Natural Hazards 2012

GNS SCIENCE TE PŪ AO

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Front – Tongariro eruption, 2012. Photo: Karen Britten, GNS Science/EQC
Back – Upper Te Maari crater, Tongariro. Photo: Lauriane Chardot, GNS Science/EQC
Inside – Mt Tongariro, 2012. Photo: Bruce Christenson, GNS Science/EQC

Natural Hazards 2012

Features

2012

Again this year we have been reminded of the relationship between the stunning physical environment we enjoy here in New Zealand and the natural hazards which can result from that same environment.

A key lesson learned in Canterbury is the value in understanding both the likelihood of natural hazard events and the potential impacts and consequences should the event occur. Our resilience as a nation depends on managing the impacts of future events to tolerable levels, and the research of the Natural Hazards Research Platform is integral to achieving this.

Earthquakes in Canterbury continue to cause anxiety and uncertainty in the region, but on the positive side the seismic activity is lessening and recovery has transitioned to rebuild, supported by the work and advice of the Natural Hazards Research Platform, The advice has enabled people and organisations to make informed decisions and move on with their lives.

In 2012 the research has continued to effectively inform more immediate policy decisions, such as the life-safety risk assessment in the Port Hills of Christchurch, and associated zoning decisions. As well, research has contributed to an improved understanding of seismic hazard, soil liquefaction, building performance and organisational resilience. A key development in 2012 has been the Platform's work in the area of societal resilience. The CERA Wellbeing Survey undertaken by Platform Partners with CERA and its strategic partners have tracked the recovery of individuals and communities and provided timely and valuable feedback to social agencies to better enable them to meet the changing requirements of individuals and communities.

Adversity has provided an opportunity to acquire significant new research knowledge alongside the immediate application of existing knowledge. The importance of both components cannot be overestimated, as research provides the basis for good, evidence-based policy development and it provides confidence to community, officials, and decision-makers.

Past government investment in natural hazards research has provided the baseline knowledge enhancing our response, recovery and rebuild efforts in Canterbury. We will continue to invest: Budget 2011 allocated $3 million per annum for four years to the Natural Hazards Research Platform. In addition, the Ministry of Business, Innovation and Employment's 2012 Investment Round included grants totaling over $7 million over the next four years that will support research in the economics of resilient infrastructure, the analysis of the seismic responses of underground services, and resilient infrastructure through effective organisations

This research and the lessons learned apply not only to an earthquake scenario but are also generic to other potential natural hazards such as tsunami, volcanic eruption and extreme weather, and therefore have widespread application throughout New Zealand. As a result we are better able to understand our risk and manage our exposure to natural hazards more effectively.

We can be justifiably proud of the work being done by the partners of the Natural Hazards Research Platform, GNS Science, NIWA, the University of Canterbury, Massey University, University of Auckland, and Opus International Consultants. Their collective work programme is gaining international attention and respect. I would like to congratulate all partners for their exceptional programme of work, and for this annual publication which once again is a very interesting, informative and important read.

The Natural Hazards Research Platform continues to demonstrate the value of considered and relevant research and its ability to add immense value to our lives and wellbeing.

Hon Gerry Brownlee
Minister for Canterbury Earthquake Recovery, Transport, and the Earthquake Commission

Platform Manager's Perspective

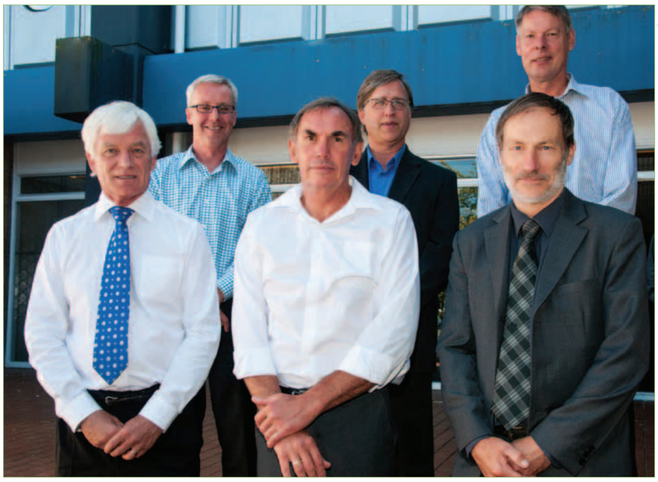
As the frequency of Canterbury's earthquakes has diminished there has been a marked transition in confidence to truly begin the rebuild. Repairs and consents for new buildings are ramping up, particularly in the last few months of 2012. In tandem we have been reminded of the threat posed by volcanoes with relatively minor, but disruptive eruptions at Tongariro and White Island. A swift and coordinated response by the Natural Hazards Research Platform saw the nation's volcanologists and atmospheric scientists working together, and highlights the value of our integrated approach.

From earthquakes to volcanoes, the catch cry for 2012 has been to learn and apply the lessons from natural hazard events. Hazard events have also raised awareness of how we communicate natural hazards science - to the public, to media, and to policy agencies. Looking back, communicating in terms of 'risk'– the consequences and impacts of events – may be more effective than communicating about 'hazards'. In this issue, we ask "What is risk?," and discuss the recommendations coming forward as revisions to the Resource Management Act.

The Platform is working closely with the Ministry of Business, Innovation and Employment (MBIE), Building and Housing Group to expedite research called for in the recommendations of the Canterbury Earthquakes Royal Commission. In this issue, MBIE's Building and Housing group provide commentary on the recommendations. The Platform's engineering researchers, along with key stakeholders, gathered for a workshop in February 2013 to coordinate the research effort.

"…communicating in terms of 'risk'– the consequences and impacts of events – may be more effective than communicating about 'hazards'."

Platform research continues to underpin evidence-based policy development, such as building code revisions based on aftershock modelling. Landslide mapping and quantifying the risk to life posed by potential future rockfalls in the Port Hills has culminated in Christchurch City Council reports and in land zoning decisions, funded in part by the Platform's Short Term Recovery programme. Scientists in the Platform's societal resilience theme have been instrumental in monitoring social well-being following the earthquakes. The CERA Wellbeing Survey is a multi-organisational, multi-disciplinary approach to tracking the public's recovery in Canterbury. These and many of the engineering, risk, and insurance lessons learned from Christchurch are gathering widespread international attention.



The Platform Management Group. Back row (l-r): Peter Benfell, Opus; Pierre Quenneville, U. Auckland; Jarg Pettinga, U. Canterbury; Front row (l-r): Murray Poulter, NIWA; Kelvin Berryman, Platform Manager, GNS Science; Terry Webb, GNS Science. Absent: Peter Kemp, Massey University

We have also made excellent progress in other areas of Platform research. This continues apace but is sometimes hidden behind the glare on Canterbury and earthquake-related matters. Of note is work on extreme wind over topography, applicable to wind loading on buildings and infrastructure, such as Transpower's towers; the vulnerability of port facilities to tsunami; much improved resolution of weather forecasts including tornados; improved resilience of electrical insulators to shorting due to volcanic ash loading; continued improvements to the hazards and vulnerability functions available in the RiskScape modelling tool; and improved societal resilience to natural hazards as a result of community engagement and education.

Many of the lessons from Canterbury are generic across all hazards, and can be applied at home, work and in our wider communities. I encourage everyone to learn more about the natural hazards around us so that we become a more resilient New Zealand.

➔ Kelvin Berryman, Manager
Natural Hazards Research Platform ■

Learning from the Canterbury Earthquakes

As a nation we will never forget those who lost their lives on 22 February 2011 – it is important that we honour them by using what we have learnt from the earthquake and rebuild to build more resilient buildings in the future.

As a result of the earthquakes we now know a lot more about how buildings perform. We have a better appreciation of how building vulnerabilities such as; unreinforced masonry, inadequate stair seating details and non ductile columns can lead to building failure and life-safety risk.

We also better understand the impact of land behaviour during earthquakes on the way buildings perform. Now land in much of Canterbury is categorised so that appropriate investigations are undertaken to enable the right type of foundations to be designed and built for the land on which they sit.

And ultimately, we now know that business as usual will never be enough post an event of this magnitude.

Last year the Canterbury Earthquakes Royal Commission delivered its findings over seven volumes.

Overall the Government has accepted the conclusions of the Royal Commission accepting 121 recommendations. A further 49 recommendations, that will require a law change, have been accepted in principle.

The Ministry of Business, Innovation and Employment has the lead on 177 of the 189 recommendations made by the Royal Commission and a large amount of work is already underway.

This includes work on revising the Building Code with regards to the structural performance of buildings.

Other key areas the Ministry is working on include earthquake-prone buildings policy, post-disaster building management and land and geotechnical issues.

With regard to managing earthquake-prone buildings the Ministry consulted with the public earlier this year - holding a series of workshops to seek a wide range of opinions. Over five hundred submissions were received on a set of proposals around timeframes for strengthening or demolishing earthquake-prone buildings.

It is important that we get this right, the decisions we make now could save lives in the future. We need to take our time and properly consider the views of those who have made submissions. Therefore decisions on earthquake-prone building policy will be made later in the year.

The Building System Improvement Programme has been developed as an overarching programme to collect and progress all the areas of work that seek to strengthen national building performance as a result of what we have learnt from the Canterbury Earthquakes. This programme addresses four key areas of work over a three to five year timeframe. The outcome of this work programme will be a system that people are confident delivers buildings that are safer in and after an earthquake.

One of the four key areas has a strong engineering and technical focus. It will continue the work providing technical guidance, information and regulatory support to those working on the Canterbury rebuild as well as identifying ways of reducing risks from natural hazards for the whole country.

The second key area of work is focussed on incorporating lessons from the Canterbury Earthquakes into the Building Code, its supporting documents and engineering design practices. This work on structural performance standards and practice will help people have more confidence in the performance of future New Zealand buildings.

Thirdly the Ministry is working to better prepare New Zealand to assess buildings post-disaster by establishing a standing team of appropriately qualified assessors and enabling a systematic and documented approach to the investigation of building failure.

The fourth and final plank of the programme is ensuring that this country's existing commercial buildings perform to expected levels and that the public are aware of any that do not. It is proposed that buildings identified as earthquake-prone will be strengthened or demolished over a defined time period.

These four key areas of work will be underpinned by a portfolio of research projects. Several research themes have been identified and include; the performance of reinforced concrete buildings, performance of steel framed buildings, unreinforced masonry, soil foundation interactions, seismic issues, general lessons from building evaluations and new building technologies.

The Natural Hazards Research Platform has a key role in supporting the Ministry's Building System Improvement Programme over the next three to five years. The expertise and test facilities of the core Platform members and their subcontractors are essential to deliver the research that is needed to deliver the research results into the Building Code, its supporting documents and engineering design practices.

The Ministry is actively working with the Platform to map out how current and planned research addresses the priorities identified in our work programme and whether there are any gaps. We will continue working with the Platform and other key players including EQC and BRANZ, to find ways to address any gaps identified.

To ensure that research answers the relevant questions in a timely and effective way we need to work together.

→ Ministry of Business,
Innovation and Employment,
Building System Performance Branch

Royal Commission recommendations, Volumes 1-7

Low-Damage Structures

The long-term social and economic costs of earthquakes are highly dependent on how the built environment responds to the event. Critical infrastructure, such as hospitals, power stations and key lifeline bridges, must be available post-earthquake to ensure optimal response and minimal disruption, while the ability of businesses to return to regular operation is vital for a functioning economy. Low-damage structures are an emerging area of research and development that offer an effective solution to this challenging problem.

Low-damage structures have, at their heart, a range of novel energy dissipation devices. These devices are used to dissipate energy and mitigate response to shaking in place of traditional design approaches that rely on structural yielding and damage to achieve their goals.

Energy dissipation devices have been developed and used in the new Kilmore St Medical Centre - one of the first new structures to rise in downtown Christchurch following the earthquakes. The Kilmore Centre uses a post-tensioned rocking steel system to allow controlled motion in an earthquake. In particular, it incorporates a range of high force to volume (HF2V) and sliding friction connections created at the Universities of Canterbury and Auckland.

HF2V connections are lead extrusion-based devices that plastically extrude lead to absorb energy and reduce response – much like making Play-Doh spaghetti or squeezing toothpaste out of a tube. Figure 1 shows the ninety-six HF2V devices utilised in the Kilmore Centre, fabricated under a contract with Alan Reay Consultants Ltd and the building owner Nobby Holdings Ltd. The sliding friction devices use slotted steel plates and different shim materials to reduce the relative motion between structural elements through friction.

Fig. 1. HF2V devices destined for the Kilmore St Medical Centre.

Fig. 2. Some of the multi-disciplinary research team (l-r): Prof Geoff Chase, Dr Geoff Rodgers (2007 McDiarmid Young Scientist of the Year for his work on these devices), and A/Prof Greg MacRae.

The devices work by absorbing energy to reduce structural response without damage to structural elements. Importantly, both device types have been extensively tested in laboratory conditions through the ‘Low-Damage Bridges and Composite Solutions’ programme funded by the Natural Hazards Research Platform, and will now see their first use in protecting communities.

These projects have been a collaboration between Professor Geoff Chase, Associate Professor Greg MacRae and Dr Geoff Rodgers at the University of Canterbury, and Associate Professor Charles Clifton at the University of Auckland, as well as postgraduate students.

Our devices will create more resilient cities and communities and lead the emergence of the new downtown Christchurch.

→ Contact: Geoff Rodgers, geoff.rodgers@canterbury.ac.nz

Images and data: University of Canterbury

National Infrastructure

The National Infrastructure Plan[1] has a vision that by 2030 New Zealand's infrastructure is resilient and coordinated and contributes to economic growth and increased quality of life.

The Plan is overseen by the National Infrastructure Unit (the NIU) located within the New Zealand Treasury. The NIU works with the various agencies responsible for the different infrastructure sectors to ensure a coordinated work programme is in place to deliver the Plan's vision. The Plan recognises the critical role local government and businesses play in delivering the Plan and the NIU has extensive networks throughout the infrastructure community.

Infrastructure refers to the fixed, long-lived structures that facilitate the production of goods and services and underpin many aspects of quality of life. Infrastructure is made up of physical networks, principally transport, water, energy, communications and social assets. The Plan is a strategic, future-focused document that places infrastructure in the context of economic and population growth. It seeks to provide common direction for how we plan, fund, build and use all economic and social infrastructure.

New Zealand's infrastructure is vulnerable to outages, including through natural hazards, and we have insufficient knowledge of network resilience at a national level. The NIU works with the Natural Hazards Research Platform and other research agencies to ensure infrastructure-related research is appropriately aligned with recognised priorities. It also facilitates and encourages increased collaboration between researchers, and with practitioners.

In the broader Treasury and Government context, the work of the Natural Hazards Research Platform provides valuable contributions to the National Security System administered by the Department of Prime Minister and Cabinet, to the Higher Living Standards initiative, to country risk assessments and to government level dialogue with international reinsurers.

This collaboration is leading to increased focus on economic and social values associated with national infrastructure together with interdependencies of infrastructure. Interdependencies are a complex area but increasing in importance as networked infrastructure systems are deployed and cyber-security becomes an increasing risk. The work of Resilient Organisations at University of Canterbury is particularly applicable to infrastructure organisations with specific research underway and uptake being encouraged.

Current activities of the NIU include development of Performance Indicators, and future infrastructure trends and scenarios, much of which will draw on Platform research including tsunami effects on ports and harbours, volcanic impacts, disaster recovery, RiskScape, and seismic response of underground services.

➔ Roger Fairclough,

Platform Strategic Advisory Group, Theme Leader in Infrastructure.
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1. *http://www.infrastructure.govt.nz/plan

Lyttelton Port of Christchurch

Soil liquefaction: Impacts on Urban Infrastructure, and Geotechnical Evaluation and Design

Liquefaction results in eruption of water and sediment from the ground as subsurface water pressures increase, squeezing out groundwater and leading to permanent ground deformation. The 2010-11 earthquakes triggered widespread liquefaction over approximately one third of the Christchurch urban area. Approximately 60,000 residential buildings, many multi-storey Central Business District buildings, and hundreds of kilometres of infrastructure lifelines were damaged. These lifelines included roads, buried potable water supply, waste water and storm water systems.

"... the best scientific record ... of data associated with liquefaction and consequent damage"

After every significant earthquake, we carried out reconnaissance and field inspections to document the manifestation of liquefaction and lateral spreading, and capture damage to buildings and infrastructure. The damage data were accompanied by excellent records of ground motions at strong motion stations. Geotechnical field investigations and aerial images depicting the spatial distribution of liquefaction and land damage also provided valuable data. Indeed, the 2010-11 Canterbury Earthquake Sequence has provided arguably the best scientific record in terms of quantity and quality of data associated with liquefaction and consequent damage.

Immediately after the February earthquakes, a series of Platform-funded projects was initiated in conjunction with the Christchurch City Council. One of these was a study of liquefaction impacts on buried pipes, which summarised the seismic events and focussed on performance of the potable water and waste water networks. These analyses characterised patterns of damage that have been verified over time with further excavations and repair of the wider networks. Older, more brittle pipes from the earliest decades of Christchurch's development failed at higher rates than more modern plastic pipes, but in some areas whole sections of network were destroyed regardless of pipe type due to overwhelming ground deformation caused by liquefaction and lateral spreading.

A Liquefaction Resistance Index Map (at right), based on mapped liquefaction and groundwater and recorded seismic data from strong motion stations was a significant outcome. This map has been used since late 2011 to inform and guide engineers and designers at the Stronger Christchurch Infrastructure Rebuild Team (SCIRT), who are repairing and renewing critical services across the city.

Our current focus is on the impacts of liquefaction on land, buildings and infrastructure, followed by the lessons learnt from the performance of various structures during the earthquakes. This work will allow us to improve geotechnical practices and procedures (national and international) applied to land investigation, design of foundations, and lifelines engineering in potentially liquefiable soils. It will also provide the basis for in-depth understanding of liquefaction and other associated phenomena.

