ES13: Computer models and statistical methods in Earth sciences

Conveners: Gwenn Flowers[1], and Derek Bingham[2]

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Session Description

Complex computer models are increasingly used to understand geophysical processes, in many cases replacing experiments or enabling experiments that are physically or logistically impossible. Increases in computing power have made computational tools widely applicable to large-scale problems in Earth and environmental sciences, while developments in uncertainty quantification and computer model calibration, validation and prediction have begun to target these applications. This session is intended to bring together statisticians interested in Earth, ocean and atmospheric sciences with geoscientists of all stripes interested in using computational models and physical data to make inferences about complex systems. We invite contributions that focus on (1) using computational models and physical data for parameter estimation and prediction in complex systems within Earth sciences; (2) quantifying uncertainty in projections made from geophysical models; (3) inference for multi-model ensembles; (4) geophysical problems that require or lend themselves to statistical/computational methods and (5) emergent research at the intersection of statistics and Earth sciences.

Primary Affiliation: Earth Surface Processes / Geophysics

NOTE: THIS DOCUMENT CONTAINS INFORMATION FOR ALL SESSION SUB-SECTIONS. PRESENTER ABSTRACTS ARE FOUND AT THE END OF THE DOCUMENT.

SCHEDULE MAY BE SUBJECT TO CHANGE.

ORAL SESSION ES13a

Chairs: G. Flowers and D. Bingham **Room: GEOG 100**

Wednesday, May 31st

TIME	AUTHORS	TITLE
9:00	Ofir Harari, Nadya Moisseeva, Rachel M. Altman, Douw Steyn and William J. Welch	Statistical Modelling of Seasonal Patterns and the Effect of the Oceanic Niño Index on Rainfall in the Nicoya Pensinsula, Costa Rica
9:15	Matthew Pratola and Ying Sun	A Comparison of Approximate Bayesian Computation and Stochastic Calibration for Spatio-Temporal Models of High-Frequency Rainfall Patterns
9:30	Sonja Surjanovic*, Derek Bingham, and Gwenn Flowers	Using computer model uncertainty to determine optimal design of mass-balance stake networks
9:45	Sam Pimentel, Simon Tse, Andrea Storto, Gerasimos Korres, Dimitra Denaxa, Eric Jansen, and Isabelle Mirouze	A statistical-dynamical operator for assimilating sea surface temperature observations in ocean models
10:00	Thomas J. Aubry* and A. Mark Jellinek	Parameterization of entrainment and condensation in an integral model of volcanic plume
10:15	Jordan Aaron*, Scott McDougall, and Natalia Nolde	A Methodology for Probabilistic Prediction of Rock Avalanche Motion Using a Numerical Runout Model

POSTER SESSION ES13

Chairs: G. Flowers and D. Bingham **Room: ESB Atrium**

Wednesday, May 31st

Poster No.	AUTHORS	TITLE
P01-ES13	Matthew T. Pratola, Ofir Harari, Derek Bingham and Gwenn Flowers	Design and Analysis of Experiments on Non-Convex Regions, with Application to Glacier Mass-Balance Estimation
P02-ES13	Valentina Radic, Kathi Unglert, and Mark Jellinek	Machine Learning Method for Pattern Recognition in Volcano Seismic Spectra
P03-ES13	Scott McDougall, Nafis Jalil, Jordan Aaron, Andrew Mitchell, John Whittall, Damian McClarty and Marc-André Brideau	Development of an online database and empirical hazard mapping tool for rock avalanche runout estimation

P04-ES13	Hossein Foroozand* and Steven V. Weijs	Hydrologic Forecasting in Mountain Basin Using Ensembles of ANN and BNN Models: A Case Study of Kashkan River Basin
P05-ES13	John Lindsay, Wanhong Yang, Duncan D. Hornby	Drainage network analysis of topologically noisy vector stream data using a priority-flood algorithm
P06-ES13	Kathryn De Rego*, J. Wes Lauer, Brett Eaton and Marwan Hassan	Numerical modeling of channel width change and migration on decadal timescales

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SUBMITTED ABSTRACTS

ES13-01 Statistical Modelling of Seasonal Patterns and the Effect of the Oceanic Niño Index on Rainfall in the Nicoya Pensinsula, Costa Rica

