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RESEARCH CONFERENCES

ESF-COST High-Level Research Conference

Extreme Environmental Events

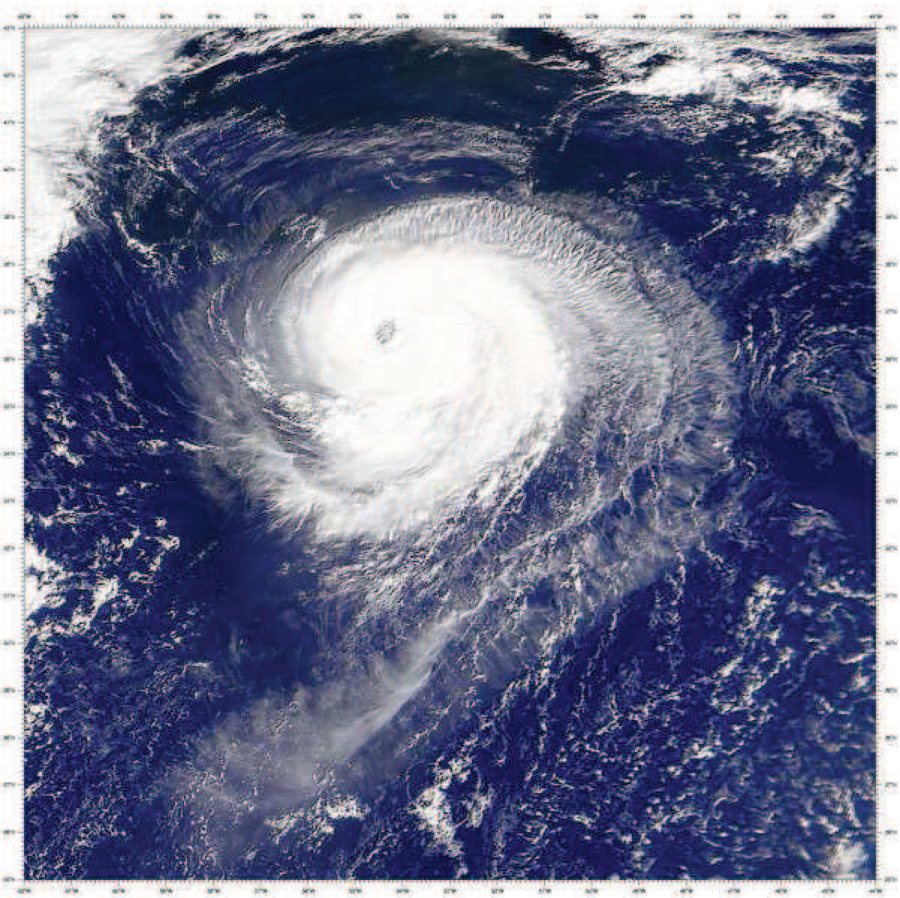
Selwyn College• Cambridge • United Kingdom

13 - 17 December 2010

Chair: **Dr. Andrew Parnell**, School of Mathematical Sciences, University College Dublin, IE

www.esf.org/conferences/10345

Highlights & Scientific Report



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Conference Highlights

Please provide a brief summary of the conference and its highlights in non-specialist terms (especially for highly technical subjects) for communication and publicity purposes. (ca. 400-500 words)

The recent European Science Foundation High-Level research conference on Extreme Environmental Events brought together a diverse group of scientists interested in understanding the causes and effects of extreme events. The conference was organised by statisticians, for whom the study of extremes is underpinned by decades of research into their properties and effects. The mathematical basis allows us to make predictions as to how often extreme events might occur, and their likely magnitude when they do.

There were 3 main groups present at the conference: statisticians, as mentioned above; climatologists/meteorologists, interested in the behaviour of weather systems; and biologists/ecologists, looking at the behaviour of ecosystems when exposed to extremes. Each of the groups presented the latest findings in their field with the goal of linking together the different disciplines to improve our understanding of extremes.

The theory behind extreme events and their prediction is an especially complicated aspect of mathematical research. For this reason, many scientists work on simple data sets containing only a single extreme value at a single site (for example, maximum daily temperature in London). The statisticians present at the meeting showed the latest methods available for measuring multiple extremes (for example maximum daily temperature and precipitation level) whilst simultaneously monitoring many different locations. Other methods were shown which allow for estimating increases in the number of extreme events over time. These methods are starting to appear in software packages and so are available for use by other scientists.

