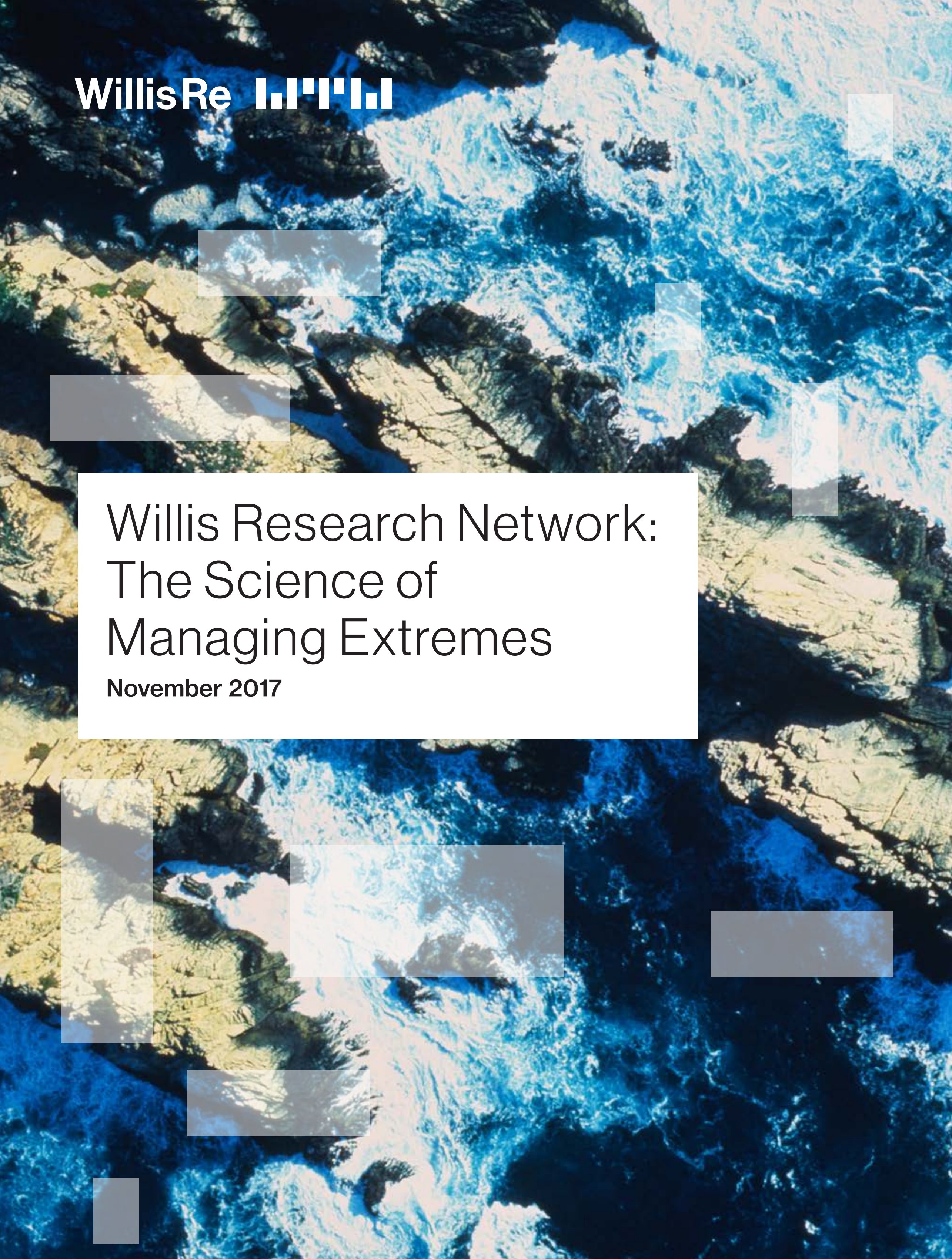


Willis Re

# Willis Research Network: The Science of Managing Extremes

**November 2017**

# Foreword

As we enter the 12th year of the Willis Research Network (WRN) it is inspiring to witness the continued and flourishing of collaboration between academic and industry partners across the world.

The tragic disasters in the US, Caribbean, Mexico, Peru, India and elsewhere in 2017 have issued us all with new demands in our collective mission to understand these risks to protect the lives, livelihoods and assets of exposed populations worldwide. The 2017 WRN compendium illustrates leading edge research and application across a full spectrum of risks including flooding in south-east Asian Cities and El Niño related modeling in Latin America. With so much news from climatic events this year it is important to remember the ever present threat from seismic risks. This year's case studies illustrate particular focus on our seismic risks research programme including tsunami, volcanic eruptions, earthquake vulnerabilities, liquifaction and risk communication.

The WRN continues to support some very long-term relationships and partnerships and none more so than that with Professor David Stephenson at Exeter University and Dr Greg Holland at NCAR in Colorado with Dr James Done our WRN Fellow since 2008, celebrating a decade of industry-academia collaboration. We cover these in this edition and it is upon these enduring and trusting relationships that great research and work flourish, complimented by our newer partnerships and members.

Looking ahead, the discipline we still call catastrophe risk modeling is about to go through a revolutionary expansion. A growing concern around climate and natural hazard risk is creating demand to apply our sector methods, metrics and models far more widely. We are seeing a concerted push by governments and agencies to expand coverage to developing countries and widen access to new user groups and structural needs beyond the insurance sector alone. At the same time we are seeing a new generation of risk modeling platforms and open architecture frameworks that will expand these possibilities. The next five years is likely to see a transformation of the risk modeling adoption and the WRN will be at the heart of that new landscape.

Finally it's my pleasure to thank all our WRN members and Willis Towers Watson team that drives our work forward and our clients and market partners that make it possible, collaborate on projects, employ the research and provide our sense of purpose.

**Rowan Douglas CBE**
Chairman, Willis Research Network

# About Us

The Willis Research Network (WRN) is an award winning collaboration between academia, the finance and the insurance industry. The WRN was created and formed to strengthen the practical links between science, policy and industry in order to tackle the key risks the global insurance and reinsurance industries are facing. Through the WRN, Willis Towers Watson has managed to team up with more than 50 world-leading and renowned institutions to develop dynamic and innovative solutions to overcome challenges of risk and resilience.

The vision of the WRN is to enable clients to make better and more informed decisions in an increasingly complex, interconnected and uncertain world. Since its inception, the WRN has sought to help clients, private and public institutions gain the greatest possible understanding of risk, allowing the insurers and the reinsurers to deliver effective financial protection at optimum terms. The WRN has confronted the challenges of managing risk and delivering resilience within environmental systems, financial markets and public policy as well as developing multidisciplinary, global and collaborative research programmes with specific and applied products. Through research, the WRN can deliver long term strategic tools for both Willis Towers Watson and clients, incorporating solutions into insurance sector models, methodologies and transactions to improve the market's understanding, resilience and coverage of risk. Alongside our longer term program we continue to identify projects with tangible outputs for our clients within shorter frame deliverables, allowing us to respond to market movements and deliver solutions as they are needed.

The WRN is involved in disciplines such as climate and weather, hydrology, seismology, volcanology, economics, terrorism, cyber, technology risks and data, casualty analytics and emerging risks. The research concentrates on risk management, the sharing of the costs of natural and man-made hazards with emphasis on the built environment, infrastructure, supply chain risk, contingent exposure, credit risk, cost of capital and the future of the insurance market. The WRN assists the research behind hundreds of peer-reviewed academic articles including a number of pioneering research papers and journals.

# The Willis Research Network Research Pillars

- Economic Capital and Enterprise Risk Management
- Natural Hazard and Risk
- Man-made and Liability Risks
- Core Technologies and Methods

# Flagship projects
# Hail Hazard Assessment

## Knowing Where Hail Will Likely Occur

Billion dollar losses from hail damage have become a common sight over recent years not only in North America, but also in other continents such as Europe or Australia. Usually only a single thunderstorm cell is producing large hailstones that severely damage cars, buildings and infrastructures. But how can we know where hail may strike next? Unlike other small-scale perils, hail hazard is not concentrated in clear geographical regions such as faults or coastlines. In addition, hailfall is not directly measured by current meteorological monitoring systems, as no automated detection system is routinely used by the weather services.

