz** (Technical University of Catalonia, Spain, visiting SAMSI) is working on applying univariate and bivariate extreme value theory to daily Spanish electricity prices and other variables associated with them. She has also started a collaboration on Energy Markets with Nikita Tuzov, PhD student of the Department of Statistics, Purdue University.

7. **Meteorology and Hydrology Applications**.

   Mendez B. and Pericchi L.R. (2008) "Assessing Conditional Extremal Risk of Flooding in Puerto Rico". *Stoch. Environ. Res. Risk Assess.* (in press).

   **Luis Pericchi** also gave the talk (co-authored with Beatriz Mendes, Abel Rodriguez and Scott Sisson) "Experiences with Modeling in Multivariate Extremes", Joint Statistical Meetings, Denver, August, 2008.

8. **Hurricanes. Yongku Kim's** work on statistical modeling for Atlantic tropical storms based on climate factors such as northern (spatial) Atlantic sea surface temperature, global surface temperature and Atlantic multidecadal oscillation has yielded promising preliminary results.

9. **Inference on Networks**. **Ian Dinwoodie** (Duke University, visiting SAMSI during 2006/07) has submitted two papers: "Statistical Estimation of Available Bandwidth" by Ian H. Dinwoodie (*Journal of Statistical Computation and Simulation*, September 2007) and "Markov chains, quotient ideals, and connectivity with positive margins" by Yuguo Chen, Ian H. Dinwoodie and Ruriko Yoshida (to appear in a volume dedicated to G. Pistone, Cambridge University Press). He gave a talk "Network Inference from Indirect Measurements" at the Department of Statistics, UIUC.

## 4.4 Environmental Risk Analysis (ERA) Working Group

### 4.4.1 Organization and Membership

This group formed during the Opening Workshop, inspired particularly by the talk given by Dr. Anne Smith during that workshop. The Environmental Protection Agency (EPA) is charged under the Clear Air Act with promulgating air pollution standards that are "requisite to protect the human health". Commonly regulated pollutants include particulate matter, ozone, sulfur dioxide, nitrogen dioxide and carbon monoxide. Part of the process of setting air pollution standards is an assessment of the scientific literature to assess the adverse health effects of air pollution. Many statisticians and epidemiologists are involved in this work. Another part of the EPA review, in which statisticians have been less involved, is the "risk assessment", in which quantitative estimates of health effects are translated into specific scenarios of health outcomes under various proposed forms of the air pollution standard. This process has become particularly important this year because of the EPA's review of the ozone standard, which resulted in a new standard being announced in March 2008 (75 parts per billion for the maximum daily 8-hour average ozone, down from 84 ppb under the previous standard). The statistical assumption underlying this risk assessment, however, are poorly understood, especially regarding the uncertainty of the resulting estimates. The overall aim of this group was to investigate and quantify several aspects of this risk assessment.

Regular participants were:
David Bell, Duke
Michela Cameletti, SAMSI
Rosalba Ignaccolo, SAMSI
Yongku Kim, SAMSI/Duke
Amy Nail, N.C. State University
Bahjat Qaqish, UNC-Chapel Hill
Richard Smith, UNC-Chapel Hill

### 4.4.2 Activities

Oct 15: Amy Nail. Quantifying local creation and regional transport using a hierarchical space-time model of ozone as a function of observed NOx, a latent space-time VOC process, emissions, and meteorology.

Oct 22: Michela Cameletti. Computer intensive procedure for mapping and modeling a spatio-temporal process and its uncertainty
Oct 29: Bahjat Qaqish. Review of NMMAPS.
Nov 5: Yongku Kim. Change of Spatiotemporal Scale in Dynamic Models
Nov 12: Rosalba Ignaccolo. Review of the paper Everson, PJ and Morris, CN (2000). Inference for multivariate normal hierarchical models. *J.R.Statist. Soc. B* **62**, 399–412.
Nov 19: Eric Gilleland (NCAR) on a review of Wikle, CK and Cressie, N (1999), A dimension-reduced approach to space-time Kalman filtering. *Biometrika* **86**, 815–829.
Nov 26: David Bell, review of Chen et al. (2007), Outdoor air pollution: ozone health effects. *Am.J.Med.Sci.* **333** (4), 244–248.
Dec 3: Richard Smith. Reanalysis of NMMAPS database on ozone and mortality.
Dec 10: Group discussion on NMMAPS data
Jan 28: Yongku Kim on a rollback application to NMMAPS ozone data
Feb 6: Rollback and Programing Issues
Feb 11 and Feb 13: Ozone Risk Modeling including Rollback
Feb 25: Ozone Risk Modeling including seasonal issues
March 3: Ozone Risk Modeling : continued
March 17: Relative risk analysis and other modeling issues

### 4.4.3 Research Outcomes

The EPA works to develop and enforce regulations that implement environmental laws enacted by Congress. The EPA is responsible for researching and setting national standards for a variety of environmental programs. A recent example is the decision to lower the ozone standard to 75 parts per billion (ppb).