Ofir Harari[1], Nadya Moisseeva[2], Rachel M. Altman[3], Douw Steyn[2],
and William J. Welch[4]

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Abstract
Monthly rainfall data collected over a 25-year period at two stations in the Nicoya peninsula of Costa Rica are modelled. The data exhibit strong seasonal effects, with an extremely dry season from roughly December to March. There are two peak-rainfall periods per year, centered around May and September, punctuated by a mild mid-summer drought. The intra- and inter-annual variation in the high-rainfall periods is critical for water management. Quantifying the variation is one focus of the FuturAgua research project (www.futuragua.ca), which is directed towards understanding water availability, use and governance in the Nicoya peninsula and the implications for agriculture, electricity generation and tourism. Within that context the study presented here models the intra- and inter-annual variation in rainfall. A log-normal model for monthly rainfall treats the pattern of the two peaks via two Gaussian-shaped basis functions, with magnitudes, locations, and spreads of the basis functions estimated from the data record. Moreover, the model allows the magnitude of each peak to depend on the Oceanic Niño Index (ONI). The nonlinear model is fit using Bayesian Markov Chain Monte Carlo. Of particular interest in the study's findings is the establishment of statistically and practically significant effects of ONI. Negative or positive values of ONI are associated with a substantial increase or decrease, respectively, in mean rainfall for both peaks. The advantages and disadvantages of alternative statistical models will also be reviewed briefly.

Presentation type: Oral Presentation

ES13-02 A Comparison of Approximate Bayesian Computation and Stochastic Calibration for Spatio-Temporal Models of High-Frequency Rainfall Patterns

Matthew Pratola[1] and Ying Sun[2]

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Abstract
Modeling complex environmental phenomena such as rainfall patterns has proven challenging due to the difficulty in capturing heavy-tailed behavior, such as extreme weather, in a meaningful way. Recently, a novel approach to this task has taken the form of so-called stochastic weather generators, which use statistical formulations to emulate the distributional patterns of an environmental process. However, while sampling from such models is usually feasible, they typically do not possess closed-form likelihood functions, rendering the usual approaches to model fitting infeasible. Furthermore, some of these stochastic weather generators are now becoming so complex that even simulating from them can be computationally expensive. We propose and compare two approaches to fitting computationally expensive stochastic weather generators motivated by Approximate Bayesian Computation and Stochastic Simulator Calibration methodologies. The methods are then demonstrated by estimating important parameters of a recent stochastic weather generator model applied to rainfall data from the continental USA. [149 words]

Presentation type: Oral Presentation

ES13-03 Using computer model uncertainty to determine optimal design of mass-balance stake networks

Sonja Surjanovic[1*], Derek Bingham[2], and Gwenn Flowers[3]

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Abstract
Computer models are used as surrogates for physical experiments in many areas of science. They can allow the researchers to gain a better understanding of the processes of interest, in situations where it would be overly costly or time-consuming to obtain sufficient physical data. In this project, we give an approach for using a computer model to obtain designs for a physical experiment. The designs are optimal for modelling the spatial distribution of the response across the region of interest. An additional consideration is the presence of several tuning parameters to the computer model, which represent physical aspects of the process but whose values are not precisely known. In obtaining the optimal designs, we account for this uncertainty in the parameters governing the system. The project is motivated by an application in glaciology, where computer models are often used to model the melt of snow and ice across a glacier surface. The methodology is applied to obtain optimal networks of stakes, which researchers use to obtain measurements of summer mass balance (the difference between the amount of snow/ice before and after the melt season).

Presentation type: Oral Presentation

ES13-04 A statistical-dynamical operator for assimilating sea surface temperature observations in ocean models

Sam Pimentel[1], Simon Tse[1], Andrea Storto[2], Gerasimos Korres[3], Dimitra Denaxa[3], Eric Jansen[2], and Isabelle Mirouze[2]