We use state-of-the-art field investigations and experiments in our geotechnical laboratory to analyse the development of liquefaction and consequent ground deformation and their effects on various engineering structures. For example, we have recovered 'undisturbed

Left: Gel-Push sampling of Christchurch CBD soils

samples' of CBD soils from up to 12 m depth (the first such recovery in New Zealand; left). We have tested those soils in the laboratory to precisely evaluate their liquefaction resistance. The results of these tests will be used to scrutinise the accuracy of current practices for liquefaction evaluation. They will also provide critical input into advanced dynamic analyses in which effects of liquefaction on CBD buildings can be simulated in great detail. Our research is strengthened by collaborations between the University of Canterbury, Christchurch City Council, SCIRT, and with international researchers in the United States and Japan.

Nearly half of the total economic losses of ca. NZ $30 billion were related to liquefaction and lateral spreading. We have to do better in addressing liquefaction hazard and minimizing its effects in future strong earthquakes.

➔ Matthew Hughes & Misko Cubrinovski.
Contact: Misko.Cubrinovski@canterbury.ac.nz

Images and data: University of Canterbury

Right: Dr Matthew Hughes pictured with the Liquefaction Resistance Index map developed with Professor Misko Cubrinovski.

Platform-funded Students

The Natural Hazards Research Platform supports approximately 50 students across five research themes. The Platform must maintain certain critical science capabilities and develop new capabilities where needed in order to achieve important national outcomes. The involvement of graduate students in research programmes provides a source of future scientists and invigorates established research programmes.

Stuart Fraser (PhD student, Emergency Management. Massey University & GNS Science Joint Centre for Disaster Research). Stuart's research looks at the need for tsunami vertical evacuation facilities in coastal areas where there is little or no high land to evacuate to. His focus is on local tsunami, which have a travel time of less than one hour between wave generation and arrival at the coast. Stuart's research comprises numerical modelling of onshore inundation, investigation of evacuation behaviour among coastal residents and tourists, and testing different approaches to evacuation simulation. The methodology will enhance identification of communities in which vertical evacuation facilities are required and will aid decision-making in the development of such facilities.

Unreinforced Masonry: Observations of Wall-to-Diaphragm Adhesive Connections

Background

There are approximately 3,800 unreinforced masonry (URM) buildings remaining in New Zealand that provide a sense of identity for many communities. Our goal is to develop seismic retrofit solutions to significantly reduce the risk to life and preserve New Zealand's heritage townscapes.

The Interim Report released by the Canterbury Earthquakes Royal Commission recommended that: "throughout New Zealand, URM buildings should be improved by bracing parapets, installing roof ties and securing external falling hazards in the vicinity of public spaces; and. these recommendations should be implemented as soon as practicable."

Our project was funded in the Platform's recent contestable round to address these recommendations.

Wall-to-Diaphragm Adhesive Connections

The connections between walls of URM buildings are a critical to the building performing well in an earthquake. Following the Canterbury earthquakes, field observations of clay brick URM buildings revealed numerous cases where anchor connections joining masonry walls or parapets with roof or floor diaphragms appeared to have failed (Fig. 1). This was more frequent for adhesive anchor connections than for through-bolt connections (i.e. anchorages having plates on the exterior façade of the masonry walls). In many cases these failures could be attributed to the low shear strength of masonry, wide

Fig. 1. Example of insufficient embedment depth of adhesive anchors.

Platform-funded Students

Yuanzhi Chen (PhD student, Engineering. University of Auckland). Yuanzhi's research addresses the impact of high vertical ground motions on New Zealand bridges and infrastructure in a holistic manner. She is interested in the interaction between soil, foundation and structures under simultaneous horizontal and vertical earthquake excitations. The outcomes of her research will play a significant role in future low-damage earthquake-resistant design of structures, especially in near-source regions.

anchorage spacing, insufficient embedment depth of anchors, and/or poor workmanship.

Subsequently, we carried out an in-field test program to further evaluate the performance of adhesive anchor connections between unreinforced clay brick URM walls and the roof or floor diaphragm. We undertook approximately 400 anchor tests conducted in eleven existing URM buildings located in Christchurch, Whanganui and Auckland (see Fig. 2).

Our aim was to identify failure modes of adhesive anchors in existing URM walls and the influence of key variables on anchor load-displacement response, such as strength of the masonry materials (brick and mortar), anchor rod diameter size, quality of installation, and more. In addition, we investigated the comparative performance of bent anchors and anchors positioned horizontally (Fig 3).

We found that anchors positioned horizontally provided superior performance (both in pull-out strength and stiffness) in comparison to bent anchors, and an optimal rod diameter of 16mm was established. Moreover, installing adhesive anchors as per the manufacturer's instructions was critical to achieving adequate performance This study is still in progress; future research will investigate the effects of vertical accelerations (building motion in an earthquake) on the pull-out capacity of adhesive anchors.

➔ Dmytro Dizhur & Jason Ingham.
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Images & data: University of Auckland.

Fig. 2. Typical test set-up used for pull-out anchor testing.

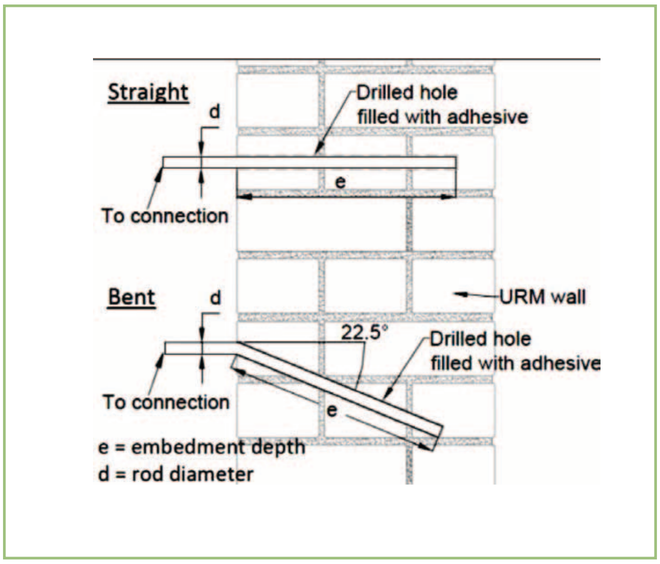
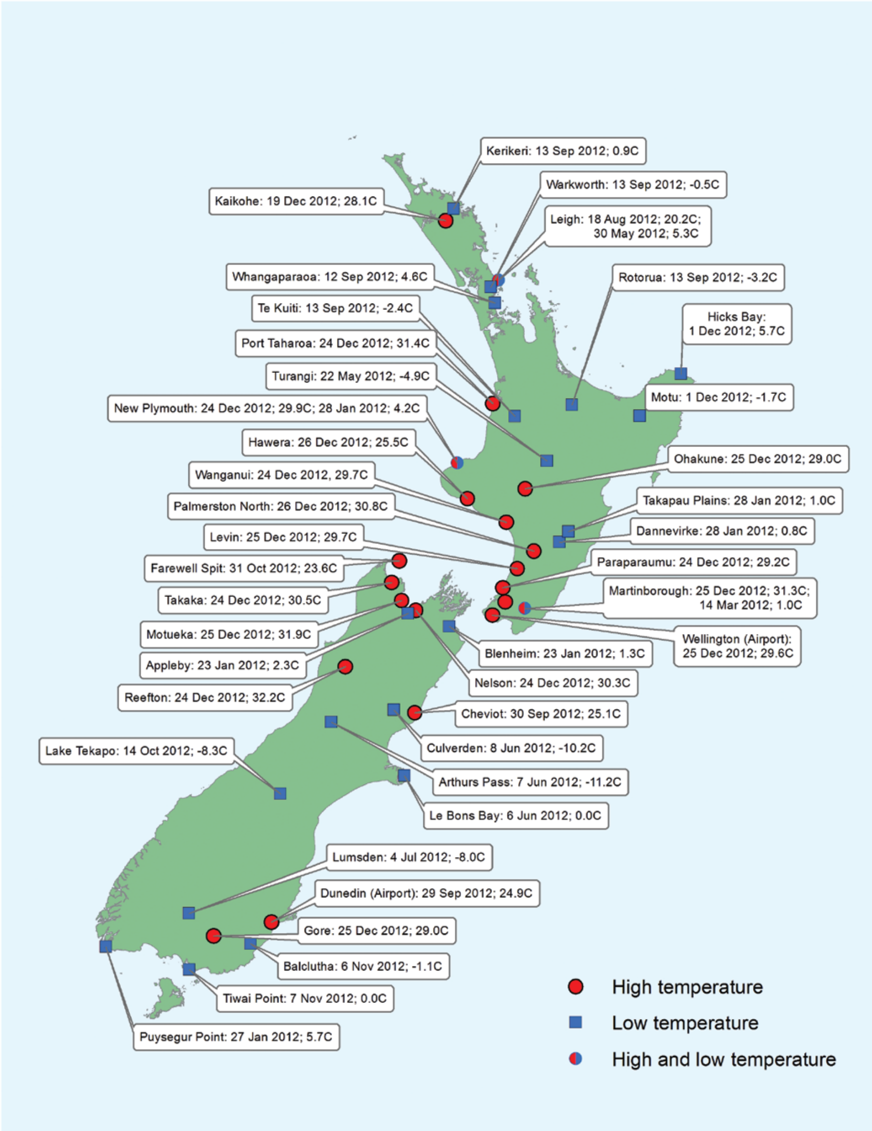


Fig 3. Typical diaphragm-to-wall horizontal & bent adhesive anchors.

Temperature

Mean annual temperatures for 2012 were below average (more than 0.5°C below the long-term average) over the northeast of the South Island, as well as for Wellington, Wairarapa, parts of the Manawatu, and between the Tararua District and the Waikato. Mean annual temperatures were generally near or slightly below average (within 0.5°C of the long-term average) elsewhere. The nation-wide average temperature for 2012 was 12.5°C (0.1°C below the 1971–2000 annual average) using NIWA's seven-station temperature series which begins in 1909. Five cooler than normal months (January, February, March, June, and November) and three warmer than normal months (July, August, and December) characterised the year.

The highest mean annual temperature for 2012 was 15.8°C, recorded at Whangarei. The lowest mean annual temperature for 2012 (excluding high altitude alpine sites) was 6.7°C, recorded at Chateau Mt Ruapehu (central North Island). The highest recorded air temperature for 2012 was 34.5°C, recorded at Gisborne on 19 December, and the lowest recorded air temperature for 2012 (excluding high altitude alpine sites) was -11.8°C, observed at Darfield (Canterbury) on 7 June.



Record-breaking high temperatures (and humidity) were recorded over much of New Zealand between 22 and 27 December as subtropical air was delivered to the country by the passage of ex-Tropical Cyclone Evan. In contrast, the snowfall event on 6 June set new extreme minimum temperature records for the month, and in some cases, broke all-time (any month) records. Lincoln (near Christchurch) reached a maximum temperature of 0.7°C on 6 June, the second lowest maximum temperature record since records began there in 1881. Whakatane was the sunniest location in 2012, recording 2602 hours, followed by Nelson (2584 hours) and Lake Tekapo (2562 hours).

→ Source: NIWA National Climate Centre

Geological Hazards Overview

Mt Tongariro, 2012. Photo: Karen Britten, GNS Science/EQC

Volcano

Our timely advice during the Mt Tongariro eruption has shown the benefits of long-term underpinning science. Researchers from the Natural Hazards Research Platform are also involved in the Global Volcano Model, an international network for developing best practice methodologies for volcanic hazards and risk assessments. This project, initially funded for three years by the UK Natural Environment Research Council, aims to coordinate a wide range of complementary research around the globe. New Zealand is a founding partner in GVM through the Platform.

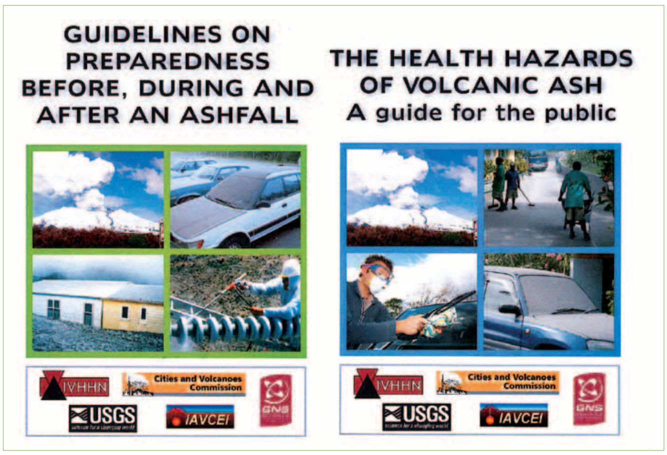
Platform researchers also play a key role in the International Volcanic Health Hazard Network (IVHHN), a research partnership dedicated to understanding volcanic health hazards with input from 25 international organisations, including GNS Science. Two pamphlets have been prepared: 'Preparing for ashfall' and 'Health hazards of ash'. Both are available on the IVHHN website and give excellent visibility to our programme.

Massey University continues to make progress on lahar warning systems for Mt Ruapehu in collaboration with Horizons Regional Council, the Department of Conservation, and for the Mt Tongariro area with Genesis Energy.A major scientific achievement of the Massey team has been the publication in the journal *Geology* of probabilistic forecasting models for large scale debris avalanches at Mt Taranaki. By using one of the most detailed long-term records of flank collapse from almost any volcano worldwide, researchers have been able to develop time-varying forecasts of potential probabilities for collapse, along with the size/magnitude of collapse. This is the first realistic attempt at such a quantification of the most extreme hazard type at Mt Taranaki. A paper was published on the 2006 and 2007 phreatic events at Ruapehu volcano by GNS Science researchers and collaborators which shows that there are changes in the tremor signature prior to small eruptions. These results may improve future eruption forecasting.

Earthquake

The seismology team continues to investigate the conditions necessary for earthquake initiation and associated ground motion. This includes investigating earthquake rupture processes, seismic energy attenuation, and site effects. The outcomes result in regional seismic hazard models, influence building design standards, and contribute to the development of robust mitigation strategies.

We developed an expert elicitation process to assess seismic hazard models for the Canterbury region.



Damage to the Christchurch Basilica. Photo: Margaret Low, GNS Science.

International experts were invited to a workshop in November 2012, where a number of different models were presented and discussed by the panel. One of the outcomes has been a regular update of the probability of aftershocks in the Canterbury region, posted on the GeoNet website[1]. We also continue to work with the Southern California Earthquake Center (SCEC) to advance the testing of earthquake forecasting models. This is a key part of our activities connected with the Collaboratory for the Study of Earthquake Predictabilty (CSEP)[2], a broad international collaboration.

The 2010 Darfield earthquake generated a 30 km surface rupture along the Greendale Fault. Near the western end of the Greendale Fault rupture there are high quality data sets, including pre- and post-earthquake LiDAR and ground surveys, and detailed fault mapping. In a recently published paper, these data sets have been combined to yield the most comprehensive picture of kinematics and deformation on any stretch of surface fault rupture worldwide.

A special issue of NZ Journal of Geology & Geophysics contains more than 20 papers on the Canterbury earthquake sequence that are attracting national and international attention.

Another significant achievement has been the bench-marking of our Pylith software, presented at the 2012 SCEC annual meeting. Pylith is a finite element code for the solution of dynamic and quasi-static tectonic deformation problems, and has expanded to involve research input from USGS, Cornell, Harvard, CalTech, and Purdue universities.

Numerous presentations and talks have been given to stakeholders, covering results and lessons from the Canterbury earthquake. Our work informs the related 'It's Our Fault' programme, and continues to underpin GeoNet advancements.

Landslide

The active landscapes team continues to focus on risk mitigation strategies through understanding landslide initiation and movement processes. Our work on earthquake-induced mass (slope) movements has received considerable attention. The Platform funded a short term recovery project to investigate Port Hills cliff

Houses destroyed by rockfall in Redcliffs, Christchurch. Photo: Graham Hancox, GNS Science

collapse and rock fall, with additional support supplied by the Christchurch City Council and CERA. These reports are available on Christchurch City Council's website[3]. The data from Christchurch will inform our understanding of how slopes in the Wellington region may respond to strong ground shaking. This latest body of work has been funded by the Platform, and supports the research activities of two PhD students and two M.Sc students at the University of Canterbury.

Our international collaborations continue to be successful. The University of Durham's Institute of Hazard Risk and Resilience is collaborating in our revisit of historical earthquakes, such as the 1929 Murchison and 1968 Inangahua earthquakes, both of which triggered landslides over large areas. Our research collaboration with the Landslide Research Centre, Disaster Prevention Research Institute at Kyoto University, Japan enables us to use their state-of-the-art laboratory equipment to provide new insights into landslide deformation in the Port Hills.

Tsunami

While no significant tsunami events affected New Zealand in 2012, we continue to be susceptible to tsunami from both far- and near-field sources. Far-field sources affecting New Zealand arise from distant events, such as with the 2011 Tohoku earthquake-tsunami sequence. Near-field sources originate within a few hundred km, or less than 1 hour travel time from a given coastal point. These can be generated from local faults,

1. http://info.geonet.org.nz/display/home/Aftershocks
2. http://www.cseptesting.org/
3. http://www.ccc.govt.nz/homeliving/civildefence/chchearthquake/hillsidecrackrepairs.aspx

subduction thrust events, and submarine landslides. An integrated Platform approach is leading these research areas, relating geological hazards data with risk and infrastructure concerns.

Dr Joshu Mountjoy (NIWA) is leading a team researching near-field tsunami sources from submarine landslides within the Cook Strait Canyon. This three-year Platform contestable project will quantify the likelihood of landslide tsunami in coastal areas in the Wellington and Marlborough regions. The team is developing and testing numerical models for landslide-tsunami generation and assessing the sensitivity of tsunami to complex seafloor terrain to ensure wave generation is as realistic as possible. The resulting model workflow for probabilistic landslide-tsunami hazard assessment will become a template for application to other areas where a landslide tsunami hazard exists. Their research findings will be shared with local government authorities and tailored for inclusion as a hazard module in Riskscape.

A view of a flooded street with some houses destroyed, others standing, Kesennuma City, Miyagi Prefecture. This area was affected by subsidence of around 75 cm, and flow depth of around 6 m. Photo: Stuart Fraser and IStructE Earthquake Engineering Field Investigation Team.