In addition to reviewing the available literature on the health effects of ozone, the EPA did its own analysis of the potential impact of new regulations by analysis of 12 large metropolitan areas. The main aim of the ERA Working Group is to carry out an extensive analysis using data from 95 cities, including the 12 used in the EPA's analysis. The aim is to look at several issues related to the potential impact of lower standards.

To assess the impact of lower standards, a model is needed for how ozone levels would change if they were to meet a new standard. For this purpose the EPA uses "roll-back functions" that predict those changes. Mainly, three roll-back functions are used: proportional (with or without a threshold level); quadratic roll-back; Weibull roll-back.

Issues to be addressed include: 1) The extent of variability of the estimates for each city; 2) The sensitivity of the analysis to various risk models inclduing the adjustment for PM10. 3) The ozone measure used in the regression model (daily average, daily maximum, maximum 8-hour average). 4) The inclusion or exclusioin of days with high temeratures. 5) The different roll-back functions.

The plan is to estimate the effect of different standards including the recently approved standard of 75 ppb in addition to other possible standards such as 70, 65 and 60 ppb.

The analysis outlined above aims to assess not only the the various forms of statistical variability involved in assessing the impact of various regulation, but also the sensitivity of the analyses to various model assumptions, and uncertainity about the model itself.

## 4.5 Service Sector Risk

### 4.5.1 Organization and Membership

Tim Bedford, Strathclyde Business School
Lea Deleris, IBM
Jonathan Hosking, IBM
David Ríos Insua, Universidad Rey Juan Carlos, Spain
Huijing Jiang, Georgia Institute of Technology
Jesus Ríos, SAMSI
Fabrizio Ruggeri, CNR-IMATI, Italy
Huiyan Sang, Duke University
Nicoleta Serban, Georgia Institute of Technology
Farhad Shafti, Strathclyde Business School
Haipeng Shen, UNC-Chapel Hill
Lesley Walls, University of Strathclyde
Saeid Yasamin, Indiana University

### 4.5.2 Research Outcomes

The group is currently working on two papers:

1. Reduced order models for Bayesian risk analysis. A technical report has been written, and one additional numerical example need to be finished.

   It's conceivable that the group will follow up this paper with another one that focuses on Bayesian discrete even simulation with application to workforce management in labor-intensive service systems such as call centers or emergency rooms.

2. Statistical service classification for risk management.

   (a) A pilot dataset has been compiled. Initial statistical analysis has been performed, and shows promising results. The findings from this paper would be of interest to companies such as IBM. There is a difficulty getting real industrial data but efforts are being made in this direction.

   (b) An abstract has been submitted for presentation as the Frontier of Services Conference to be held in Washington DC this October. Acceptance notification will be sent out early May.

(c) The group had also accepted an invitation to present the project at this year's INFORMS conference (again) in DC this October.

(d) One hope is that the presentations can lead the group to some data-holders that are interested in sharing their data.

The intention is to write up the paper and submit for publication in *Technometrics* or some similar journal.

As part of the data quest efforts, the group also outreached to various business providers to get them interested in their projects and eventually willing to contribute data. Some examples include IBM Europe and Genesys Labs of Alcatel-Lucent.

# 5 Other Activities

## 5.1 Courses

Two graduate courses were held at SAMSI associated with the Risk Program.

### 5.1.1 Fall Course

Course Title: *Decision Theory and Risk Analysis.* Instructors: Dipak Dey, University of Connecticut; Larry Brown, University of Pennsylvania; David Rios, Universidad Rey Juan Carlos.

Course Day and Time: Thursday 4:30 - 7:00, beginning August 30, 2007 Room 104 NISS Building

Short Course Description: Fundamental concepts for decision theory and use of expert opinion as applied to risk analysis. Exponential families: sufficiency, minimaxity, admissibility. Decision rules and risk: loss functions, convexity, risk analysis. Estimation, analysis and model selection: Minimax, shrinkage, Bayes, hierarchical Bayes, empirical Bayes, data and opinion as prior information.

