

LLOYD'S

LLOYD'S SCIENCE OF RISK

2012 CONFERENCE



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1 FOREWORD

The application of science is part of Lloyd's DNA. From encouraging smallpox vaccinations at the turn of the 20th century to supporting the benefits of workplace sprinklers, throughout our history we have used scientific evidence to help us understand, and reduce, risk.

Three years ago we launched the Lloyd's Science of Risk prize to help increase insurers' knowledge of risk and encourage further research into new and emerging risks. For 2012, we focused on two categories – natural hazards and climate change.

Once again, I was delighted to see the level of engagement between those from the worlds of insurance and academia who attended our Science of Risk conference to share their knowledge and insight. I am pleased we continue working so well with the Technology Strategy Board and Research Councils to support that exchange.

Deciding on the winners has always been a difficult choice. This year, with our focus on just two specific categories and over 60 papers, it was even more so.

In the field of climate change, subjects included coastal flooding and cliff erosion, soil volume and shrinkage, the exposure of port cities and European sea-level rises. In the natural hazards category, papers included a new method of flood inundation modelling, mapping US wind speeds, extra tropical cyclones in the North Atlantic, New Zealand earthquake location modelling and a study into the prevalence of UK landslides.

The quality of entries, and their potential for direct application for insurers, made the task of shortlisting and selecting final winners as hard as ever. I would like to thank all those who entered and offer my personal congratulations to the winners, runners up and all shortlisted entrants.

The practical application to which many of the entries are already being put and the partnerships forged between insurers and scientists to develop them further is enormously encouraging. The work represented here represents just the latest stage in the ongoing relationship between science and risk mitigation which Lloyd's has always prized so highly.



Dr Richard Ward
Lloyd's Chief Executive



2 SCIENCE OF RISK CONFERENCE 2012

The Science of Risk prize winners and runners up were announced by Lloyd's CEO Dr Richard Ward at a conference held in the Lloyd's building on 29 November 2012. The conference was held in partnership with the Natural Environment Research Council and the Lighthill Research Network, and gave the two category winners, as well as the runners up, the chance to present their work to an audience of insurers, brokers, academics, catastrophe modellers, consultants and lawyers.

Professor Paul Bates was awarded the top £5,000 prize in the Natural Hazards category. His paper aims to reduce the time and costs involved in analysing flood data used to predict the probability and severity of future flooding. Typically, insurers and governments currently use flood prediction models that are accurate to post code level; by developing faster, more refined algorithms, Professor Bates has enabled much quicker, more accurate, building-level analyses.

Professor Bates explained that the benefits of the research are numerous; flood risk analysts will be able to produce more accurate models in less time and at lower cost, insurers will benefit from better risk management, the general public will be better informed on purchasing flood insurance, government maps will be more accurate and, in the event of a flood, emergency services will be better prepared.



Dr John Elliott was named runner up in the Natural Hazards category, with his paper on seismic hazard in Christchurch, New Zealand. He analysed satellite radar measurements, combining them with observations from the field, seismology and topography in order to build up a picture and model the locations of slip on the faults. The work also highlights the danger of growing cities that are perched above hidden fault zones in regions not previously considered to be at great risk.



In the Climate Change category, the winning paper, by Professor Richard Dawson of Newcastle University, examines the risks associated with flooding and coastal cliff erosion. Together with colleagues from the Tyndall Centre for Climate Change Research, Professor Dawson developed a unique and integrated assessment system that combines simulations of climate change projections, coastal hydrodynamics, coastal morphology, flood defence reliability, inundation and land use change. This system enables a variety of flood scenarios, and changes in expected annual damage, to be compared quantitatively.

Whilst the paper focuses on the Norfolk coast, the content is applicable to any area of flood risk. With rigorous data collection and analysis in high-risk, low-lying, high-population coastal areas, Professor Dawson's work will enable better management of flood risk, preservation of life and property, and the limitation of associated insurance losses.

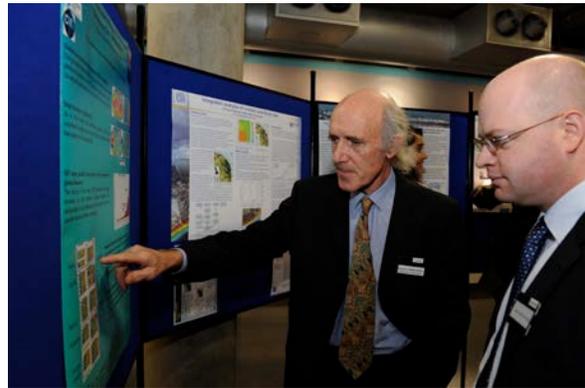
There were two runners up in the Climate Change category; Anna Harrison of the British Geological Society analysed the relationship between shrink-swell occurrence and climate in south-east England, providing insights into the factors influencing the level of subsidence claims. Meanwhile Dr Ben Booth, of the Met Office, analysed aerosols as drivers of 20th century North Atlantic climate variability; this work is expected to change the way in which we view the human impact on changing weather risks.

Each Category winner was presented with a winning certificate and a cheque for £5000. The runners up in each Category also received certificates and cheques for £1000.





Photo caption: During an extended coffee break, attendees had a further opportunity to explore the work of shortlisted entrants in more detail by viewing academic posters explaining the ideas behind their papers. This interactive session allowed conference attendees to network whilst discovering new areas of potential interest.



SCIENCE OF RISK 2012 FINALISTS



From left to right: Richard Dawson (Climate Change winner), John Elliott (Natural Hazards runner up), Anna Harrison (Climate Change runner up), Ben Booth (Climate Change runner up) and Paul Bates (Natural Hazards winner)

3 THE JUDGING PANEL

Applications for Lloyd's Science of Risk prize were reviewed by a panel of expert judges, which included representatives from research bodies, regulators and Lloyd's.

They considered the quality and relevance of the research to the insurance industry, its financial significance and the originality of the paper.

JUDGING PANEL

Judge	Title	Organisation/Body/Regulator
Dougal Goodman	Chief Executive Officer	The Foundation for Science and Technology
Trevor Maynard	Head	Lloyd's, Exposure Management
Lauren O'Rourke	Aggregates & Loss Modelling Manager	Argo International
James Orr	HoD, General Insurance Risk Specialists	Financial Services Authority
Vicky Pope	Head of Integration and Growth	Met Office
Duncan Wingham	Chief Executive	Natural Environment Research Council

4 2013 SCIENCE OF RISK PRIZE

If this booklet inspires you to apply for the 2013 Science of Risk Prize, we would be delighted to receive your application. Equally please feel free to encourage colleagues or friends to submit an application.

For further information about the prize or if you have any questions on the application process, please email scienceofrisk@lloyds.com.

5 CLIMATE CHANGE

5.1 WINNER

Richard Dawson

Integrated analysis of risks of coastal flooding and cliff erosion under scenarios of long term change

Coastal erosion and especially coastal flooding are major sources of insured (and uninsured) risk internationally. Coastal flooding is the largest potential insurance loss in the UK and this paper quantifies how coastal management choices influence flood and erosion risk on very broad spatial and temporal scales. There are clear tradeoffs between erosion and flood impacts – preventing erosion can increase flood risk in nearby lowlands, and vice versa.

Climate change with its associated rising sea level, and possible increases in the frequency and/or the intensity of storms and changes in wave climate can be expected to increase the risks of coastal erosion and flooding in most coastal locations around the world. These changes are particularly concerning because at least 600 million people and maybe as much as 10% of global GDP are within 10metres of mean sea level. In 2006 the ABI estimated that a 1 in 200 year flood event would cause £6.2bn financial losses in the Thames Estuary alone, and £16bn after 40cm sea-level rise. Further property development would compound these losses.

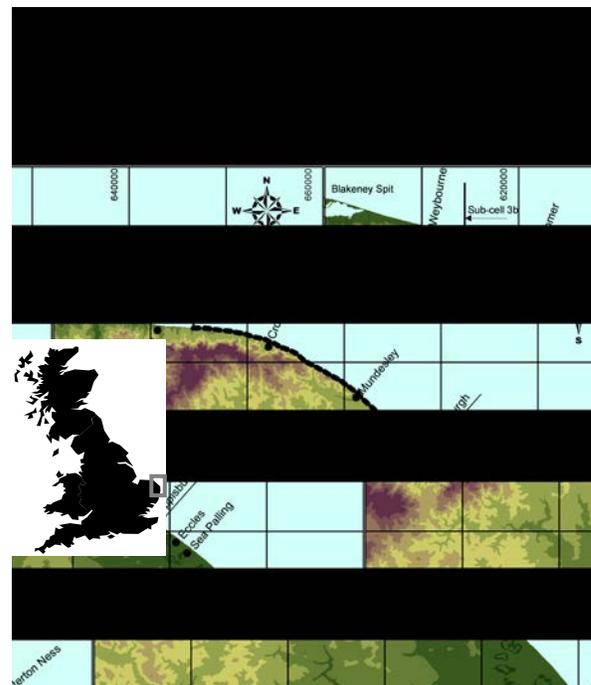
To understand climate and socio-economic influences on risk, and the resulting choices and pathways to successful management and adaptation, broad-scale integrated assessment of erosion and flood risk is essential. Due to their complexity the risks of flooding and erosion are usually managed independently and locally, yet frequently they are interconnected by exchange of sediments along the shore. Simply put, if beach levels fall, flood risk in adjacent low-lying coastal areas increases and *vice versa*.

In this study, Professor Richard Dawson, and a group of colleagues from the Tyndall Centre for Climate Change Research, addressed this complex challenge by developing a unique integrated assessment system that couples simulations of climate change projections, coastal hydrodynamics, coastal morphology, flood defence reliability, inundation and land use change. The integrated assessment enabled the outcomes of coastal management, socio-economic and climate change scenarios for flooding and erosion hazards to be compared quantitatively, for the first time, in terms of changes in expected annual damage.