Dr William Power (GNS), Professor Bruce Melville (University of Auckland), and Dr José Borrero (eCoast Ltd) are working together to improve tsunami warnings and real time hazards assessments in New Zealand's ports and harbours. This research will provide MCDEM with a set of guidelines and a decision making tools for estimating the onset time, severity, and duration of tsunami-induced water levels, currents, and surges at ports and harbours. Their studies will include analyses of recent far-field tsunamis in New Zealand combined with numerical modelling that takes into account the size and location of the tsunami source, as well as local basin and shelf scale effects. Power and Melville aim to integrate the research results into the decision-making structure of the Tsunami Experts Panel (TEP), a group of tsunami scientists who advise MCDEM in the event of a significant, trans-oceanic tsunami event. This information will enhance MCDEM's ability to respond to a far-field tsunami hazard and give site-specific recommendations of the hazard in real time. ■

A view from a small hilltop shrine in Yuriage Ward, Natori City, Miyagi Prefecture 11 weeks after Japan's earthquake/tsunami sequence. Debris clearance had already begun in this area by the time the photos had been taken - see the cleared foundation on the left hand side of the image. Photo: Stuart Fraser and IStructE Earthquake Engineering Field Investigation Team.

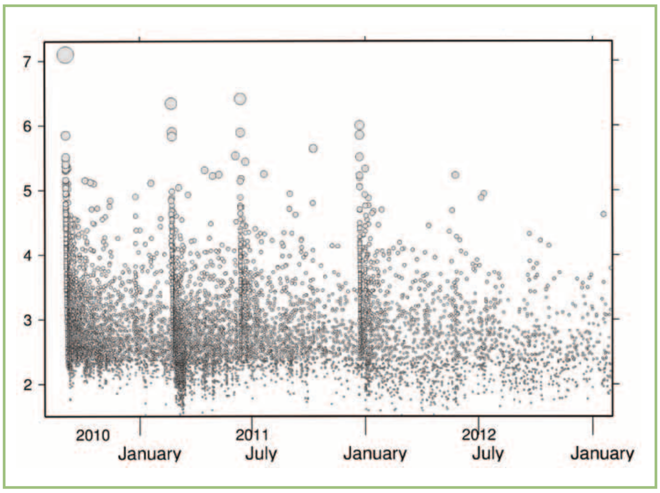
Earthquake Activity

About 1,200 earthquakes were reported felt in New Zealand in 2012. The most powerful of these was a magnitude 7.0 that occurred on 3 July, centred in the Taranaki Bight, 60 km south of Opunake, at a depth of 230 km. GeoNet received over 12,000 felt reports for this earthquake, which was felt from Northland to Southland and caused minor damage in Whanganui, on the Kapiti Coast and in Lower Hutt.

Canterbury aftershocks continued throughout the year, with most of the activity occurring in the period from January to May. The most damaging earthquakes in New Zealand in 2012 were among these, with a few reports of localised moderate damage for the larger events. The strongest of these aftershocks was a magnitude 5.5 event on 2 January, centred a few kilometres offshore from New Brighton and at a depth of 10 km. This caused a few instances of moderate damage in Christchurch and was felt from Otago up to the lower North Island. In January there were four other Canterbury aftershocks of magnitude 5.0 or greater, one just 12 seconds earlier than the magnitude 5.5 event. The only other large Canterbury event in the year was a magnitude 5.2 event on 25 May. The last Canterbury event of magnitude 4.0 or greater in 2012 was a magnitude 4.3 that occurred on 21 September.

Other significant earthquakes for the year were:

- On 19 January, a shallow magnitude 5.8 event centred 200 km southwest of Tuatapere was felt from Stewart Island to Christchurch. Two aftershocks of magnitude 5.5 were also reported felt. A total of about 700 felt reports were received for these events.
- On 3 February, a magnitude 5.1 event, centred 80 km south of Opunake at a depth of 220 km, was felt strongly in the Wellington region, and was reported felt from Taranaki to Canterbury.
- On 21 July, a shallow magnitude 5.9 event centred 170 km east of Ruatoria was felt from the Bay of Plenty to Picton.
- On 31 August, a magnitude 5.2 event, centred 30 km south-west of Haast at a depth of 5 km, was felt widely in the South Island and caused minor damage in Haast.
- On 15 October, a magnitude 5.2 event, at a depth of 200 km under Tokoroa, was felt throughout the North Island and in the upper South Island.



Graph depicting the Canterbury earthquake sequence, each circle representing an earthquake event, its magnitude plotted over time. The heightened activity over 2010-2011 is visible as darker peaks; which have diminished over time. Data: GNS Science, Geonet.

- On 17 October a magnitude 5.5 event centred near Taupo at a depth of 110 km was reported felt from Auckland to Otago, most strongly in the Bay of Plenty. Over 6,300 reports were received for this earthquake.
- On 28 October, a shallow magnitude 4.5 event centred 30 km south-west of Wanganui was felt throughout the south-west of the North Island, most strongly in Whanganui. Three aftershocks were also reported felt.
- On 8 December, a magnitude 5.8 earthquake centred 180 km under Tokoroa was felt from Kaitaia to Dunedin, most strongly in the Bay of Plenty area and along the east coast of the North Island, where there were scattered reports of minor damage. A record 12,500 felt reports were received for this event.
- A sequence of earthquakes occurred offshore Tolaga Bay, between October 2012 and January 2013, with four events with magnitude > 4. Swarm-type activity such as this sequence occurs frequently offshore EastCape, and along the Hikurangi margin, and may be indicative of "slow-slip" deformation on or near the interface between the subducted Pacific crust and overlying Australian plate. ■

We thank GeoNet for providing data used in this report.

Risk and RiskScape Overview

Our group looks at risk in relation to natural hazards, with considerable focus on the Canterbury earthquakes, tsunami, and now events at Tongariro. The outputs of our risk studies are incorporated into RiskScape.

RiskScape is a modular, multi-hazard regional risk evaluation programme developed in partnership between GNS Science and NIWA. It comprises three input components, namely hazards, inventory, and vulnerability, and an engine that integrates and inserts the resulting losses into the impact module. The hazard modules simulate earthquake ground shaking, distal volcanic ash[1], tsunami and flood inundation and extreme wind storms. A suite of vulnerability functions is provided for each inventory class. Vulnerability functions relate the impact (or loss) to the intensity of the hazard to which inventory items are exposed at specific locations. The inventory module replicates our community. It comprises assets fixed in location (i.e. buildings, contents, infrastructure) or move about with time (i.e. people and vehicles).

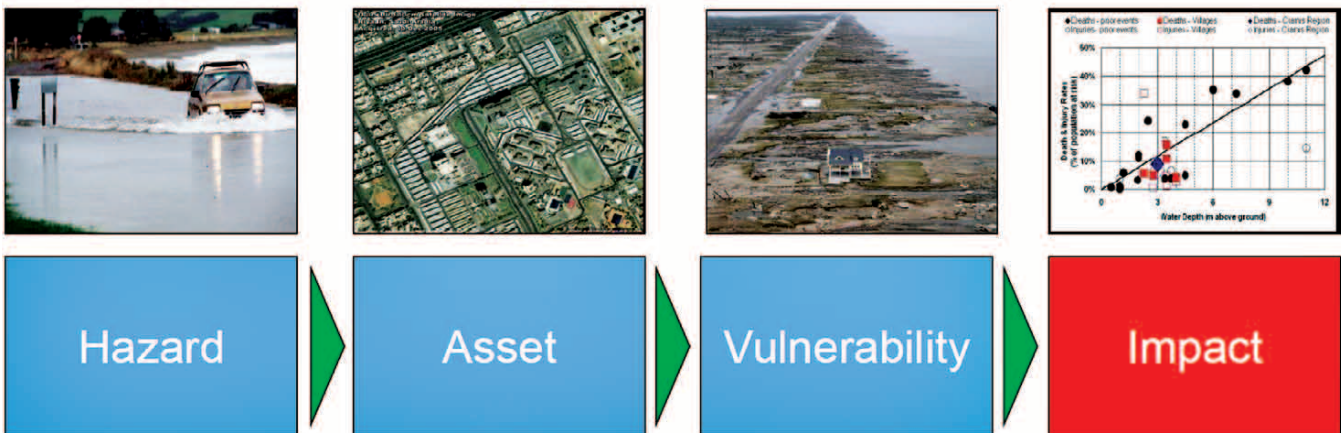
The specific uses to which RiskScape will be applied are still evolving. Several toolboxes have been developed that enable users to enter their own data (both hazards and inventory) and to test the impacts of various planning and mitigation decisions. These include, for example, setting floor levels so as to avoid flood/tsunami inundation, creating new subdivisions on green fields previously unoccupied, or testing different levels of strengthening on earthquake-prone buildings. Over the past year we've added direct-loss fragility modules for three utility systems (road, electricity, water supply) that can be applied to flooding and are being calibrated for earthquake and volcanic ash. The shaking intensity or Modified Mercali Intensity model (MMI) has been modified to incorporate instrumental ground shaking intensity readings from GeoNet. A hydrological landslide hazard model has been developed and is undergoing testing. The first-generation storm-tide inundation model, combining various sea-level rise and recurrence interval storm-tide levels is under evaluation for a pilot study area (Nelson). Proximal volcanic hazard models for lahar, pyroclastic surge and lava flow have also been identified and are being evaluated as to their suitability for introduction into RiskScape.

A three-year project to address the lessons learned from Christchurch will allow us to acquire and apply building damage and loss data with utility across engineering, insurance, regional planning and policy. It includes developing a New Zealand building typology catalogue, acquiring damage and consequential loss data experienced by sample buildings across Canterbury, and developing mechanical models for up to six dominant building types, comparing the fragility and vulnerability functions derived from these models.

Work is underway to develop a RiskScape-Probabilistic model wherein the risk from diverse hazards of differing likelihood and intensity can be compared. The development of this component has advanced over the past year and it is expected to provide a basis for prioritising mitigation measures across different communities on a common basis for the first time.

RiskScape Version 0.2.80 has been released for application to central and local government agencies. ■

1. Fine volcanic ash that can remain in the atmosphere for days or months and be transported great distances.



Building Riskscape on a generic risk framework has enabled its modular design

Flood, Heavy Rainfall and Landslide

Significant rain before New Year's Day caused rivers to peak on 1 January, with the Whakatane River having a flood greater than that of the 50 year return period; this was followed by eight notable rainfall events over the course of the year. These heavy rainfall events triggered over 150 landslides impacting roads, houses and other infrastructure.

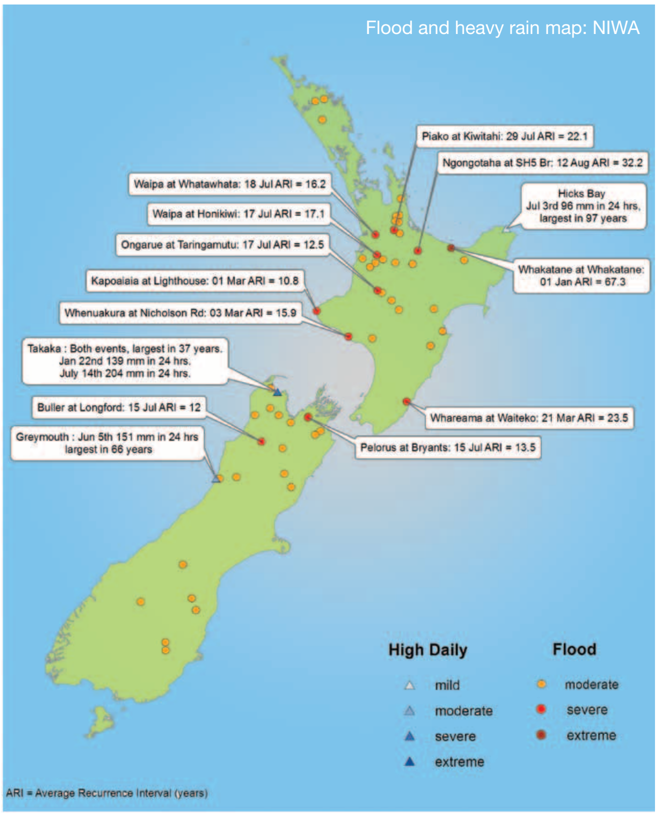
Photo: Dave Allen, NIWA.

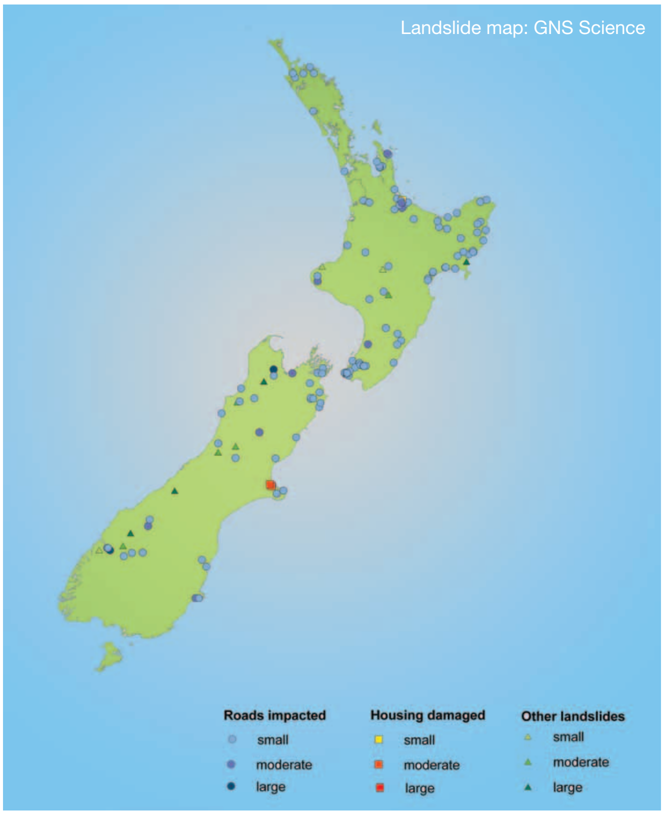
Incidents of heavy rain from February to August caused flooding and slips throughout New Zealand, in particular in Otago, Nelson, Marlborough, Canterbury, Taranaki, Northland, and central and southern North Island. The most significant rainstorm-triggering landslides occurred on 18-20 March, when heavy rains caused major storm damage in the East Cape, Gisborne and Hawke's Bay regions. Gisborne was isolated by slips and tree-falls that blocked numerous roads. The railway line from Napier to Gisborne was affected by three large washouts near Wairoa, which forced the permanent closure of the line.

Heavy rain and flood closed off state highways and isolated major centres (Gisborne on 20 March; Westport on 16 July). Of note were significant road closures on SH2 as a result of landslides. On 3 March, an earlier slip in the Waioeka Gorge, inland from Opotiki, was reactivated causing the closure of the road for nine months. Workers were forced to evacuate the area when it became unstable. The Manawatu Gorge finally opened to traffic on 19 September, after being closed by a large landslide in September 2011. Work continued on the affected road until November.

Rivers with significant flooding included the Whareama, Ongarue, Waipa, Ngongotaha, Whenuakura, Kapoaiaia, and Piako Rivers in the North Island; the Pelorus and Buller in the South Island. Severe flooding of the Waitoa River (July) was estimated as at least a 1-in-20 year event, and of the Ngongotaha River (August) as a 1-in-30 year event.

2012 ended with the Milford Sound receiving intense rainfall, causing significant landslide and rockfall (boulder size estimated at 200 tonnes) that blocked the main access road, trapping 120 visitors. ■





Low Rainfall and Drought

Annual rainfall totals for 2012 were below normal (less than 80 percent of annual normal) in western areas of the North Island between Whanganui and the Kapiti Coast, and for Fiordland. It was the driest year on record for Whanganui and Secretary Island. It was also a relatively dry year (with rainfall between 80-100 percent annual normal) for the south, west, and north of the South Island, and across much of the remainder of the North Island (except for Gisborne). In contrast, above normal rainfall (more than 120 percent of annual normal) was observed for Gisborne, as well as for parts of Central Otago, and between Oamaru and Timaru.

The driest of the regularly reporting gauges was Alexandra, which recorded 378 mm of rainfall. Spring was relatively dry for much of the North Island, as well as Nelson and Marlborough. At the start of summer (1 December), soils were extremely dry for the time of year across much of the North Island (except for Gisborne and northern Hawke's Bay), as well as in Nelson and Buller. Dry conditions persisted through the first half of December across much of New Zealand, and significant soil moisture deficits were in evidence mid-December across much of the north and east of the South Island, as well as Hawke's Bay, Wairarapa, much of the Manawatu, and parts of Northland, Auckland, Bay of Plenty, and Gisborne. As at 1 January 2013, significant soil moisture deficits were present in parts of Auckland, Waikato, Bay of Plenty, Gisborne, Hawke's Bay, Wairarapa, Manawatu, Wellington, Nelson, Marlborough, Kaikoura coast, Canterbury, Otago, and central Southland. Although no state of drought was declared in New Zealand in 2012, these conditions led into widespread drought in early 2013.

➔ Source: NIWA National Climate Centre

Angela Hunt crossing a dry dam normally used to supply stock with drinking water (Gaskin's farm; Wairarapa). Photo: Dave Allen, NIWA.

Matauranga Maori Ruapehu

The Tongariro National Park area is a special place in New Zealand, recognised for its volcanoes, biodiversity and cultural heritage, resulting in dual World Heritage status. While New Zealand excels in conserving the Park's biodiversity and managing the risk from its volcanoes, the recognition of its cultural value is something that many New Zealanders and scientists struggle with. Similarly, those working in the area of volcanic hazards sometimes forget that Maori have been responding to, and recovering from, volcanic eruptions for over 800 years. In recognition of this, the project He haerenga mōrearea - A hazardous journey: Exploring Mātauranga Māori for assessing volcanic hazards and improving monitoring approaches and iwi/hapū planning, funded in 2012 through the Natural Hazards Research Platform's Contestable grants fund, is working with Iwi to explore and document the matauranga Maori (Maori knowledge) of our volcanic landscape.

