Natural Hazards 2013

GNS SCIENCE TE PŪ AO

Massey University

UC UNIVERSITY OF CANTERBURY Te Whare Wānanga o Waitaha CHRISTCHURCH NEW ZEALAND

THE UNIVERSITY OF AUCKLAND

OPUS

NIWA Taihoro Nukurangi

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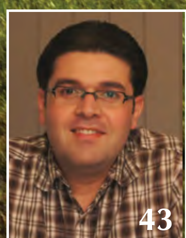
Cover credits:

Front cover: Large waves along the Esplanade, Owhiro Bay, Wellington. Photo: Dave Allen, NIWA

Back cover: Storm damage along the Esplanade, Owhiro Bay, Wellington. Photo: Dave Allen, NIWA

Inside cover: Damaged irrigator in the aftermath of the Canterbury wind storm. Photo: Dave Allen, NIWA.

CONTENTS



2013

Natural hazards have no respect for time, the composition of communities or their vulnerabilities. The goal of civil defence emergency management in New Zealand is to create communities that are resilient to the myriad of natural hazard threats – from floods and storms, earthquakes and tsunami to volcanic eruptions, bushfires and cyclones.

Resilient communities are those that understand and manage their natural hazards. As Minister of Civil Defence, I am conscious of the vital role that science and research plays in civil defence emergency management. It enables us to understand the forces of nature that create natural hazards, and is critical in helping to develop the strategies and initiatives that help us to manage the consequences of these.

In some situations, time is of the essence. As our science improves, so can our warning systems. This can help save lives.

The Government's investment in this science and research has been applied through the Natural Hazards Research Platform and is led by GNS Science, with support from NIWA, the University of Canterbury, Massey University, Opus Research, the University of Auckland and other research providers. The Platform's work not only underpins New Zealand's research efforts for emergency management at home; it also provides us with a connection to international research programmes that enable us to share, compare and deepen our understanding.

Its activities have implications for every aspect of civil defence emergency management - from managing risks to guiding awareness and readiness, informing those managing a response, and contributing to recovery processes. Natural Hazards is the annual report of the Platform and serves to highlight the breadth and depth of research projects, along with their potential for building strong, well-prepared and resilient communities.

Similarly, the audience for Natural Hazards is wider than just the scientist; it is also those from the wider community who are involved in civil defence emergency management. The key to emergency management success is having an evidence base that expands our understanding and generates processes that cover the most likely scenarios, along with challenging us to consider those contingencies that are at the fringes of our experiences and imagination. I hope this annual report will therefore stimulate interest, and provoke thought and discussion.

Thank you to all who have contributed to civil defence emergency management and ultimately, the safety of our communities through research, analysis and experience. It is a proud record that is well illustrated through the examples in this report.

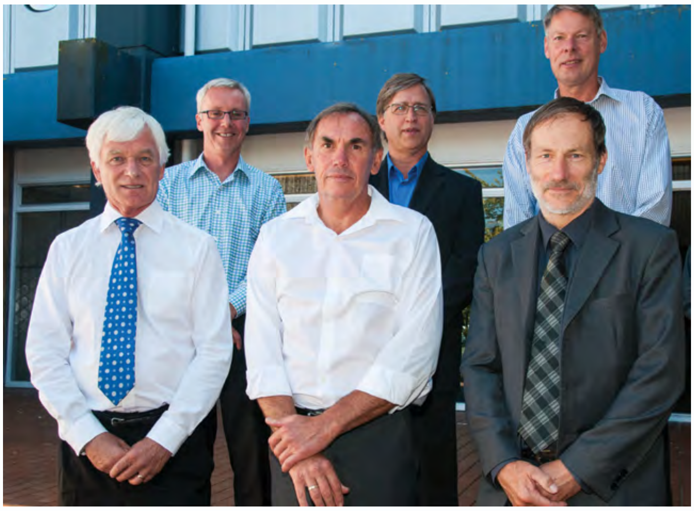
Hon. Nikki Kaye
Minister of Civil Defence

Platform Manager's Perspective

In looking back at 2013, members of the Natural Hazards Research Platform were engaged in a great diversity of activities – excellent research, expanded engagement with stakeholders domestically, and enhanced international collaborations. Advice was provided to many government departments, to local government agencies and, in the background, to major infrastructure initiatives. The Platform was called upon to present perspectives on natural risk at many fora, and the topic of natural hazard risk and resilience was selected as one of the nation's ten national science challenges.