Research at the Karlsruhe Institute of Technology (KIT) focuses on identifying hail-bearing storms in satellite and radar image archives and deriving their climatological distribution. Only the most severe thunderstorms, frequently rotating 'supercells', generate updrafts strong enough to support large hailstones which grow by accretion of supercooled water droplets. Novel algorithms have been developed to detect signatures of these phenomena in remote-sensing datasets and to extract the extent and severity of the storms. Numerical model reanalysis helps to select the most hail-specific signals across a large range of climate zones. This information is then used by Willis Towers Watson for stochastic hail risk modelling.

## Modeling Hail Events in Europe

During some of the major past hail events in Europe, in particular Andreas (Germany, 2013) or Ela (France/Belgium 2014), several distinct hailstorms contributed almost equally to the damage, while still being associated with the same large-scale weather pattern (the eponymous low pressure system).

This complex structure is crucial in understanding their large damage sums. This motivated further research to improve the representation of such groups of storms in the latest version of the Willis Research Network (WRN) European Hail Model. It includes the purely stochastic generation of hailstreaks constituting an event, with the distribution being derived from past events. As a result, the tail of the loss distribution for modeled events is now much closer to historic losses.

## Hail Hazard in Australia

The strong concentration of population and exposed values in the capital regions of the Australian states means that losses are also concentrated in relatively few catastrophic events such as the 1999 Sydney hail storm or the 2014 Brisbane hailstorm. Relatively little was known about the spatial distribution of hail hazard across the continent. In an ongoing collaboration with natural catastrophe specialists from the Willis Re Sydney office and satellite experts at NASA Langley, WRN scientists have designed a hail hazard map of Australia based on cloud top and radar detection methods. A particular challenge was the identification of hail hazard in the tropical Northern part of Australia, where thunderstorms are abundant, but very few cases of hail are reported. However, the methods developed for the WRN European Hail Model were successful in generating the most plausible pattern. Hail hazard in Australia is highest in north-eastern New South Wales around Grafton and generally high in a strip near the coast from Brisbane to Canberra. South-east Queensland, New South Wales and Victoria, but also parts of Southern Australia, Western Australia and Tasmania have significant levels of hail frequency. The knowledge on hail frequency can be used to adjust premiums or justify investments in hail-proof equipment and infrastructure.

## Karlsruhe Institute of Technology

Working with experts at the leading European hail risk research institution, Willis Research Fellow Dr. Heinz Jürgen Punge has been liaising with the Analytics and Model Development team in London and regional offices to identify key applied aspects of hazard quantification.

KIT

Karlsruher Institut für Technologie

Flagship projects

# Modeling Volcanic Ash Dispersal in the Atmosphere

There are more than 1,500 active volcanoes in the world. On average 12 eruptions per year can be expected globally, some lasting several weeks. Once in the atmosphere volcanic ash particles are transported over large distances by wind before settling on the ground. Volcanic research has evolved significantly in recent years, mainly thanks to the incorporation of deterministic and probabilistic tools to better understand, quantify and manage volcanic hazard and risk.

Several tools have been published in the last decade by scientific groups around the world working on the various geological hazards associated with volcanic eruptions. These allow modeling of the damage caused by volcanic products such as lava flows, pyroclastic density currents, and volcanic ash fallout. Although these tools are primarily aimed at helping governments and civil authorities to manage volcanic crises and their impact on nearby economies, the aviation industry is starting to pay attention. This is partly owing to events such as the 2010 Icelandic eruption, which raised awareness about the vulnerability and exposure of intertwined industries to volcanic events.

Atmospheric dispersion of hazardous substances resulting from volcanic eruptions or sand storms can affect all air transport stakeholders such as airlines, airports, air navigation service providers, and of course passengers. Volcanic ash dispersal models are used to predict atmospheric concentration of particles in time and space based on:

- Meteorological conditions (mainly wind)
- Eruption scenario (eruption duration, mass eruption rate, ash emission height, physical properties of particles)

To bridge the gap between science and industry, our new Willis Research Network member, the Barcelona Supercomputing Center (BSC), a world-renowned institution in the development of computer applications for science and engineering and leaders in modeling volcanic ash dispersal in the atmosphere, is working on the development of solutions for air traffic management (ATM) in the event of volcanic eruptions. This initiative is aimed at merging volcanic ash model forecasts and ATM databases (airports, routes, Flight Information Regions and actual flights) to evaluate impacts based on user-defined criteria; such as concentration thresholds, and maximum engine dose for volcanic ash at different altitudes. The tools can be adapted to account for the impact of mineral dust and other hazardous substances in the atmosphere.

We are confident that research collaborations such as these have the potential to add value and help the aviation sector in the event of a volcanic eruption and volcanic ash dispersal.

## Barcelona Supercomputing Center

The Barcelona Supercomputing Center - Centro Nacional de Supercomputación (BSC-CNS) - is a national supercomputing centre specialized in high-performance computing (HPC). They manage MareNostrum, one of the most powerful supercomputers in Europe. Their mission is to research, implement, manage and transfer technology and knowledge in the area of HPC to facilitate progress in a variety of scientific fields, with a special emphasis on Computer, Life, Earth and Engineering Sciences. They joined the WRN early 2017.

BSC
Barcelona Supercomputing Center
Centro Nacional de Supercomputación

Flagship projects

# Ground Motion Risk Profiling

Subsidence is the largest insured, natural ground motion peril risk affecting residential property in the UK and affects as many properties on an annual basis as floods. Historical analysis of claims data and volumes demonstrates a highly variable incident rate and cost. Information from the Association of British Insurers (ABI) shows volume varying from 28,000 to 55,000 claims per annum with yearly costs of £140 million - £390 million (165 million – 460 million Euro) in the last decade. It is forecast to significantly grow with climate change (research by Zurich Re, Environmental Agency and Lloyd's of London). European research (sponsored by Swiss Re) predicts a 50% increase in soil subsidence across Europe by 2040, following on from a 50% increase they reported in 2006 over the period 1951-1970.

In addition to this European research there are two further pieces of work in the UK which further support the forecast of increased subsidence frequency:

- The Environment Agency predicts climate changes with increased flood and drought, with a drought equivalent to 1976 occurring every 10 years. It was the 1976 drought, and the extensive subsequent subsidence incidents that lead to the UK Government working with the insurance industry to include insurance cover for 'subsidence, heave and landslip' within the building insurance policy.
- The British Geological Survey (BGS) undertook research on behalf of the Lloyd's of London insurance market and predicted a 29-34% increase in subsidence in the next 10 years in the UK. This increase will be greatest in areas under the London Clay formation (above which sits the UK's largest population!)