### 5.1.2 Spring Course

Course Name: *Extremes and Case Studies in Risk Analysis.* Instructor: Pilar Muñoz.

This was taught as an Independent Study course.

## 5.2 JSM

The Risk program has organized three Topic Contributed Paper sessions at the 2008 Joint Statistical Meetings, sponsored by the ASA's Section on Risk Analysis.

Session 1: Bayesian Modeling of Extreme Events.

Organizer(s): Dipak Dey, University of Connecticut
Chair(s): Bani K. Mallick, Texas A&M University
Wednesday August 6 2008, 2:00-3:50 pm.

1. A Bayesian Framework For Adversarial Risk Analysis — Jesus Ríos, SAMSI; David Ríos, Universidad Rey Juan Carlos; David Banks, Duke University
2. Semiparametric Functional Estimation Using Quantile Based Prior Elicitation — Elijah Gaioni, University of Connecticut; Dipak Dey, University of Connecticut; Mircea Grigoriu, Cornell University
3. Bayesian Hierarchical Modeling For Extreme Values Observed Over Space And Time — Huiyan Sang, Duke University; Alan Gelfand, Duke University
4. Thresholding for Multivariate Extreme Values — Kobi A. Abayomi, Duke University
5. Bayesian Model Selection Of The Farlie-Gumbel-Morgenstern Copula For Describing Two Generalized Extreme Value Variables — Vered Madar, SAMSI

Session 2: Risk Analysis For Industry And The Environment

Organizer: Richard L. Smith, The University of North Carolina at Chapel Hill
Chair: Elizabeth C. Shamseldin, University of North Carolina
Sunday August 3 2008, 2:00-3:50 pm.

1. Quantifying Local Creation And Regional Transport Using A Hierarchical Space-Time Model Of Ozone As A Function Of Observed NOx, A Latent Voc Process, Emissions, And Meteorology — Amy J. Nail, North Carolina State University; John F. Monahan, North Carolina State University; Jacqueline Hughes-Oliver, North Carolina State University
2. An Analysis Of The Potential Impact Of Various Ozone Regulatory Standards — Rosalba Ignaccolo, Universita' degli Studi di Torino/SAMSI; Yongku Kim, Statistical and Applied Mathematical Sciences Institute; Bahjat Qaqish, University of North Carolina at Chapel Hill; Michela Cameletti, Universita' degli Studi di Bergamo/SAMSI; Richard L. Smith, The University of North Carolina at Chapel Hill
3. Multivariate Generalized Linear ARMA Processes: An Application To Hurricane Activity — Evangelos Evangelou, University of North Carolina; Richard L. Smith, The University of North Carolina at Chapel Hill; Amy Braverman, Jet Propulsion Laboratory
4. Probabilistic Risk Analysis For ICT Industry — Jose A. Rubio, Universidad Rey Juan Carlos; David Rios Insua, Universidad Rey Juan Carlos
5. Seismic Risk Analysis — Mircea Grigoriu, Cornell University

Session 3: The Samsi Program On Risk Analysis, Extreme Events, And Decision Theory

Organizer: Richard L. Smith, The University of North Carolina at Chapel Hill
Chair: Nell Sedransk, National Institute of Statistical Sciences
Tuesday August 5 2008, 10:30 am – 12:20 pm

1. Extreme Co-Movements And Extreme Impacts In High Frequency Data In Finance — Zhengjun Zhang, University of Wisconsin

2. Modelling multivariate extreme dependence — Xiao Qin, Beihang University; University of North Carolina; Richard L. Smith, The University of North Carolina at Chapel Hill; Ruoen Ren, Beihang University

3. Multivariate Analyses Of Extremes — Luis R. Pericchi, University of Puerto Rico, Rio Piedras; Beatriz Mendes, Universidade Federal de Rio de Janeiro; Scott Sisson, University New South Wales; Abel Rodriguez, University of California, Santa Clara

4. Downscaling Extremes: A Comparison Of Extreme Value Distributions In Point-Source And Gridded Precipitation Data — Elizabeth C. Shamseldin, University of North Carolina; Richard L. Smith, The University of North Carolina at Chapel Hill; Stephan Sain, National Center for Atmospheric Research; Dan Cooley, Colorado State University; Linda O. Mearns, National Center for Atmospheric Research

5. Hurricanes And Global Warming — Richard L. Smith, The University of North Carolina at Chapel Hill; Evangelos Evangelou, University of North Carolina; Gabriel A. Vecchi, Geophysical Fluid Dynamics Laboratory; Thomas R. Knutson, Geophysical Fluid Dynamics Laboratory

# 6 Education and Outreach

In this section we include individual reports from the postdoctoral fellows and graduate students supported by the SAMSI Risk program, and of the undergraduate workshop that was held in November 2007.