The approach was applied to 72km of shoreline on the East Anglian coast of England. The analysis demonstrates that over the 21st Century flood risk is expected to be an order of magnitude greater than erosion risk. Over this timeframe, the main drivers of risk are a combination of:

- rising sea levels;
- natural and manmade morphological change, that lowers or raises beach levels;
- altered exposure to flooding and erosion due to socio-economic changes.

Significant benefits in terms of mitigating flood risk can be obtained by allowing previously defended cliffs to erode naturally. These benefits are greatest under high sea level rise scenarios. The economic and social implications for cliff-top communities of such a policy are problematic. However, the changes in risk are predicted to be quite steady over the first half of the 21st Century, allowing time for planned adaptation. Given the slow turnover of housing and infrastructure, plans for managed retreat from parts of the coast need to be implemented now if excessive adaptation costs are not to be incurred later.



Location of the study area, major settlements and land elevation. The area at risk of cliff erosion is indicated by the dotted line.

Increases in wave height (resulting from altered storm intensity) are less significant than these factors and only noteworthy if accompanied by high sea-level rise. Possible changes in wave direction have a more noticeable influence on coastal morphology, but this does not translate into significant changes in economic risk.

Interestingly, there is a rapidly increasing sensitivity of flood risk for rates of mean sea-level rise greater than about 4.5mm/year (corresponding to a global atmospheric carbon dioxide concentration of 715 parts per million). Such a high degree of non-linearity for potential impacts of sea level rise has significant implications for policy makers concerned with global emissions mitigation.

The study area has experienced centuries of flooding and cliff erosion, including the infamous storm surge of 1953. However, the site has attracted significant controversy in recent years after coastal defences protecting cliffs from erosion at Happisburgh were deemed uneconomic and removed in 1992, leading to short-term erosion of up to 10metres per year and loss of many properties. Although the nature of the risk profiles will differ, rising sea levels and socio-economic pressures are posing similar challenges along many other stretches of coastline around the world, making this particular location a test case for insurers and other stakeholders involved in 21st century coastal risk management.

Insurance is a crucial part of integrated coastal management. Insurers with coastal portfolios need to recognise the connectivity between the various geomorphological features that comprise the natural coastal system and thus the consequential tradeoffs in risk that result from different management policies. Quantification of these risks provides better and more consistent information to decision-makers, enabling management policies concerning different hazards and involving multiple stakeholders to be more effectively understood and communicated. The economic analysis of risk strengthens the argument for allowing some of the coastline to return to a more natural configuration and for negotiation between insurers, landowners, householders and planners to facilitate this change.

You can read this paper at http://eprint.ncl.ac.uk/file_store/production/45060/5D45CA22-DEA9-4FC4-B714-F3CD775E9577.pdf (open access) and <http://www.springerlink.com/content/3372n29608754q16/> (subscription required)

5.2 RUNNERS UP

Ben Booth

Aerosols implicated as a prime driver of twentieth-century North Atlantic climate variability

Losses from weather related risks are preconditioned by slowly evolving changes in ocean temperatures. Not only do these changes influence how active Atlantic Hurricanes will be over a given decade they are also linked to wide spread impacts on temperatures, rain, river flow and drought, including such notable events as the 1930s dust bowl in the US. More than this, these variations in ocean temperature drive coherent changes to weather risks in geographically remote regions that provide a challenge in how we underwrite our weather related losses.

Although individual hurricanes or flooding events such as experienced in the UK in September 2012, can not be individually attributed, there is much evidence that the risks of such events are strongly modulated by Atlantic temperatures. Warm temperatures in the North Atlantic coincide with large increases in average hurricane damage in the continental USA. This amounted to approximately \$20 billion during the 1996 to 2005 period when the Atlantic experienced relatively warm temperatures, compared to less than \$4 billion during 1976 to 1985 when conditions were cooler. Warm Atlantic conditions are also linked with persistent reductions in summer rainfall and drought in the South West and Great Plains regions in North America; with increased rainfall including extremes on the Atlantic seaboard; increases in European summer rainfall and temperature increases across USA and central Europe. Remarkably, the impacts even extend beyond regions neighbouring the North Atlantic, with persistent South America and African drought linked to warm and cool Atlantic temperatures respectively. Wider still are important links with Indian monsoon rainfall, modulation of El Nino variability and its impact on extreme weather and the North Pacific climate. In short the North Atlantic has acted as a slowly evolving metronome which predetermines our exposure to weather risks on multi-year time-scales over widespread and diverse geographical locations.

Our new study challenges the prevailing paradigm within the scientific community that these Atlantic temperature variations arose as a result of natural ocean oscillations. For the first time our study, published in Nature this year, shows using physically based climate simulations, that historical changes in emissions of industrial aerosols together with large volcanic events may in fact explain much of the past Atlantic temperature variability. Our new results arise from the greater understanding of how industrial pollution particles, known as aerosols, interact with clouds, a process which was largely neglected in previous climate model studies. Indeed, we find that industrial particle-cloud interactions account for 80% or more of their total impact on Atlantic temperatures. This leads to an appreciation that historical emissions are likely to have played a vastly enhanced role in past Atlantic temperature variations. These aerosols mostly consist of sulphur based particles, emissions of which have substantially reduced since the 1980s, in response to a concerted international effort to tackle a different environmental problem, acid rain. Going further back, periods of rapid industrialisation and hiatus during the inter-war/great depression, lead to increases and slowdowns in aerosol emissions. Our study suggests that this led to previously unexpected changes in Atlantic temperatures that preconditioned our exposure to weather related risks. In other words, post 1980s increases in Atlantic temperatures and associated increases in hurricane activity, European summer rainfall and temperatures, reduced rainfall and river flow in central and southern USA and reduced African drought, are linked in this study to past European and North American emission policies.

This new work is expected to change much in the way we view human impact on changing weather risks, establishing pathways which link past human aerosol emissions to periods of high or low impact weather events, such as decades of high hurricane activity or persistent drought, and highlighting a role of future emission policy in influencing how we experience weather risk in the future. In this vein it also highlights potential for non-local impacts from Atlantic aerosol changes from geoengineering schemes. Because of its implications this work has subsequently been subject of two Nature news articles and received mention amongst others on the front page of the FT in the UK and National Public Radio in the USA. Indeed, this work emphasises how improved understanding of future emission policies for Atlantic aerosols, will be inform a much larger part of future predictability in Atlantic temperatures and hence projections of regional losses from weather related risk, related to coherent changes in hurricane activity, regional drought, rainfall and flooding events.

You can read this paper at <http://www.nature.com/nature/journal/v484/n7393/full/nature10946.html> (subscription required)

Anna Harrison

The relationship between shrink-swell occurrence and climate in south-east England

Climate change is one of the biggest environmental problems that the UK faces. Increased understanding of the impacts is vital to enable adaptation to, and mitigation of, the consequences. Analysis and modelling of the relationship between climate and shrink-swell behaviour of susceptible soils has been carried out to increase understanding of the potential consequences of changes in precipitation and temperature on ground movement in the south-east of England during the coming century and beyond.

Clay soils are susceptible to shrinking and swelling, and the associated change in volume is one of the main causes of subsidence that damages our buildings. Clay soils that are very susceptible to volume change are found in many areas of the UK, but are most common in the London area and south east England where formations such as the London Clay occur.

This research has found that the preceding 2 years of rainfall has a strong influence on the ground saturation, and thus the potential of subsidence in our buildings. Therefore, rain events have to be considered within the context of the rainfall of the preceding 2 year period, to assess the present potential of shrink swell to occur. Only when the 2 yearly period of rainfall has been calculated and considered does an indication of the moisture within the ground and the susceptibility of swelling and shrinkage become apparent. Furthermore, for the first time, a relationship has been recognised between subsidence and temperature showing a tipping point identified when warm temperatures start to have an impact on subsidence claims. This effect builds upon the levels indicated by rainfall.

Analysis of historical climate data, and comparison with subsidence claims data (Association of British Insurers), demonstrates this relatively close relationship of subsidence with previous precipitation. Boundaries are identified, with precipitation above 394mm for the previous two years, leading to a lower level subsidence claims, and below 350mm leading to a higher incidence. Combined with this inverse relationship, a direct relationship with temperature is identified, with a rise above 22.60C in the mean maximum temperature for an accounting quarter leading to a peak in claims. To model a projection for susceptibility of south-east England to future climate change, UKCIP02 forecast climate data were used, and combined with the British Geological Survey national shrink-swell GeoSure geohazard dataset. Preliminary results demonstrate the most noticeable increases in subsidence susceptibility are within the areas underlain by the London Clay formations, with other clay-rich formations also being identified, including glacial till.

Despite this being a preliminary model, these significant results provide an insight into the factors influencing levels of subsidence claims. They identify geographical areas of higher susceptibility and the potential for changes in ground movement for the coming century. Looking to the future, warmer drier summers and increases in annual temperature and rainfall variability are suggested for the UK. What is considered a heat wave today is likely to be the usual in the 2050s and cool in the 2080s. Therefore, applying these research findings to gain a stronger understanding of the complexities of subsidence claims in the coming years, could prove to be invaluable to the insurance industry.

This work builds on over 10 years of research by the British Geological Survey (BGS) investigating the geotechnical and mineralogical factors controlling volume change behaviour of UK clay soils and mudrocks. This developed a strong understanding of the relationship between the geotechnical parameters and the shrink-swell susceptibility of clay, but only for steady-state climatic conditions. Similarly, the BGS's geohazard susceptibility datasets, such as GeoSure have been developed without considering the effects of longer-term changes in precipitation or temperature arising from climate change. This present study was carried out to address concerns raised by users of these BGS datasets caused by increased awareness that climate change is influencing geohazard occurrence in the UK.

The publication and research have been recognised and reported in 'New Civil Engineer' and 'Ground Engineering' magazines. Studies continue at the BGS improving the understanding of the relationships between rainfall, temperature and shrink swell. Other potential factors controlling the levels of subsidence claims are also being considered to refine the current model.