## H-Ground – A Unique Ground Motion Risk Profiling Service

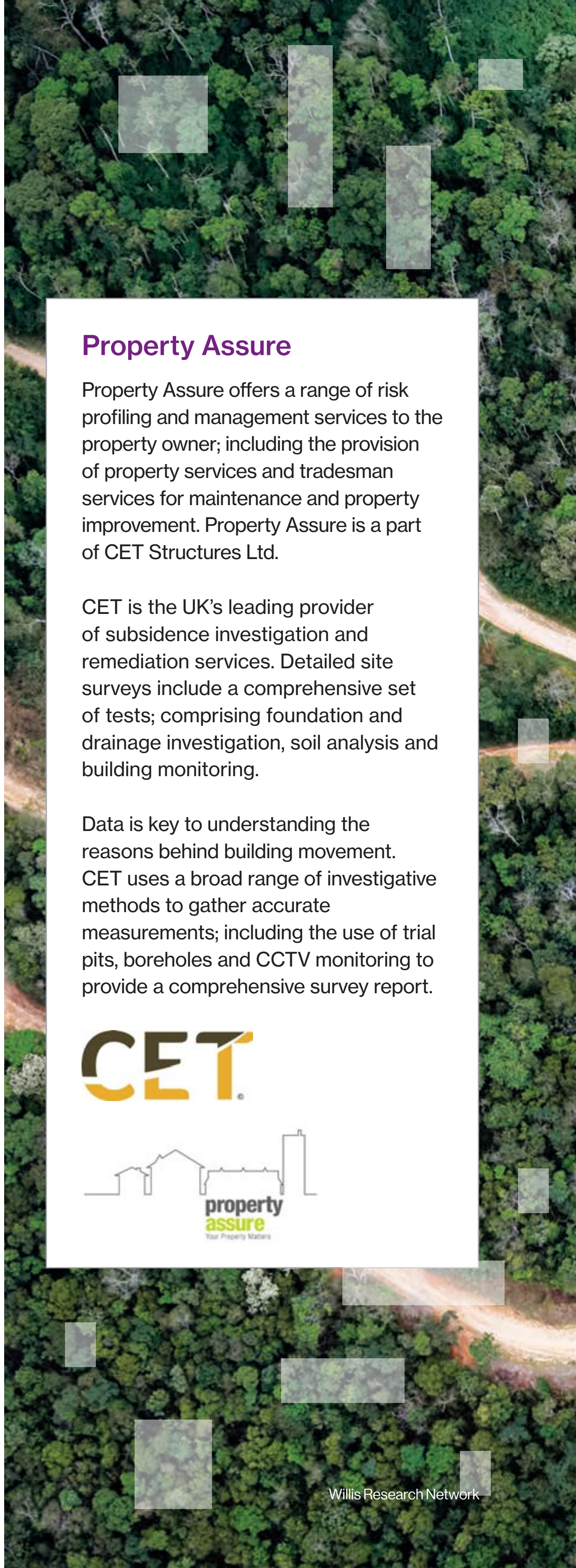
This WRN collaboration with Property Assure (as part of their European Space Agency project) has supported the design, development and testing of a new area and property specific subsidence risk profiling algorithm that can be applied to book profiling, underwriting and claims management and ultimately catastrophe Modeling.

The algorithm (Core Subsidence Hazard Score) has integrated the key drivers of subsidence:

- Property age, type and construction (as this determines the extent of the foundations),
- Soil type (particularly those susceptible to shrink swell, and fine soils that can be washed away),
- Tree location (roots in shrink swell soil account is a major cause of subsidence)
- Drainage (age and type)

The Core Subsidence Hazard Score is further augmented with specific satellite data that shows actual extent and history of ground motion. The model is validated against Property Assure's significant database of actual subsidence claims and further calibrated by the National Physical Laboratory.

The model is in demonstration testing, and focussed on the area within the M25 (London, UK), however will be readily scaled upon testing completion.



## Property Assure

Property Assure offers a range of risk profiling and management services to the property owner; including the provision of property services and tradesman services for maintenance and property improvement. Property Assure is a part of CET Structures Ltd.

CET is the UK's leading provider of subsidence investigation and remediation services. Detailed site surveys include a comprehensive set of tests; comprising foundation and drainage investigation, soil analysis and building monitoring.

Data is key to understanding the reasons behind building movement. CET uses a broad range of investigative methods to gather accurate measurements; including the use of trial pits, boreholes and CCTV monitoring to provide a comprehensive survey report.

Flagship projects

# A Global Historical Tropical Cyclone Wind Footprint Dataset

How do I assess Tropical Cyclone (TC) risk in regions with sparse historical data? How do I validate the decay of inland TC winds in existing catastrophe models? These questions are critical to understanding the viability of re/insurance markets. The National Center for Atmospheric Research teamed up with the University of Hawaii and Willis Towers Watson to explore these questions through the development of a new global dataset of historical TC wind footprints.

The approach to modeling historical global TC wind footprints offers a state-of-the-science update to today's catastrophe models. The team modeled storm-scale winds using a parametric wind field model and then added the effects of coastlines, mountains and variable land-use using a physical model of winds close to the ground. This unique modeling approach is based on published work and is applicable to any landfalling TC worldwide.

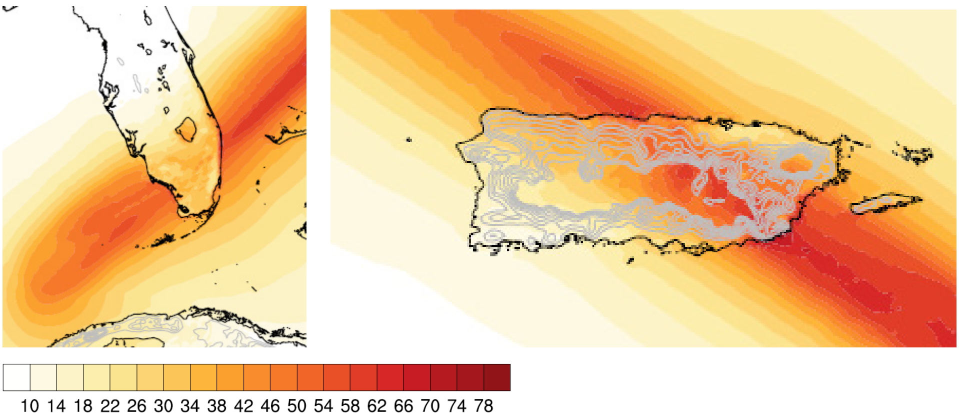
The modeled wind footprints for historical TCs compare favorably to surface station observations, existing analyses, and high-resolution numerical simulations using the Weather Research and Forecasting model. The figure below shows the simulated swath of maximum surface wind speed for Hurricane Wilma (2005) across South Florida. The simulation captures the reduction of surface winds at the coast and variable land use effects inland.

## National Center for Atmospheric Research

Senior Academic Dr. Greg Holland and current Willis Research Fellow Dr. James Done have been working with the WRN for many years, helping us improve our understanding of tropical cyclone impacts through their multi-sectoral research and variety of partnerships.

NCAR
NATIONAL CENTER FOR ATMOSPHERIC RESEARCH

**Figure:** Simulated swaths of maximum surface wind speed (m/s) with Wilma (2005) over Florida (left) and Maria (2017) over Puerto Rico (right)




Source: NCAR

A full set of approximately 200 global historical footprints has been generated and the dataset will be made available through Willis Towers Watson. Planned next steps are to couple this new modeling technology with TC hazard models to build synthetic event sets and new views of global TC risk.

# Flagship projects
# Global Risk Index

## Analysing Risk

The risk of major shocks to the global economy is increasing. The world's economy is growing, technology risks are proliferating and the interconnectivity of a global society potentially deepen the impact of any individual risk. The Global Risk Index, developed by the University of Cambridge Centre for Risk Studies, has designed metrics (such as GDP@Risk) to assess how economic production for 300 world-leading cities could suffer from any of the 22 perils in five broad categories as defined in their Taxonomy of Threats. The Centre identified these threats as the most significant risks to the global economy through an extensive study of shocks to society and the economy over the past 1000 years, and an analysis of the recent developments in the threat environment. The Lloyd's 'City Risk Index 2015-2025 ' website provides a useful example of how these analytics are deployed.

## Cascading Interactions Between Threats

As the world's trading networks become more interconnected, shocks in one place create consequences in many other parts of the world, affecting supply chains, customers, investors, and counterparts elsewhere. The impact of a shock that occurs today is more widespread and costly than ever before. Some of the most catastrophic shocks of the past have been initiated by an event which then triggers subsequent events in a cascade of escalating consequences. Examples include a war provoking a sovereign crisis, or a natural catastrophe causing a power outage which causes social unrest. The permutations of cascading events are explored systematically from threat to threat.

## How Bad Could it Get? Identifying Trillion Dollar Scenarios

The Cambridge Global Risk Index identifies scenarios of possible but improbable events that could cause more than one trillion dollars in losses. This is the point at which losses are likely to move stock markets, resulting in wider systemic effects. These can be events which impact regions of multiple cities, with wide ranging effects on trade and international business, or cascading events, where one shock triggers escalating consequences, or both.