The climatologists and meteorologists at the meeting are concerned with using weather and climate models to predict the occurrence and long-term trend in extreme weather events such as hurricanes and droughts. The climatologists present showed how the increase in greenhouse gas concentrations might contribute to the number of extreme events at a global scale. The effect was shown to be particularly strong in extremes of temperature and rainfall over the Alps as we move towards the end of the 21st century. The meteorologists present showed how the interaction between land and atmosphere gave rise to many severe weather events, as well as several techniques for using large-scale weather models to provide more local estimates of extreme weather behaviour.

The biologists and the ecologists at the meeting presented a number of large-scale experiments on plant behaviour when exposed to various extremes of heat and moisture. Their key finding was that extremes of heat must be accompanied by dry periods in order to cause lasting damage to ecosystems. The timing of such extremes is also important: occurring earlier in the growing season has a longer-term damaging effect. Other research showed the long-term impacts of previous severe winters and dry summers in the UK, and the relationship between biodiversity and recovery times for ecosystems exposed to such extremes.

The conference was particularly memorable for the severity and impact of extreme events on human and animal populations throughout recent history. A number of insightful talks contained videos and photos of the severe effects of short-term extreme changes in air pressure, precipitation, plate tectonics, volcanic behaviour and many others. However, such extremes are dwarfed by those that have happened in earth's longer-term history or in the Universe at large.

☐ I hereby authorize ESF – and the conference partners to use the information contained in the above section on ‘Conference Highlights’ in their communication on the scheme.

Scientific Report

Executive Summary

(2 pages max)

The aim of the Extreme Environmental Events conference was to bridge scientific disciplines all linked via the theme of uncertainty and extremes. At present, a number of scientists use out-dated and inappropriate statistical methods to analyse large and important data sets in order to ascertain the frequency and magnitude of extreme events. By introducing them to modern techniques, and combined with their access to data and understanding of weather and ecosystems, it was hoped that there may be an increase in scientific collaborations between different communities.

The conference attendees came from approximately three scientific groups, each containing a diverse mix of ages and backgrounds. The groups were: statisticians, interested in mathematical theory regarding the occurrence of extreme events; climatologists/meteorologists, with interest in weather and climate models which may predict extreme events and may show up temporal and spatial patterns in their occurrence; biologists/ecologists, interested in the impacts of extreme events on plants and ecosystems. Each group was asked to prepare material which would highlight the link between the different disciplines.

Statistical research in extremes is mostly focussed in one of two areas. The first is analysing data which are maxima (or minima) via the generalised extreme value (GEV) distribution. The other is the estimation of observations over a given threshold (known as peaks-over-threshold or POT) via the Pareto distribution. The key research presented at the conference on these themes concentrated on extending their application to situations where multiple extremal indices require joint inference, when data are spatially-indexed, or when the occurrence of extremal values is dynamically changing over time. The solutions presented for these problems focussed on copula methods, and the Smith and Brown-Resnick processes.

Research presented by the climatological and meteorological groups concentrated on 3 main areas. First, how might extreme values taken from climate models be used satisfactorily, given uncertainty in a climate model ensemble, and in the models themselves? Some speakers took climate model output and produced interesting forecasts of how extremes might occur at a set date in the future. Others used so-called model emulators to short-cut climate model runs, though theory on combining emulators with extremes is lacking. A second thread looked at the atmospheric conditions required for extreme events to occur. A key finding was that interaction between land and atmosphere was far more important than that of the ocean-atmosphere in producing extreme weather events. The final thread looked at how extremes might be incorporated into traditional detection and attribution modelling of anthropogenic influence on the climate system. A number of methods were proposed, though results varied based on the particular extremal index used.

The biological and ecological group present at the meeting were more focussed on impacts of extreme events rather than their prediction. A number of groups now have large-scale experiments running to simulate the effects of extreme drought. Key findings here include the requirement for dryness to coincide with high temperatures to produce maximal damage to the ecosystem. Such findings call for increased use of multivariate extreme value statistical methods. Similarly, the timing of drought and the biodiversity of the ecosystem in question can have highly variable impacts.