## 6.1 Guang Cheng (Postdoctoral Fellow, SAMSI and Duke)

Guang Cheng completed his postdoc in Summer 2008. He is now an assistant professor position in the Department of Statistics, Purdue University.

### 6.1.1 Completed Papers

1. Guang Cheng (2007) Semiparametric Additive Isotonic Regression (Under Revision)

2. Guang Cheng and Helen Zhang (2008), Efficient Estimation and Consistent Variable Selection for Partial Spline Models (under revision, to be submitted to *Annals of Statistics*).

3. Guang Cheng (2007), One-Step M-estimator for Semiparametric Models (In progress)

4. Guang Cheng, Yufeng Liu and Helen Zhang, (2008) Linear or Nonlinear Automatic Selection for Partial Linear Models (In Progress)

### 6.1.2 Other Activities

1. Invited talk about"Semiparametric Additive Isotonic Regression" in Nonparametric Conference 2007, Columbia, SC. Also to be presented at the JSM in August 2008.

2. I have begun research collaboration with Prof. Nicoleta Serban at Georgia Tech when she visited SAMSI in the fall semester of 2007. Our collaboration focuses on Hierarchical Functional Data Modelling.

3. I have also worked on the theoretical problem proposed by Prof. Richard Smith about multivariate extensions of the Ledford-Tawn approach. I hope to have some results by the summer of 2008.

## 6.2 Jesus Ríos (Postdoctoral Fellow)

### 6.2.1 Research interests

Risk analysis, Decision analysis, Negotiation analysis, Game Theory

### 6.2.2 PhD Program

University/Department: Rey Juan Carlos University (Spain), Department of Statistics and Operation Research

Dissertation Advisor: David Ríos

Year of Ph.D.: May 2006

### 6.2.3 SAMSI Research

SAMSI Research Mentor: David Ríos

### 6.2.4 Course(s) (fall and spring)

Decision theory and risk analysis

### 6.2.5 Workshops Attended (and Workshop Support Tasks)

1. Opening workshop;

2. Risk: Perception, policy and practice

3. EXTREMES: Events, Models and Mathematical Theory (poster presentation)

4. RISK Revisited: Progress and Challenges (talk presentation)

### 6.2.6 Special Tasks

Webmaster (September 2007 December 2007)

### 6.2.7 Talks and presentations

10/17/2007: Analyzing Adversarial Threats
Two-Day Undergraduate Workshop: November 9-10, 2007

1. Discovering Influence Diagrams with GeNIe: Decision analysis for risk management;
2. Discovering Game theoretic concepts with Gambit for adversarial risk analysis

### 6.2.8 Working Group I: Adversarial risk

Special Tasks for Working Group: webmaster
Presentations to Working Group: 10/11/2007: Modelling the others: Game theory Rationality vs. Bayesian approach
10/18/2007: Some adversarial risk models
10/25/2007: A possible alternative approach to adversarial risk analysis
11/15/2007: Asymmetric information in adversarial risk analysis
01/31/2008: Our framework for ARA: The assessment problem. Example: Bidding in a Auction
02/07/2008: Random games and the commutativity issue
02/21/2008: The Auction problem

### 6.2.9 Research Area and Plans

Application of game theory, risk analysis and portfolio theory to adversarial decision settings, like in terrorism, business competition... Emphasis on issues related with how to model adversarial dynamic decisions, external uncertainties and modeling adversaries behavior as well as on computational issues.

### 6.2.10 Research Progress Report and SAMSI Program Final Report

Research Project Title: Foundations of adversarial risk analysis, with David Banks, David Ríos
Review of ideas from game theory, decision analysis and probability risk analysis that have been applied in adversarial decision making. We propose an improved approach and illustrate it with examples in antiterrorism and corporate auction biddings
Research Contributions (publication submissions, articles in preparation, etc.):

1. Paper submitted to Group Decision and Negotiation journal: Balanced increments and concessions methods for arbitration and negotiations
2. Paper completed Adversarial risk analysis

Presentations outside SAMSI (including invitations for future talks):