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Abstract
The diurnal cycle of sea surface temperature (SST) is a fundamental signal of the climate system. Although vertical resolution in ocean general circulation models (OGCM) has been reduced to about a metre at the near surface most models do not properly resolve near-surface thermo-dynamical processes. In low wind and/or high insolation conditions the diurnal cycle in skin SST can be large, thus degrading the accuracy of the ocean surface analysis and prediction. Furthermore, this also presents challenges in assimilating satellite SST observations because infrared sensors (e.g. AVHRR, SEVIRI) measure the skin SST (10 μm depth) and microwave sensors (e.g. AMSR-2) measure a sub-skin temperature (1 mm depth). There is therefore a need for a dynamically-based observation operator for the assimilation of SST observations that can account for near-surface thermo-dynamical processes. In this paper an ocean column model that explicitly resolves the diurnal cycle of SST is used to estimate diurnal variability in SST over the Mediterranean Sea for 2013-2015. The modelled diurnal SSTs are validated against SEVIRI measurements. A canonical correlation analysis (CCA), which examines cross correlations between two datasets, is presented. Here we cross correlate high resolution profile data from the ocean column model with satellite skin SST measurements. The CCA is calculated in various categories of meteorological conditions. This analysis is then used to derive a statistical-dynamical observation operator. The operator can be used for assimilating SST observations, at appropriate depth and time, and is designed to be easily implemented in any OGCM data assimilation system. This approach to constructing the dynamically-based statistical observation operator may be applicable to wider applications in the Earth Sciences where poorly represented small scale thermo-dynamical processes have a large impact on relationships between observations and state quantities. [285 words]

Presentation type: Oral Presentation

ES13-05 Parameterization of entrainment and condensation in an integral model of volcanic plume

Thomas J. Aubry[1*] and A. Mark Jellinek[1]

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Abstract
Integral model of volcanic plume are widely used, in particular in case of volcanic crisis, because they are simple and fast tools. However, in these models, the turbulent entrainment of atmosphere into the plume and the condensation of entrained water vapor must be parameterized. To evaluate existing parameterizations, most studies test how a model reproduce the height of the volcanic plume from the eruption source conditions. However, no study encompass all of the following criteria to our knowledge: i) using observational data with plume height and eruption source conditions independently constrained ii) using observational data with eruptions spanning the entire regime parameter space in which explosive eruption occur (e.g. strong and weak wind, or low and large source Richardson number) iii) accounting for the influence of atmospheric conditions iv) accounting for large uncertainties in observational data v) testing several parameterizations. In this study, we compile a database of 94 eruptive phases for which we estimated eruptive parameters values (e.g. mass eruption rate) and the associated uncertainty. Syneruptive atmospheric conditions are retrieved from the NCEP-NCAR reanalysis. Using a Monte Carlo approach, we evaluate the best set of entrainment and condensation parameters for four different parameterizations, and compare the performance of each of them. Our work is a critical step in providing guidance on the best integral plume model to use, and place constraints on each entrainment or condensation parameter and the associated uncertainty. Critically, the hypothesis that wetter atmosphere results in higher volcanic plume height is rigorously tested for the first time. We will expand our database with the total grain size distribution for each eruption, and test parameterization of particles sedimentation which is ignored in this study.
[277 words]

Presentation type: Oral Presentation

ES12-06 A Methodology for Probabilistic Prediction of Rock Avalanche Motion Using a Numerical Runout Model

Jordan Aaron[1*], Scott McDougall[1], and Natalia Nolde[2]

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Abstract
Rock avalanches are extremely rapid, flow-like landslides that can travel long distances at high velocities. Managing the risk posed by this natural hazard requires a methodology to predict the motion of rock avalanches before they occur. There are many sources of uncertainty when predicting rock avalanche motion, so forecasting must be performed in a probabilistic context. Rock avalanche motion can be simulated using numerical models. One numerical modelling approach, termed the 'equivalent fluid approach', replaces the complex and heterogeneous rock avalanche material with a simple fluid whose behavior is governed by internal and basal rheologies. The simulated behavior of the rock avalanche is then controlled by the parameters that govern the basal rheology, which are constrained through back-analysis of case histories. This work details the preliminary results of a methodology to determine a joint probability density function for the parameters that govern simulations of rock avalanche motion. A database of 24 rock avalanche case histories has been assembled and analysed. The results of this work show that, for a given case history, parameter values are non-unique, and dependent on the path materials that the rock avalanche encounters. Combining back-analysis results in order to make probabilistic predictions of rock avalanche motion requires consideration of these sources of uncertainty. The output from this procedure allows users to make probabilistic hazard maps, a necessary step in quantitative risk analysis. [226 words]