A number of other themes were raised during the conference, reflecting the diversity of expertise interested in the scientific content. A number of speakers looked at the topic of Geohazards and were concerned with estimating short-term weather extremes with large human impacts. In particular, there was discussion on the poor performance of existing linear statistical models in predicting events with return periods longer than a thousand years. Other interesting talks focussed on extremophiles; animals living at the extremes of climate, and the possibilities for extreme events on other planets in the solar system.

Scientific Content of the Conference

(1 page min.)

- *Summary of the conference sessions focusing on the scientific highlights*
- *Assessment of the results and their potential impact on future research or applications*

The three main themes of the conference were:

1. Extreme events and statistical methodology;
2. Modelling of extreme environmental events;

3. Impacts of extreme events.

There were 16 invited speakers, each giving a 35 minute talk, together with approximately 35 short talks of 15 minutes each, and around 25 posters. Unfortunately two of the invited speakers under theme 1 pulled out of the conference at late notice and so could not be replaced. A third invited speaker under theme 1 fell ill during the week of the conference. Thus theme 1 was slightly under-represented; though there were fortunately a number of other statistically-literate attendees which enabled reasonable progress to be made.

A key aspect of the conference was the definition of an 'extreme event'. The term extreme itself represents a relative position; what is extreme now may not be extreme in the future, or even to those who are already used to such conditions. However, it is extremes that most affect humanity and interest will always lie in predicting and understanding extreme events rather than computing simpler averages or average changes. A number of the invited speakers attempted to define the term 'extreme events' in the context of the research they were presenting.

Naveau (theme 1) defined extremes in terms of probability distributions. Extreme value research in statistics focusses on extremes that lie beyond the range of the given data. Other speakers (Nadim; theme 3, Beniston, theme 2) defined extreme events as being percentiles of a probability distribution (such as the 5th or the 95th). Such an approach is compatible with the definition of 'extreme' by the Intergovernmental Panel on Climate Change. The National Science Foundation definition, as pointed out by Nadim (theme 3) is less rigorously defined; “an event significant in terms of its impact, effects or outcomes”. The biologists and ecologists at the meeting attempted definitions based on large changes in the mean state. Huntley (theme 3) proposed three different types of extreme event, each corresponding to the degree of dissonance between the current vegetation and the persistence of the climate state.

Below is an outline of the different contributions of the speakers towards the themes outlined above:

Theme 1:

The basic statistical methods used in extreme value research were outlined in a talk by Naveau. This included the introduction of max-stable processes and the relationship between different standard probability distributions and the three types of extreme value distribution. He then presented some recent work on multivariate extremes of temperature and precipitation based on a copula-style approach.

This baseline talk allowed for the other speakers to extend and generalise these ideas. Parey showed how non-stationarity in the mean of GEV distributions can be used to understand the 2003 heatwave experienced across Western Europe. Gregenson showed a simple spatial extreme value model for extreme rainfall in Denmark.

Other speakers presented more theoretical developments to the GEV framework:

- Baxevam showed how ideas in extremal process theory can link an alarm and a catastrophe stochastic process together to reduce false warnings and long lead-times.
- Raillard presented recent work on POT modelling using the Smith process. The work is particularly relevant to those working with irregularly-spaced data.
- Koh showed how extreme observations may be separated from outliers by use of a thresholding method with application to equatorial wave dynamics
- Kwasniok presented a method for combining a deterministic model for barotropic flow with existing extremal theory via a mixture modelling approach.

Theme 2

Under theme 2, the majority of speakers presented research looking at the inference that can be drawn from extreme predictions taken from climate models. Many speakers used the standard IPCC idea of defining climate as a probability density function, thus changes in mean and variance will yield heavier tails and thus more extreme weather. The extremes used for analysis here therefore tended to be indices or percentiles created from climate model output.

Hegerl and Zwiers used their presentations to introduce various methods for detection and attribution in climate model studies of extremes. Here, climate model control runs are contrasted with those with elevated greenhouse gasses in an analysis-of-variance type approach to match observed data. The method is well-studied for detecting changes in means but theory for using extremes is still under-developed. There are a number of reasons for the failure of these attempts, most importantly because climate models do not simulate extremes well. Zwiers proposed two possible solutions; running the detection and attribution method on the parameters of the GEV distribution, or directly embedding the method within the GEV framework. The former is possible but inflexible, the latter requires substantial theoretical development.