1. Presentation scheduled at GDN 2008 in Coimbra in June 08

2. Presentation scheduled at JSM 2008 in Denver, Colorado in August 08

Research Project Title: Computations for adversarial risk analysis, with David Ríos

Specific Goals and Accomplishments (results): It project focuses in computational issues for finding nondominated solution in a collaborative framework (eg, two countries collaborating for managing risks by sharing resources to mitigate terrorist attacks or natural disasters), Nash equilibria in adversarial settings and prescriptive recommendations based on a Bayesian/Game theoretic analysis of adversarial actions (following our framework proposed in our first project)

Research Contributions (publication submissions, articles in preparation, etc.):

1. Paper submitted to Decision Analysis: Supporting group decisions over influence diagrams
2. Paper in preparation: Computations in adversarial risks (skeleton of the paper prepared, all required reading done)

#### 6.2.11 Future Research Plans (after completion of SAMSI Program)

I have a new appointment from April, 1st 2008 at Aalborg University (Denmark).

### 6.3 Vered Madar (Postdoctoral Fellow)

Dr. Madar graduated from Statistics and OR, Tel-Aviv University, Tel-Aviv, Israel, (PhD, 2007) working under Professor Yoav Benjamini. At SAMSI she has been working in the program on Risk Analysis, Extreme Events and Decision Theory, under the mentorship of Dipak Dey and Nell Sedransk.

#### 6.3.1 SAMSI Activities

- Attended Risk Analysis course (fall)
- Attended all SAMSI's 2007/08 workshops (fall and spring)
- Postdoc-Grad Student Seminar: Bayesian Modeling of Bivariate Extremes with Applications (Nov. 7).
- Poster at SAMSI Extremes Workshop (January 23)

#### 6.3.2 Undergraduate Workshop

Specifics to be added later

### 6.3.3 Bayes Risk Working Group

- Special Tasks for Working Group: Webmaster
- Presentation to Working Group: "Some Thoughts on Bayesian Modeling of Bivariate Extremes (Dec, 6)
- Research Area (1): Bayesian Model Selection for the Generalized FGM copula in the bivariate case when both marginal distributions are general extreme value.
- Research Area (2): Prior elicitation in the bivariate extreme value situation and some related modeling issues.

### 6.3.4 Multivariate Extremes (Methodology) Working Group

- Presentations to Working Group: "Introduction to Multiple Comparisons (Nov. 15)
- Planned Research: NonBayesian Copula Selection when both marginal distributions are general extreme value.

### 6.3.5 Other Research

Papers from Ph.D. Research (work in progress):

- The Variable-Ratio Simultaneous Confidence Intervals (self)
- The Quasi-Conventional Simultaneous Confidence Intervals for Better sign Determination (with Yoav Benjamini and Philip B Stark)
- The Quasi-Conventional Intervals Under Dependence (self)
- An inequality for multivariate normal probabilities of nonsymmetric rectangles.

Presentations of Other Research: UNC stat seminar, January 14: The Quasi-Conventional Simultaneous Confidence Intervals.

## 6.4 Sourish Das (Graduate Student)

Mr. Das is PhD Student, University of Connecticut, Department of Statistics, working under Dr. Dipak Dey. His expected completion date of PhD is Summer 2008. His mentor at SAMSI has been Dipak Dey.

### 6.4.1 Activities attended

- Opening Workshop (Sep 16–19, 2007)
- Workshop on Risk: Perception, Policy and Practice: October 3–4, 2007.

### 6.4.2 Presentations

- Postdoc-Grad Student Seminar: Hitchhikers Guide to Presentations
- Postdoc-Grad Student Seminar: Analysis of Hurricane Activity in West Pacific and Indian Ocean; 11/8/2007
- Undergraduate Workshop: Presented Analysis of Hurricane Activity
- Undergraduate Workshop: Helped Prof. Dey and Prof. R. Smith organizing the session on hands on experience. I gave them a data set on Hurricane Activity at Atlantic Ocean since 1851 to 2006. Students analyzes that data set using R.
- Graduate Fellow Presentation Poster (title and abstract to be added later)

### 6.4.3 Report on Research

The main area of research is Bayesian Extreme Value Theory.

I am developing Bayesian Method of analyzing extreme category in Multinomial-Dirichlet model, especially, in the context of the Hurricane data of Indian Ocean (southern hemisphere region) and Pacific Ocean (West pacific region). Here the storms are categorized into 5 category; where estimating the probability of rare category (that is category 5 hurricane) is challenging. This work will be a part of the 3rd chapter of my Ph.D. dissertation.