You can read this paper at <http://www.sciencedirect.com/science/article/pii/S0016787812000363>(subscription required)

SHORTLISTED ENTRIES

Susan Hanson

A global ranking of port cities with high exposure to climate extremes

This research emerged as a result of the landfall of Hurricane Katrina on Louisiana in 2005 and the major flood damage for New Orleans and the surrounding region, and wider economic implications (e.g., the temporary spike in global oil price). Hurricane Katrina caused the evacuation of 600,000 people and claimed 1,836 lives. It resulted in insured losses of some \$71 billion, while the total economic impact in Louisiana and Mississippi alone may have exceeded \$150 billion. The long-term consequences are also significant and to date, the population and economy of New Orleans is well below pre-Katrina levels. This event reminded us that coastal flooding is one of the major hazard and insurance perils internationally. This risk is increasingly concentrated in a set of major cities which are usually important ports, which hence are also vital lifelines for the associated area. These risks are dynamic and while many of the cities are known, before this study there was no systematic global perspective on the ranking and possible changes in these cities through the 21st Century.

Hence, the Organization for Economic Cooperation and Development (OECD) supported research (in their Cities and Climate Change programme) to understand the exposure to extreme sea-level events at the global scale in 2005, and how it might change by the 2070s, due to a range of climate, environmental and socio-economic drivers. The research was conducted collaboratively between public and private sector organisations in the UK and France. The research was led by Susan Hanson, University of Southampton, Prof. Robert Nicholls, University of Southampton, Dr. Stéphane Hallegatte, Centre International de Recherche sur l'Environnement et le Développement and Météo-France, and Dr. Jan Corfee-Morlot, OECD. Insurance industry expertise and data processing was provided by Risk Management Solutions, London (by authors Ranger and Herweijer).

Ideally, we would like to have considered estimates of risk, expressed as an average annual damage. However, it was recognised that data on probability of flooding was not available. Hence, it was decided to consider the exposure to coastal flooding under a 100 year event. The exposure metric reflects the damage if there is a major event which overwhelms the defences/coping capacity.

Methods

The method is based on drawing together a range of different global datasets.

First a set of port cities was defined for analysis based on 2005 values. This identified 136 port cities with more than one million people based on UN city and port databases. They are located all around the world's coast except in high latitudes. Then a population versus elevation relationship was developed using the high resolution global datasets on elevation and population. This allowed the population in the 100 year flood plain to be defined. Assets were then estimated using insurance-derived indicative estimates of 5 times GDP/capita per person.

For the future analysis to 2070s a range of driver scenarios were developed that were deliberately high end and consistent with OECD socio-economic scenarios to get a feel for the maximum change that could be possible. The drivers that were considered are:

- population and gdp change, including the effects of urbanisation;
- global sea-level rise;
- increased storminess due to climate change (where considered possible in the IPCC AR4 report);
- human-induced subsidence in susceptible cities built of deltas.

Results

The analysis suggests that about 40 million people (0.6% of the global population, or roughly 1 in 10 of the total port city population in the cities considered) are currently exposed to a 1 in 100 year coastal flood event. For assets, the total value exposed in 2005 across all cities considered is estimated to be US\$3,000 billion; corresponding to around 5% of global GDP in 2005 (in international USD). The USA, Japan and the Netherlands have the highest national exposure.

By the 2070s, total population exposed could grow more than threefold due to the combined effects of sea-level rise, subsidence, population growth and urbanisation with asset exposure increasing to more than ten times current levels, or approximately 9% of projected global GDP in this period. On the global scale, population growth, socio-economic growth and urbanization are the most important drivers of the overall increase in exposure particularly in developing countries, as low-lying areas are urbanized. Climate change and subsidence can significantly exacerbate this increase in exposure.

Exposure is concentrated in a few cities: collectively Asia dominates population exposure now and in the future and also dominates asset exposure by the 2070s. Importantly, even if the environmental or socio-economic changes were smaller than assumed here the underlying trends would remain.

Implications

This research shows that exposure (and hence risk) is growing in coastal areas due to a range of drivers and insured losses could grow substantially unless this issue is addressed. Importantly, climate change is just one dimension of the problem. Hence, there are high potential benefits from a portfolio of risk-reduction planning and policies at the city scale to address this issue. It would be in the interest of the insurance industry to promote these measures, particularly targeting the most exposed cities identified in the paper.

You can read this paper at http://www2.lse.ac.uk/CATS/publications/papersPDFs/83_Ranger_GlobalRanking_2011.pdf (open access)

Mark Pickering

The impact of future sea-level rise on the European Shelf tides

The impact of coastal flooding is an increasing risk for property insurers. Major European cities border the European Continental Shelf. To date the majority of scientific literature has assumed that tidal ranges in individual locations will remain constant with rises in sea level.

Our recently published paper entitled 'The impact of future sea-level rise on the European Shelf tides' demonstrates that tidal ranges will change by location with Sea Level Rise. These findings are also supported by observations. This research provides new insight into the changes of tidal ranges for 32 locations bordering the North Sea, the Irish Sea and the English Channel.

This paper represents a substantial step forward in our scientific understanding of one of the critical perils, flooding. Coastal flooding occurs when a combination of factors come together to produce unusually high water levels. The components making up the high water levels are known to be the mean sea-level, the tidal amplitude and the meteorologically driven storm surge component. A great deal of research has gone into measuring historic and predicting future sea-level rise. Similarly possible changes in the storm surge climatology in the future have been thoroughly investigated using hydrodynamic models forced by wind fields from climate models. One area which has received less attention in the last decade is the tide itself, a fundamental aspect of any coastal inundation event. A large number of storm surges occur every year on the European Shelf but cause no inundation and have minimal impact as they occur near the low water of the tidal cycle. To understand the risk of flooding requires a full understanding of the tides.

Tidal science is one of the longest researched areas of oceanography and yet it is a commonly held misconception that we know all that there is to be known about the tides merely due to the fact we have developed very accurate methods for tidal prediction. It is often stated in classical theory that the tides are a stationary phenomenon only varying in accordance with the known variations in the astronomical forcing, for example the spring neap tidal cycle and the equinoctial tides. In fact our research shows that there is still more to be learnt about the tide's behaviour even with tidal science being a relatively mature discipline.

Our paper identifies a new risk previously dismissed in the literature, the interaction between the mean sea-level and the tidal amplitude. By performing numerical simulations of the tides with future sea-level rise, alterations in the tidal characteristics (tidal phase and amplitude) are identifiable. A two meter (2m) sea-level rise scenario is the focus of the paper as it represents a worst case scenario for 2100. It is found that given 2m of sea-level rise there are substantial changes in one of the primary components of the European Shelf tide, the M2 component. The M2 component is the principal tidal constituent on the European Shelf; it is driven by the gravitational attraction of the moon and causes a twice daily peak in the water levels. Changes in the amplitude of this principal tidal constituent have implications for coastal flooding as this constituent makes up a large part of the tidal range on top of which the surge component occurs.

The changes in the M2 tide (as shown in Figure 4 of the paper) are spatially non-uniform across the European Shelf. Decreases in M2 tidal amplitude with sea-level rise occur on the northwest coast of France and the southwest coast of the UK and increases occur on the north coast of the Netherlands and the northwest coast of Germany. These non-uniform increased and decreased amplitudes mean that some regions may experience decreased as well as increased flood risk around the European Shelf. To look at whether the tidal response is linear with respect to the sea-level rise imposed, a 10m sea-level rise scenario was tested. This showed the response in the Gulf of St Malo and Bristol Channel to be fairly linear however the North Sea response was strongly non-linear. These non-linear and spatially non-uniform responses of tidal amplitude mean that the sea-level rise and tide need to be explicitly modelled in storm surge simulations rather than added at a post processing stage.

The largest regularly occurring tidal amplitudes are the spring tides when the M2 and S2 tidal components are in phase. Changes in the spring tide with 2m sea-level rise are shown to be as large as 43cm and 49cm of amplitude decrease at Newport and Saint Malo respectively and 34cm and 35cm of amplitude increase at Harlingen and Cuxhaven respectively.

Previously this interaction between mean sea-level and tidal amplitude has been disregarded (as shown in Table 4) as unimportant. However our research suggests that identification of the tidal changes requires a sufficiently high resolution model, a non-conservative sea-level rise scenario and a multi point analysis across the full model domain which was lacking in some previous studies. The model used in the investigation has been continuously developed and validated since the 1980s and is used operationally for the Dutch storm surge forecasting by the KNMI (The Dutch Met Office). Further validation against Proudman Oceanographic Laboratory observational cotidal charts is also provided.

Our paper was thoroughly peer reviewed by 3 reviewers before being published in Continental Shelf Research (CSR) which is a highly regarded oceanographic journal with an impact factor of 2.088. Shortly after its publication in March, our paper held the position of most downloaded CSR article for some weeks. At the time of writing the paper is still the sixth most downloaded article. The journal website also has video animations which assist insurers, policy makers and scientists in visualising the results.

The implications of changing tides with sea-level rise extend beyond flood risk and are also substantial. For example, there may be alterations to renewable energy resources, sediment transport pathways and dredging requirements as well as ecology at tidal mixing fronts and intertidal habitats. It is interesting to note that trends in tidal characteristics are starting to be identified in the observations with some locations such as the German Bight correlating well with the model results. This suggests not only is there potential for substantial changes in tidal amplitudes with future sea-level rise but that changes in the tide are already occurring.

Our research presents a new risk to the insurance industry which has the ability to both increase and decrease flood risk around European coastlines. Research currently being undertaken as part of my PhD is examining the same phenomenon on a global scale and initial results suggest that changing tides with sea-level rise are a risk along many coastlines throughout the developed and developing world. With the majority of the world's megacities located in coastal zones, this could hold substantial financial implications for the insurance industry and governments.