Challenor presented some developments in creating GEV processes for climate model outputs. The main goal of his talk was to use emulators of climate models to predict extremes. The emulators used are stochastic approximations to deterministic climate models, fitted via multi-dimensional Gaussian processes, and based on a small number of climate model runs at different boundary conditions. There are substantial challenges involved in building the emulators, relating to the choice of boundary conditions and the structure of the autocovariance, amongst others. The methods presented here involved the slowing down of the Meridional Overturning Circulation (MOC) according to the simple GENIE climate model. The results shown indicated probabilities as high as 30% by the year 2100, though the simple nature of the model and the inflexibility of GEV distribution in this case may lead to over-estimation. Better results may be obtained via the extremal Brown-Resnick class of processes.

Other issues raised by climatologists and meteorologists at the meeting:

- The general need for a better link between extreme value theory and the data produced by climate models
- The link between land and atmosphere as being important in causing extreme weather, with the link being much less strong between atmosphere and ocean. (Martus)
- A link between extreme rainfall and volcanoes. (Yim)
- Sudden air pressure changes causing very rapid flooding of towns and cities (Sepic)

Theme 3

The third theme of the conference concerned impacts of extreme events. Beniston spoke about using outputs of climate models to look at the impact of extreme weather events in the Alps. Taking percentiles from ensemble runs of multiple climate models he was able to show the effects of temperature and precipitation extremes for the 2100, assuming the climate models are correct. In particular, he looked at combinations of temperature and precipitation, and categorised the future scenarios as being warm/wet, warm/dry, etc. The results showed that the hot, dry summer of 2003 is likely to be the norm over the Alps by the year 2100.

Beierkuhnlein, Jentsch and De Boeck all presented work from large field-studies looking at the impacts of extreme weather events on plants and ecosystems. De Boeck showed research on exposing plants to extreme drought and heatwaves, and combinations of the two, based on 50-years present-day return levels. He showed that heating on its own had little impact; most damage occurred during both heat and water stress. Jentsch and Beierkuhnlein presented a longer-term experiment. Their key results concerned the timing of extreme events and their effect on the composition of the ecosytem. They showed that, whist a drought that occurs late in the year may cause damage to plants, an earlier occurrence in the seasonal cycle is much more severe. Such a finding has implications for all three themes at the conference.

Huntley distinguished between different types of extreme event and their impacts, being either persistent or temporary in nature. He then explored how various historical events fitted into these categories; most notably the cold winter of 1962/63 and hot summer 75-76 in the UK, and the more marked 8.2k event. He showed that some types of extreme event, and the inertia they generate within an ecosystem, can contribute to permanent damage and even extinction of certain plant and animal species.

A final key aspect of theme 3 was that of geohazards. Ettema and Nadim presented recent work showing how risk is quantified in studies to determine the potential impacts of extreme events. A general discussion point was the difficulty of feeding in uncertain extremal estimates to risk models. In particular, Nadim showed how the linear relationships often used to extrapolate the return periods for extreme events such as earthquakes were not fit for purpose.

Other themes raised under theme 3 included:

- That the effects of extreme weather events can have low variability impacts or high variability impacts, and that predicting which will occur is a difficult task (Kreyling)
- The biodiversity of an ecosystem strongly affects plant survival under extreme weather. Plants grouped together tend to have better survival rates than those that are randomly scattered (Nijs)
- That the loss of humidity when coupled with droughts causes the most damaging effects (Fischer)

Forward Look

(1 page min.)

- *Assessment of the results*
- *Contribution to the future direction of the field – identification of issues in the 5-10 years & timeframe*
- *Identification of emerging topics*

A number of discussion topics were raised during the conference. The topics were arranged such that those interested in each could discuss them in small groups, then report back to others for a plenary session. Groups were encouraged to think about the grand challenges in each area, and then propose potential shorter-term projects for immediate advancement of the scientific area. An overwhelming desire throughout the groups was the need for statisticians to engage more with other disciplines, and the need for climate modellers/biologists to learn more statistics!