### University of Cambridge Judge Business School Centre for Risk Studies

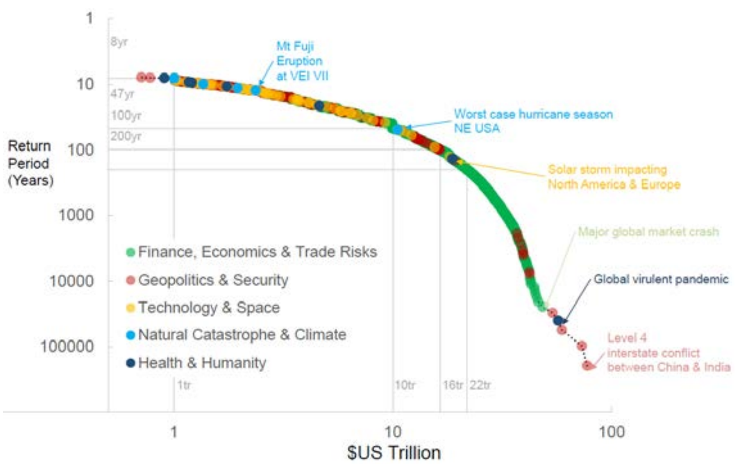
The Centre for Risk Studies provides frameworks for recognising, assessing and managing the impacts of systemic threats. The research programme is concerned with catastrophes and how their impacts ripple across an increasingly connected world with consequent effects on the international economy, financial markets, firms in the financial sectors and global corporations.

UNIVERSITY OF CAMBRIDGE
Judge Business School

## Resilience Strategy Support Tool for Corporate Risk Management

The Global Risk Index provides a holistic and quantified framework for analysis of corporate risk exposure with consistent methodologies for a normalised view across the enterprise. A corporate resilience strategy can then be designed which may include optimising insurance purchasing, reducing scenario impacts in the modeling process. Modeling requirements include a schedule of company locations weighted by value to the business and ideally an organograph detailing location interdependencies along with supply, distribution & demand networks.

**Figure:** Global Catastrophe Exceedance Probability Curve




Source: https://www.jbs.cam.ac.uk/fileadmin/user_upload/research/centres/risk/downloads/170622-slides-raisshaghaghi.pdf

Flagship projects

# UK Landslide Tsunami

## Arctic Climate Change and Tsunami

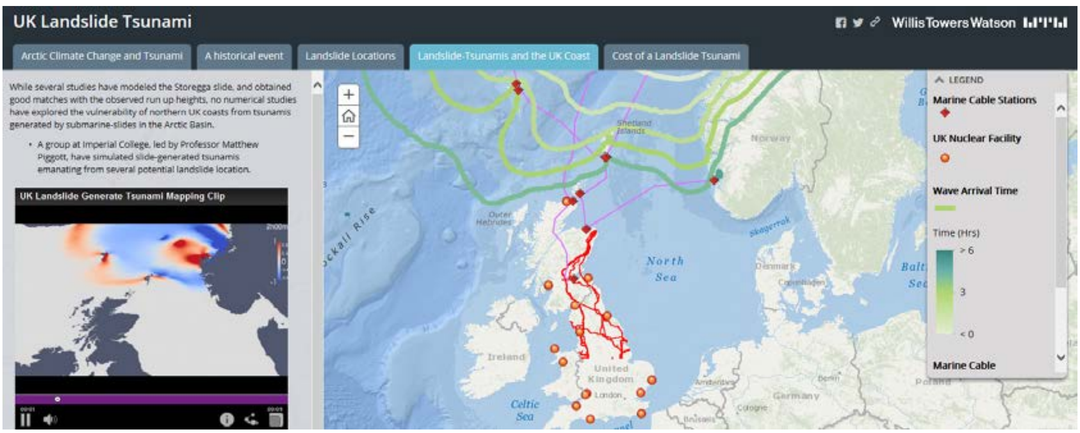
A group of scientists from several UK institutions, headed by the National Oceanography Centre and in collaboration with the Willis Research Network set-out on a four year mission to assess the hazard posed to the UK by tsunamigenic submarine-landslides in the Arctic. Large landslide events and ensuing tsunamis in the Arctic can occur perhaps in as little as a few tens of thousands of years whereas smaller events can occur at intervals of just a few thousand years. This poorly understood natural hazard is currently not part of the National Risk Register of Civil emergencies, a document outlining the UK government's assessment of the potential impact of various hazards (including natural and accidentally occurring accidents and malicious threats).

## Arctic Climate Change and Tsunami

Submarine landslides can be far larger than terrestrial landslides and many generate destructive tsunamis. The Storegga Slide in 6,200 BC is one of the largest recorded landslides. This truly prodigious mega-landslide displaced about 3,200 cubic kilometres of sediment is enough to cover the whole of Scotland to a depth of more than 40 metres. While several studies have modeled the Storegga slide and obtained good matches with the observed run up heights, no previous numerical studies have explored the vulnerability of northern UK coasts to tsunamis generated by submarine-slides in the Arctic Basin. This project investigated the potential wave heights and degree of inundation along the coasts of the UK.

## Cost of a Landslide Tsunami

It is the economic impact to the UK assets of various landslide-generated tsunami scenarios that is of particular interest to the insurance sector. A highly significant finding is that even submarine slides a fraction of the size of Storegga could produce waves that would inundate the UK coast with devastating consequences. The North to North Eastern coasts of Scotland, the Shetland islands, Orkney and Faroe islands are particularly exposed to this hazard and modeling work has shown that landslides a third of the size of the Storegga event can be equally, if not more so, damaging to the UK than this historical event.




Source: http://willis.maps.arcgis.com/apps/MapSeries/index.html?appid=f0d53a10cfd34b4797370004244b3224

### Imperial College

Imperial College's Department of Earth Science and Engineering is one of the world's leading centres that combines the study of Earth Science and Engineering.

Imperial College London

### National Oceanography Centre

The National Oceanography Centre is the United Kingdom's centre of excellence for oceanographic sciences. They provide national capability and leadership for ocean science.

National Oceanography Centre
NATURAL ENVIRONMENT RESEARCH COUNCIL

# Flagship projects

# Coulomb Aftershock Forecasts Following Large Mainshocks:

## Towards Rapid, Automated Assessment of Financial Losses

Almost all earthquakes are followed by aftershocks, and some aftershocks are large enough to cause additional damage. There also are numerous examples of aftershocks larger than their mainshock, or that are closer to an urban center, and so cause much higher losses. While there is no known way to predict mainshocks, aftershocks undergo very predictable frequency decay (the rate of shocks 10 days after the mainshock is 1/10th what it is on the first day, etc.). In addition to occurring on the fault rupture, they also occur in distinct spatial lobes. All these aftershock features can be modeled by Coulomb stress transfer. Together, these attributes make aftershock forecasting a tractable problem of immense societal and commercial importance. Despite more than 30,000 journal papers on Coulomb stress transfer, current vendor models generally ignore aftershocks, and current aftershock models use only statistical methods to forecast where and when they will strike, essentially ignoring the insights from Coulomb stress transfer.

The Willis Research Network (WRN) is sponsoring a project with Temblor, Inc. and its CEO and co-founder Ross Stein, to use Coulomb stress transfer to automatically identify the sites where aftershocks will preferentially strike, the sites where they will be inhibited, and to capture how these effects diminish with time. This will enable real-time, time-dependent post-mainshock forecasts. The project goal is the ability to modify vendor stochastic event sets to incorporate the revised quake rates, so that Willis Towers Watson and its clients can generate loss exceedance curves that reflect the rapidly changing hazard in time and space.