You can read this paper at <http://www.sciencedirect.com/science/article/pii/S0278434311003578> (subscription required)

Nicola Ranger

Deep uncertainty in long-term hurricane risk: Scenario generation and implications for future climate experiments

How will the frequency and intensity of Atlantic tropical cyclones change, on average, over the next 10 years and what does this mean for insured losses? These are important questions for long-term business strategy. But, if you search for the answer in the academic journals you will find at least 12 different scientific studies since the early 2000s, each giving a different picture of future risk, and each giving a strong case for why their projections are the most relevant and robust.

Even for the most simple and fundamental metrics, such as the frequency of landfalling hurricanes, still even the most recent studies can give contradictory results. To make things harder, different studies use different metrics altogether, making them incomparable to most users!

A concern is that this uncertainty and lack of clarity over the robustness of current science and projections could paralyse our ability to prepare for future changes in risk.

This study aims to help overcome this challenge by addressing three questions:

- o What can current science tell us about long-term risk and insured losses?
- o How should we interpret current science and apply this knowledge in reality?
- o In what new science should we invest to help clarify the picture of future risk?

The central goal of this paper is to produce a set of risk scenarios that represents the range of plausible futures in the 2020s and 2090s, based on the most recent science and in a form that is relevant and easy to apply by users in the insurance industry. The scenario set is complemented by analyses of the robustness of the underlying climate model projections to draw conclusions about how such risk scenarios should be weighted, interpreted and applied in practice.

The study involves five key innovations that are relevant to the insurance industry:

1. The study went beyond the current literature to produce a set of hazard scenarios that are independent of any one model or forecasting technique.
2. State-of-the-art hazard projections from the existing literature are presented in a consistent form to allow easy comparison and application within risk models.
3. Hazard scenarios are applied to a standard catastrophe risk model to generate a set of risk scenarios for one illustrative region, Florida USA. Metrics presented include average annual losses and exceedence probability (EP) curves.
4. The underlying hazard projections are analysed to assess whether different risk scenarios can be weighted and how they should be interpreted by users.
5. Analyses are applied to suggest priorities for future investment in science to better inform long-term business decisions in the insurance industry.

The study is the result of a two-year, multi-disciplinary collaboration between scientific institutions, catastrophe risk modellers and the insurance industry. Experts were engaged through one-to-one meetings and workshops to identify the relevant questions and to explore the interpretation of current science for users in the insurance community. Contributing experts included Kerry Emanuel (MIT), Greg Holland (NCAR), Thomas Knutson (GFDL), Gabriel Vecchi (GFDL), Howard Kunreuther (Wharton), Erwann Michel-Kerjan (Wharton), Lenny Smith (LSE) and colleagues from RMS and Munich Re.

Key Findings

Future risk and insured losses:

- o In the near-term, natural variability is likely to remain the main driver of the level and volatility of US hurricane risk. But, it is possible that the combined effects of manmade climate change and natural variability could create notably higher levels of risk and insured losses within the decade.
- o The volatility of losses appears to be more sensitive to manmade climate changes, in absolute terms, than the average losses. Even in the 2020s, some scenarios suggest significant changes in the probabilities of multi-billion USD losses, while changes in average annual losses are more moderate. For example, in the highest scenario, the 1-in-250 year loss increases by 50%.
- o In the long-term, current science gives little clarity over whether US hurricane risk will increase or decrease. In some scenarios, wind-related hurricane losses in Florida halve by the 2090s, while in others, losses increase four-fold due to climate change alone. Trends in exposure would further inflate losses.

Interpretation and Application of Current Science:

- We find that it is not possible to exclude any one scenario, or meaningfully weight them based on current evidence. Without additional information, each scenario should be treated with equal confidence.
- We conclude that the direct use of single or sets of hazard projections in risk management decisions, without an appropriate treatment of uncertainty, could lead to poor risk management decisions and unnecessary risks.
- We suggest that tools such as 'robust decision making', which account for the range of plausible risk futures, may be useful in applying such a set of scenarios.

Priorities for Future Investments in Science:

- A better understanding of the role of natural variability (versus manmade climate change) in driving current and past variability in tropical cyclone activity and the climate of the Atlantic. We show that understanding the past is crucial to building better forecasts of the future and that a robust attribution of extreme events could contribute to that.
- Deeper analyses of the adequacy and robustness of current climate models and forecasting techniques. There are many urgent questions – for example, does the fact that current models are unable to replicate the relationship between windshear and sea surface temperatures imply an inadequacy for forecasting?
- Focussing climate forecasting efforts on exploring and quantifying the range of plausible future risk, given the uncertainties, rather than on producing a set of 'best-guesses' based on the latest 'state-of-the-art' modelling technique.
- Narrowing the range of uncertainty by tackling the key sources of those uncertainties, for example, Atlantic windshear.
- Refining the collection/analyses of observations to identify early signals of changes in tropical cyclones, and the climate conditions that drive them.

You can read this paper at <http://www.sciencedirect.com/science/article/pii/S0959378012000337> (subscription required)

Philip Reid

Global synchrony of an accelerating rise in sea surface temperature

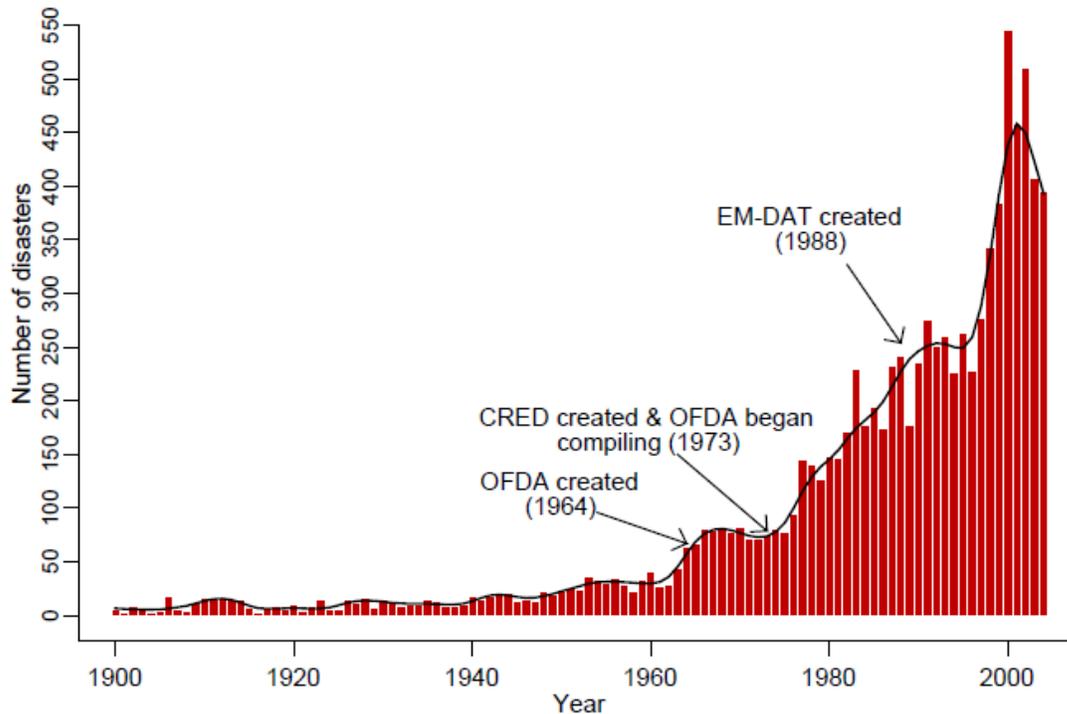
Our paper shows that tropical oceans are the 'beating heart' of climate change with sea temperatures increasing in steps that are linked to sharp rises in the occurrence of global disasters

The world's oceans are pumping warm tropical water towards the poles with important consequences for life on Earth according to our recently published paper in the Journal of the Marine Biological Association of the UK. The tropical regions of the Indian, Pacific and Atlantic Oceans appear to be "acting like a heart", accumulating heat and then pulsing it in bursts across the planet. Philip C. Reid, working at the Sir Alister Hardy Foundation for Ocean Science and the Plymouth University Marine Institute, and Gregory Beaugrand at the National Centre for Scientific Research (CNRS) in France have described for the first time a globally synchronous pattern of pulsed, short-term emanations of warm temperatures that pass along continental shelves, from tropical seas to the poles. Patterns of synchronous warm sea surface temperature anomalies are shown to extend from the equator towards the poles in both hemispheres. A suggested hypothesis to explain the patterns is that currents carrying warm tropical water along the equator, when they reach continental shelves, peel off in northerly and southerly directions, travelling as shelf slope currents along the shelf-line towards the poles. Many of the pulses coincide with El Niño events – and their heat content has increased substantially in intensity over the period of study.

In our study we mapped and statistically analysed average monthly sea surface temperatures for every two-degree square of latitude and longitude, from 1960 until 2008 for the whole global ocean, with a finer single degree resolution along continental shelves. In a multivariate statistical analysis we show for the first time that the dominant pattern of temperature variation is seen in the tropical oceans and that this has shown step increases around 1976, 1987 and 1998 with especially high temperatures throughout the first decade of the new millennium. These step changes coincide with well-documented ecosystem changes known as regime shifts and provide an explanation for what has appeared previously as the coincidental timing and connection of a wide-range of observed hydrographic, ecosystem and cryospheric (frozen ice/snow) events on both sides of the equator. There is a remarkable degree of symmetry, both north and south of the equator, and very clear spikes in the temperature, especially in El Niño years followed by a short period of cooling before the temperatures appear to increase to a new level.