With the volcanic activity from Tongariro and Whakaari (White Island) in 2012, tangata whenua in these areas are asking questions about their role in emergency management and how they can maintain their cultural connections with changing management regimes. Ngati Rangi, whose rohe [area] encompasses the southern side of Mt Ruapehu, were dealing with these and related questions following the 1995-96 series of eruptions at Mt Ruapehu and the subsequent tephra dam issues and 2007 lahar, particularly when the cultural values of the Maunga [mountain] became a public issue. During this time

Professor Vince Neal (l. Massey University) and Che Wilson (r. Ngati Rangi, Rangatira) talking about volcanic hazards and traditional volcano monitoring techniques at Lake Rotokura. Photo: Massey University.

Ngati Rangi voiced their position on many issues to uphold and protect their ancient ancestral connections to the Maunga. Ngati Rangi has remained constant in their belief that volcanic activity is an expression of their ancestors' power to create life and land and therefore this should continue to occur naturally.

Ngati Rangi recognises the need to articulate its beliefs and traditional practices to government agencies, local authorities and scientists in a form that fits with western science understanding of the landscape. The ability to document and transfer traditional Iwi knowledge (Matauranga Maori) to fit in line with today's management practices can be difficult. Other areas of science and resource management recognise and incorporate matauranga Maori in new methods; this project seeks to initiate the same interaction in geosciences by specifically focussing on matauranga Maori of one of New Zealand's most active volcanoes, Mt Ruapehu.

Massey University has over the years worked with Iwi living under volcanoes, supporting them with volcanological information and assisting with archaeology, environmental management and ecological research. Within the last few years this relationship has been strengthened with Ngati Rangi through the Volcanic Risks Solutions group developing research with input from Ngati Rangi and ensuring staff and students are aware of Ngati Rangi tikanga when working on the volcano, as well as experiencing Ngati Rangi manaakitanga on their Marae and in their rohe.

Our project investigates Ngati Rangi oral histories, traditional monitoring systems and matauranga, or knowledge, with an aim to integrate traditional practices into current scientific thinking and future

Hannah Rainforth *et al* 2012 "Exploring indigenous knowledge for assessing volcanic hazards and improving monitoring approaches." 7th Cities on Volcanoes Conference, 19-23 Nov 2012, Colima, Mexico.

hazard management. The Iwi would also like to re-establish traditional volcano monitoring sites.

Professor Tai Black from Massey University is part of the project team and sees this as an opportunity to reinstate traditional language or Te Reo used to describe landscapes, geomorphology, geology and volcanic processes and products. This language will be explored with kohanga and kura to involve the next generation of Ngati Rangi and have the Iwi more involved in volcanic processes and hazard management in the future. Manaaki Whenua - Landcare Research Ltd scientist Garth Harmsworth will be using new spatial, geo-visualisation techniques to view and present the cultural landscape in news ways to better present areas of significance to other agencies.

Maungarongo Marae, Ohakune, under the view of their ancestor, Kahui Maunga and Ruapehu. Photo: Massey University.

In turn, Ngati Rangi have a dedicated Iwi researcher, Hannah Rainforth, working with her people to better record their traditions and practices around the volcano. Hannah presented initial results at *Cities on Volcanoes 7* at Colima, Mexico in November 2012 and was one of the only indigenous peoples to present their experiences living under an active volcano and a Ngati Rangi view of risk and hazard.

Having Ngati Rangi and Iwi in general more involved in Natural Hazards and developing and monitoring indicators that are relevant to their lives, will help communicate risk and aid Iwi in remote communities to be better prepared in the face of a natural hazard.

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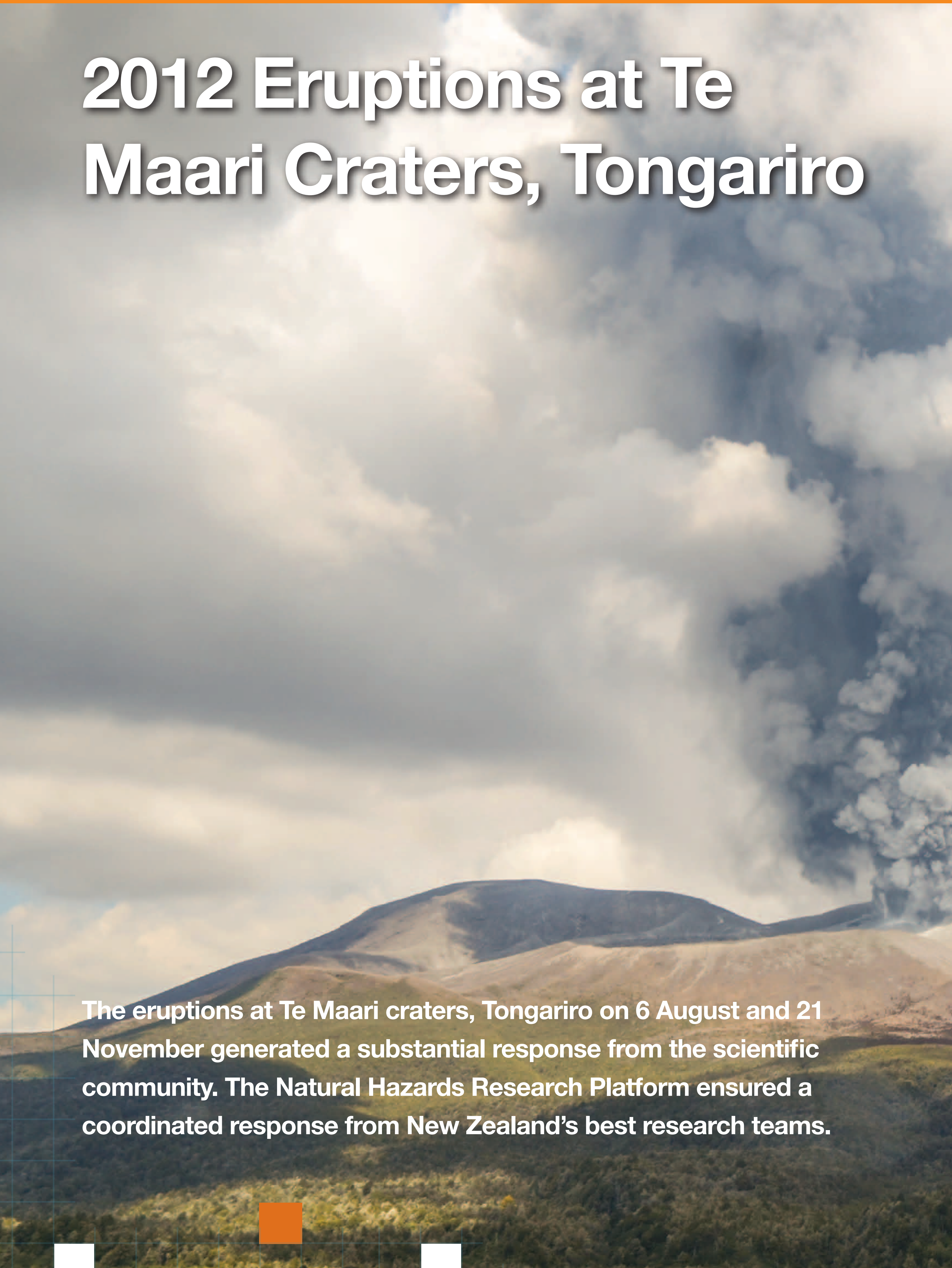
2012 Eruptions at Te Maari Craters, Tongariro



The eruptions at Te Maari craters, Tongariro on 6 August and 21 November generated a substantial response from the scientific community. The Natural Hazards Research Platform ensured a coordinated response from New Zealand's best research teams.

Most of our volcanology research is in the Geological Hazards theme, but across the Platform there are many people working on different aspects of volcanoes, including atmospheric monitoring and forecasting (NIWA) and emergency management (Societal Resilience theme). We monitor the volcanoes through the EQC-funded GeoNet project and research their past behaviour with Platform funding in close collaboration with nearly all New Zealand universities. Under the Guidelines to the National Civil Defence and Emergency Management plan, we are tasked with providing specific advice on geological hazards and risks. The aim of the Platform is to coordinate quality science from across New Zealand so that authoritative information on volcanic hazards is delivered to responding agencies with clear, consistent messages put before the public.

Tongariro has an interesting geological history. It was formed by eruptions from at least 12 vents over the last

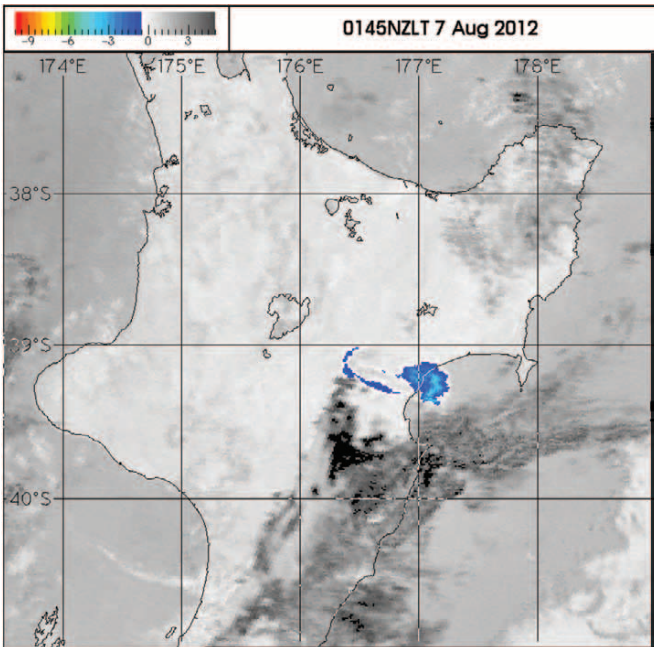
Tongariro eruption, 2012. Photo: Craig Miller, GNS Science /EQC/GeoNet.

275,000 years. The youngest vent is Ngauruhoe, now thought to be ca. 4,500 years old. At least three large eruptions occurred between ca. 10,000 and 15,000 years ago with widespread ashfall. Past eruptive activity is made up predominantly of lava flows and ashfall with some lahars, flank collapses and pyroclastic density currents. Historical eruptions have been documented and the best records are from 1892 and 1896-7.

Tongariro had been dormant for over a century in July 2012, when activity increased beneath its northern slopes. Significant changes in the Te Maari fumarole discharge had occurred since May, suggesting gases from the deeper, higher temperature system were emerging and making their way to the surface. Small tectonic earthquakes are not uncommon in this area, but the signals recorded in July had low frequency resonant characteristics, commonly thought to be related to fluid movement (either magma or gases).

Seismo-acoustic studies revealed that immediately prior to the eruption on 6 August, a sequence of small micro-earthquakes and persistent tremor occurred for about four minutes. The micro-earthquakes had low frequency energy consistent with a subsurface volcanic process, while the pre-eruption tremor had a wider range of frequencies. The main eruption was marked by strong seismic signal that lasted for about one minute.

During this time, scientists at NIWA and MetService monitored the atmosphere. NOAA satellite infrared observations can be used to discriminate between water vapour and ash cloud. Combining the infrared signatures of the ash cloud with vertical temperature profiles from NIWA weather model NZLAM indicated that the initial plume reached an altitude of approximately 12 km. MetService weather radar also detected the eruption but is limited to ash particles larger than about 500 μm and these only reached altitude of about 7 km. As atmospheric winds carried the plume eastward it decreased in altitude; by the time it passed over the Hawke's Bay it had lowered to near 4 km. By the afternoon of 7 August ash was still visible in MODIS satellite imagery far out to sea off Hawke's Bay. Particle trajectory analyses based on NZLAM forecast output also verified well against observed ash fall and gas observations, where sulphurous smells, sometimes mistaken for blocked sewers, were reported at many locations from Hunterville to Wellington and even 500 km away at North Brighton Beach in Canterbury.



Difference in 11 µm and 12 µm emissions as detected by NOAA 18 satellite at 1:45 am NZST on 7th Aug. False colour map: Blue indicates volcanic ash; Grey indicates water cloud. Data: NIWA.

"Ashfall tends to have a chronic, cumulative effect and can travel 100 km and more."

Potential volcanic hazards during an eruption

There are a number of hazards that can occur from an eruption on Tongariro. Based on the past geological record, we can determine which hazards are the most likely and what impacts they might have. When an explosion occurs, the initial part of the eruption fires ballistic projectiles away from the vent area. These rocks tend to be hot, dense and are commonly up to a metre or so across. They result in impact craters and can cause severe injury and building damage.

A second common phenomenon from explosive eruptions is a pyroclastic density current. These are fast moving, warm to very hot clouds of ash and gas travelling at tens to hundreds of kilometres per hour; they can lead to bush/forest fires and the more energetic flows lead to complete vegetation and building destruction.

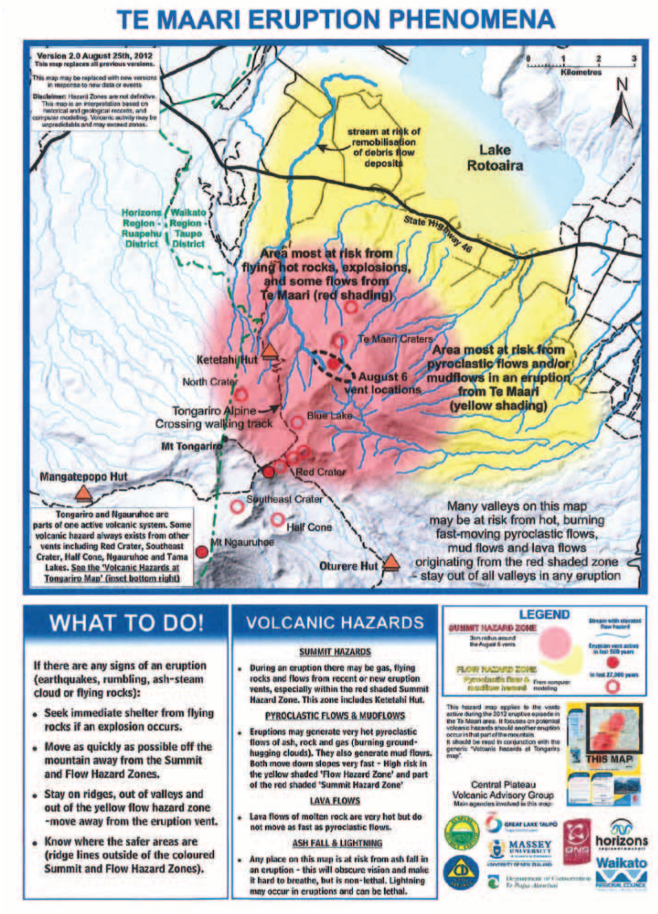
A less immediate impact is from ash fall. This tends to be thicker closer to a vent, but even in small amounts (less than a few millimetres thickness) can result in infrastructure damage, agriculture impacts and building damage. Ashfall tends to have a chronic, cumulative effect and can travel 100 km and more downwind.

Remobilisation of ashfall or other deposits results in lahars. These are mixtures of ash, rock and water that can be formed from lake breakouts, by rainfall washing material from the flanks of volcanoes or by snow melt. They tend to stay predominantly in valleys and cause a hazard to people and infrastructure in valleys. Past Tongariro eruptions have also produced lava flows, but these tend to be slow moving and although can give rise to bush fires and destroy everything in their path, the life safety risk to people is low. The August eruption displaced 320,000 cubic metres of material from the flanks of the vent area in the form of a landslide, generating a 2.5 km debris flow from source that blocked a valley. The resulting dam and the lake which formed behind the dam presented a changing hazardscape. Computer simulations and their results were combined with new topography to help us predict landscape changes over time.

Debris flow, 6 August 2012. Photo: Steven Sherburn, GNS Science/EQC.

Sampling fumaroles at White Island. Photo: Karen Britten, GNS Science/EQC.

From these events we developed a new phenomena map. This map incorporates flow hazards modelling from



Massey University and includes expert opinion based on current activity and past geological record. This map represents the coordinated effort between science, councils, New Zealand Transport Agency (NZTA) and Civil Defence and Emergency Management (CDEM) groups.

Current Understanding

Analyses of gas, ash and rocks collected from Te Maari now suggest that the eruption was driven primarily by

magmatic gas pressurising the near surface hydrothermal system. We believe there is magma somewhere under the volcano, but from the data we are unable to determine exactly where. So although it seems that magma did not reach the surface in either the August or November eruptions, the involvement of magma in future eruptions cannot be ruled out.

Key lessons learned

Communication amongst the science teams generally worked well and the use of an open wiki and email lists enabled immediate sharing of data, photos and discussion points. Regular updates proved critical, ensuring everyone was aware of the situation. Dynamic hazard and risk assessments were valuable to key end users, particularly when making decisions about public and staff safety in areas close to the vents.

Overall, consistent messaging is important for providing quality information to responders, but also for joint information statements from CDEM, scientists, landowners and other key parties. This has been made easier by the long-term relationships that have been built up over the years via the Central Plateau Volcanic Advisory Group, led by regional CDEM groups, with key science organisation involvement. ■

Contact: G.Jolly@gns.cri.nz

Shane Cronin and Jonathan Procter led the Massey University response. Photo: Massey University.

Videoconference debrief. Photo: Steven Sherburn, GNS Science/EQC.

Activity at White Island and Ruapehu

The months of August through to December 2012 proved to be a busy time of the year for Platform's volcanologists. Heightened activity occurred at Tongariro, Ruapehu and White Island; raising volcanic and aviation alert levels. The most publicised activity was centred on the Upper Te Maari crater at Tongariro, described in our special report.

Events at White Island

During 2011 and early 2012 Crater Lake on White Island slowly evaporated to expose steam vents and form two large muddy pools. However, sometime between 27-28 July, the lake level rose quickly by about three to five metres. Vigorous flow of gas and steam through the lake was visible from the air.

From early July there had been intermittent periods of volcanic tremor. Tremor is not uncommon at White Island but in early 2012 it had been at very low levels. At about 5 am on 5 August, a small explosion occurred and was recorded by one of the webcams on the island. A new vent had formed in the crater and was vigorously emitting ash and gas. A small ash cone was built in the lake, around the main area of degassing. This was the first time ash had been produced from White Island since 2001 and represented the start of a new phase of activity.