Presentation type: Oral Presentation

ES12-07 Design and Analysis of Experiments on Non-Convex Regions, with Application to Glacier Mass-Balance Estimation

Matthew T. Pratola[1], Ofir Harari[2], Derek Bingham[3] and Gwenn Flowers[4]

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Abstract
Modeling a response over a non-convex design region is a common problem in diverse areas such as engineering and geophysics. The tools available to model and design for such responses are limited and have received little attention. We propose a new method for selecting design points over non-convex regions that is based on the application of multidimensional scaling to the geodesic distance. Optimal designs for prediction are described, with special emphasis on Gaussian process models, followed by a simulation study and an application in glaciology.

Presentation type: Poster

ES13-08 Machine Learning Method for Pattern Recognition in Volcano Seismic Spectra

Valentina Radic[1], Kathi Unglert[1], and Mark Jellinek[1]

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Abstract
A common approach to analyzing the temporal evolution of volcano seismicity is the visual inspection of spectrograms. However, manual identification of characteristic spatiotemporal patterns is practically cumbersome and inherently subjective. This led to the use of statistical and machine learning methods , such as Self-Organizing Maps (SOM), Principal Component Analysis (PCA) and clustering, to provide quick and objective identification of spectral patterns related to impending eruptions. In this study we develop and evaluate an algorithm applied on a synthetic volcano seismic spectra generated from the observed spectra from Kılauea Volcano, Hawai`i. Our goal is to retrieve a set of known spectral patterns that are associated with dominant phases of volcanic tremor before, during, and after periods of volcanic unrest. The algorithm is based on training a SOM to identify the most characteristic patterns to which a PCA is then applied to identify an optimal set of patterns (dimensions) that represent the essence of the whole spectrogram. Our results show that, regardless of the level of white noise in the spectra, the algorithm can accurately reproduce the characteristic spectral patterns and their occurrence in time. The ability to rapidly classify spectra of volcano seismic data without prior knowledge of the character of the seismicity at a given volcanic system holds great potential for real time or near-real time applications, and thus ultimately for eruption forecasting.

Presentation type: Poster

ES12-09 Development of an online database and empirical hazard mapping tool for rock avalanche runout estimation

Scott McDougall[1], Nafis Jalil[1], Jordan Aaron[1], Andrew Mitchell[2], John Whittall[2], Damian McClarty[2] and Marc-André Brideau[2]

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Abstract
Rock avalanches are low frequency, high magnitude landslides. They are important geohazards to consider in mountainous terrain because they can travel long distances and cause complete destruction across very large areas. Rock-avalanche runout can be estimated using methods ranging from mechanistic-deterministic to empirical-probabilistic models. The remarkable mobility of rock avalanches has been studied for well over a century, however, much scientific debate still surrounds the possible mechanisms contributing to their long-runout behaviour. This limitation increases the value of empirical approaches. Landslide mobility is often characterized using an empirical parameter known as the 'fahrböschung angle', defined as the inclination (from horizontal) of the line connecting the crest of the landslide source area with the distal toe of the deposit. Several workers who have compiled case history data have shown that there is a general inverse correlation between rock avalanche volume and fahrböschung angle. Regression analyses can be carried out on volume-fahrböschung angle data to establish prediction confidence limits that are useful for rapid, probabilistic estimates of rock avalanche runout as part of screening-level hazard or risk assessments. In the present study, several previously-published rock avalanche datasets have been combined and supplemented with new data compiled from 46 previously-published Canadian events. Additional geological and landslide attributes have also been gathered for each case in the datasets, with the goal of identifying sub-trends that may help improve the quality of runout estimates, as well as our understanding of fundamental long-runout mechanisms. Work is in progress to make all of the data freely available in an open access online database. A web-based hazard mapping tool linked to the database, which produces runout exceedance probability isolines for a given rock avalanche volume and crest location, is also currently at an advanced stage of development. [289 words]

Presentation type: Poster

ES13-10 Hydrologic Forecasting in Mountain Basin Using Ensembles of ANN and BNN Models: A Case Study of Kashkan River Basin

Hossein Foroozand[1*] and Steven V. Weijs[2]