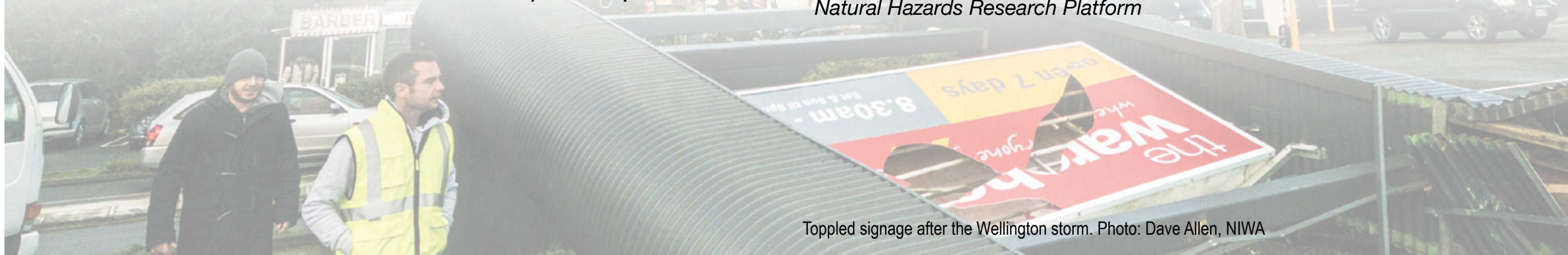
There were three significant natural hazard episodes through the year – earthquakes in Cook Strait in July and August, major weather events in Nelson and Bay of Plenty in April, and in Canterbury in September, and ongoing volcanic unrest and eruptions at White Island from January to October. While none of these events resulted in damage comparable to the Canterbury earthquakes of 2010–2011, they contributed to about $200 million of insured losses during the year. The Cook Strait earthquakes caused major damage in Seddon, but in Wellington they served as a timely reminder of the need for addressing earthquake-prone building issues, for improving the resilience of infrastructure networks and operational procedures for critical transport services. The severe Canterbury windstorm in September resulted in significant damage to the farming sector, yet the wind speeds were less than occurred in a severe storm in 1975. The lack of preparedness in filling pivot irrigators with water (see inside cover) and having back-up generators for milking greatly exacerbated the damage and economic loss.

On a positive note key relationships were strengthened through the year. At the Platform's annual Stakeholder Workshop, more than 120 representatives from 40 stakeholder agencies contributed to the day's proceedings that began with keynote presentations from Minister Gerry Brownlee as Minister of Canterbury Earthquake Recovery and of Transport; Fran Wilde as Chair of Greater Wellington Regional Council; and from Roger Sutton as Chief Executive of Canterbury Earthquake Recovery Authority (CERA). Elsewhere, the Platform's perspectives on the need for natural hazard risk management and resilience-building were sought in regards to public-private partnerships, and by stakeholders such as NZ Transport Authority, KiwiRail, NZ Council for Infrastructure Development, CERA, Treasury, and Insurance Brokers Association of NZ. Internationally, there was science collaboration with the European Commission, Japan, and the USA; and continued engagement with the Global Earthquake Model (GEM) Foundation, the Integrated Research on Disaster Reduction Programme of ICSU and UNISDR, and the World Bank's Global Facility for Disaster Reduction and Recovery. The momentum of engagement and influence in bringing about awareness and improvements in resilience to natural hazards has continued to build substantially since the Platform was established in 2009. New Zealand is a small country but we are leading the way in hazards reduction, readiness, response, and recovery.