Ongoing monitoring from August to October showed that gas output was reasonably constant and that ash venting had stopped.

In early December, a monitoring team noticed that a rubbly lava dome had been extruded in the ash cone sometime over the previous weeks. This is the first extrusion of solid lava on a New Zealand volcano since the 1950s, when lava flows were erupted at Ngauruhoe. Activity then declined to lower levels by the end of 2012.

Events at Ruapehu

A series of small earthquakes were recorded under Mt Ruapehu in early November. It is unusual to see earthquakes directly under the cone and, coupled with anomalous gas analyses, this suggested that the volcano was in a heightened state of unrest. One critical observation was that the temperature of the crater lake had remained static for over seven months, whereas it normally cycles between about 15°C and 40°C every few months. This suggested that perhaps there was a blockage at some depth under the crater lake preventing heat and gas from being transferred from deep in the volcano to the surface, and that pressure might be building towards a small eruption, such as seen in 2006 or 2007. These signals of heightened unrest were how Ruapehu closed the year. Data: GeoNet ■

Lava dome in eruption crater, White Island. The dome is made of thick, relatively cool and congealed lava and has prominent spines. The dome is about 20 – 30 metres across. Photo: Steven Sherburn, GNS Science/EQC.

Assessing Impacts of Volcanic Ashfall

Volcanic ash may not be the most spectacular or lethal product of an explosive volcanic eruption, but it is the most widespread, and the most likely to affect towns, cities and farmland in the North Island. Freshly-erupted ash contains a range of potentially toxic soluble elements, which are released either rapidly or more slowly upon contact with water or body fluids. Following an eruption, it is normal for the public, civil authorities and agricultural producers to have concerns about the effects of ashfalls on human and animal health, drinking water supplies, crops and soils. In addition, ashfalls can interfere with the functioning of critical lifelines such as electricity and drinking water supplies.

Our group has an overall goal of increasing New Zealand's preparedness for volcanic ashfall. We carry out reconnaissance trips to areas impacted by ashfall, backed up by testing the properties of the ash in laboratories at University of Canterbury and Massey University. We have developed a particular focus on central Patagonia, because of the frequency of explosive eruptions there and the similarity of the landscape and climate to New Zealand, meaning that lessons are readily transferable here. Following the 2011 eruption of Puyehue-Cordón Caulle (Chile), towns downwind of the eruption in

The NZ field team (l to r): Heather Craig, Tom Wilson, interpreter David Dewar and Carol Stewart) on Chile/Argentina border, February 2012. This area was covered in up to 50 cm pale grey pumice fragments from the June 2011 eruption of Puyehue-Cordon Caulle volcano. Photo: Carol Stewart, University of Canterbury.

Argentina continue to be severely affected by fine airborne ash. The extremely arid and windy conditions have also prolonged the effects of the eruption, as the deposited ash is unconsolidated and easily resuspended in windy conditions. The eruption has also had severe effects on livestock farming in the region, with stock losses of 40-60 percent.

Testing of electricity network components in high voltage lab in the University of Canterbury's electrical engineering facility. The purpose of this work is to increase our understanding of the factors that can lead to electricity outages following volcanic ashfall. PhD student Johnny Wardman has used a dual approach of both carrying out post-eruption impact assessment studies, and laboratory-based testing. Photo: Grant Wilson and Johnny Wardman, University of Canterbury.

Eruption at Te Maari crater, Mt Tongariro

Following the Te Maari eruption on 6 August, we documented the infrastructural impacts and liaised with infrastructure managers. The eruption deposited ash up to a maximum thickness of 2.5 mm over a small area to the northeast and east of the vent.

The closest infrastructure to the vent was the water supply catchment for Tongariro/Rangipo Prison, which is located on the northeast slopes of Mt Tongariro right under the area of maximum ashfall. Although a substantial quantity of ash was deposited in the stream feeding the plant, the plant had sufficient storage capacity to be able to be shut down for seven days while testing for water contamination was carried out by the local Public Health Unit, and also to protect the plant from damage caused by suspended ash entering the intake.

Transpower's high voltage (Bunnythorpe to Wairakei) transmission lines also cross the area in which ashfall was received, alongside the Desert Road. About 2 mm of ash fell on the insulators, but this was not enough to cause problems such as insulator flashover, which can in turn lead to power outages.

Whilst the eruption produced only a small volume of ash, its properties proved interesting. Leaching experiments to determine the soluble salt composition of the ash were carried out at Massey University on an urgent

basis to address the concerns of health and agricultural agencies. These experiments showed that the ash had high concentration of water-soluble elements, particularly calcium and sulphur, and moderate levels of potentially-toxic fluoride. This high soluble salt content also gave the ash the property of being highly conductive to electricity (the highest we have ever observed). Thus, while the ash had hazardous properties, its overall risk to infrastructure, public health and agriculture was limited by the small volume produced.

We aim to translate research findings into practical advice on ash preparedness and mitigation strategies. One of our most popular initiatives has been a poster series sponsored by the Auckland Engineering Lifelines Group, giving preparedness advice to managers of electricity networks, airports, roads, wastewater treatment plants and water supply systems. We are currently upgrading these posters, to incorporate our latest research findings from field studies. We also continue to co-lead the International Volcanic Ash Impacts Working Group, a collaboration involving University of Canterbury, GNS Science and colleagues from the United States Geological Survey, British Geological Survey and various other universities to update and coordinate volcanic ash research and communicate our findings.

The eruption may have been small, but it was a valuable test of New Zealand's volcanic ash collection and analysis capabilities, and our ash preparedness resources. It has also stimulated closer working relationships between the Natural Hazard Research Platform and a variety of key stakeholders. Not bad for a little burp from Tongariro.

Massey postdoctoral fellows Anke Zernack and Natalia Pardo test ash from the 2012 Te Maari eruption. Photo: Massey University.

➔ Carol Stewart & Tom Wilson.
Contact: Carol.Stewart@canterbury.ac.nz

Platform-funded Students

Lauriane Chardot (PhD student, Volcanology. University of Canterbury/GNS Science) - Using White Island volcano as a case study, Lauriane's research investigates how changes in volcano hydrothermal systems may explain some of the geophysical monitoring signals observed during volcanic unrest, using a multi-disciplinary dataset and a holistic numerical modelling approach. Lauriane is interested in the hydrothermal-related source of the signals observed during an unrest episode because changes within a volcano hydrothermal system may precede and/or hinder magmatic signatures in monitoring observations. The ultimate aim for this project is to improve the detection of future activity at White Island volcano.

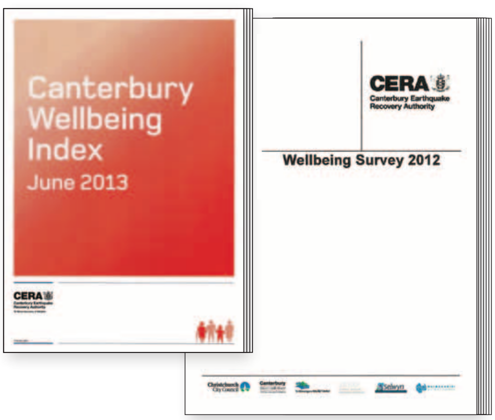
Societal Resilience Overview

The Societal Resilience theme aims to help individuals and organisations prepare, respond, and recover from natural hazard events.

Three main research groups are involved: a GNS Science-led consortium in partnership with Te Runanga o Ngāi Tahu, CERA, Massey, Canterbury, Victoria, and Otago universities and a range of other local and international partners; Resilient Organisations (ResOrgs) which is a collaboration between researchers across New Zealand, particularly at Universities of Canterbury and Auckland, and with strong linkages to a range of industry partners within New Zealand and internationally; and an Opus Research- led group that includes collaborations with BERL, Victoria University, BRANZ, and a range of stakeholders.

The Canterbury earthquakes and their aftermath continue to provide a focus for much of the activity, but projects also address other thematic risk issues and hazard-specific problems. The international literature on recovery is very thin and the work that the Platform researchers are doing is significantly advancing knowledge in this space. This can be seen in the range of international collaborations and publications that are flowing from the work.

Some of the research questions our theme addresses include: What are the key social, cultural and economic factors that lead to resilience? What planning, policy and organisational frameworks are necessary to reduce risk? How can hazard and risk information better inform planning, public decision making and risk management processes? How effective are our emergency management procedures and crisis management practices?

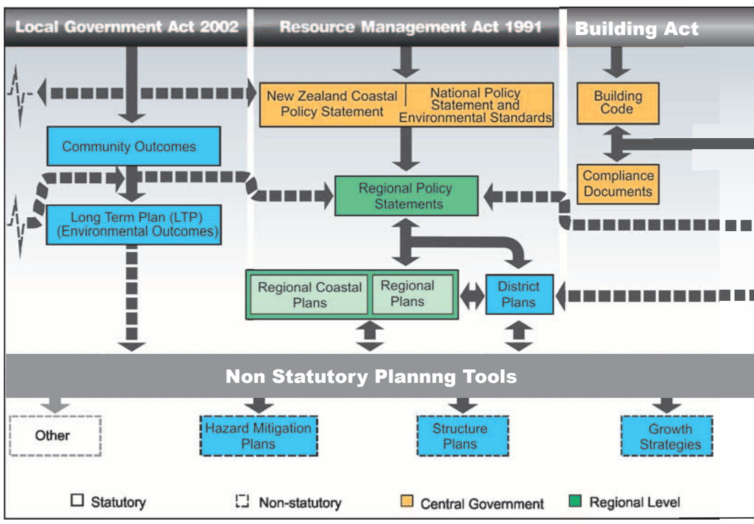


Emergency Management Office meeting.

A significant achievement has been the release of the CERA Wellbeing Survey[1] and Canterbury Wellbeing Index. The Canterbury Wellbeing Index tracks the progress of the social recovery across greater Christchurch, with additional data provided by the Survey. The Wellbeing Index includes datasets from twenty-eight Government departments, and is to be utilised as a resource for all social science researchers examining resilience and recovery. There is no other example of a recovery dataset in existence.

In this issue of Natural Hazards, we look at three projects coming out of the Societal Resilience theme but working across thematic boundaries: (i) risk and the Resource Management Act, (ii) economic lessons from Christchurch and (iii) updates from the Opus research programme on Christchurch's recovery.

1. Led by CERA in partnership with the Platform, Christchurch City Council, Waimakariri District Council, Selwyn District Council, Canterbury District Health Board and Te Runanga o Ngāi Tahu.



What is Risk? Risk and the RMA

What is risk? Are all risks equal? How do you measure a reduction in risk? Whose risk is it? These are some of the questions the Natural Hazards Research Platform is asking about risk.

'Risk' is a widely used term in natural hazards research, and following the Canterbury earthquakes it has gained greater attention - not just in the research community, but for decision makers within councils and those living in 'at risk' communities. The proposed changes to the Resource Management Act 1991 (RMA) provide an example of this increased attention. Currently, **risk** is not included in the RMA, only **natural hazard.**

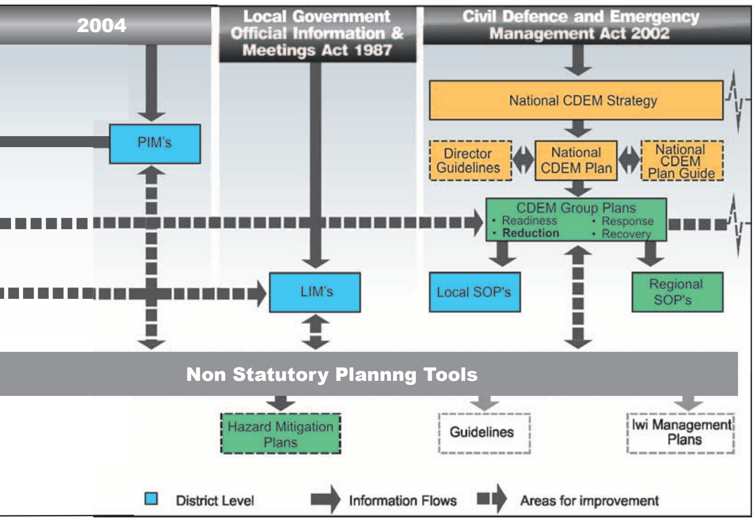
In 2011, the Minister for the Environment established a Technical Advisory Group (TAG) to undertake a comprehensive review of Sections 6 and 7 of the RMA. These sections cover:

Section 6: Matters of national importance which must be recognised and provided for;

Section 7: Other matters which require particular regard by decision makers.

Partly in response to the Canterbury earthquakes, the TAG was requested to give "[g]reater attention to managing issues of natural hazards noting the RMA issues arising from the recent Canterbury earthquakes."

In response to the TAG recommendations, Ministry for the Environment released the discussion document 'Improving Our Resource Management System' for consultation. This included a proposed new Section 6: Principles, which includes matters to be recognised and provided for. Included in these matters is "the risk and impact of natural hazards."



While the terminology needs reviewing (i.e. 'impact' is a function of 'risk'), this proposed change would ensure that a risk-based planning approach would have to be considered as part of any resource consent application, plan change, or plan policy formulation. However, the RMA is just one in a suit of legislative tools that contribute to managing natural hazards and their associated risks. Figure 1 shows the five key statutes which, if integrated in policy effectively, provide a comprehensive framework for risk reduction. The hashed lines show relationships which can be strengthened to improve risk reduction.

While the concept of risk underpins the intent of these statutes, the term 'risk' is only defined by the Civil Defence Emergency Management Act 2002. This states risk is the 'likelihood and consequences of a hazard' (section 4). Risk has not been defined as part of the TAG report, and it is questionable if the definition under the CDEM Act would transfer to the RMA – the definition of a natural hazard currently differs between the RMA, Building Act, and CDEM Act. However, there is a common theme between these statutes in their purposes, in that they refer to the community well-being of social, economic, cultural, environment, health and safety. These can become a key focus for any consequence-driven risk assessment.

The Platform supports the inclusion of risk within the RMA as a matter of national importance. We recommend that 'risk' – as defined by CDEM Act 2002 – is included in the 2013 round of RMA amendments.

It critical that, as researchers, we are aware of how our hazards research – and the risks posed to New Zealand - are understood and effectively communicated. National guidance on what constitutes an acceptable risk should be developed, ensuring a consistent approach nationwide. Future research areas will include defining risk concepts for land-use planning; how to incorporate uncertainty into policy; and how to communicate concepts of risk to decision makers, key stakeholders and communities.

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Images and data: GNS Science

Left: Legislative roles and responsibilities for hazard management in New Zealand

Economic Lessons from Christchurch

Researchers from GNS Science and Motu are investigating some of the microeconomic consequences of the Canterbury earthquakes. The research comprises two broad themes: (i) lessons from business and labour market outcomes and (ii) lessons from property market outcomes.

Business and labour markets

Recent analyses have begun to uncover the 'big picture' impact of the earthquake events on Christchurch businesses and workers. We know that the number of business locations dropped substantially in the year following the February event – down 2.5 percent overall, and down 34.6 percent in the CBD (Statistics New Zealand 2012). We know too that workers have left the region (some leaving New Zealand), and that retail activity has been relatively weak. Consistent with the declining workforce, firms have reported difficulty hiring workers in Christchurch, with employers attributing this mainly to people leaving the area and to difficulty in attracting new staff to Christchurch.

"What do property markets reveal about the risk preferences of businesses and households?"

Our study aims to dig deeper, at the microeconomic level, to learn more about outcomes for affected firms and workers. We are using comprehensive unit record labour market and business performance data (the Linked Employer-Employee Data (LEED) and Longitudinal Business Database (LBD), respectively). Linked together, these data provide a powerful tool for understanding the post-event recovery.

The detail of the data enables us to address multiple questions. In particular, we are able to follow individual workers (anonymously) to measure subsequent economic outcomes including change in earnings and employer, relocation decisions, benefit transitions, spells out of work, and migration decisions. For firms, we can examine survival, relocation and employment decisions, and – as more data becomes available – changes in productivity and profitability.

One key advantage of microdata is the ability to look at whether outcomes vary across worker or firm-types. As the differential survival rate of businesses by location vary, there is unlikely to be a single common post-earthquake recovery story. Some workers and firms were harder hit by the earthquakes than others. For example, we will pay particular attention to outcomes for workers who lost their jobs because of firm closures, or who moved from the region.

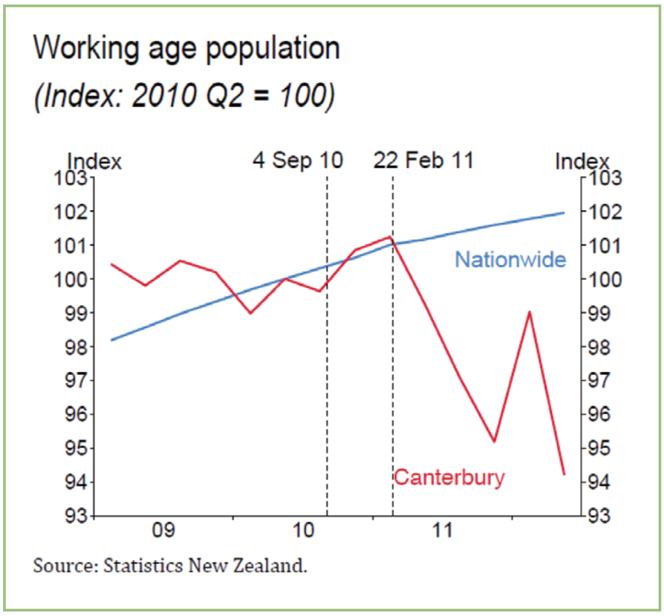
Property markets

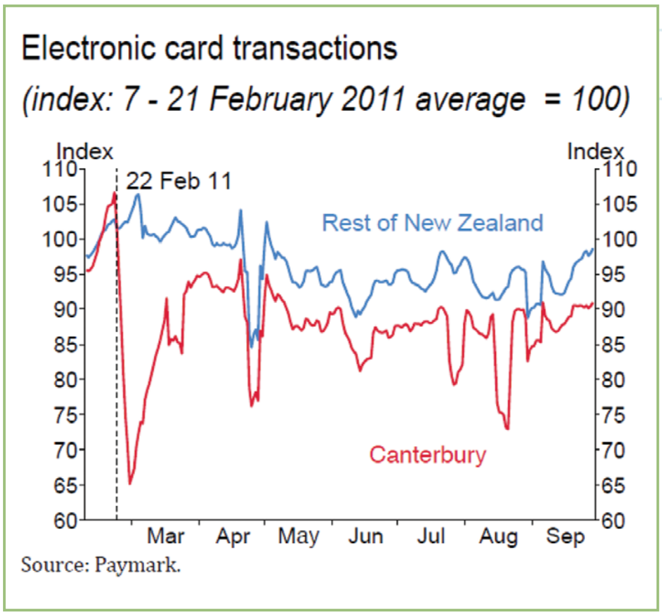
We will also investigate a series of closely related questions on the role of information provision about seismological hazards and the perceived value of seismic strengthening. Here, we will use property market transactions recorded in areas not directly affected by the earthquakes but potentially prone to future seismological hazards.