### Temblor, Inc.

Temblor is a Silicon Valley tech company providing personal, immediate, and credible sources of seismic risk understanding and solutions. Their free mobile and web app and daily blog have gained 900,000 users worldwide in under 16 months, and their enterprise projects for insurance and financial clients has given them an understanding of key unmet needs. Temblor's CEO Ross Stein, CTO Volkan Sevilgen, and collaborator Shinji Toda from IRIDeS of Tohoku University, are the world leaders in Coulomb stress transfer, and will lead this effort.

temblor®

Through Temblor, WRN is able to catalyse the extensive, validated research on Coulomb stress transfer into an industry tool to meet the demand for the most accurate loss estimates during evolving earthquake sequences. The Norcia-Amatrice (Italy) sequence in late 2016, and the Chiapas-Puebla-Oaxaca (Mexico) sequence in September 2017, are only two of the most recent examples of how hazard rapidly changes in the wake of large earthquakes. By adjusting catastrophe model outputs and performing stress tests based on these findings, Willis Re aims to present clients with a range of insurance options to improve their risk management strategies.

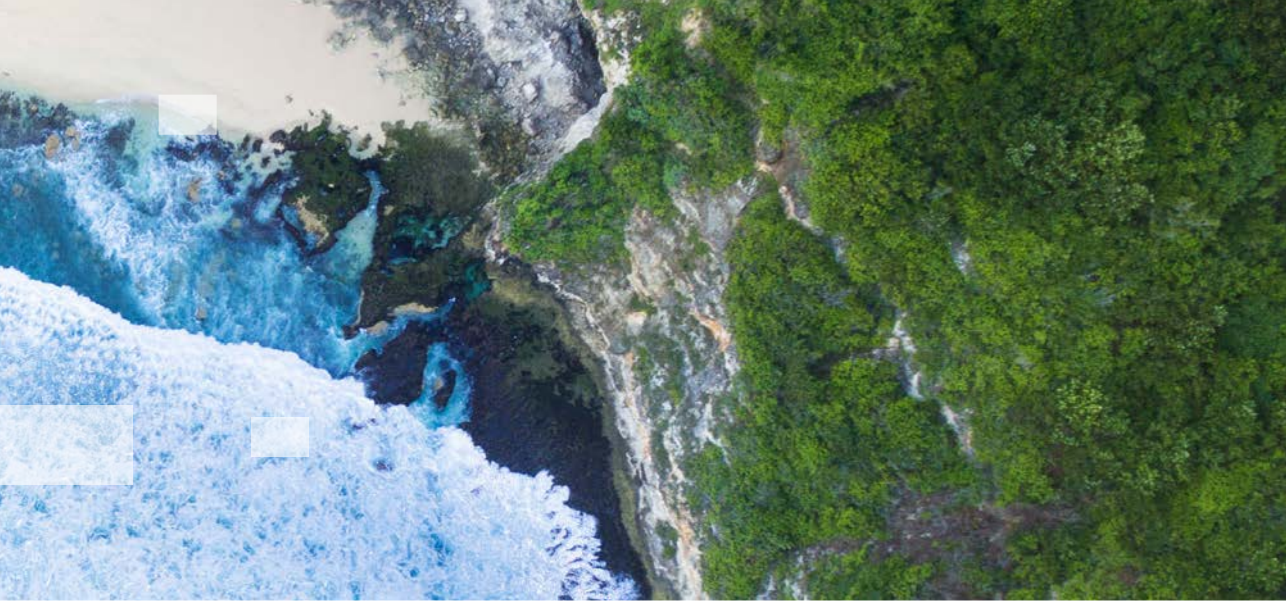
Flagship projects

# Characteristics of U.S. Tropical Cyclone Flood Insurance Claims:

## Storm Surge versus Freshwater

The record breaking losses associated with U.S. landfalling tropical cyclones (TCs) in recent decades including the catastrophic events of 2017 continue to highlight that the United States remain highly vulnerable to TC risk. While wind and storm surge flooding risks are always significant for landfalling TCs, recent Willis Research Network funded work by the Wharton Risk Management and Decision Processes Center at the University of Pennsylvania has highlighted the corresponding significant risk of freshwater flooding stemming from the associated TC heavy precipitation.

The purpose of this study is to extend the research on freshwater flood risk and simultaneously provide further insight into residential flood claim impacts by analyzing the differences in TC freshwater and storm-surge residential claim dollar losses. We used actual claim data from the National Flood Insurance Program (NFIP), the main provider of flood insurance in the U.S., resulting from 28 tropical cyclones that have affected the U.S. from 2001 to 2014. This allowed for an analysis of roughly 465,000 total NFIP TC residential flood claims which we further split by storm-surge and freshwater. This work revealed the extent to which tropical cyclones cause significant freshwater flood damage, and provided insight into how storm and location characteristics translate into losses. Study results illustrated that freshwater claims from tropical cyclones frequently exceed storm surge claims in number



and amount. It further identified variation in claims and damage by state, storm, and designated flood hazard zones. It served as a modeling framework for estimating residential losses associated with tropical cyclones.

This detailed claim information and analysis should be useful for verification of existing inland flood catastrophe model loss amounts, as well as provide a better understanding of claim characteristics for underwriting, accumulation and risk-financing purpose. It should also be useful in understanding the role that claims data can play in providing input for developing risk-based premiums and addressing issues of affordability.

### Wharton Risk Management and Decision Processes Center

Willis Research Fellow Dr. Jeffrey Czajkowski at Wharton, under the supervision of Professor Howard Kunreuther and Dr. Erwann Michel-Kerjan, has focused largely on an analysis of tropical cyclone related inland flooding through analysis of the National Flood Insurance Program, but he also keenly collaborated with other fellows, past and present, working on related themes.

Wharton
UNIVERSITY of PENNSYLVANIA

Flagship projects

# Extreme Flooding

## Clustering and Persistence

Spatial and temporal clustering of extreme events is a common behaviour of hydro-meteorological phenomena that has significantly influenced the design of vendor catastrophe models and reinsurance programs worldwide, and more generally the approach to natural hazards risk assessment.

Among natural disasters occurring between 1994 and 2013 globally, floods were the main threat in terms of number of events (43%; 2,937 events) and affected people (55%; 2.4 billion of people). Flooding was the third most expensive type of disaster in terms of recorded lost assets (US$ 636 billion) after storms (US$ 936 billion), and earthquakes (US$ 787 billion). Similarly, 1,816 worldwide inland flood events affected more than 2.2 billion persons in the period 1975-2001, indicating the enormous impacts of flood disasters on a worldwide scale.

Flood events cluster at different spatial and temporal scales according to different generating mechanisms. Within a year (intra-annual scale), some of the worst flood events happen when rainfall events occur in quick succession across a basin, such that the rainfall from the first one saturates the ground, and then the second simply adds rainwater that cannot be absorbed, leading to bursting riverbanks and breached defences. Severe flooding can also result from the downstream confluence of upstream flood waves affecting mainstream and tributaries. Across years (inter-annual scale), flood clustering appears as an alternation of flood-poor and flood-rich periods, likely related to decadal climate fluctuations.

## Newcastle University

Professor Chris Kilsby and current Willis Research Fellow Dr. Francesco Serinaldi at Newcastle University have significant expertise in the physical mechanisms and statistical analysis of extreme rainfall and river flooding. In addition, Dr. Serinaldi's research is world leading in terms of the development of methods to understand the spatial dependence and clustering of extreme processes in hydrology.

## Flood Analysis and Modeling: Data-Driven Stochastic Methods for Reinsurance Purposes

Given the intrinsic complexity and multi-scale nature of flooding, statistical analysis and stochastic modeling of publicly available streamflow data sets provide a viable approach to get insights and develop effective and efficient tools to inform reinsurance procedures. Recent research developed within the WRN (Serinaldi and Kilsby, 2016)[1] showed that flood clustering can be explained in terms of persistence. This implies that the alternation of sequences of flood events in flood-rich and flood-poor years should be expected and should be considered a natural behaviour. Persistence has also a twofold effect on the magnitude of collective risk, resulting in higher probability to observe no losses for long periods, and more extreme annual losses when floods occur. These results provide new insights into the clustering of stream flow extremes, paving the way for more reliable simulation procedures of flood event sets to be used in flood risk management strategies.