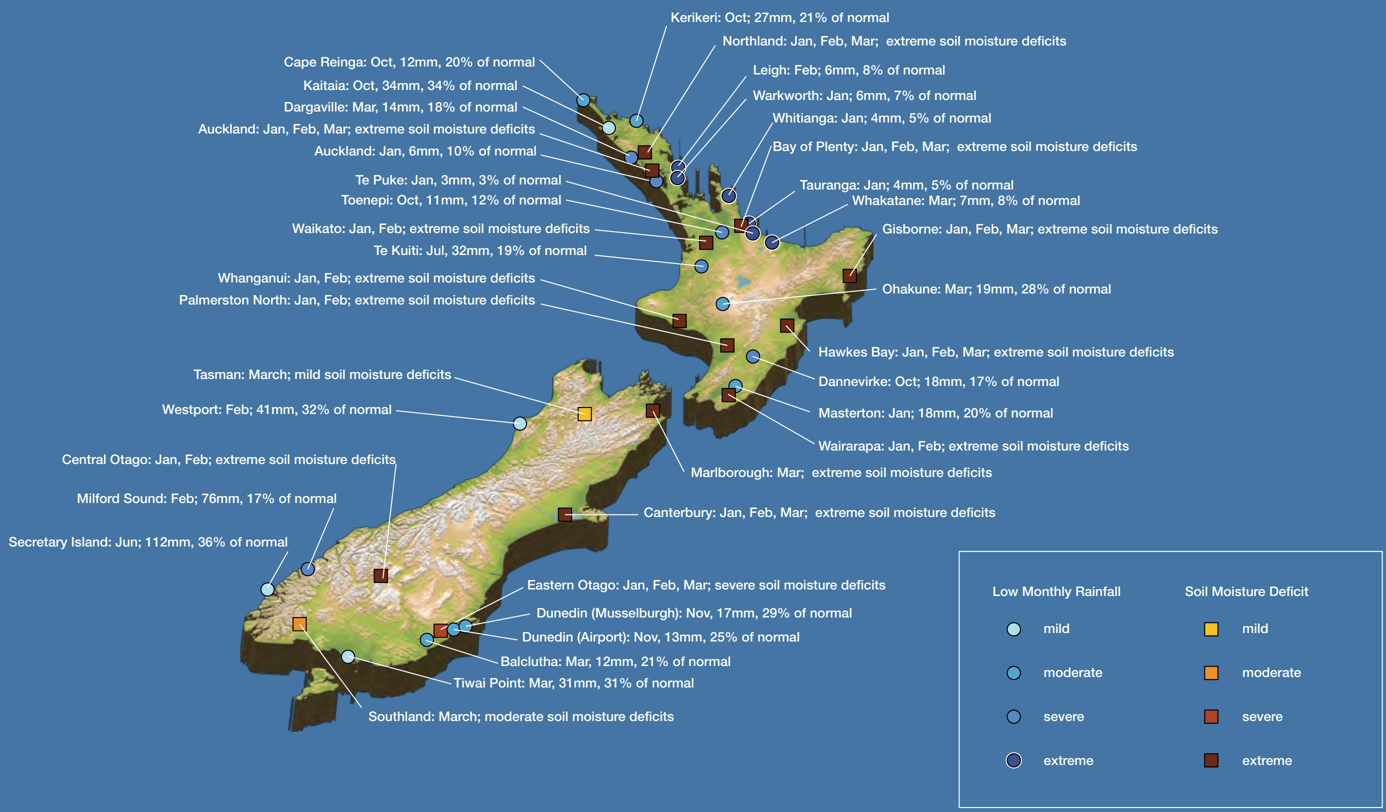
The Platform Management Group. Back row (l-r): Peter Benfell, Opus; Pierre Quenneville, U. Auckland; Jarg Pettinga, U. Canterbury; Front row (l-r): Murray Poulter, NIWA; Kelvin Berryman, Platform Manager, GNS Science; Terry Webb, GNS Science. Absent: Peter Kemp, Massey University

Kelvin Berryman, Manager
Natural Hazards Research Platform



Toppled signage after the Wellington storm. Photo: Dave Allen, NIWA

Low Rainfall & Drought



A significant drought affected the North Island and Westland between January and April 2013. This drought was one of the most extreme on record for New Zealand. The cause was the persistence of slow-moving or 'blocking' high pressure systems over the Tasman Sea and New Zealand during the summer, which stopped low pressure systems and fronts from approaching the North Island. The El Nino-Southern Oscillation was deemed not to be a contributing factor. The Ministry for Primary Industries declared 'an adverse event due to drought' for the entire North Island on 15 March, and for Buller and Grey districts on 22 March.

At the end of the year soils were drier than normal across western and central parts of the North Island, especially about western and central Waikato, the Central Plateau, as well as across and west of the Tararua Ranges.