Intuitively, the risk of exposure to a hazard lowers property values because people prefer a safe location to a hazardous one. The size of this hazard-induced discount can be established by statistical methods, and it is directly related to the perceived value of seismic strengthening. What do property markets reveal about the risk preferences of businesses and households? Is there any evidence that the earthquakes served as a source of new information causing people to update their preferences? For example, strong anecdotal evidence indicates that businesses are now less willing to locate in earthquake-prone buildings. Are households likewise less willing to settle in areas where soil liquefaction is possible? If so, by identifying the trade-offs they make between risk and property values, we can draw conclusions about changes in the public's willingness to pay for natural hazards risk mitigation.

The implications can be far-reaching. If, for example, it turns out that people systematically downplay seismic risks in their location decisions, there may be a rationale for government intervention such as adopting stricter building standards and mandating information provision about such risks. For instance, authorities may need to prevent, or impose strict covenants on, local developments that are subject to natural hazard risk despite the market indicating a perceived high value for such developments. In these circumstances, because market prices will be inefficient, risk models that analyse community losses from natural hazards events based on observed prices may also need to be adjusted.

The way in which information about the potential hazard is communicated may also matter. In the aftermath of the earthquakes, some city councils chose to change the





wording on Land Information Memoranda (LIMs) to give greater prominence to the risk of soil liquefaction. Others chose not to change their LIMs. We will employ this variation in the manner of hazard disclosure to identify the effect, if any, the policy change had on property values.

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Figures from Parker, Miles and Daan Steenkamp (2012) "The economic impact of the Canterbury earthquakes", Reserve Bank of New Zealand Bulletin 75(3) pp13-25

Re:START village project in the Cashel Mall brought in shipping containers to assist business owners and revitalise the city centre. Photo: CERA

The Christchurch Recovery: The Shaken City Becomes the Shifting City.

Cities are dynamic and continually undergoing change, but it is self-evident that following the Canterbury Earthquakes Christchurch has changed abruptly and dramatically. The recovery will provide not just a very altered city, but a significantly altered Canterbury region. People and businesses have moved to new accommodation or premises, through necessity or by choice. Some moves are temporary and some permanent; a proportion of the moves originally intended to be temporary will also become permanent as the people and businesses embed into their new location and lifestyle. This very process of movement alters the nature of the recovery, for while the places that were left decline, the new locations thrive and attract further influx. This thereby lessens the need for return to the pre-event situation.

At Opus Research we are using secondary data to explore this. These secondary sources often provide earlier indicators of change and at finer scale than possible with the official statistics. The use of secondary data also helps avoid survey-fatigue of an already heavily surveyed population and ensures interactions with the Canterbury people are minimised to those that are both necessary and useful. For example, data on redirected mail has built a database of temporary and permanent moves. Compared with pre-earthquake trends, it indicates a 170 percent increase in domestic migration. Additional datasets include origin/destination spatial analysis of electronic eftpos and credit card transactions within the city which reveal the extent that economic activity has shifted. Understanding this spatial change to economic activity within the region is imperative because business agglomerations increase business growth, attract new businesses to the location and have significant impacts for transport infrastructure.

Our research is also examining

Jared Thomas and Grace Rive. Photo: Opus.

thresholds of reduced liveability of the damaged neighbourhoods and the interaction with duration experienced, at which these movements are triggered. This builds upon work by Sonia Giovinazzi[1] at University of Canterbury who reviewed various agencies' responses to temporary housing needs after the February earthquake.

We have already studied some of the initial movements of households. In the first months

Opus' Societal Resilience Team. (From left: Vivienne Ivory, Joel Burton, Grace Rive, Vince Dravitzki, Kate Mora, Abi Beatson, and Felicity Powell. Absent: Jared Thomas, Abigail Harding. Photo: Opus.

Platform-funded Students

Sara McBride (PhD student, Risk Communication. Massey University & GNS Science Joint Centre for Disaster Research) Sara is a communication practitioner and researcher in the areas of risk & disaster communication, community engagement and emergency response. She has worked extensively as a disaster communication advisor in New Zealand and the Pacific, and as a Communications Officer at Environment Canterbury both before and after the Christchurch earthquakes. Sara's project is funded by the United States Geological Survey to identify lessons from the Christchurch earthquake that can be applied to improve preparedness public information and communication campaigns in similar areas in the USA.

following the earthquakes many people had to seek alternate accommodation. People billeted for 11 weeks on average with other households, often family. We have found these arrangements were successful, that the new composite household worked effectively together, and that both billets and hosts considered the arrangement could have been extended by a further five weeks (on average). Overall this study highlighted findings from previous studies that New Zealanders consider themselves resourceful and they feel that this resourcefulness will enable them to deal with the aftermath of disasters and in some ways compensate for their lack of preparation.

Our studies on effects of business relocation reveal that these new locations enable business to continue to operate but often lack face-to-face business and social contact that facilitates effective operation and creates good employment environments. This study will continue as a longitudinal study over the next two phases of recovery. Phase I is anticipated to be a consolidation of the new economic spatial pattern caused by the post-earthquake movements as businesses and people flow into Christchurch as the rebuild commences. When the rebuild is well advanced, Phase II is likely to be an economic tension between these locations and the rebuilt CBD, as it seeks the return of those former businesses. If successful, this will leave the temporary locations weakened. This work builds upon previous Platform research into business resilience and recovery conducted by Resilient Organisations, and will link with the Platform's parallel business and labour market analysis being conducted by Levente Timar (in this issue).

In addition to natural hazards specialists, the audience for this work also includes economists, transport and urban planners, and geographers and will link to other research programmes approaching the issue of resilient cities from other perspectives.

→ The Opus Research Team
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1. Short Term Recovery Progamme; www.naturalhazards.org.nz

Application of New Adaptive Modelling Techniques in Hazard Forecasting

Why use adaptive models?

Many natural hazards can be forecast by numerically simulating fluid flow in either the atmosphere or the ocean. Typically this involves setting up a computational grid of discrete points in space covering the region of interest, on which various quantities associated with the fluid are evaluated (e.g. wind velocity, wave direction). The horizontal distance between the grid points is referred to as the model's resolution. Equations derived from physical laws are then used to describe how these quantities evolve in time.

Running a forecast model on even the fastest supercomputer will face some limit in the number of grid points that can be used to produce a forecast in a usefully short time and we must decide before we start where we will need finer resolution. But for some problems we don't know this in advance. For example a tropical cyclone may have a 50 km radius, but could occur anywhere in a region of the tropical Pacific too large to cover uniformly at a fine enough scale to resolve the details of the cyclone's wind (and wave) fields.

One way to address this problem is to use adaptive methods to allow the spatial resolution of the computational grid to be adjusted as events unfold, allowing for fine resolution in regions where the properties of interest vary rapidly, and coarser resolution elsewhere. An example of this approach is the Gerris Flow Solver being developed in the Multi-Hazards Forecasting System research programme at NIWA. For two dimensional applications, this uses a quadtree structure to locally refine the spatial resolution of a model grid. A "parent" cell can be

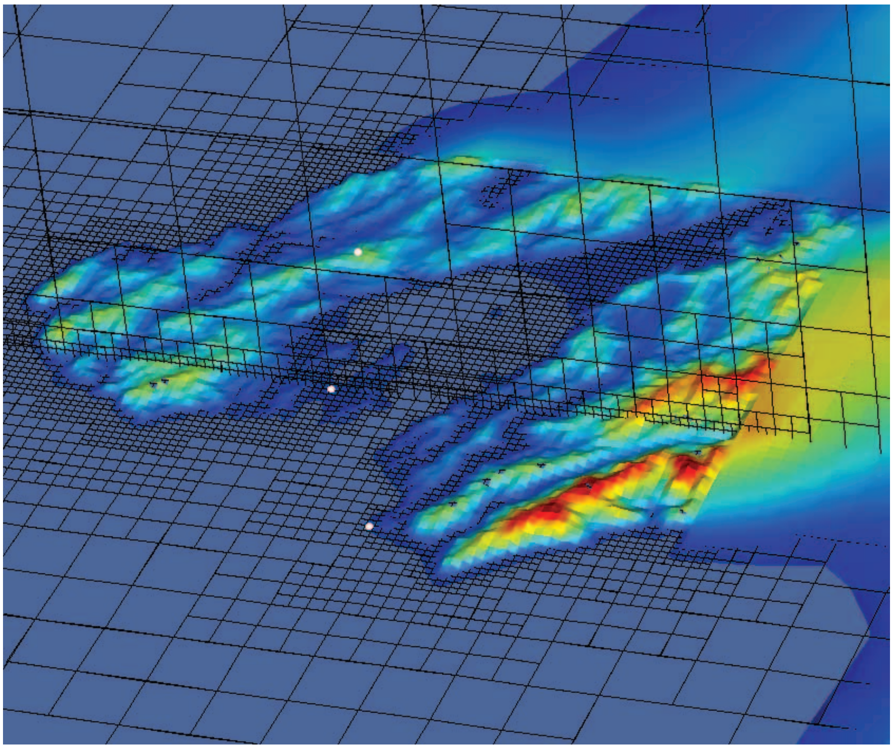

Fig 1a. Map showing the initial t = 0 s Gerris grid configuration in the horizontal and vertical, and the high resolution terrain, coloured according to height above sea-level. The resolved terrain resolution decreases with distance away from the centre of the domain (Wellington Airport) and the Airport, Mt KauKau and Baring Head are depicted by white dots in the image.

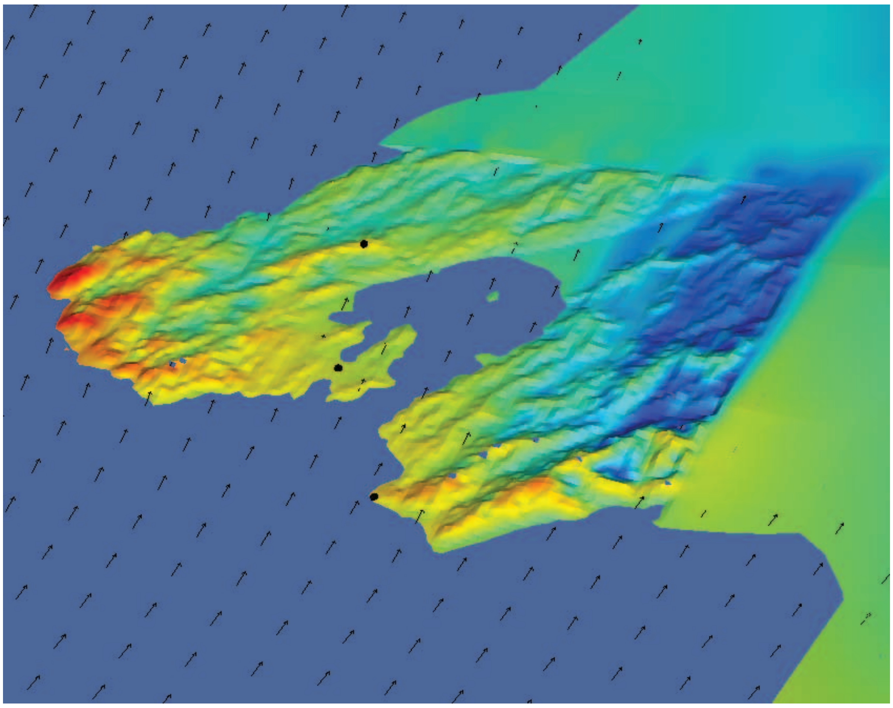

Fig 1b. Surface wind speed and wind direction vectors over the Wellington region 11 hours into the Gerris simulation. The image clearly shows the west coast experiencing much higher wind speeds than the 3 observation stations (depicted by black dots).

subdivided into four "child" cells. This process can be repeated as many times as necessary, or reversed to coarsen the grid. In three dimensions, an "octree" structure is used, refining a cubic parent cell by subdividing it into 8 cubic child cells. See grids displayed in Figure 1a and in the article on *Wind speed monitoring* (Fig 2. on page 40).

The following sections describe how adaptive methods are being used to improve the accuracy and timeliness of wind, wave and tsunami forecasts.

Gerris applied to strong winds in Wellington

Gerris has been used to simulate a severe wind storm event that hit Wellington on 12th March 2010. A mid-afternoon southerly wind change brought with it a period of intense rainfall and extremely strong and damaging wind gusts, peaking at 122 km/h at Wellington Airport, 146 km/h at Mt KauKau and 216 km/h at Baring Head on Wellington's exposed south coast. Using initial and lateral boundary conditions from the NZLAM-12 numerical weather prediction model (see Natural Hazards Update 2007, 20-21), Gerris was used to simulate the wind field 10m above the surface during this event at horizontal cells down to 333 m in size. The adaptive grid and much higher resolution terrain indicate that areas such as the west coast (see Fig 1b) where no observations are available also experienced very high wind speeds. The finer detail is also of benefit for highlighting residential areas that might be expected to experience higher wind speeds and thus incur greater damage than others. Using Gerris in this way is an inexpensive method for obtaining highly localised wind forecasts at resolutions not yet computationally affordable with a full-scale numerical weather prediction model.

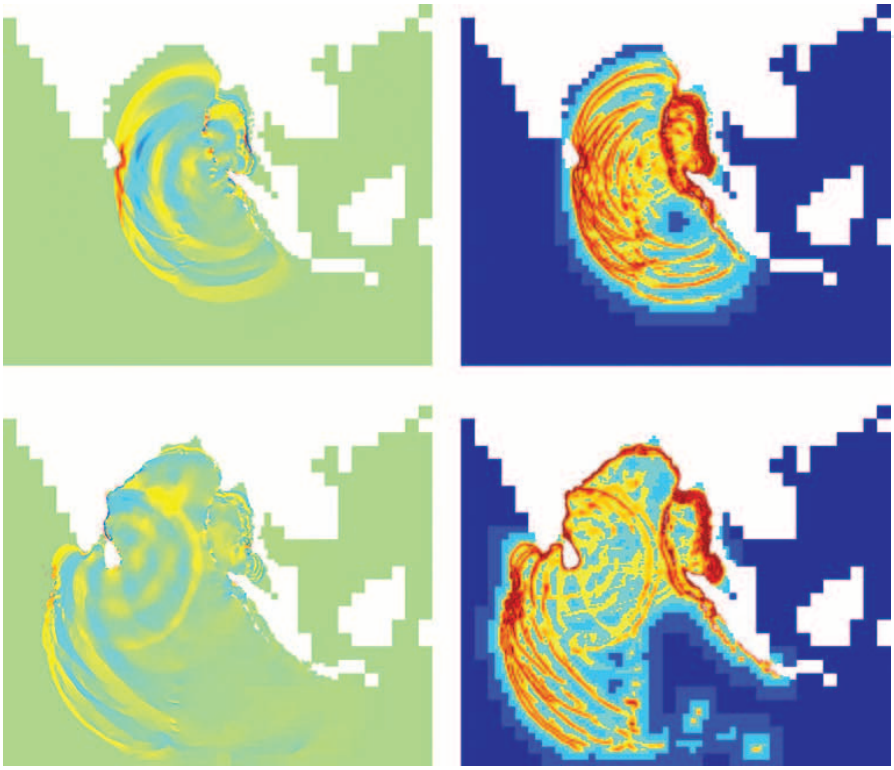

Fig 2. 2004 Indian Ocean tsunami at t = 2 hours (top) and t = 3.5 hours (bottom). The left column shows wave elevation (crests are red and troughs are blue). The right column shows spatial resolution of the adaptive mesh, ranging from 101 nm (dark blue) to 0.8 nm (dark red).

Indian Ocean Tsunami

In December 2004, a fault rupture off the Sumatra coast produced damaging tsunami waves throughout the Indian Ocean basin. Simulation of such an event requires a model domain covering a large spatial extent, but also needs to resolve the wave front, and the topography it interacts with, at much finer scales, so the adaptive Gerris model offers a very efficient way of simulating this event. Figure 2 illustrates the wave elevation field and the corresponding adaptive mesh at 2 hours and 3.5 hours after the initial fault rupture. The model starts with a very coarse resolution, but refines the mesh around the advancing wave fronts, using a dynamic terrain reconstruction procedure to create the needed bathymetry "on-the-fly".

After 2 hours, the wave front has just reached Sri Lanka, so that the eastern side of the island is resolved at the maximum resolution (0.8 nautical miles) while the western coastline still uses the much coarser resolution (50 nm). After 3.5 hours, the wave front reaches the Maldives (previously unresolved) and wave reflections off the eastern coastline of Sri Lanka are also evident.

The complex individual wave fronts due to the staggered fault rupture and initial dispersion are also tracked individually at high resolution. Some areas (e.g. the dark blue patch south of the Aceh Peninsula in the top right of Fig. 2) have already been traversed by the wave fronts and have returned to coarser resolutions, appropriate to resolve the smoother elevation field there. ■

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Images and data: NIWA

Wind Speed Monitoring over the Belmont Hills

How good is the Wind Loading Standard at estimating wind loads for structures in rugged terrain where direct wind measurements are not available? The New Zealand Wind Engineering Consortium, which consists of an informal group of scientists from NIWA, GNS Science, Opus Research and the University of Auckland Engineering Department, has received funding from the Natural Hazards Research Platform to investigate how the vulnerability of New Zealand's built environment to wind damage can be reduced by improving procedures for estimating design wind speeds.