Similar to persistence, spatial dependence can describe spatial clustering of floods events. Continued research in this respect (Serinaldi and Kilsby, 2017)[2] resulted in a novel modeling approach devised to reproduce spatial dependence and temporal persistence, thus allowing the simulation of stochastic event sets matching the properties of the observed ones. This framework allows for a quantitative assessment of the likelihood of simultaneous large flood events occurring in major trans-national river basins. This is of particular interest for large regional underwriters where correlations across multiple territories can significantly influence losses and reinsurance prices.

Since the definition of flood event and corresponding duration plays a key role in reinsurance contracts, a data-driven approach was set up to identify flood events across river networks (Serinaldi et al, 2017)[3]. This methodology provides valuable information such as the likelihood of observed events exceeding a given duration and their extent, according to historical records. This information can improve reinsurance practices, avoiding one-fits-all procedures and introducing the possibility of region-tailored policies.

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[1] Serinaldi F, Kilsby CG. (2016) Understanding persistence to avoid underestimation of collective flood risk. Water, 8(4), 152.

[2] Serinaldi F, Kilsby CG. (2017) A blueprint for full collective flood risk estimation: demonstration for European river flooding. Risk Analysis, 37(10), 1958-1976.

[3] Serinaldi F, Loecker F, Kilsby CG, Bast H (2017) Flood tracking along river networks: a data-driven analysis for reinsurance purposes. Under review.

Flagship projects

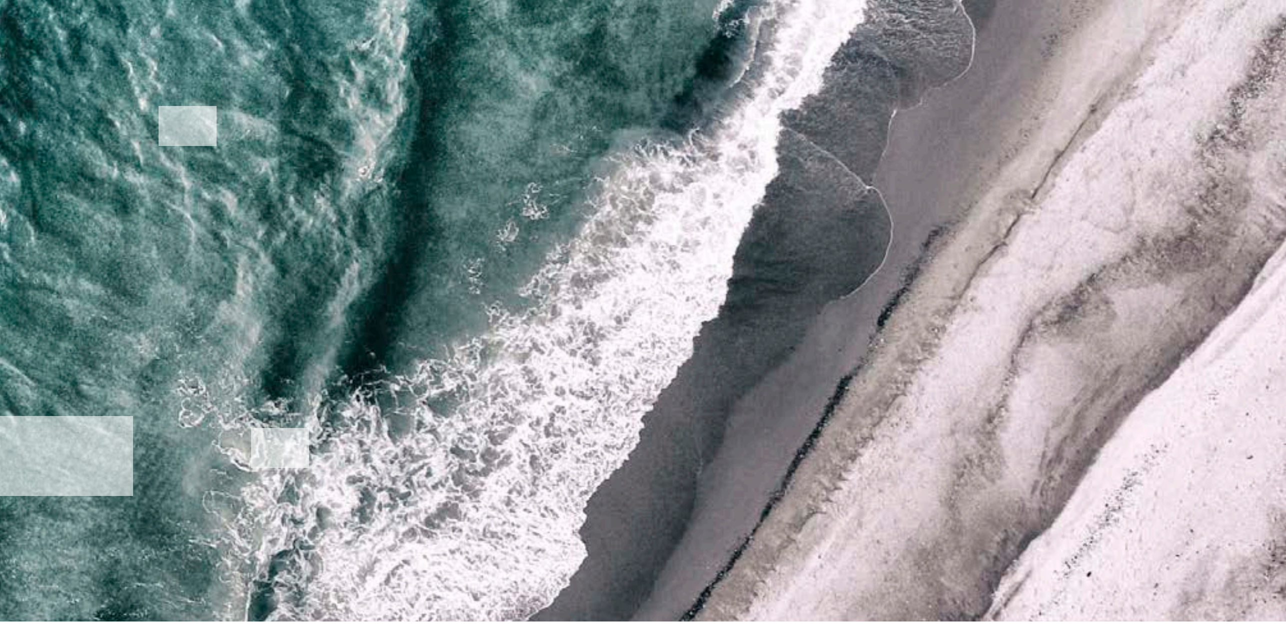
# European Windstorm Risk

## Dealing with Scarce Data

Damage due to European windstorms is typically best understood through wind gusts. Gust speed data bring quantitative knowledge, but often have short or unreliable records. It is the extreme – or tail - events that lead to damage, but their rarity makes the lack of data inevitable. Consequently estimating the magnitude and frequency of tail events becomes a challenge, especially understanding their effect on multiple places at once. Catastrophe models produce synthetic natural hazard data based on a set of desired properties, thus increasing data amounts and in turn giving more reliable tail event estimates.

## The Joy of Statistics

WRN members at the University of Exeter have developed a purely statistical framework to generate natural hazard data, which was awarded the Lloyd's Science of Risk Prize[1] in 2016 for "increasing the understanding of risk". The framework uses both extreme value theory and geostatistics. For European windstorms, together these ensure that reliable extreme gust speeds are simulated at any combination of one or more places within a given region.



## Data Science for Reinsurance

Willis Re and the University of Exeter work together producing in-house tools for understanding European windstorm impacts. One existing tool uses extreme value theory - as part of the prize winning framework - to give probability estimates for exceeding any wind gust speed anywhere in Europe. A future extension will allow Willis Re to generate over 100,000 years worth of high-resolution windstorm events in just a few minutes.

## University of Exeter

The University of Exeter joined the WRN in 2007. Dr Ben Youngman and Professor David Stephenson work closely with Willis Re's Model Research and Evaluation Team to develop statistical models, often to solve problems raised by European windstorm risk.

UNIVERSITY OF EXETER

[1] Youngman, BD and DB Stephenson, 2016. A geostatistical extreme-value framework for fast simulation of natural hazard events. Proceedings of the Royal Society of London A 472 20150855.

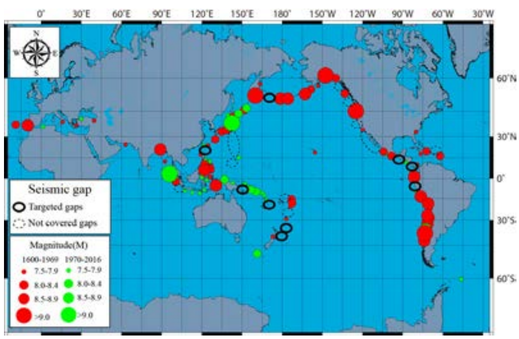
Flagship projects

# Seismic Gaps as the Sources for Future Tsunamis

A tsunami is a low-frequency high impact threat to communities and societies in coastal areas with the potential of changing the landscape in a very short time. The International Research Institute of Disaster Science (IRIDeS) at Tohoku University, a pioneering and leading centre for tsunami research, and a Willis Research Network member before the 2011 tsunami, has been producing cutting-edge research in the area of tsunami risk assessment worldwide and state of the art tools for tsunami simulation for many years. More recently, they have been studying and identifying tsunami-prone areas globally. Their results are particularly relevant for areas where new evidence is suggesting a higher risk than previously believed. This is done by accounting for seismic-triggered tsunami gap zones such as the Aleutian Islands, Central America, New Zealand, SW Pacific and the Philippines.

The IRIDeS study highlights how potential gaps in historical catalogues might not account for local, smaller scale, earthquake-triggered tsunamis. These events, which a century ago might have gone unnoticed, could cause large economic disruption today in highly populated coastal areas. IRIDeS performed further assessment of tsunami potential based on seismic gap areas and compared these with previously published results from the historical tsunami assessment.

**Figure 1**




Source: IRIDeS

Figure 1 shows the seismic gaps in the Pacific Ocean, selected according to what has been specified in some prior studies. The size of the potential earthquakes in the seismic gaps was estimated taking into account the length of the seismic gap and the largest size of past earthquakes. Numerical tsunami simulations were performed for the selected seismic gap scenarios.