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Abstract
Water is a highly complex resource. Water moves in a strongly dynamic cycle of precipitation, runoff, and evaporation, with extreme temporal and spatial variations that completely govern its value to people and ecosystems. Moreover, the impact of climate change and its associated uncertainties has highlighted the role of the hydrological model on accurate prediction of flow hydrograph. Particularly in mountain hydrology, there are more complexity and uncertainty in the system due to the inherent rapid changes in temperature and elevation which are hard to capture. Therefore, it is necessary to identify and use an appropriate tool for monitoring the amount of rainfall and runoff using the measurement of scarce stations and exact interpolation of provided information. One of the characteristics of the neural networks is that they provide a computational or mathematical technique which is powerful for modeling systems where the explicit form of the relationship between the variables involved is unknown. Thus, it theoretically suits the problem of relating rainfall to a runoff since it is a highly nonlinear and complex problem. In this study, various Artificial Neural Networks (ANN) and Bayesian Neural Networks (BNN) models are developed to forecast the streamflow in Kashkan river basin. The results are analyzed to study the performance of different ensembles of ANN and BNN models on their accuracy in prediction and computational time.

Presentation type: Poster

ES12-11 Drainage network analysis of topologically noisy vector stream data using a priority-flood algorithm

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Abstract
Drainage network analysis includes several common operations that quantify the topological organization of streams. Stream ordering operations are a common example applied in fluvial geomorphology, hydrology, and ecology. Network analysis operations are frequently performed on stream networks that are derived from digital elevation models (DEMs). While these methods are satisfactory for application with fine-resolution DEM data, they are not well suited to application with coarse-resolution DEMs or in low-relief landscapes and at large geographical extents. In these cases, drainage network analysis based on mapped vector stream data is a better approach. This study presents a novel vector network analysis technique for performing stream ordering, basin tagging, identification of main stems and tributaries, and the calculation of total upstream channel length and distance to outlet. The algorithm uses a method for identifying outlets and determining the flow directions within vector stream networks using a priority-flood method. The approach can handle topological errors in the input hydrography that have challenged previous methods, including disjoint links, conjoined channel heads, and heterogeneity in the upstream-to-downstream digitized direction of links. The new algorithm was applied to test vector stream datasets of two extensive study areas within Southern Ontario and New Brunswick, Canada. The tests demonstrated that the new algorithm can efficiently process very large hydrographic layers. While robust against many of the topological conditions that challenge other methods, the new method experiences issues with disconnected streams, which can manifest in an edge effect. The method can provide a good alternative to DEM-based approaches to drainage network analysis in certain application areas, particularly when stream burning would otherwise be necessary to enhance the DEM representation of streams. [271 words]

Presentation type: Poster

ES13-12 Numerical modeling of channel width change and migration on decadal timescales

Kathryn De Rego[1*], J. Wes Lauer[2], Brett Eaton[1] and Marwan Hassan[1]
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Abstract
One of the primary ways that river systems respond to short and long-term variations in flow and sediment supply is through an adjustment in channel width. Increases in shear stress on banks caused by flood flows and changes in channel shape lead to widening via bank erosion. Narrowing occurs following deposition on channel margins and vegetation growth on exposed surfaces. These width adjustments lead to the exchange of sediment between channels and floodplains which, over long timescales, are expressed as river migration. Few numerical models exist that treat widening and narrowing as separate processes and are practical to use on decadal timescales. Consequently, it is common practice among river modelers to assume that channel width remains constant over time, even when the floodplain may be an important source and sink of sediment. We have adapted a one-dimensional bed evolution model to account for width change using separate functions for channel widening and narrowing. The model was applied to two sets of reaches along the Elwha River near Port Angeles, Washington. The first was affected by the construction and later removal of two hydroelectric dams. The second is not significantly affected by anthropogenic disturbance and acts as a ‘control’ section. Dam emplacement led to channel narrowing along with a coarsening of the bed texture. The dammed set of reaches experienced less than half the bank erosion of the control reach, despite having a 20% larger discharge. Even so, in the alluvial reaches just downstream of the dam, floodplain sediment accounted for most of the supply in this sediment-starved system. Following dam removal, migration increased significantly. About a quarter of the bed material sediment entering the study area was sourced from the floodplain. This study reveals that channel banks constitute important sources of sediment and should be considered in decadal-scale modeling projects. [300 words]

Presentation type: Poster