The 5 main topics discussed were:

1. How might extreme value theory be applied better to environmental data?

The group felt that a number of rapidly advancing statistical topics need to be brought to the attention of those interested in extremes. These topics include: modelling time dependence and non-stationarity, choice of thresholds, and multivariate extremes, amongst others. Software is already available (in the statistical package R) to handle bivariate extremes, but nothing beyond. A key aspect where users felt there was a particular requirement for development to be made is that of spatial interpolation of extremes such as in a catchment basin. The development of extremal processes, and their use and availability to the wider scientific community was felt to be key in furthering progress.

2. How can we better extract extremes from climate models with realistic estimates of uncertainty?

The group noted that the uncertainties relate to: structural uncertainties (eg model resolution), parameterisation uncertainties (eg convection, wind gusts, etc) and initial condition uncertainties. A problem remains that such uncertainties 'cascade' through the modelling framework to give a wide range of possible impacts. This is undesirable but necessary.

A number of proposals were put forward for reducing uncertainty including: better understanding of the non-linear physical processes, better observations and so improved model validation, higher-resolution models with improved parameterisations, and increased use of palaeoclimatic data to constrain uncertainties. A useful short-term step is to increase the use of statistical methods such as emulators in understanding the behaviour of climate models.

Many of these goals, however, are related to the general understanding of the climate system, and are less focussed on extreme events. Another group specifically focussed on extremes and suggested projects which may aim to recreate the extremal values only of the 20th century. They also encouraged increased dialog between climate modellers and extreme value specialists.

3. How might different interactions between land/atmosphere/ocean affect the occurrence of extreme events?

This small group discussed methods by which models of vegetation and atmosphere could be coupled and validated via increased use of satellite data. Research projects under this topics may look at: the role of vegetation in exacerbating extreme events, the behaviour of climate model simulations under variations in land use; how mode shifts from El Nino to La Nina affect extreme events; or how statistical downscaling might be used to couple climate models with hydrology or vegetation.

4. How might we better incorporate uncertainty and causation in risk models?

The major challenges discussed by this group concerned the lack of high-quality data available for risk models, particularly with respect to uncertainty. It was felt that end-users of risk models had little desire to see full accounting of uncertainty; a single number was all that was required but could not account for the variation in return levels for extreme events. This group particularly felt an increased desire for communication between the disciplines represented at the conference, with increased incentives for collaboration.

5. What kind of extreme events influence ecosystems and how can they be predicted for future climate?

This group focussed on impacts and ecosystems. The causes of ecosystem impacts were thought to be hard to identify, given the research presented at the conference showing the subtleties in extremes that can distinguish between a small decline and a mass extinction of species. The next immediate steps required included a desire for a 'taxonomy of extremes' to enable better communication between and within disciplines.

▪ Is there a need for a foresight-type initiative?

The topics discussed at this conference were more general than any topic or theme covered by a single journal or academic group. However, there are strong and overlapping links between the disciplines, and a keen desire to meet and discuss more often. The conference itself (as pointed out in the talk by Kolev) contains similarities and overlaps with many different COST initiatives. The most obvious foresight activities which may arise out of such a conference are:

- An edited volume detailing the links and research progress made by the different groups. Such a volume is in the early stages of preparation.
- A strong need for advanced statistical courses for environmental scientists, climate modellers, meteorologists, biologists, and ecologists. Furthermore, there needs to be an increased aspiration from research and funding leaders to have their estimates statistically validated.

There is a clear demand for further conferences on this subject bringing together connected research on extremes and environmental events.

Atmosphere and Infrastructure

▪ The reaction of the participants to the location and the organization, including networking, and any other relevant comments

The conference facilities were excellent and the general atmosphere due to the meeting being held in a traditional Cambridge college contributed to an excellent meeting. The organisational support of Antje Teegler was superb. She put the delegates and speakers at ease and nothing was too difficult to organise or arrange.

On a personal note, there are some things as conference chair I would organise differently if running the conference again. First, I would increase the amount of discussion time as there seemed to be a strong desire to discuss ideas further. This increase would have to come at the expense of some of the short talks. A second poster session may have enabled such a re-arrangement.

Date & Author:

27th January 2011, Andrew Parnell