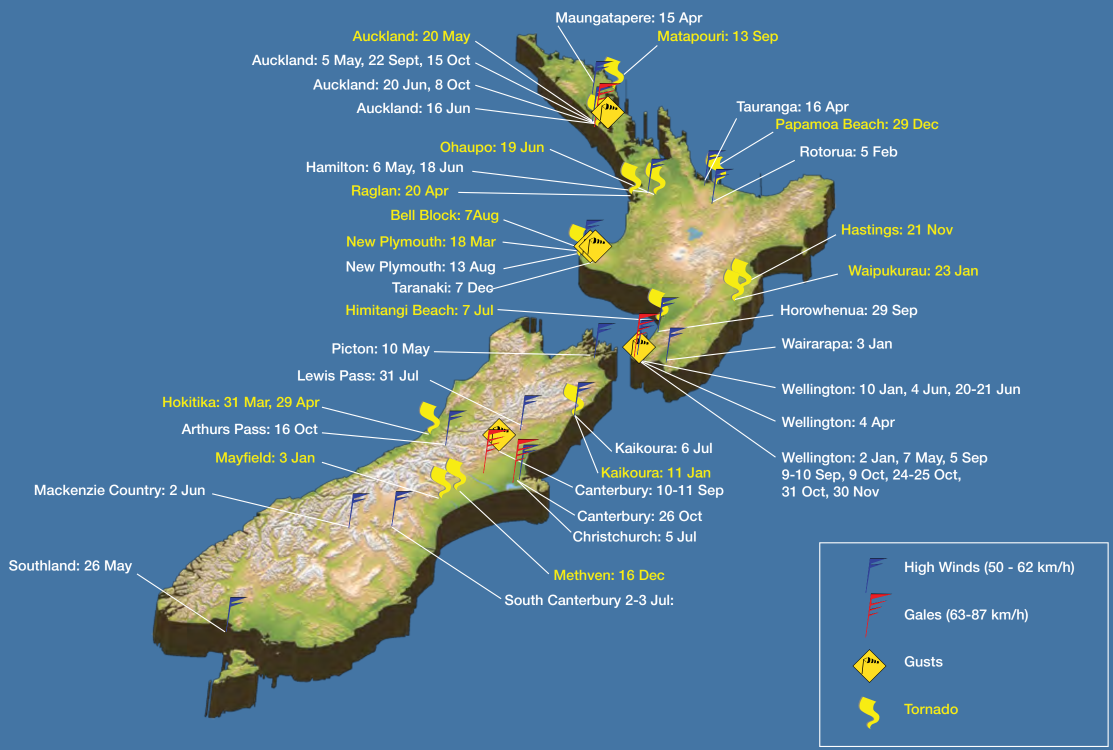
2013 was the driest year on record for Toenepi (near Morrinsville), Taupo, and Turangi which received just two-thirds of their normal annual rainfall. The driest locations overall were: Lauder with 453 mm of rainfall, followed by Alexandra with 455 mm, and Cromwell with 492 mm.

In contrast, soils were wetter than normal throughout the Coromandel Peninsula, the Bay of Plenty, and many eastern parts of the South Island. Near-record high annual rainfall was recorded at three inland locations in the southern South Island. Rainfall was near normal for the remainder of the country.

Prepared by Nava Fedaeff, NIWA

Drought in Wairarapa. Photo: Dave Allen, NIWA

Wind & Tornadoes



2013 featured damaging winds for Canterbury and Wellington that were the worst in decades.

Tornadoes which damaged property or felled trees were reported at Kaikoura on 11 January, Waipukurau on 23 January, New Plymouth on 18 March, Hokitika on 31 March, on farmland near Ohaupo (Waikato) on 19 June, at Himitangi on 7 July, at Matapouri (near Whangarei) on 13 September, and Hastings on 21 November.

Waterspouts moving ashore also caused damage at Raglan on 20 April, Papamoa on 29 December, and Hokitika on 31 December. The highest recorded wind gust was 202 km/h at Mt Kaukau, Wellington on 20 June, with the next highest being 191 km/h at Mt. Potts, Canterbury on 10 September.

Aside from tornado events, damaging and disruptive winds due to gales and thunderstorms occurred on at least forty-three other days, notably in Canterbury on 10-11 September. See '*Increasing Resilience to Weather Hazards*' for more on the Canterbury wind storm. A strong but less powerful storm on 5 July resulted in power outages to about 10,000 Christchurch homes. Downed powerlines sparked scrub fires in inland Canterbury, causing two homes to be evacuated and destroying a farm shed. A truck and trailer unit was blown over on SH1 north of Kaikoura, and trees and powerlines were brought down throughout the Marlborough and Canterbury regions.

A 110 km/h 10-minute mean wind speed corresponds to the threshold for a Category 1 Atlantic Hurricane.

The Wellington region also experienced severe winds, with the storm of 14-15 October being one of the worst in the last decade. However, the southerly storm of 20-21 June was the most memorable. Mean 10-minute speeds at Wellington Airport reached 103 km/h with gusts of 140 km/h. This storm caused widespread damage to infrastructure and vegetation in the region. About 30,000 homes were without power, and the Fire Service attended over 900 callouts on the night of 20 June. Trees were felled, roofs blown off, and windows smashed due to the wind. The airport was closed to all flights during the worst of the storm, and train, harbour ferry and interisland ferry services were cancelled. While some compared this event to the Wahine Storm of 1968 in terms of wind, measurements suggest it was not as extreme. It was, however, the worst southerly event in Wellington since the 1970s.