## 6.5 Elijah Gaioni (Graduate Student)

Elijah Gaioni is completing two papers that have come out of discussions that arose during the Bayes Risk working group meetings. Both papers address the problem of inadequate numerical data by incorporating quantile-based expert information into the statistical modeling framework. The first paper is a joint work with Mircea Grigoriu, Elijah and myself, entitled Semiparametric functional estimation using quantile based prior elicitation. The first draft of this paper has been completed, and it will be submitted to a peer-reviewed journal shortly. The second paper models river behavior where the emphasis is on the joint modeling of the extreme and non-extreme components of the process. This paper is nearly finished and will also be submitted to a peer-reviewed journal when it is completed later this semester.

(a) Semiparametric functional estimation using quantile based prior elicitation. (Dipak Dey, Mircea Grigoriu, Elijah Gaioni)

(b) Incorporating expert opinion into the joint modeling of extreme and non-extreme components of river flow. (Elijah Gaioni, Dipak Dey)

The extreme river flow work will continue to be sponsored by the Center for Environmental Statistics and Engineering through the current semester and possibly future semesters.

### 6.5.1 Report on Research

This report summarizes my activities and research related to the Bayes Risk group at SAMSI.

There are three main research projects Ive been involved in. The first has resulted in the paper entitled Semiparametric functional estimation using quantile based prior elicitation, which is a joint work with Mircea Grigoriu and Dipak Dey. The second, which is nearing completion and will also be written up as a paper, deals with extreme values in river flow phenomena. The third is an extension of this second paper to the multivariate case and is a work in progress. All papers will be submitted to peer-reviewed statistics journals for publication. Further, since these topics are highly interrelated each will contribute one chapter towards my Ph.D. thesis.

The first paper addresses the problem of incorporating vague prior information, as specified through a small number of quantiles, into marginal distribution estimation. An optimal prior distribution consistent with this information is sought in a semiparametric framework. The functional of interest may then be used for predictive purposes. In order to overcome computational difficulties an innovative means of nonparametrically representing the prior distribution is employed. The statistical software package R is being used to implement this methodology.

The second avenue of research mentioned pertains to the study of extreme river flow events. These events were modeled as mixtures of gamma and extreme value distributions in a Bayesian framework. Both the extreme and non-extreme components of such processes were jointly modeled. The decision to tackle this particular problem arose out of a working group discussion held shortly after the Risk Analysis, Extreme Events and Decision Theory program. In particular, we explore flash flooding in Texas using response and covariate information obtained from the United States Geological Survey (USGS) website. The covariates are introduced through a generalized linear model and serve to enhance the predictive capacity of the model.

Preliminary results for both of the first two papers mentioned above have already been presented at numerous working group meetings, and during SAMSIs graduate student seminar, and at the University of Connecticut student seminar. Talks at the New England Statistics Symposium, INAR, and JSM are also planned.

Much of the mathematics for the third paper, which deals with the multivariate extension of the case mentioned above, has already been completed. The correlation structure between the different multivariate responses is introduced through the mixing parameters, and it naturally accommodates responses that are measured on different scales. The implementation details have yet to be completed, though they will build on the R code used for the univariate version.

In addition to the presentations mentioned above, I participated in an undergraduate workshop. During this workshop on November 9th I gave a presentation covering some of the basic statistical elements that could be incorporated into an analysis of the extreme component of river flow. Subsequently, an interactive session was conducted during which undergraduate students applied what they had learned using the extRemes package in R. At the end of the one-day workshop, the graduate and undergraduate students spoke over dinner about possible careers in the mathematical sciences.

As I continue my studies at the University of Connecticut, support for the second and third papers mentioned above will be provided by the Center for Environmental Statistics and Engineering. Weekly meetings through WebEx provide the basis for continued joint collaboration.

### 6.6 Evangelos Evangelou (Graduate Student)

I participated in the "Risk Analysis, Extreme Events and Decision Theory Program at SAMSI as a graduate fellow. Being a graduate student, I am still in the process of learning and familiarizing myself with new research ideas and topics, and my involvement in the program has greatly contributed towards expanding my research horizons. The courses offered, the seminars and the working groups at SAMSI have had a significant impact to my research.