The discovery of this new mechanism by which heat from the tropics is being moved in what appears to be a pulsating manner has major and wide-ranging implications for mankind, influencing energy consumption, weather, extreme events, the cryosphere, forest fires, heat waves, droughts and ecosystems. The timing of the step changes has especial relevance to the insurance industry as it appears to coincide with observed sharp rises in the global occurrence of disasters as documented by the OFDA/CRED International Disaster Database - www.em-dat.net - Université Catholique de Louvain, Brussels – Belgium. See graph:

OFDA/CRED Database



Total number of reported natural disasters in the world: 1900 to 2004

A step increase in the number of disasters in ~1976 coincided with a major regime shift in the North Pacific and many other events at this time, the second around 1988 and a third in the late 1990s. While we do not discuss the relationship of the timing of these events to changes in sea surface temperature in our paper it is an area that we are actively researching. As an exemplar we can show that the regime shift which Reid and colleagues first described in the North Sea in 1987/88 is known to have had substantial impacts on fish stocks and coincided with mass blooms of algae in Norway that killed many thousands of salmon with substantial losses for the insurance industry. The effects of this step change are not confined to the sea, but are evident widely in terrestrial systems. The timing coincides with the start of the melting of snow in the alps with enormous consequences for the skiing industry and is reflected in plants and agriculture in Europe evident as changes in the timing of plant growth in the spring. It may be coincidental, but a recent study by Harisson published in the Proceedings of the Geologists Association showed that there was a step increase in both the number of domestic subsidence claims and gross incurred claims in 1989; a lag in such claims is to be expected. The timing of the next event, the 1997/98 shift coincides with the biggest El Niño ever with wide ranging impacts on the insurance industry in that year and in the decade afterwards.

Perhaps of greatest concern is the timing of these events with changes in the cryosphere (The parts of the Earth where water is in solid form as ice or snow.). The step increases in warm sea surface temperature anomalies coincide with major reductions in the thickness and extent of polar sea-ice in the Arctic and to the west of the Western Antarctic Peninsula in the late 1980s. Subsequent melting of ice shelves in Antarctica and Greenland coincided to a strong degree with the late 1990s step change in temperature. Snow cover averaged for the whole of the Northern Hemisphere has shown a dramatic large decline exactly coinciding with the ~1987 step change in sea surface temperature. This decline and associated changes in the permafrost have large insurance implications on a hemispheric scale.

To conclude, warm tropical waters appear to be acting like a heart, accumulating heat and energy that is increasing in steps at approximately decadal intervals. If this pattern continues, global temperatures may continue to rise in sudden jumps – and the evidence suggests that the rate of rise is accelerating. The oceans are playing a key and little understood role in transferring heat towards the poles that is released to the atmosphere to transfer to the land with wide ranging consequences for the insurance industry.

You can read this paper at <http://journals.cambridge.org/action/displayAbstract?fromPage=online&aid=8702903>
(subscription required)

6 NATURAL HAZARDS

6.1 WINNER

Paul Bates

A simple inertial formulation of the shallow water equations for efficient two-dimensional flood inundation modelling

Claims for flood damage are a major source of attritional losses in the insurance industry, and extreme floods can generate major losses that trigger re-insurance contracts. For example, the Summer 2007 floods in the UK cost the industry some £3.5Bn, whilst insured losses from the recent Thailand floods have been estimated to be of the order of \$15Bn. Models to predict flood risk are therefore much in demand by the insurance industry, and a variety of commercial and in-house computer codes are used across the sector. Insurers and re-insurers also make frequent use of the model-based flooding assessments developed by national Governments, such as the Flood Map produced for England and Wales by the Environment Agency.

The critical component in a flood model is an algorithm to convert river flow, rainfall or coastal extreme water levels to water depths and velocities across the modelled domain, and which are then used to estimate damage and loss. Such algorithms lie at the heart of catastrophe flood models and are computationally very expensive. This is a particular problem for the insurance industry where such calculations need to be performed repeatedly for different portfolios and scenarios, and each time over whole territories. In order to make possible the calculations modellers either need to compromise the physical representation or apply the model using a coarse resolution grid. Often both solutions have to be adopted, and either will lead to poor simulations. For example, most catastrophe flood models applied by the insurance industry represent the flow physics as a simple diffusion wave, solve this using a technique that leads to incorrect flood spreading and employ a 50m or greater grid resolution that is too large to represent buildings. Whilst this leads to reasonable computational costs it is easy to show that for urban areas, where the majority of risks are located, that such an approach will lead to significant errors in loss estimates. Instead accurate risk estimation in urban areas requires models that better represent flood dynamics and which can make full use of high-resolution laser mapping terrain data to resolve flows around individual buildings. Critically, this extra work (more terms in the equations, more grid cells in the model) needs to be achieved for no increase in computational cost.

Our study, published in the Journal of Hydrology and undertaken at the University of Bristol with support from the Willis Research Network, went back to first principles in order to find a solution to this problem. Commencing with the equations describing the fundamental physics of flood flows we developed a new set of equations for wide area, high-resolution flood modelling that overcame the limitations of previously developed schemes used by the insurance industry. The solution in the end turned out to be counter-intuitive: we were able to make the model faster by making it more complex. Hence we were able to make our model both better and cheaper at the same time. By adding back in the effect of mass and inertia to the flow equations we were able to make them run with a larger stable time step which led to an overall reduction in computational cost. Whilst the equations we derived were known to the hydraulics community no one had developed a method to solve them that did not lead to extreme instability. The key advance made in our paper was to find a way to do this.

We undertook rigorous testing of our new equations to demonstrate their accuracy for three flood modelling problems of increasing complexity where the true solution was known. In all cases we showed the ability of our new equations to match the true solution as well or better than the approach currently applied in catastrophe risk models, but at a fraction of the computational cost. We then conducted a final test demonstrating the ability of the new method to solve a real world flooding problem for a site in Glasgow, UK. Computational time savings of 1 to 3 orders of magnitude were achieved, and the maximum speed up seen over the standard insurance industry method was 1120x. As model computational cost goes up by almost an order of magnitude for each halving of the grid resolution this means that with the new method a 5m model can be run at the same cost as a 50m model based on the currently used approach. At 5m scale flood models can actually simulate flow around buildings in urban areas, thereby allowing risk to be estimated at the individual property rather than post code level.

For a mature field like hydraulics where the fundamental equations describing flood flow have been known since the middle of 19th Century, and ways to solve these equations on digital computers have been available since the 1950s, advances tend to come in small increments. Science that makes a large difference to capability is exceptionally rare, yet with the developments outlined in our paper this is exactly what we have been able to achieve. Whilst at first reading our paper appears heavily theoretical, its implications are profound and immediate for insurance industry flood risk analysis. The paper places in the public domain the blueprint for how to build a better flood inundation model in a way that is truly 'open source'.

The impact of the publication is already being felt by the insurance industry. To our knowledge, flood models based on the equations outlined in our paper are under development at Willis Analytics, Ambiental Ltd. and HR Wallingford Ltd. Numerous academics are also developing their own research tools based on the principles we have outlined. In time these methods will be used to inform risk analysis and pricing, and will stimulate research to improve flood modelling methods yet further.

You can read this paper at <http://dx.doi.org/10.1016/j.jhydrol.2010.03.027> (subscription only)

6.2 RUNNER UP

John Elliott

Slip in the 2010–2011 Canterbury earthquakes, New Zealand

In September 2010, a large earthquake surprised the population of the South Island of New Zealand. It ripped a 30 kilometre tear across farmland outside the city of Christchurch. In just a few seconds, roads, trees and fences were jolted sideways and permanently shifted by up to four metres. Fortunately, no one was killed. However, insured losses were over \$4.4 billion US dollars (Source: Swiss Re Economic Research & Consulting). Despite being an earthquake 500 times smaller than the Chilean earthquake six months earlier in February, the losses were over half that of the much larger South American earthquake. This pair of earthquakes made up the two biggest insured losses for 2010.

Then, less than six months later in February 2011, another quake shot up right under the city of Christchurch. This time, the sheer proximity of the earthquake resulted in the deaths of 186 people and a partial exodus as others sought temporary refuge elsewhere. This earthquake was 20 times smaller than the earlier one outside the city, but this time it resulted in insured losses 3 times greater, totalling \$12 billion. The insurance industry contribution to the overall economic losses of this event of \$15 billion was therefore 80%, reflecting the greater insurance penetration due to mandatory residential earthquake insurance. The Japanese earthquake and tsunami three weeks later caused three times as much insured loss, but was 28,000 times more energetic.

Both the earthquakes in New Zealand occurred on previously unknown faults, hidden beneath the gravels of the Canterbury Plains on which the city lies. The earthquake danger for the region of Christchurch was thought to lay on mapped faults high up in the hills and snow-capped mountains.

In this study, I have carefully analysed satellite radar measurements and combined them with observations from the field, seismology and topography to build up a picture of the earthquakes and model the locations of slip on the faults. By using a range of techniques and different data sets I was able to make an improved overall assessment of these events compared to other groups. My model shows the earthquakes ruptured a complex series of hidden fault segments, with up to 8 metres of motion on the faults underground. More importantly, in doing this I have shown that the hazard for the city's inhabitants may not have gone away. The fault segments that I have mapped out from the satellite data show a jump between the two earthquakes. The satellite measurements show that there has been no seismic fault slip in between these two earthquakes in the region to the south-west of the city. If there is a fault structure in this area, then these two earthquakes have placed it under greater pressure, leaving a stressed seismic gap large enough to generate a similarly sized earthquake. Some of the preliminary data imagery from this study and the conclusions regarding potential remaining risk were highlighted in a BBC news online article (<http://www.bbc.co.uk/news/science-environment-12668190>) just two weeks after the Christchurch earthquake.

Earthquakes occur when the ground snaps along faults once the pressure from strain in the Earth has exceeded their strength. Previous measurements of New Zealand that probed the deformation and pressure build-up of the islands using GPS measurements had shown that the region in which these earthquakes occurred was not under much strain compared to the rest of the country. However, I was able to show that the pattern of faulting in these two earthquakes was consistent with the direction of this small pressure build-up. Therefore, an important conclusion is that these small strain pressures really do matter, and we should not focus just on regions with the greatest previous seismicity nor the fastest, most obvious faults. We should also invest in revealing hidden hazards on these slower, lesser known faults that have not caused any earthquakes in our short historical record and are therefore commonly missed in the shadow of more obvious and larger faults. This point was illustrated by last year's small earthquake felt in Washington and much of the north-eastern USA, that the earthquake risk for the US is not limited to California.