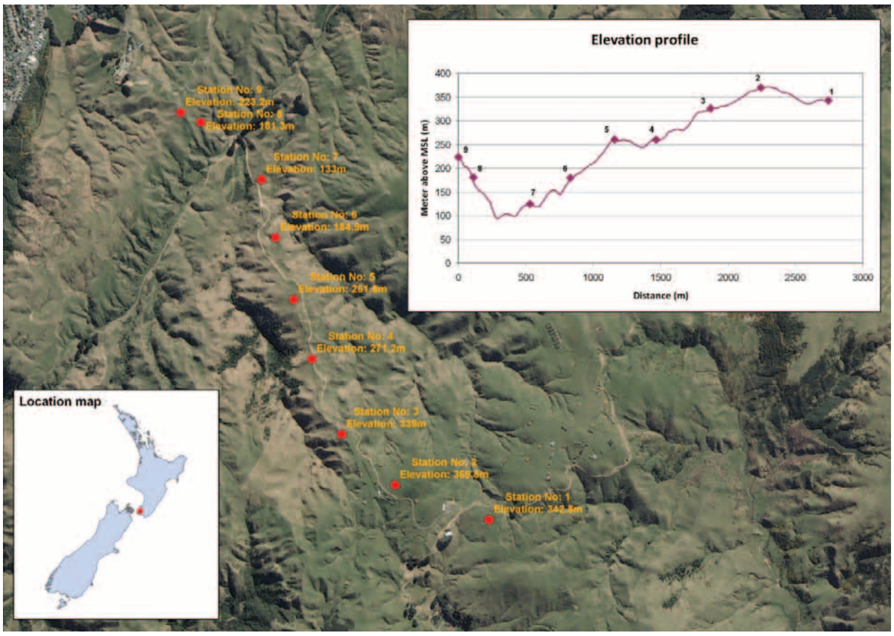

Fig 1. Location of the anemometers in Belmont Park with an elevation profile.

Wind and building codes

New Zealand's hilly geography and its location in the path of the 'roaring forties' means that wind loadings are an important consideration when it comes to our building codes. Hill shape has a huge effect on wind-speed and can increase its force up to threefold compared to nearby flat terrain. This makes the ratio of wind speed over a hill divided by the wind speed at a nearby, upstream flat site (commonly referred to as the hill-shape multiplier) very important when considering wind action on buildings and structures located on hilly sites.

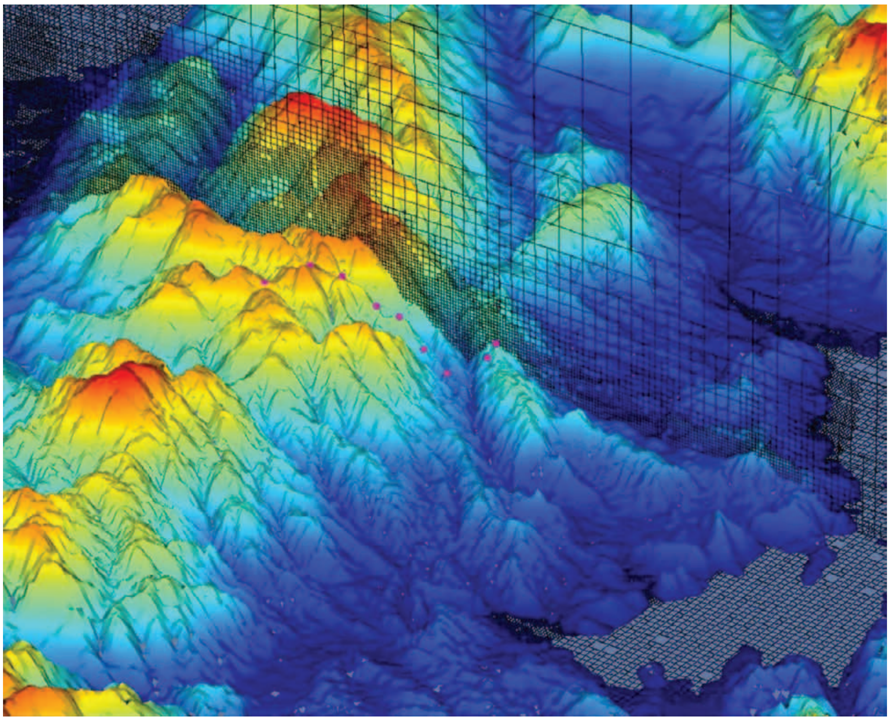

Fig 2. CFD model GERRIS topography (highest peak in foreground ~ 400 m), mast locations (purple dots 1 to 9 from left to right) and adaptive grid along a NNW-SSE cross-section through Belmont Park (northern half of the domain) viewed from the NE.

Wind speed investigations by the Consortium to date

Wind speeds have been measured, for an 18-hour period of severe gale force northwesterlies in February 2011, along a line of anemometers running from west to east across Belmont Park (Fig. 1) and compared with speeds observed at a nearby site unaffected by the hills to estimate hill-shape multipliers. This event has also been simulated with computational fluid dynamic (CFD) computer modelling using Gerris (Fig. 2),wind tunnel testing (Fig. 3), and an empirical model (WASP), and the results compared with estimates based on application the existing loading standard.

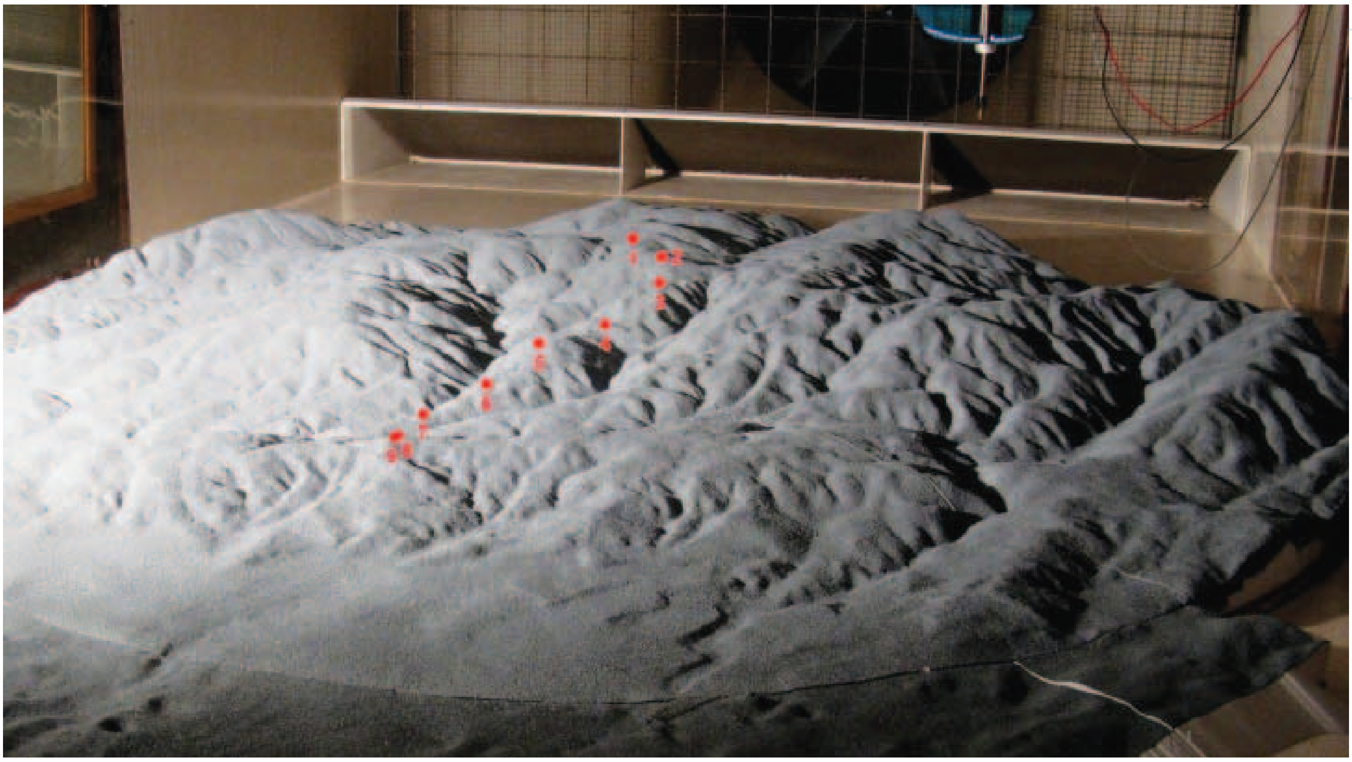

Fig 3. 1:2000 wind tunnel model of the Belmont terrain viewed from the NW. The anemometer locations correspond to the numbered red dots running up the ridge in the centre of the picture.

Preliminary Results

While the results (displayed in Fig. 4) from CFD and wind tunnel modelling agreed quite well with the measured hill-shape multipliers - mostly within 15 percent and frequently within 5 percent - the estimates based on application of the loadings standard differed from measured values by as much as 40 percent. Estimates based on the loading standard were also found to vary considerably (up to 40 percent) depending on the interpretation of the loadings standard by different operators.

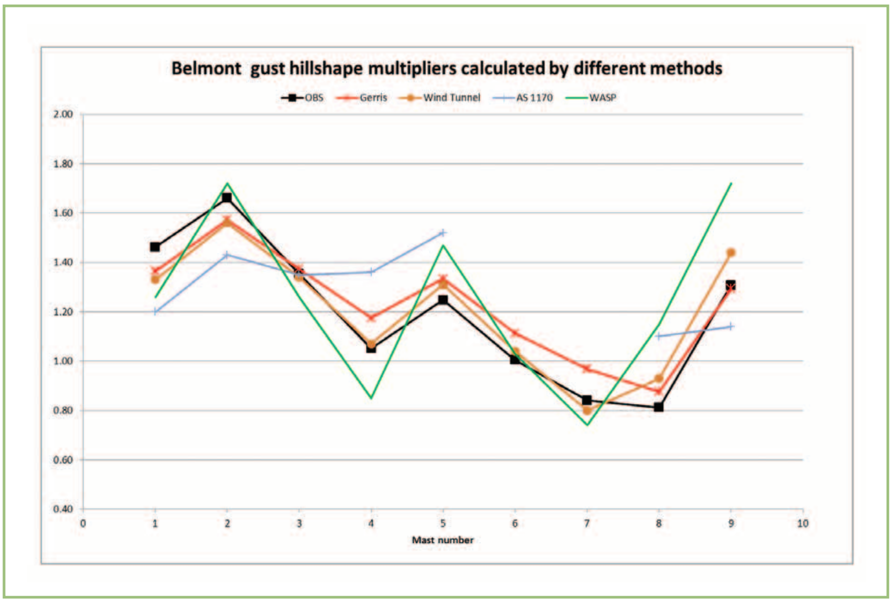

Fig 4. Hill-shape multipliers at 5 m at each mast location for a wind direction of 345° as determined by measurements (black), CFD - Gerris (red), Wind Tunnel (brown), CFD - WASP (green) and AS/NZS 1170 loadings standard (blue).

Further field studies and modelling

Further field studies and modelling for a greater range of wind speeds, directions and mast heights will be made over the next year with the aim of improving the wind loading standards to make them more relevant to New Zealand conditions.

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Images and data: NIWA

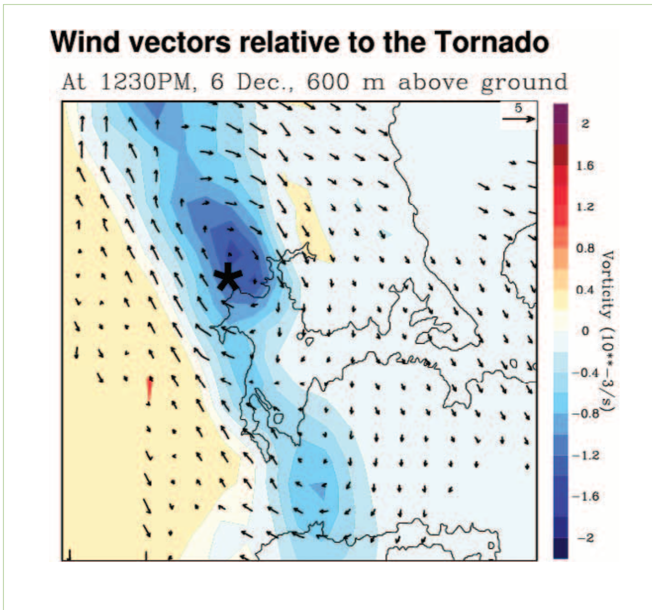
Forecasting the Low-Level Meso-Vortex of the Hobsonville Tornado

What is a tornado, what is a meso-vortex?

A tornado is defined as a violently rotating, narrow column of air, between 10-1000 m in diameter that extends to the ground from the interior of a thunderstorm. A meso-vortex (also called a mesocyclone) refers to a cyclonic (clockwise rotation in the southern hemisphere) circulation with core diameters that vary from 3–9 km. The meso-vortex is considered the parent circulation that spawns a tornado. Studies indicate that about half of all low-level meso-vortices detected were tornadic, suggesting that a reliable forecast of the meso-vortex associated with a thunderstorm could lead to improved accuracy in forecasting tornado occurrence. Given the typical scale of a meso-vortex, and provided reliable initial conditions are available, a convection-resolving Numerical Weather Prediction (NWP) model running on a 1 km horizontal grid (see *Adaptive Modelling Techniques*, this issue), should be able to forecast the presence of meso-vortices.

Hobsonville Tornado: 6 December 2012

A tornado with peak wind speeds of between 170 km/h (EF1[1] as estimated by damage surveys) occurred in the Hobsonville suburb of Auckland at around 12:30 pm on 6 December 2012. After successfully simulating the mesocylcones associated with the Taranaki tornado



Simulated horizontal wind vectors relative to the tornado and vorticity (shading) at 600m above the ground from an NZCONV forecast initiated at 6 am (NZST) on Dec 6, 2012. The dark blue indicates the area of enhanced vorticity, and the star symbol denotes the location of Hobsonville and the thin solid lines denote coastlines.

outbreak of 2007 with a model nested to 2 km grid spacing, NIWA has started running daily experimental 1 km grid spacing forecasts over New Zealand (using NZCONV, the New Zealand CONVection-resolving NWP model). In this instance, the model was able to forecast the meso-vortex (Fig 1) that spawned the tornado six hours in advance.

The figure below left shows the NZCONV-forecast vorticity (measure of the spin) and wind vectors relative to the observed tornado location over Hobsonville at 12:30pm on December 6, 2012. The wind vectors clearly show clockwise rotation corresponding to a negative vorticity maximum indicating the presence of a meso-vortex. However, the simulated winds at the surface are weaker than those that were observed on the ground. The main reason for this is the inability of NZCONV to resolve the actual tornado development. A range of refinements to the model have been identified to further improve the accuracy of tornado forecasts.

Future research

We have identified a range of refinements needed to further improve the accuracy of tornado forecasts. Future research within the Multi-Hazards Forecasting System programme will determine which of these factors is most critical. Our first step will be to improve the currently crudely represented effects of land surface heating in NWP models. It is hoped that these improvements, particularly in urban areas, along with higher resolution NWP models, will lead to better forecasting of meso-vortices and ultimately provide longer lead times for tornado warnings.

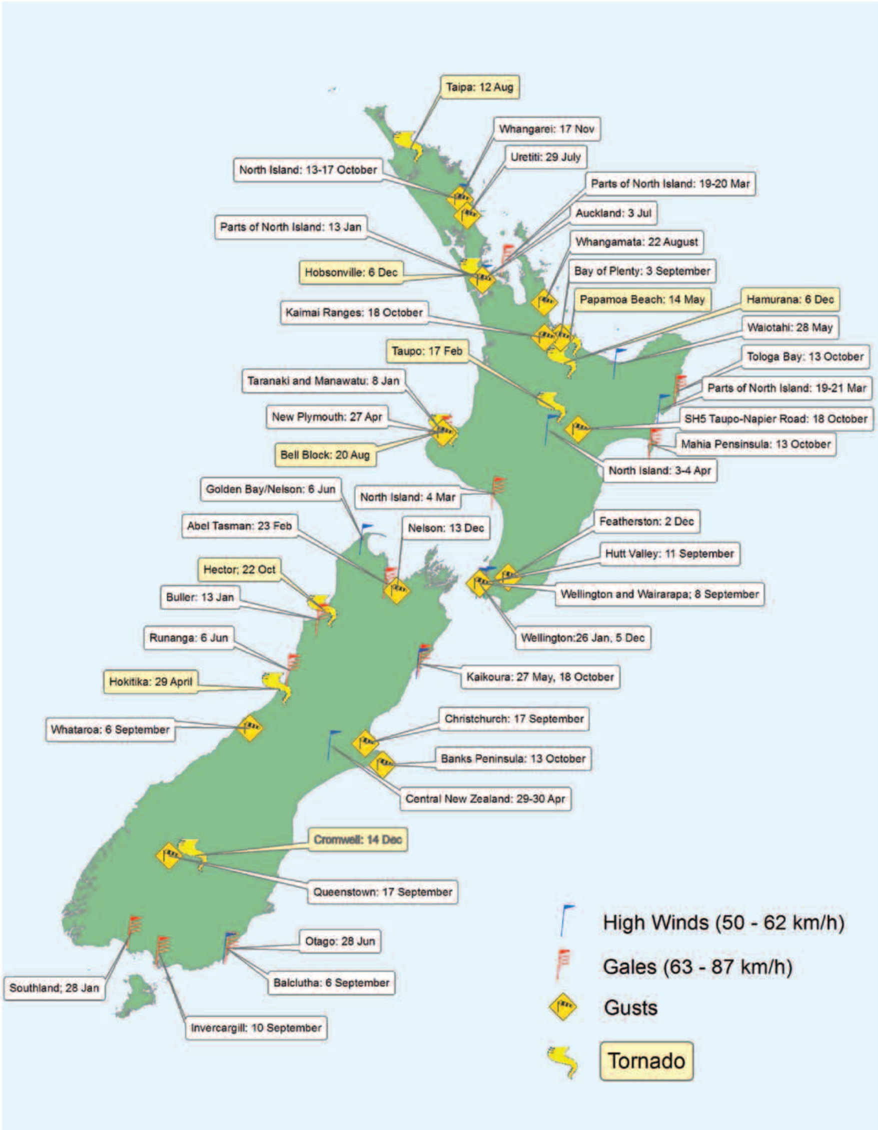
➔ Contact: Ed Y. Yang, Y.Yang@niwa.co.nz

1. The EF Scale (Enhanced Fujita Scale) measures the strength of a tornado from F0 to EF5 based on damage.

Images and data: NIWA

Wind & Tornadoes 2012

The most significant wind hazard events for New Zealand in 2012 were the Hobsonville tornado of 6 December which killed three people, injured seven, and did approximately $10 million of damage; and the North Island storm of 3-4 March which, with sustained winds of over 90 km/h, damaged power networks, homes and forests, particularly in the Whanganui and South Taranaki areas. Aside from the Hobsonville tornado, other locations to experience tornadoes were Taupo, Taipa (near Kaitaia), Hokitika, Hector, Papamoa Beach, Hamurana, and Cromwell. Water spouts and funnel clouds were also sighted on at least four occasions including rare sightings off Lyall Bay in Wellington on 15 May. In general, 2012 had a mix of windy and quieter months, with January, March, September, and October being quite windy. The highest recorded wind gust was 206 km/h at Cape Turnagain, Wairarapa on 2 December, with the next highest being 185 km/h at both the Rock and Pillar Range on 31 January and also at Cape Turnagain on 18 and 25 October.