My course work at SAMSI included two courses, one in each semester. The first course introduced us into new issues such as prior elicitation and adversarial risk. The latter constituted the topic of my class project. Under the guidance of Dr. Ríos Insua, I developed an idea for modeling actions that result to random payoff. A classic example is a terrorist attack where the government is placing resources to defend its region while the terrorist chooses an action for attacking. In my project, I suggested modeling the loss as a beta distributed random variable times a constant and then look at the expected loss. For the second course, I focused on modeling financial time series. I worked together with Dr. Munoz on modeling five stocks from the European market. For these series, we found that the models that fit best are GARCH or E-GARCH with t distributed errors.

My contribution to the working groups consisted in participating in discussions and holding two presentations. In the "Multivariate Extremes  Applications working group I presented the earlier mentioned financial time series project. I also participated in the "Multivariate extremes Methodology working group where I presented a paper for analyzing time series data following the Poisson distribution. This paper was proposed by Dr. Smith as a method to be used to analyze hurricane occurrences in the Atlantic and investigate the correlation with sea surface temperature; his idea was to analyze the two variables as a bivariate time series to remove the autocorrelation and then test for correlation between them.

During the SAMSI undergraduate workshops, I had the opportunity to provide students with an introduction to the methodology for extreme value analysis. At the same time, I guided students in the use of computer software in the practice session. During breaks I had the opportunity to talk to them and answer their questions regarding graduate studies.

Among other activities, I also attended the SAMSI seminars, where I became familiar with typical extreme value analysis topics such as modeling the dependence on extreme values for different variables and estimation of the parameters of M4 processes. Overall, these seminars have nurtured and greatly expanded my interest and knowledge in extreme value theory, both at a theoretical and practical level.

## 6.7 Xiaoyan Lin (graduate student)

Xiaoyan Lin is a graduate student from the University of Missouri, Columbia, who is visiting SAMSI from February to May. Following is a report of her current research.

The idea is to get reference prior under partial invariance structure and to prove the reached prior at least has a proper posterior.

### Reference priors under partial invariance structure

*Theorem*

Suppose $(\boldsymbol{\theta}, \boldsymbol{\xi})$ is the parameter, where

- a component of $\boldsymbol{\theta}$ is the parameter of interest;
- for each fixed $\boldsymbol{\xi}$, $p(\boldsymbol{x} \mid \boldsymbol{\theta}, \boldsymbol{\xi})$ has the same group invariance structure with the reference prior being the right-Haar prior $\pi^{RH}(\boldsymbol{\theta})$;
- natural compact sets are of the form $\Theta_c \times \Xi_c$,

the reference prior is then

$$\pi(\boldsymbol{\theta}, \boldsymbol{\xi}) = \pi^{RH}(\boldsymbol{\theta})\pi^{R}(\boldsymbol{\xi} \mid \boldsymbol{\theta}_0),$$

where $\pi^{R}(\boldsymbol{\xi} \mid \boldsymbol{\theta}_0)$ is the conditional reference prior given some fixed $\boldsymbol{\theta}_0$; this will not depend on the chosen value of $\boldsymbol{\theta}_0$.

As a special case, consider a family of densities,

$$p(x \mid \mu, \sigma, \boldsymbol{\xi}) = \frac{1}{\sigma} g\left(\frac{x-\mu}{\sigma}, \boldsymbol{\xi}\right), x \geq \mu, \tag{1}$$

where $\sigma > 0$ and $\boldsymbol{\xi} \in \Xi \subset \mathbb{R}^k$. Here $\mu$ is a location parameter and $\sigma$ is a scale parameter. $g$ is a known density depending on $\boldsymbol{\xi}$ only. Suppose we are interested in $\boldsymbol{\theta} = (\mu, \sigma)$. The right haar prior for $\boldsymbol{\theta}$ is

$$\pi^{RH}(\mu, \sigma) \propto \frac{1}{\sigma}.$$

It is easy to see that the reference prior $\pi^{R}(\boldsymbol{\xi}) = \pi^{R}(\boldsymbol{\xi} \mid \boldsymbol{\theta}_0)$ for $\boldsymbol{\xi}$ can be derived from the model $\{g(y, \boldsymbol{\xi}), \boldsymbol{\xi} \in \boldsymbol{\Xi}\}$. Obviously, the generalized Pareto distribution and the generalized extreme value distribution belong to the family.

### Current Results

1. The three parameter Pareto distribution

$$f(x \mid \mu, \sigma, \xi) = \frac{1}{\sigma}\left(1 + \xi\frac{x-\mu}{\sigma}\right)^{-1-\frac{1}{\xi}}, \tag{2}$$

where the support is $x \in (\mu, \infty)$, if $\xi \geq 0$, and $x \in (\mu, \mu - \frac{\sigma}{\xi})$, if $\xi < 0$.