These observations point to a potential emerging risk. Earthquakes are unlikely to be increasing in frequency. However, population growth and migration into urban centres has created megacities, particularly in the past few decades in developing countries. These cities are acutely susceptible if there is an unknown fault right beneath the city, as was the case with Christchurch. An important example may be Beijing, which has grown a lot in a short time relative to how often earthquakes happen in any one place, and there is a lack of obvious faulting in surface geomorphology relative to many other parts of China. However, there have been significant earthquakes in the surrounding region, and there is some strain build up recognised in GPS measurements. China will experience increasing earthquake insurance penetration as its economy continues to expand and the potential insured losses will likely increase.

In summary, I have highlighted a possible continuing seismic hazard around the city of Christchurch, which is still recovering, and still has a large potential for future insurance losses. Furthermore, this work highlights the danger of growing cities that are perched above hidden fault zones in regions not considered to be at the highest risk. My future

research will contribute to the wide scale mapping of these small strains using satellite data across the Eurasian continents, looking at the potential hazards associated with cities in countries like China.

You can read this paper at <http://www.agu.org/pubs/crossref/2012/2011JB008868.shtml> (subscription required)

6.3 SHORTLISTED ENTRIES

Hannah Jordan

Mapping a nation's landslides: a novel multi-stage methodology

Up to 350,000 homes in the UK are in areas at risk from landslide activity. This equates to £57 billion worth of housing stock being vulnerable to landslide-related damage (using December 2010 average purchase price). Natural shallow geological hazards (geohazards) including landslides, shrink-swell clays and collapsible ground, represent the largest contributor to building damage in the UK: greater even than damage from flooding, extreme weather or mining activity.

Insurance industry payments for landslide-related damage between 1991 and 2010 have averaged £3-400 million per year. A recent spate of 55 landslides across the country has resulted in 3 deaths and 8 injuries in the last 9 months alone. Of these landslides, 19 caused damage to the rail network, including 3 train derailments whilst more than 15 damaged roads and buildings across the country.

Traditionally, the UK was regarded as not being especially prone to landslides. Many of the main landslide triggering factors such as large earthquakes and extreme climatic events are simply not experienced in the UK. However, ongoing mapping and inventory of landslides by the British Geological Survey (described in the attached paper) has revealed that the country possesses over 15,000 landslides and one of the highest recorded landslide densities in Europe. On average around 28 landslides have been reported in the media each year in Britain since 2005 and this number is likely to increase in the future with predicted climate change.

In addition to new landslide events, reactivation of older 'relict' landslides is likely with changing climatic conditions. The landslides are often extremely large, reaching several 10s of kilometres across and, whilst regarded as stable under current climate conditions, may well be triggered by future potential changes in rainfall level, storm frequency and seasonal temperature differences.

The densely populated nature of the UK and the advanced infrastructure and utility networks that support this population also serves to increase the UK's susceptibility to landslides. Costs for the Ventnor Undercliff Landslide on the Isle of Wight, which sits in a relatively densely populated area, have averaged £1.4 million per year for the last 20 years in terms of structural damages, insurance costs, engineering measures and monitoring.

The high population density of the UK is also responsible for introducing another dimension to landslide activity in the country. Increasingly, landslides are being triggered or re-activated by human activity and often occur in man-made ground. Perhaps the most famous examples of such an event in the UK is the Aberfan disaster of 1966 in which 144 people died and more than 20 buildings were destroyed as a result of the collapse of a colliery spoil tip.

The attached paper presents the novel methodology that the British Geological Survey (BGS) uses to map and catalogue the UK's landslides. Through a mixture of strategic, repeat and responsive surveys, the BGS is providing accurate information on landslide location, type and size- these are essential requirements for the successful reduction of risk from landslide hazards. These surveys combine new technologies and traditional mapping techniques to deliver high quality research at the forefront of landslides investigation.

New technologies incorporated into the mapping methodology include digital 3-D aerial photograph interpretation and variable perspective 3-D topographic visualisation for 3-D virtual field reconnaissance. These techniques are used alongside field mapping with digital data capture and terrestrial and airborne LiDAR surveys. These enable rapid data acquisition, accurately positioned repeat surveys of landslide features and the development of change models to better understand landslide processes. By constantly improving knowledge and understanding of the mechanisms involved in UK landslides, the BGS is better able to model susceptibility to landslide hazards, providing vital information for planners, utility companies, landowners and the insurance industry.

For the insurance industry the results are highly significant as they help identify the most landslide-prone areas, delimit the regions of increased susceptibility and can be used to refine insurance premium calculations. This data is delivered to the insurance industry, planners, utility companies and homeowners through the BGS's GeoSure and GeoSure Insurance Products. The data also highlights areas that may be at risk in the future, informing planners of proposed infrastructure developments so that future landslide-related damage and insurance claims can be lessened. The methodology presented in the paper is also being applied in an international context, notably throughout Madagascar and aspects of the mapping techniques have even been used to map landslides on Mars.

You can read this paper at <http://www.springer.com/earth+sciences+and+geography/natural+hazards/book/978-3-642-31324-0> (in press)

Oscar Martínez-Alvarado

Sting jets in intense winter North-Atlantic windstorms

Extratropical cyclones (synoptic scale, low-pressure, mid-latitude storms) represent one of the most costly natural hazards in Europe with a single event, cyclone Kyrill in January 2007, causing an estimated direct damage of € 4.7 billion (£4.1 billion)¹. For this reason, research into both the physics behind the occurrence and the statistical properties of extratropical cyclones is very active within the academic community and the insurance/reinsurance industries. Multi-decadal climate datasets, reanalyses, are very useful tools for this research. Reanalyses combine observations and numerical models to produce the best knowledge we have of the atmosphere over periods spanning several decades in the past. However, they have relatively low spatial and temporal resolutions (e.g. grid spacing of the order of 50 km with output every 6 hours). This limits their usefulness for analysis of smaller-scale and/or transient strong wind features. We have overcome this limitation to develop a first climatology of cyclones containing sting jets.

One reason for the catastrophic impact of extratropical cyclones is their potential to produce very strong surface winds and gusts, which are associated with specific air streams within these cyclones. Two of these air streams, namely the low-level jet components of the cold and warm conveyor belts, are large and long-lived enough to be accurately forecast and present in reanalysis data. However, a third air stream has proven to be much more elusive due to its relatively smaller size and transient character. This air stream has been named the sting jet because of both its surface damaging potential and its starting location at the tip of the cloud head that circles round the cyclone's centre to the west of the cyclone. The sting jet descends from the tip of the cloud head towards the surface. As it approaches the surface it can gain enough momentum to generate very strong surface wind gusts in the dry air behind the cold front of the cyclone. The best documented example of a sting-jet cyclone is the 'Great Storm' that devastated southern England on 16th October 1987². A more complete understanding of the risks posed by sting-jet cyclones is important to prevent or mitigate possible loss of life and damage to property, a concern that is important to policy makers as well as the insurance industry.

Our article **Sting jets in intense winter North-Atlantic windstorms**, published this year in the journal *Environmental Research Letters*, is the first to address two very important questions: how often and where sting-jet cyclones occur under present-climate conditions. The main challenge encountered in this research was that sting jets are not directly represented in currently available reanalyses. To overcome this difficulty we developed a new diagnostic to identify extratropical cyclones in low-resolution datasets such as reanalyses that are likely to produce sting jets³. The development of this diagnostic drew on the results of previous research in which we clearly established the relationship between sting-jet cyclones and the release of a certain type of atmospheric instability called conditional symmetric instability⁴. This instability is termed conditional because it relies on the presence of moisture (cloud) to be released and its release leads to slanted circulations including sting jets. We have demonstrated that low-resolution models are capable of developing this kind of instability, even though they have insufficient resolution to release it realistically and so generate sting jets. By searching for these regions of instability in suitable locations, with respect to the cyclone centre and cloud head, we are able to identify cyclones that can generate sting jets.

We produced the first regional climatology of cyclones with sting jets by applying our diagnostic to the 100 most intense North Atlantic extratropical cyclones during the winter months (December-January-February) between 1989 and 2009. These cyclones were identified from the ERA-Interim reanalysis produced by the European Centre for Medium-Range Weather Forecasts (ECMWF). To demonstrate the reliability of our diagnostic a subset of 15 cyclones was simulated using an operational weather forecast model capable of resolving sting jets. Consistency was found between the observed lack or presence of sting jets in these simulations and the predicted lack or presence of sting jets in the ERA-Interim dataset. Our study showed that up to a third of the intense cyclones had the potential to produce sting jets, firmly establishing that sting jets are a relatively generic feature in extratropical cyclones in the North Atlantic. We also found that sting-jet cyclones tend to be located more to the south (relative to the entire set of cyclones) which is consistent with the need for warm moist air for the production of instability. Another important conclusion is that individual sting jet cases previously studied (such as the Great Storm) were more exceptional in their track over populated areas than in the strength of their sting jets.

Now that the methodology is established this research can be extended to include other ocean basins and to include a bigger sample of cyclones to investigate the distribution of sting jets over the whole population of extratropical cyclones.

¹<http://europa.eu/rapid/pressReleasesAction.do?reference=IP/07/1301&format=HTML&aged=0&language=EN&guiLanguage=fr>

² Browning, K. A. (2004) The sting at the end of the tail: Damaging winds associated with extratropical cyclones. *Quarterly Journal of the Royal Meteorological Society* **130**: 375-399.

³ Martínez-Alvarado, O., Gray, S. L., Clark, P. A. and Baker, L. H. (2011), Objective detection of sting jets in low-resolution datasets. *Meteorological Applications*. doi: 10.1002/met.297

⁴ Gray, S. L., Martínez-Alvarado, O., Baker, L. H. and Clark, P. A. (2011) Conditional symmetric instability in sting-jet storms. *Quarterly Journal of the Royal Meteorological Society* **137**: 1482-1500.