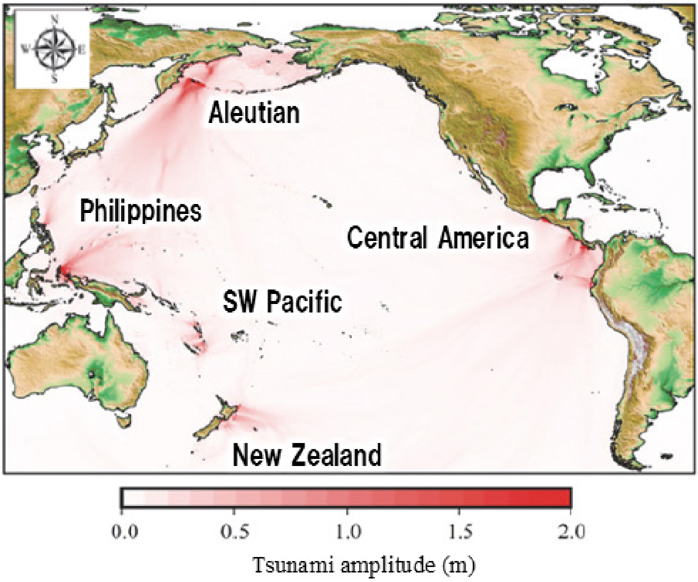
## Tohoku University

Tohoku University founded the International Research Institute of Disaster Science (IRIDeS) after having experienced the catastrophic disaster in 2011. The IRIDeS conducts world-leading research on natural disaster science and disaster mitigation, and aims to become a world centre for the study of the disasters and disaster mitigation.

TOHOKU UNIVERSITY

Figure 2 shows the simulation results of the maximum tsunami amplitude.

**Figure 2**




Source: IRIDeS

The IRIDeS findings have raised awareness in the international community, leading to collaborations with groups operating in the highlighted areas, such as New Zealand.

Flagship projects

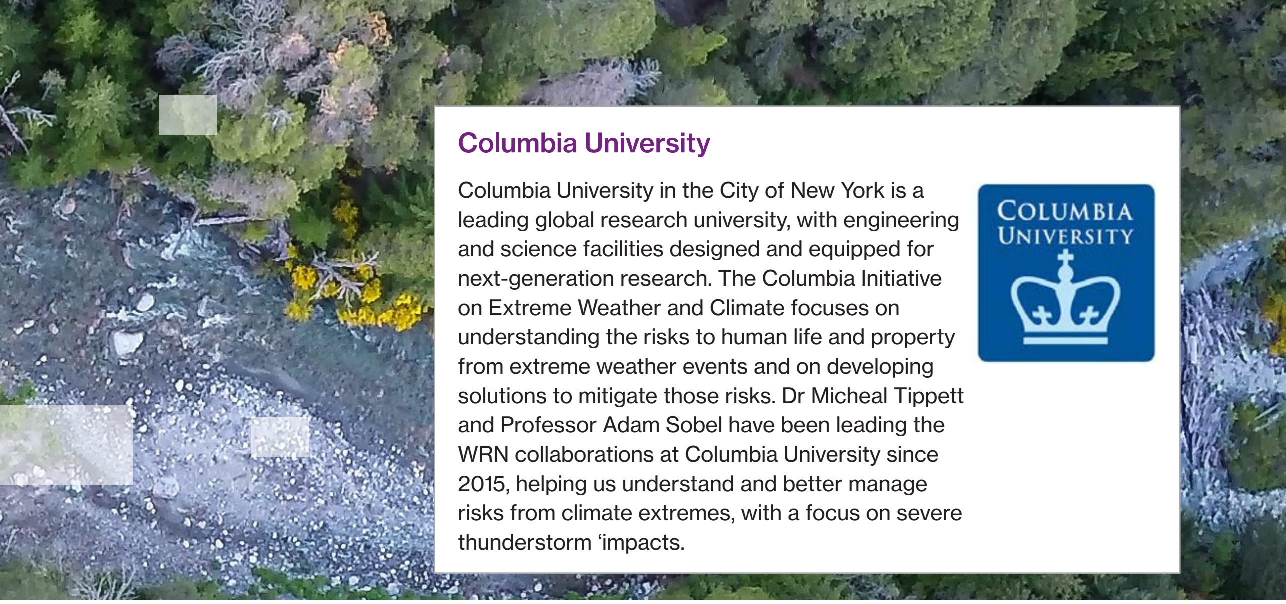
# Managing Severe Thunderstorm Risk

Thunderstorms bring a whole host of perils which can cause damage and disruption. Heavy rainfall and lightning strikes are commonly seen, but two perils in particular can cause extreme damage and destruction. When thunderstorms produce large hails stones or tornados, and sometimes both, in built up areas huge losses can follow.

Annual aggregated risk to the U.S. property industry from severe convective storm (SCS) is as high as the risk from hurricanes, based on 2003-2015 Verisk Analytics'® Property Claim Services® (PCS) loss statistics. Average annual loss (in 2016 USD) from severe convective storms is $11.23 billion compared to $11.28 billion from hurricanes. If we consider loss history from the last decade only, severe convective storm is the largest annual aggregated risk peril to the insurance industry.

## Climate Influence on SCS

Is there any way that we can predict these losses on a seasonal or annual basis? Through working with Columbia University via the Willis Research Network (WRN), we are developing ways to use the latest science relating to forecasting climate conditions such as those produced by the El Niño-Southern Oscillation (ENSO), using the latest physics-based climate models. Academic findings from the scientific community suggest that U.S. SCS frequency increases following the La Niña phase of ENSO, and decreases following an El Niño. Spatial distribution is also affected. Physics-based climate forecasting models (such as the Climate Forecast System version 2) can be used to see further into the future than every-day weather forecasting models. However, this extra lead time comes at a price, and resolution and/or complexity must be sacrificed. This means that different outputs, describing broader atmospheric features are produced at the seasonal range.



## Columbia University

Columbia University in the City of New York is a leading global research university, with engineering and science facilities designed and equipped for next-generation research. The Columbia Initiative on Extreme Weather and Climate focuses on understanding the risks to human life and property from extreme weather events and on developing solutions to mitigate those risks. Dr Micheal Tippett and Professor Adam Sobel have been leading the WRN collaborations at Columbia University since 2015, helping us understand and better manage risks from climate extremes, with a focus on severe thunderstorm ‘impacts.

## Ingredients of a Thunderstorm

These climate (or seasonal) forecast models take into account climate variations and trends such as ENSO, the Madden-Julian Oscillation, and climate change. The model outputs are used to construct a recipe developed by the WRN partners at Columbia University, which gives indices for; extreme hail events, the Hail Environment Index (HEI), and for tornados, the Tornado Environment Index (TEI). The HEI and TEI are essentially constructed from functions of wind, temperature and moisture. They describe the propensity for extreme hail or tornado events to form given the most likely atmospheric set-up over the next month. A probabilistic approach is taken to provide a range of possible futures given an initial starting state. Maps of HEI and TEI are produced to represent the coming month, which show areas with higher chance of hail and tornado events.

## Advising Industry

When the forecast is different to the observed historical record there can be clear advantage to taking note of these HEI and TEI maps. Through this work, clients can benefit from advice relating to which exposure concentrations can expect elevated levels of risk over the coming month, and be available to prepare regions for claims handling requirements and loss adjusting many weeks ahead.

# Flagship projects
# Interdependent Infrastructure

Historically earthquake engineering has focused on damage to structures due to life safety impacts but financial impacts due to infrastructure outages may also be significant. In the insurance sector, focus on infrastructure is on structural damage to large facilities and associated repair costs. However contingent business interruption losses relate more to systemic performance, which is also informative for strategic risk management.

The objectives of this project were to understand the 'best practice' in the insurance sector for infrastructure seismic risk assessment, including system performance and consideration of interdependencies.

The chosen case study location, Christchurch (New Zealand), has experienced significant damage to critical infrastructure during the Canterbury earthquake sequence in 2010-11, and unusually, much of this damage has been thoroughly documented. University College London (UCL) collaborated with Canterbury University, Orion New Zealand Ltd. and Christchurch City Council to acquire exposure and observed damage data for these two systems, which exhibit interdependency since the water supply system relies on electric pumps to extract groundwater from aquifers and to pump water into hilly areas of the city.