- when $\xi > -1/2$, the derived reference prior is

$$\pi(\mu, \sigma, \xi) \propto \sigma^{-1}[(1+\xi)(1+2\xi)]^{-1/2}.$$

  Note that it is different from the Jeffreys prior

$$\pi(\sigma, \xi) \propto \sigma^{-1}(1+\xi)^{-1}(1+2\xi)^{-1/2}$$

  in Castellanos & Cabras (2007). To ensure the valid inference using these two priors, the posterior propriety is required. In Castellanos & Cabras (2007), they have proved that using the Jeffreys prior will lead to a proper posterior. However, there seems a mistake (?) in their proof.

- when $\xi < -1/2$, there's no fisher information. Following the general formal definition, we derived that the reference prior for the standardized generalized Pareto distribution is $-1/\xi$. However, the numerical reference prior seems quite different when $\xi$ goes to $-\infty$. Therefore, I need to check the prior derivation carefully later to see if there's any mistake.

2. The three parameter generalized extreme value distribution has CDF

$$F(y) = \exp\left[ -\{1 - \frac{\xi(y-\mu)}{\sigma}\}^{1/\xi} \right] \tag{3}$$

   where the support is $x \in (-\infty, \mu + \sigma/\xi)$, if $\xi \geq 0$, and $x \in (\mu + \sigma/\xi, \infty)$, if $\xi < 0$.

   - When $\xi < 1/2$, the Jeffreys prior for the standardized GEV is

$$\pi(\xi) \propto \sqrt{\frac{1}{\xi^2}\left\{ \frac{\pi^2}{6} + (1 - \gamma - \frac{1}{\xi})^2 + \frac{2q}{\xi} + \frac{p}{\xi^2} \right\}},$$

     where $p = (1-\xi)^2\Gamma(1-2\xi)$, $q = \Gamma(2-\xi)\{\psi(1-\xi) - (1-\xi)/\xi\}$, $\gamma = 0.5772157$ is Euler's constant, $\Gamma(r)$ is the gamma function and $\psi(r) = d\log\Gamma(r)/dr$.

   - When $\xi > 1/2$, there's no fisher information. At current stage, I only have some numerical reference prior. In future, the theoretical reference prior will be explored.

3. The three parameter Weibull $(\mu, \eta, \beta)$ distribution with the density

$$p(x \mid \mu, \eta, \beta) = \frac{\beta(x-\mu)^{\beta-1}}{\eta^\beta} \exp\left( -\frac{(x-\mu)^\beta}{\eta^\beta} \right), \quad x > \mu. \tag{4}$$

Under the partial invariance rule, the reference prior

$$\pi(\mu, \eta, \beta) \propto \frac{1}{\eta\beta}.$$

For the two parameter Weibull when $\mu$ is known, the reference prior is again

$$\pi(\eta, \beta) \propto \frac{1}{\eta\beta}.$$

I have proved that when not all of $x_i$'s are equal, the posterior distribution of $(\eta, \beta)$ are proper for the two parameter Weibull distribution. In future, I will explore the posterior propriety for the three parameter Weibull using the prior $1/(\eta\beta)$.

### 6.8 Undergraduate Workshop

A two-day undergraduate workshop, organized around the themes of the Risk program, was held at SAMSI, November 9–10 2007. Presentations were delivered by:

1. Richard Smith — Statistics of extremes: Assessing the probabilities of very rare events
2. Elaine Spiller — Models of volcano avalanches: Constructing a risk map for pyroclastic flows
3. Interactive student session on extreme value modeling. Led by Evangelos Evangelou and Guang Cheng.
4. Dipak Dey — Bayesian modeling geared towards extreme events
5. Huiyan Sang — Hierarchical Bayesian modeling of extreme precipitation
6. Sourish Das — Analysis of hurricane data
7. Elijah Gaioni — Modeling river flow data and floods
8. Interactive student session, led by Jayanta Pal and Vered Madar
9. Ralph Smith — Discussion of Graduate School and Career Options
10. David Banks — Game theory and risk analysis: A smallpox application
11. Jesus Ríos, Betsy Enstrom, and Matt Heaton — Discovering game theoretic concepts useful for risk analysis
12. Jesus Ríos, Betsy Enstrom, and Matt Heaton — Discovering influence diagrams with Genie: Decision analysis and risk analysis
13. Mike Porter — Intelligent site selection models for asymmetric threat prediction and decision making