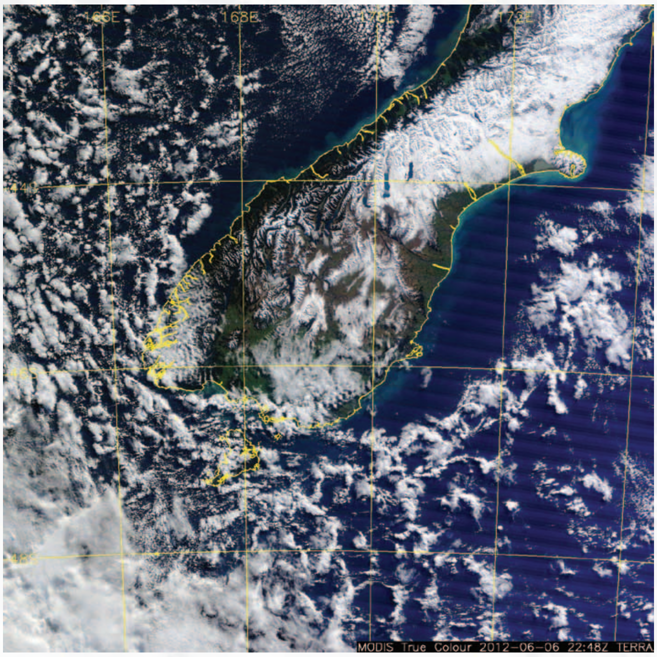
The Hobsonville tornado occurred just after noon on 6 December. Maximum max wind speeds were estimated to be close to 170 km/h. Aside from the tornadic winds, very strong straight line wind speeds of 128 km/h were reported at Whenuapai Airfield at this time. This same weather system also spawned a tornado at Hamurana (near Rotorua) later that afternoon.

Winds associated with the 3-4 March storm were widespread and severe, tearing down trees and causing property damage and power cuts throughout much of the North Island. These winds were associated with a rapidly deepening low over the Tasman Sea on 3 March which moved eastwards across the lower North Island on 4 March. Hundreds of hectares of forest were damaged and power cut to homes and farms in Taranaki, Whanganui, the Coromandel Peninsula, Te Puke, Wairoa, Kawhia, Kapiti Coast, northern Wellington, Hutt Valley, Wairarapa, Auckland, Piha, Waiheke Island and Kaipara. Cook Strait ferries were cancelled on 4 March, and flights cancelled or delayed. Nearly two weeks later, about 40 rural properties were still without power in the Patea, Waverly and Waitotara areas, as well as some farms in the Whanganui hill country. The Powerco lines company said the damage was so great during the storm that it had to completely rebuild line networks in some places. ■

Estimating Snow-Loads on Conductors. Gaps in our Knowledge.

Recent snow storms in New Zealand have damaged infrastructure and have highlighted deficiencies in the country's snow data records. This has led to questions about the snow loading standards used in this country, particularly for heavy snow-fall events at low elevations.

In August 2011, snow accretion on conductors in combination with high winds caused faults on three of Transpower's four main electricity transmission networks supplying Wellington. In some instances the faults appeared to be caused by arcing (flashover) between conductors due to the snow load, possibly in combination with high winds, causing the lines to sag excessively and/or winds blowing one conductor into another. According to the standard (AS/NZS 1170), snow loads on conductors in the Wellington area where the faults occurred would have had zero load at less than 200 m altitude, and 30 mm radial thickness (with a density of 400 kg/m³) with no coincident wind action for altitudes between 200 and 600 m. Clearly this was not the case for this event and NIWA was asked to estimate combined wind and snow loads for these lines. Using atmospheric models combined with observations, it was estimated that wind gusts of between 25 and 38 m/s were experienced along exposed sections of the lines and snow-accretions of 0.017-0.068 kg/m/h occurred. This is equivalent to about 10-40 mm of snow on the conductor over the four hours of the storm.



Satellite Image: NIWA and NASA

Snow in June. Photo: Nelson Boustead, NIWA.

The large uncertainty reflects that key parameters were not observed at the lines and also that some parameters, such as snow densities and fall-rate of snowflakes, were not recorded anywhere in the Wellington area. NIWA was also asked to provide recurrence intervals for such events to assist decision-making regarding the need to install some form of mitigation on various lines in the Wellington region. The absence of snow depth and density records (other than in old newspaper reports) meant considerable uncertainty in these estimates, as well. Currently, Ashburton is the only site in the country with continuous long-term (40 years) records.

Improving snow information

To try and get better information about significant low-level snow events, NIWA, in conjunction with MBIE and some network companies such as PowerCo and Transpower, has developed a "snow mobilisation" process. Field teams measure snow depths and densities on the ground, buildings roofs and around power lines for significant snow events. The teams also take photos and video and obtain spot measurements of temperature, humidity and wind speeds. In 2012 snow mobilisation occurred in Canterbury during and after the major 6 June snowstorm as well as around Roxburgh on 6 September. NIWA also uses social media such as Facebook and blogs[1] where the public can enter their own comments, photos, and snow depths. We also share collected snow information with affected regional councils, such as Environment Canterbury. It is hoped that over the course of many years a good collection of snowfall observations for significant low-level snow events will be developed and then applied through revised snow loading standards. ■

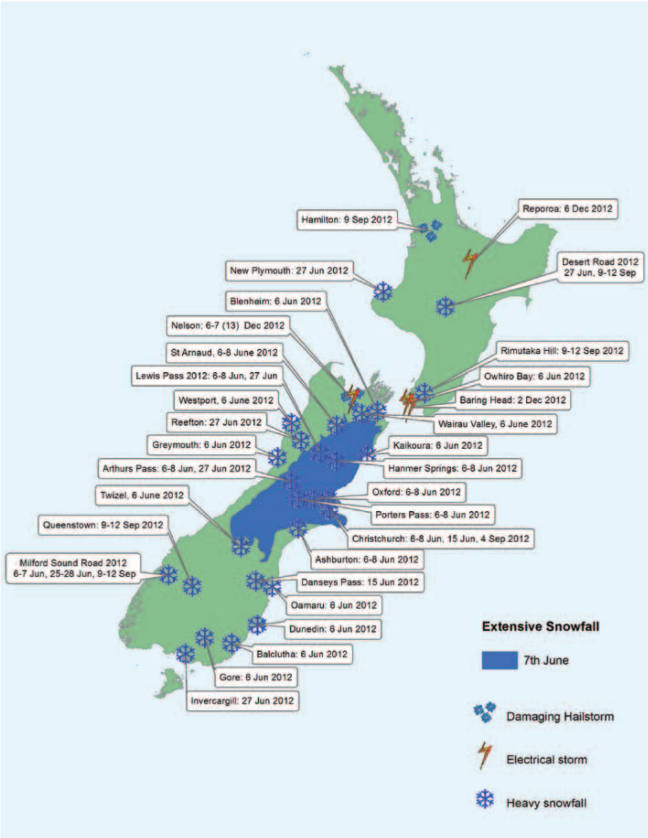
1. http://sciblogs.co.nz/waiology/2012/06/06/citizen -science-how-deep-is-the-snow-at-your-place

Snow, Hail & Electrical

During the period 6th to 7th June, heavy snowfalls occurred to low elevations over Canterbury, Otago, West Coast and Marlborough. This event resulted in many eastern and alpine South Island road closures (SH1 from Greta Valley to Waipara, SH8 between Fairlie and Twizel, and Porter's, Dansey's and Arthur's passes) and disruption of the distribution of electricity (mainly due to snow-laden trees falling on to power lines). It also caused school closures, the cancellation of bus services across Canterbury and air traffic disruptions across the South Island (black ice). A less significant snow event occurred between 9-12 September across Southland and Otago. This event resulted in regional road closures, school closures and air travel disruptions following the closure of Queenstown airport.

A severe thunderstorm hit Christchurch on 4th September, with hail damaging conservatories and cars, and lightning disrupting power supplies and delaying flights. On 9th September, hail damaged cars in the Hamilton area, and on the 6th and 7th December, hailstorms in the Nelson area caused significant damage to crops.

On 6th June in Owhiro Bay near Wellington, lightning struck a power pole, knocking out electricity and internet connections, and closing the local primary school for the day. On 2 December, a rare form of lightning storm crossed Wellington and the Wairarapa, with cloud-to-cloud lightning, but no damage. ■

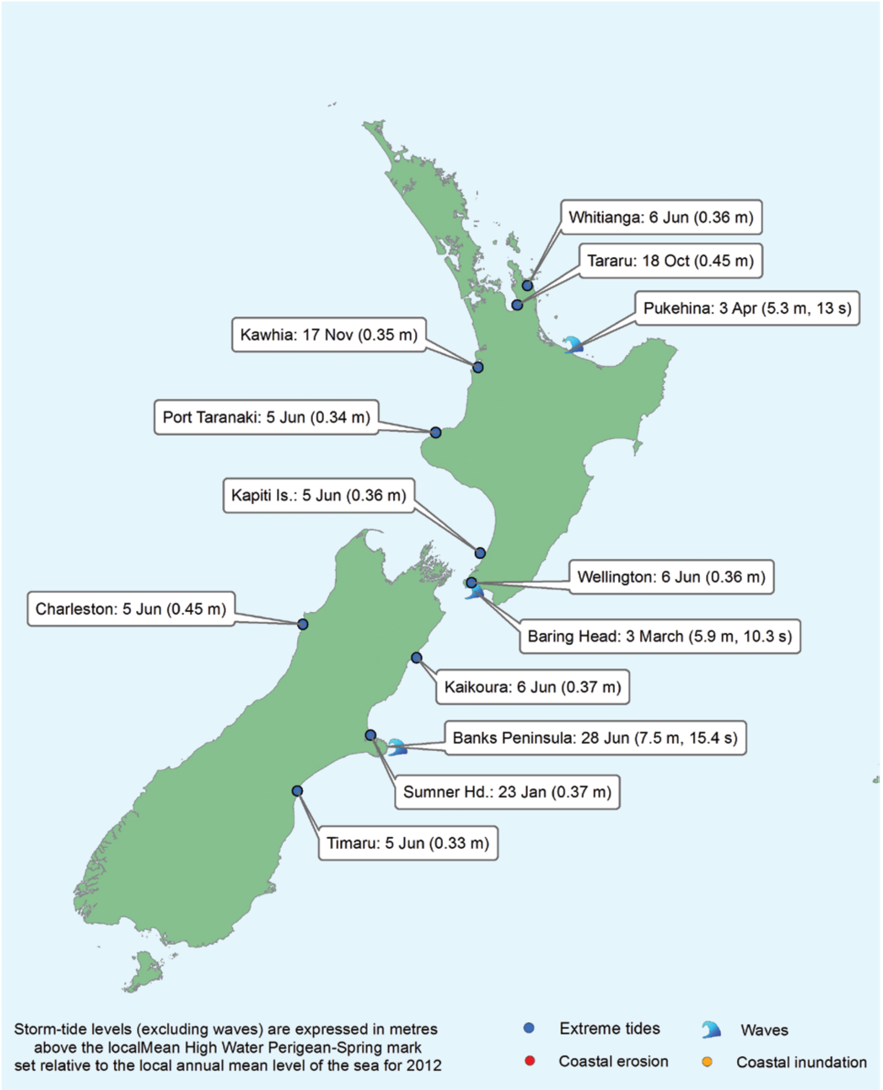


Snow above Brooklyn, Wellington. Photo: Dave Allen, NIWA.

Coastal Hazards

Waves

At the offshore sites monitored by NIWA, the highest waves were recorded off Banks Peninsula during a storm on the 28th of June, with significant wave height reaching 8.1 m. At that time, waves were coming from a mean direction of 193° (SSW) with a peak period of 15.4 seconds. The maximum individual wave height during the storm was 12.6 m. At Baring Head, outside Wellington Harbour, the largest significant wave height recorded was 5.9 m on the 3rd of March. The peak period was 10.3 seconds, and the largest individual wave recorded during that event was 8.2 m. A storm on the 3rd of April produced the largest significant wave height (5.3 m) recorded at Pukehina, in the Bay of Plenty. The peak wave period at the time was 13.0 seconds associated with swell coming from a mean direction of 48° (NE). The maximum individual wave height during the storm was 8.0 m. The wave buoy was, however, out of service during a storm on the 30th of July which wave forecast outputs indicate may have produced larger wave heights than the April event. Data sources: NIWA, Bay of Plenty Regional Council.



Extreme Tides

In 2012 all monitored sea-level gauges recorded the highest storm tide levels on days when high perigean-spring or 'king tides' were predicted*. The highest storm tide level of 0.45 m above the local Mean High Water Perigean Spring (MHWPS) mark was shared between Charleston (Westport) on 5 June and Tararu (Firth of Thames) on the 18th October. The storm tide at Charleston (and also highest at 10 other NZ gauge sites) occurred when a king tide combined with a storm surge caused by a depression travelling from the Tasman Sea over New Zealand. A king tide combined with a strong westerly wind flow over New Zealand and a depression off the east coast on 18 October resulted in the highest storm tide level in 2012 at Tararu. This tide/weather combination also resulted in Little Kaiteriteri and Kaingaroa (Chatham Islands) recording their highest storm tide levels for the year. Data sources: NIWA, Waikato Regional Council, Environment Canterbury, Port Taranaki, PrimePort (Timaru), Greater Wellington Regional Council.

Coastal Erosion and Inundation

No major coastal inundation or erosion events were reported in 2012.

Tsunami

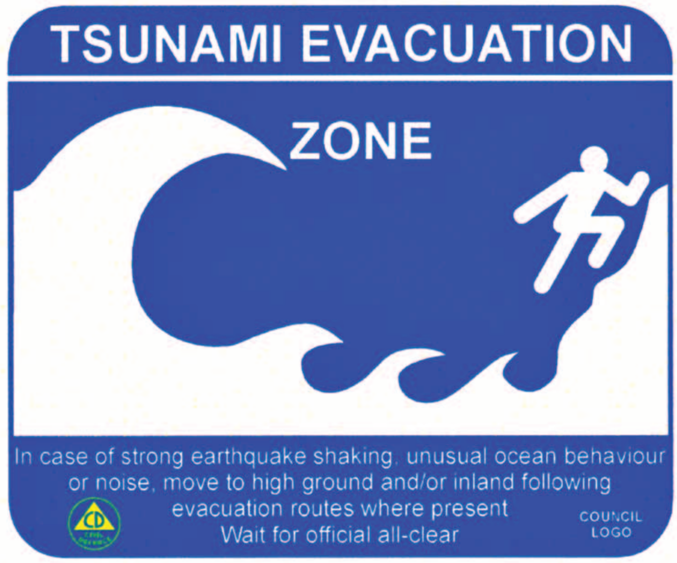
No significant tsunami events affected New Zealand in 2012

https://www.niwa.co.nz/natural-hazards/physical-hazards-affecting-coastal-margins-and-the-continental-shelf/storm-tide-red-alert-days-2013

Tsunami Evacuation

While no significant tsunami events affected New Zealand in 2012, we continue to be susceptible to tsunami from both far- and near-field sources.

We encourage everyone who lives in or visits our coasts to be aware of tsunami risk. In the event of an earthquake, follow these **recommendations** from the Ministry of Civil Defence and Emergency Management:



Generic tsunami evacuation sign

GET READY GET THRU

CD CIVIL DEFENCE

RECOMMENDATIONS

A tsunami generated in conjunction with a nearby large earthquake or undersea landslide may not provide sufficient time to implement official warning procedures.

If you are in a coastal area and -

- experience strong earthquakes (hard to stand up);
- experience weak earthquakes lasting for a minute or more;
- observe strange sea behaviour such as the sea level suddenly rising and falling, or hear the sea making loud and unusual noises or roaring like a jet engine;

Do not wait for an official warning.

Instead, let the natural signs be the warning. Take immediate action to evacuate.

Go to predetermined evacuation zones, high ground or inland. ■

The Natural Hazards Platform

The GNS Science-led Natural Hazards Research Platform was created in September 2009 by government to provide secure long-term funding for natural hazard research, and to help research providers and end users work more closely together. The Platform also includes NIWA as an anchor organisation and University of Canterbury, Massey University, Opus International Consultants, and University of Auckland as partners, and there are a further 20 subcontracts to other parties.

www.naturalhazards.org.nz

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