**Resulting Outputs**


Kongar, I., Rossetto, T., & Giovinazzi, S. (2017). Evaluating Simplified Methods for Liquefaction Assessment for Loss Estimation. Natural Hazards and Earth System Sciences Discussions, 1-32. doi:10.5194/nhess-2016-281

Kongar, I., Giovinazzi, S., & Rossetto, T. (2017). Seismic risk assessment of interdependent electric power and water supply systems in Christchurch, New Zealand. 16th World Conference on Earthquake Engineering.

Kongar, I., Giovinazzi, S., & Rossetto, T. (2016). Seismic performance of buried electrical cables: evidence-based repair rates and fragility functions. Bulletin of Earthquake Engineering. doi:10.1007/s10518-016-0077-3

Kongar, I., & Rossetto, T. (2015). A methodological hierarchy for modelling lifelines interdependencies in risk management. Proceedings of the SECED15 Conference, Cambridge, July 2015.

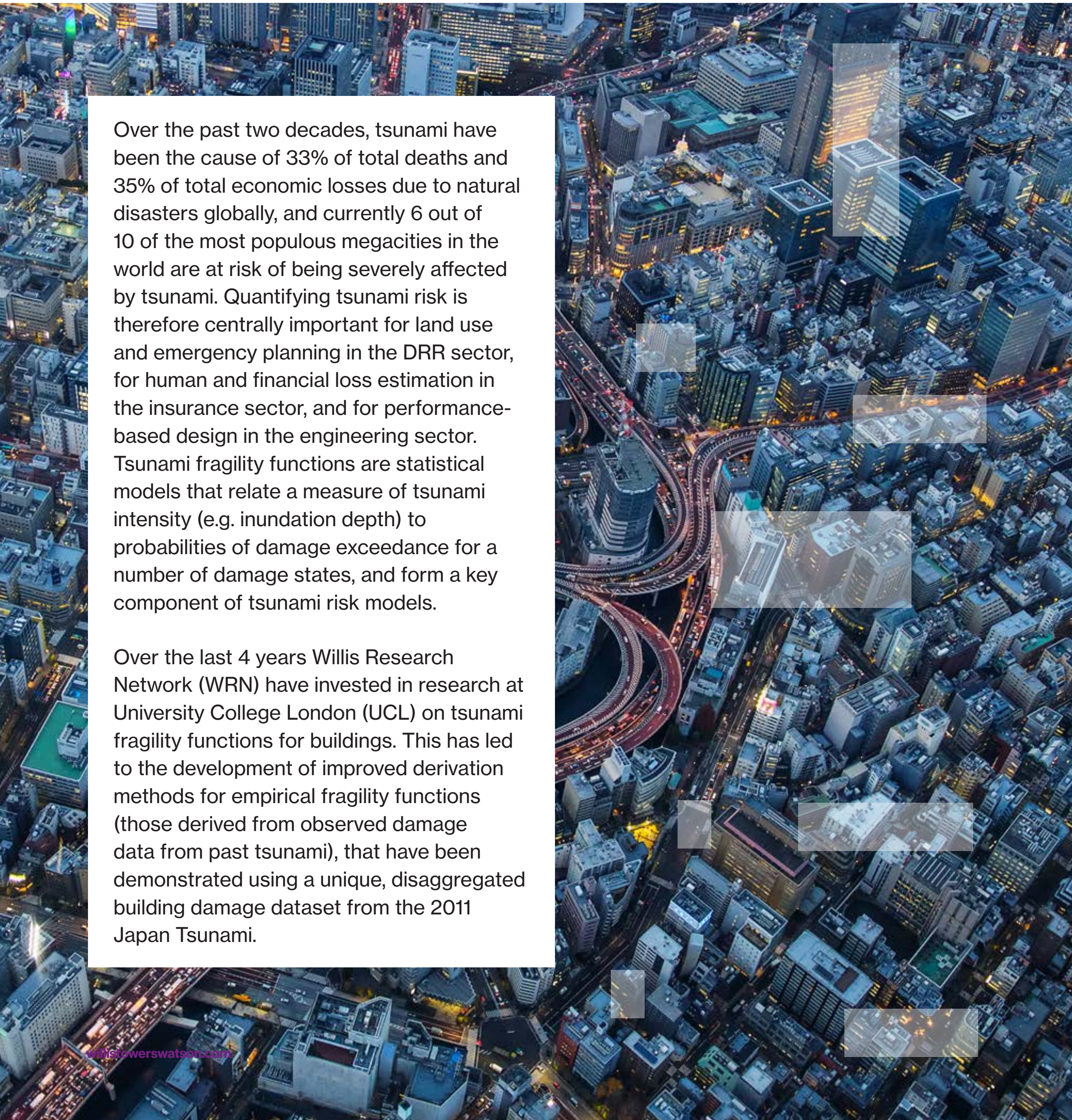
The actual damage data for the water and electricity network were used to calibrate and check the developed infrastructure performance model, which was then subjected to a 10,000 year catalogue of earthquake events. Damage to buried infrastructure from both ground shaking and liquefaction was taken into account in the analysis. The service failure frequency for both water and electric power systems was calculated, and the resulting risk curves show that modeling interdependence affects the predicted risk significantly for larger earthquake events (i.e. for longer return periods).

## UCL EPICentre

UCL EPICentre was founded in 2007 and is a dynamic multidisciplinary research group that investigates risk to society and infrastructure from earthquakes and other natural hazards.

## Flagship projects

# Tsunami Fragility of Buildings



Over the past two decades, tsunami have been the cause of 33% of total deaths and 35% of total economic losses due to natural disasters globally, and currently 6 out of 10 of the most populous megacities in the world are at risk of being severely affected by tsunami. Quantifying tsunami risk is therefore centrally important for land use and emergency planning in the DRR sector, for human and financial loss estimation in the insurance sector, and for performance-based design in the engineering sector. Tsunami fragility functions are statistical models that relate a measure of tsunami intensity (e.g. inundation depth) to probabilities of damage exceedance for a number of damage states, and form a key component of tsunami risk models.

Over the last 4 years Willis Research Network (WRN) have invested in research at University College London (UCL) on tsunami fragility functions for buildings. This has led to the development of improved derivation methods for empirical fragility functions (those derived from observed damage data from past tsunami), that have been demonstrated using a unique, disaggregated building damage dataset from the 2011 Japan Tsunami.

Fundamental research has been carried out on how time-dependent effects, ductility and overstrength (a structure's ability to maintain a load greater than its yield value) affect structural damage analysis under tsunami. This work has significant potential impact on the future design of critical structures for tsunami and has led to the proposal of highly novel approaches for analytical fragility function derivation using simplified structural analyses, which can be applied to assess buildings worldwide.

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UCL

### Resulting Outputs

**Journal Papers**

Macabuag J., Raby A., Pomonis A., Nistor I., Rossetto T., Wilkinson S. (2017). Tsunami Design Procedures for Engineered Buildings: A Critical Review. *Proceedings of the Institution of Civil Engineers: Structures and Buildings* (submitted).

Rossetto T., Macabuag J., Petrone C., Eames I. (2017). Investigation of New Relationships for Considering Ductility in the Assessment of Structures Under Tsunami Loading. *Earthquake Spectra* (submitted).

Macabuag J., Rossetto T., Ioannou I. (2017). Investigation of the Effect of Debris-Induced Damage for Constructing Tsunami Fragility Curves for Buildings, *Frontiers in Geosciences* (submitted).

Charvet I., Macabuag J., Rossetto T. (2017). Estimating Tsunami-Induced Building Damage Through Fragility Functions: Critical Review and Research Needs. *Frontiers in Built Environment - Earthquake Engineering*, Aug 2017.

Macabuag J., Rossetto T., Ioannou I., Suppasri A, Sugawara D., Adriano B., Imamura F., Eames I., Koshimura S., (2016). Investigation of Optimum Intensity Measures and Advanced Statistical Methods for Constructing Tsunami Fragility Curves for Buildings. *Natural Hazards*, Aug 2016.

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