The results of all these investigations as well as those from the study we present here have potential impact for end-users including policy makers, civil engineers and the insurance/reinsurance industry.

You can read this paper at <http://dx.doi.org/10.1088/1748-9326/7/2/024014> (open access)

Richard Murnane

Maximum wind speeds and US hurricane losses

The key research finding described in the paper is that a robust, yet simple relationship exists between economic loss and a hurricane's maximum wind speed at landfall in the United States (US). The relationship suggests that economic loss increases by 5% per meter per second increase in wind speed. As detailed below, this relationship is relevant to the insurance industry for at least three reasons. First, it can be used to generate "real-time" estimates of loss from hurricane landfall in the US. Second, it provides a mechanism for assessing how losses will grow as a result of the expected increase in hurricane intensity due to anthropogenic climate change. Third, the relationship is a possible mechanism for assessing the skill of risk models at estimating industry loss from hurricanes making landfall in the US. Below I discuss the loss versus wind speed relationship described in the paper, the relevance of these three points to the insurance industry, and the quality of the research.

The relationship between loss and maximum wind speed at landfall: The relationship between the log of normalized economic loss and maximum wind speed at landfall described in the paper is derived using quantile regression. The data are from hurricanes striking the US between 1900 and 2010. The normalized loss data accounts for inflation and changes in population and wealth. Notably, the slopes are statistically the same for all quantiles and suggest that loss increases by 5% per meter per second increase in wind speed. Our interpretation is that the centercepts for the different quantiles account for random factors such as population density and exposure and that, once these factors are accounted for, the dependence of loss on wind speed is fixed.

Estimating "real-time" loss from hurricane landfall: In the US, economic losses are generally assumed to equal twice the industry loss plus the losses paid by the US National Flood Insurance Program (NFIP). Given the magnitude of insured and economic loss caused by the landfall of a US hurricane, it is not surprising that there is significant public and private interest in "real-time" loss estimates generated using catastrophe risk models. Unfortunately, these estimates typically have a large amount of uncertainty and are often available to the public only through press releases by the model vendors. The relationship between economic loss and wind speed described in the paper provides a simple method of estimating a range of economic loss that can be easily extended to estimate industry loss.

An opportunity to verify the relationship was provided by the 2012 landfall of Hurricane Isaac. The range of industry losses as a function of wind speed and quantile is shown in the accompanying table. Industry losses are half the economic losses calculated using the relationship. Hurricane Isaac had winds of 70 knots at landfall. Thus, the 5th and 95th centiles for industry loss (exclusive of offshore loss) were estimated to be US\$0.8 billion and US\$1.8 billion, respectively, a range consistent with estimates in press releases from the model vendors.

Table. Industry loss (Billions \$) as a function of wind speed (knots).

Wind Speed	5% CI	Mean	95% CI
65	0.6	1.0	1.5
70	0.8	1.2	1.8
75	1.0	1.4	2.1

Climate change and hurricane intensity: There is understandable and significant interest in quantifying future increases in loss from hurricane landfalls. Increased exposure, greater hurricane intensity, and elevated sea level are commonly considered factors that could cause future losses to increase. Exposure increases as coastal population and wealth grow, and as hurricane intensity and sea level are expected to increase as a result of anthropogenic climate change, damage and loss are expected to increase as more property is exposed to stronger winds, higher waves, and greater inundation. The relative importance of these factors is still being debated, but changes in exposure are clearly of great importance to insurers for future increases in loss. One can estimate how, ceteris paribus, losses might increase if hurricanes become more intense at landfall using the finding that losses grow by 5% for each meter per second increase in wind speed. A 10% increase in intensity would result in economic losses ~10% higher for a storm with wind speeds of 20 m s⁻¹ and ~30% higher for storms with winds of 60 m s⁻¹, with both scenarios assuming constant exposure. These changes are significant but less than most estimates of how loss would increase due to future changes in exposure.

Assessing model skill at estimating "real-time" industry loss from hurricane landfall: All cat models have no doubt been tested using historical events. But, as almost any forecaster will attest, forecasting a new event is very different than hindcasting a historical event. In meteorology and climatology one uses forecast skill to assess the usefulness of a weather or climate forecast. Forecast skill is calculated by comparing forecasts generated by a model to forecasts generated using a reference model based on climatology and/or persistence. A skillful forecast should be of more value than a forecast with little or no skill. Currently, however, there is no independent means to assess whether a complex cat model has skill in quantifying any type of loss. In a manner analogous to that of meteorologists and climatologists, one could evaluate a risk model's skill at estimating loss if there were an appropriate reference model. The wind speed versus loss relationship described in the paper, based on a "climatology of losses", could be used as a reference model when assessing a risk model's skill at estimating economic or industry loss within a few days of hurricane landfall, providing the normalized losses are updated through time.

Quality of research: Perhaps the most direct validation of research quality is the publication of a paper describing the research in a leading peer-reviewed journal, in this case Geophysical Research Letters. Another indication of research quality is reproducibility. Anyone may replicate the results discussed here using the open-source software R and the publicly available data and code accessible through links published in the paper.

You can read this paper at <http://www.agu.org/pubs/crossref/pip/2012GL052740.shtml> (subscription required)

Tim Palmer

Towards the probabilistic Earth-system simulator: a vision for the future of climate and weather prediction

The submitted paper is based on my 2011 Presidential Address to the Royal Meteorological Society, just published in the Quarterly Journal of the Royal Meteorological Society. It is fundamentally a paper setting out my views about how weather and climate scientists should be improving their models to improve these models' estimates of weather and climate risk on all timescales, from days to a century or more. The core of the paper is based around the assertion that despite the fact that the underpinning equations of weather and climate are deterministic, at a computational level these equations should be treated as stochastic (ie as inherently uncertain). The stochasticity enters the computational equations at the parametrisation level, ie where unresolved sub-grid processes must be represented in simplified ways. In fact, work I have been leading for a decade or more has established the notion of stochastic parametrisation in numerical weather prediction. In this paper I try to outline the science rationale for this in climate prediction as well, ie across the range of prediction timescales.

This work is of fundamental importance for all users of weather and climate models, whether in the insurance sector, or other application sectors. That is to say, a key attribute of a weather or climate prediction system for it to be useful, is "reliability". In the old days when weather and climate forecasts were based on single deterministic best-guess forecasts, a reliable forecast system was one that was always right. This never happened. Indeed it is simply inconsistent with the fact that our climate system is chaotic, to imagine that deterministic forecasts could ever be reliable (even on very short timescales where error doubling times are much shorter). The community now realises this, and the era (c. 1950-2010) of deterministic numerical prediction is rapidly coming to an end.

Nowadays weather and climate forecasts are usually based on ensemble prediction systems (an area in which I have worked and to some extent pioneered over my research career). Such ensemble systems produce probabilistic rather than deterministic forecasts. However, the question still arises and it is a crucial question if users are to make the right decisions from such forecasts – Are such probability forecasts reliable? Now the word "reliability" means something more subtle than it did in the deterministic case – for example, if I predict a probability of 60% that there will be a drought in the coming season, and my forecast system is reliable, then on all previous occasions when I predicted a drought, a drought should have occurred 60% of the time.

Representing uncertainty arising from the computational approximation of the equations of motion, is crucial to forecast reliability on all timescales from a day to a century (and hence from short-range weather forecasting to long-term climate change projections). It is argued in the paper that multi-model ensembles or perturbed parameter ensembles are pragmatic and ad hoc approaches to the representation of model (the author prefers the word "simulator") uncertainty and likely to suffer from systemic failure. This suggests users have to be cautious if such multi-model ensembles indicate consensus about some prediction – it may be that this consensus arises merely because all component models have common failings.

The thrust of the paper is that stochastic representations of sub-grid processes provides a more rigorous approach to the representation of model uncertainty than is possible with conventional multi-model approaches. This work therefore has substantial implications for the weather and climate model user community.

This work is important for a second reason. It is important that as many key processes in the atmosphere and oceans are simulated in weather and climate models, using the proper laws of physics. However, for climate, processes occurring on scales smaller than about 100km cannot be simulated in this way because they occur on the sub-gridscale. A key process is deep convection occurring on scales of a few kilometres. One approach to the development of a convectively resolved global model in the next decade or so, is for weather and climate institutes to pool human and computing resources. However, the need to represent model uncertainty using multi-model ensembles is a disincentive to the pooling of resources. Development of stochastic parametrisation schemes undermines this argument and therefore opens the door to a more scientifically informed debate about the desirability of pooling resources.

This work is relevant to both natural hazard prediction and climate change prediction. It is being submitted to the former but could have been submitted to the latter. Perhaps the former is more appropriate because most of my research career has been focussed more on prediction of natural hazards.

I have spend much of my career at the European Centre for Medium Range Weather Forecasts, where I led the effort to develop probabilistic ensemble prediction systems on the medium range and seasonal timescales (including the coordination of two European Union seasonal climate prediction projects). I have won prizes from the Royal Society, the Royal Meteorological Society, the World Meteorological Organisation, the European Meteorological Society and the American Meteorological Society (Charney and Rossby Awards). I was elected a Fellow of the Royal Society in 2003 and became a Royal Society Research Professor in Climate Physics at Oxford University in 2010. I was Chair of the World Climate Research Programme CLIVAR project and sit on numerous oversight committees.

As well as being lead author and review editor of the IPCC assessment reports, I am currently a Lead Author of the Government's Foresight Report on the use of Science to help society prepare better for Natural Disasters. My research over the years is particularly relevant to this area.

You can read this paper at <http://onlinelibrary.wiley.com/doi/10.1002/qj.1923/full> (open access)

Jane Strachan

Investigating Global Tropical Cyclone Activity with a Hierarchy of AGCMs: The Role of Model Resolution

Tropical cyclones are among the most destructive environmental hazards, with intense, landfalling storms leading to significant socioeconomic impacts. Tropical cyclones account for four of the five most costly insurance losses from natural disasters over the period 1950 to 2009 (Munich Re, 2010), with U. S. hurricanes responsible for the highest natural catastrophe insurance losses. It is therefore essential that risk assessment takes into account our best understanding of how the naturally and anthropogenically varying climate system modulates storm behaviour.

The challenges addressed

- Assessment of risk related to tropical cyclones currently relies heavily on limited and often inhomogeneous historical data, which neglects the effect of a non-stationary climate system on the variability of risk.
- Dynamical global climate model (GCM) simulations offer a way of broadening our insight into tropical cyclone risk; however, this relies on the ability of GCMs to sufficiently simulate various aspects of tropical cyclone activity.
- It is essential that we address whether coarser resolution GCMs used for climate investigation and projection, and increasingly to estimate weather and climate risk, are capable of simulating tropical cyclones activity with skill.

The work presented in the paper, undertaken by the High-Resolution Climate Modelling Group at the University of Reading, documents a systematic investigation of the ability of climate models to simulating tropical cyclone activity, with a focus on investigating the tropical cyclone information gained as we increase model resolution.

Dynamical models of the global climate system are very powerful tools, and as computational capability increases, so does our ability to run these climate simulators at higher and higher resolutions, allowing the simulation of high-impact weather events in a global climate context. Given the processes involved, the ability of these models to simulate tropical cyclogenesis is a stringent test of model capability. This shows that insurance industry needs are really challenging the climate modelling community, driving exciting new research questions and the quest for even higher resolution and necessary computing power to match. Given the huge expense involved in operating high-resolution GCMs, it is imperative that we quantify the costs/benefits involved.

The Approach

The GCMs used in the study are based on the Hadley Centre Global Environmental Model, developed at the UK Met Office and to higher resolutions by the UK High Resolution Global Environmental Model team and the U. K. Japan Climate Collaboration, projects which exploited some of the world's most powerful supercomputers in the Japan, Germany and the UK.

Using a single model formulation, adjusting the grid-spacing only, allows the impact of resolution to be investigated independent of model formulation. Tropical cyclones are extracted from ensemble simulations using an objective, resolution-independent feature-tracking algorithm with identification criteria based on physical understanding of tropical cyclone systems. Storm activity identified in the model simulations are compared against available observations and additionally against storms tracked in reanalyses, which are used to bridge the comparison between tracked GCM data and observational data.

The horizontal resolutions assessed in this study range from approximately 270km to 60km, representing the resolution of models that can currently be run in coupled atmosphere-ocean mode for multi-century simulations. This may seem coarse in terms of the high spatial detail of tropical cyclones, but the ability to run global climate models for multiple centuries presents a unique opportunity to broaden the industry's assessment of the varying location, frequency and intensity of tropical cyclones.

Key findings

- The annual number of tropical cyclones and their geographical distribution are well captured at resolutions of 135km or higher, particularly for Northern Hemisphere basins.
- Simulating the interannual variability of storm occurrence requires resolutions of 100km or higher, with the level of skill being basin dependent.
- GCMs are increasingly able to capture the interannual variability of the large-scale environmental conditions that contribute to tropical cyclogenesis.
- Resolution is critical for simulating storm intensity and convergence to observed storm intensities is not achieved in the resolutions assessed, a well know issue in the community, but one which is now being addressed by statistical and dynamical downscaling approaches.

In light of the findings, it is recommend that GCMs be run at resolutions of 100km or higher for multi-decadal to multi-century model simulations that are to be used to investigate the impact of climate variability on tropical cyclone location and frequency. For intensity assessment, these resolutions can only provide an indication of relative change; for assessment of the absolute tropical cyclone intensities, very high-resolution short-term simulations, or dynamical-statistical downscaling would need to be adopted.

Implications for the insurance industry

- High-resolution global climate models, run for multi-century simulations, capture a range of both temporal and spatial scales that are known to modulate tropical cyclone activity. GCMs therefore provide a unique modelling environment to investigate how climate variability, on seasonal to interannual to multi-decadal time scales, modulates tropical cyclone behaviour and hence risk.
- The findings underpin the use of high-resolution GCMs simulations of tropical cyclone for integration into catastrophe risk assessment: where GCMs show skill in simulating tropical storm activity, they offer an alternative source of data to complement observational data. This will broaden the assessment of tropical cyclone risk and stands to revolutionise the industry's approach to catastrophe modelling.
- The use of a process-based model rather than a statistical approach, will allow the industry to gain a physical understanding of tropical cyclone variability, with strong potential for improving predictability. Skill in the simulation of interannual variability of extreme events, for example, is crucial for seasonal prediction capability.
- The study provides validation for the use of GCMs, with future scenario forcings, to investigate how tropical cyclone activity will respond to climate change.
- GCMs by definition produce global simulations, and therefore lend themselves to assessment of risk in parts of the world where there are limited observational records. A global approach also allows investigation of large-scale drivers of global teleconnections and the connected nature of weather-related risk.

You can read this paper at <http://journals.ametsoc.org/doi/abs/10.1175/JCLI-D-12-00012.1>
(subscription required)

Alan Thomson

Quantifying extreme behavior in geomagnetic activity

Space weather is a natural hazard that threatens the continuous and safe operation of modern technological systems. Our exposure to space weather is a direct result of the global reach of many of these technologies and our growing reliance on interconnected space- and ground-based hardware and networks.

However we only have about fifty years of space-based measurements of the Earth's neighbourhood to give us clues on what we can expect from space weather. Even the global, ground-based, geomagnetic record, which follows changes in space weather, only stretches back continuously for some 160 years. The Sun, the driver for space weather, has magnetic activity cycles of around eleven years. This therefore gives us access to only relatively few 'seasons' of direct space observations from which to determine the worst space weather that we could experience. However, quantifying the extremes in geomagnetic activity, from the geomagnetic record, would be an important step forward in assessing just how severe space weather could get. This is what we studied in our paper.

Extreme geomagnetic activity has itself very practical consequences for technological systems. On the ground, extreme geomagnetic variations have an impact on navigation accuracy and on the uninterrupted operation of power grids and pipeline networks. Because of the interconnectedness of the modern world, the possibility of an extended period without electrical power clearly has knock-on consequences for the public, business and governments alike.

Space weather is also a concern for aviation, particularly on cross-polar routes, and in other transport sectors, where navigation, power and communications may all be affected. Concerns are emerging in the communications sector, where space weather may affect wireless and satellite links and also in the financial sector where, for example, satellite based systems are relied on for transaction time-stamping. An extensive discussion of the spectrum of space weather impacts is given in a Lloyd's '360 Risk Insight' report: http://www.lloyds.com/News-and-Insight/360-Risk-Insight/~media/Lloyds/Reports/360%20Space%20Weather/7311_Lloyds_360_Space%20Weather_03.pdf

Well-known examples of space weather impacts on power systems include the March 1989 magnetic storm that resulted in a blackout across Quebec and reports of damage to US nuclear plant power transformers. More recently a less severe magnetic storm in October 2003 led to a blackout in Malmö, Sweden, and wider reports of transformer damage, for example in South Africa. However, the 'Carrington Event' of September 1859 is regarded as the most extreme space weather event in the modern record. The Carrington Event caused fires at telegraph offices (the 'Internet' of the day), electrocution of telegraph operators and observation of the Aurora Borealis at near equatorial latitudes. Unfortunately only patchy data, including patchy magnetic data, exists on the Carrington Event, probably making it impossible to ever fully quantify.

In our study – published in the American Geophysical Union journal 'Space Weather' - we used a number of decades of one-minute averaged magnetic data from magnetic observatories across Europe. We used the technique of extreme value statistics to explore the extremes in these magnetic field variations and in their one-minute rates of change. We applied de-clustering and thresholding techniques to the magnetic storm data to properly isolate the truly large events. Europe is an excellent 'laboratory' for such a study, containing a dense network of high quality, long-operating magnetic observatories across a wide span of latitude and longitude. Because space weather and geomagnetic hazard is a continental to global scale phenomenon, what we learn from the European data will readily apply across the world. One minute sampling is also appropriate for the phenomenon as it captures variability that is smoothed out by other reported magnetic measures and indices.

The extremes in our data were expressed in terms of the variations that might be observed every 100 and 200 years in the horizontal strength and in the 'declination', or compass direction, of the magnetic field. Rapid changes in the magnetic field in the horizontal plane allow us to estimate the hazard to power grids, pipelines and even to railway networks. Rapid and large amplitude changes in the compass direction will clearly affect navigation applications, for example, the precision navigation of undersea wellbores to oil and gas targets.

Our paper represents the first time that magnetic data have been treated in this way, and in a manner intended to be accessible by engineers and risk analysts keen to estimate impact on technological systems.

We found that both the measured and extrapolated extreme values generally increase with latitude though there is a marked maximum in estimated extreme levels between about 53 and 62 degrees north, including the UK. Across Europe compass variations may peak at 8 degrees per minute, and horizontal field changes may reach 4,000 nanotesla per minute, in one magnetic storm, once every 100 years. For storm return periods of 200 years the equivalent figures are 11 degrees per minute and 6,000 nanotesla per minute. For context, in the UK the Earth's magnetic field is approximately 50,000 nanotesla in strength and the compass direction is currently around two to five degrees west of true north, depending on location. Both of these measures naturally change only slowly over many years due to processes acting within the Earth's liquid iron core.

How have our results been used in practise? In the UK the figures have informed the government's National Risk Register in 2011 and 2012. The data have also been used in a study by National Grid Company and British Geological Survey to determine the 'hot spots', that is, the 'at risk' transformers in the UK high voltage network. A Royal Academy of Engineering report on space weather and technological risks, due this autumn, will contain a summary of these activities and expected impacts. The author has been invited onto a North American Electrical Reliability Council panel to help assess the continental US exposure to space weather. Our work has therefore already helped the power industry and governments to begin to properly quantify the risks faced by society through loss of electrical power.

You can read this paper at <http://nora.nerc.ac.uk/14806/1/extremesanalysis.pdf> (open access)