Prepared by Richard Turner, NIWA

Increasing Resilience to Weather Hazards

The costs of weather related hazards is increasing. During 2013 insured losses for weather related events were more than $174 million, the second most expensive year since records began in 1968. Of this amount, $74.5 million relate to the event of 10 – 11 September, when Canterbury was subjected to the strongest wind storm since 1 August 1975. This storm caused downed power lines and trees, damage to houses, businesses and farms, and overturned trucks, boats, and caravans. About 28,000 houses and businesses were without power overnight. Over 800 irrigators were damaged and there were significant business interruption costs. Recorded peak wind gusts ranged from 100 to 140 km/h. This event exposed the susceptibility of much of our built rural infrastructure to weather related hazards – which may be expected to occur more frequently in the future.

The most cost effective approach to improving resilience to weather hazards is through accurate forecasting that informs decisions which minimise the impact of such events. In the case of centre pivot irrigators, the loss of which led to significant insurance claims and impacts on farming operations in Canterbury, simple mitigation measures could have significantly limited the damage. This presupposes that accurate and specific forecasts of such events can be made, and that users have sufficient confidence in them that they will take action in advance of the predicted events. Here, we outline some of the research that will make our infrastructure more resilient to such weather related hazards in the future.

To solve the scientific problems associated with forecasting high impact weather events in the presence of New Zealand's complex terrain, the following are required:

- A computer model of the weather that can simulate the atmospheric processes acting at the scale of New Zealand's landscape and location in the mid-latitudes;
- Real time streams of satellite, aircraft, radar, balloon, ship and land surface observations that can be incorporated in the weather model to ensure that forecasts are accurate with respect to event intensity and timing;
- A supercomputer that can quickly carry out the vast number of computations implied by the points above, ensuring end users have the longest possible time to prepare for predicted hazardous events.

During 2013 NIWA scientists developed and began testing a new ultra-high resolution numerical weather prediction model, the New Zealand Convective Scale Model (NZCSM). Every 6 hours, this model forecasts the weather on a 1.5 km horizontal grid covering the

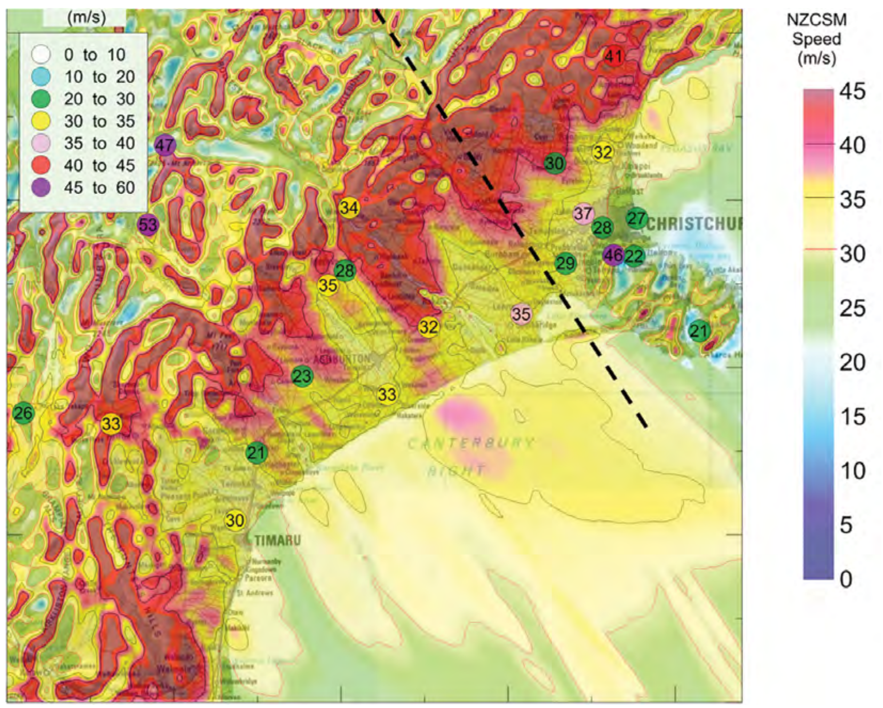


Figure 1: The spatial composite of the maximum NZCSM 10 m (above ground level) 30 minute wind gust simulations for the period from 0600 to midnight (NZST) on 10 September, together with observed (automatic weather station) maximum gust speeds for this period – using the same colour scheme as that used for the NZCSM data. The dashed line indicates the location of the eastern half of the vertical cross section plot shown in Figure 2.

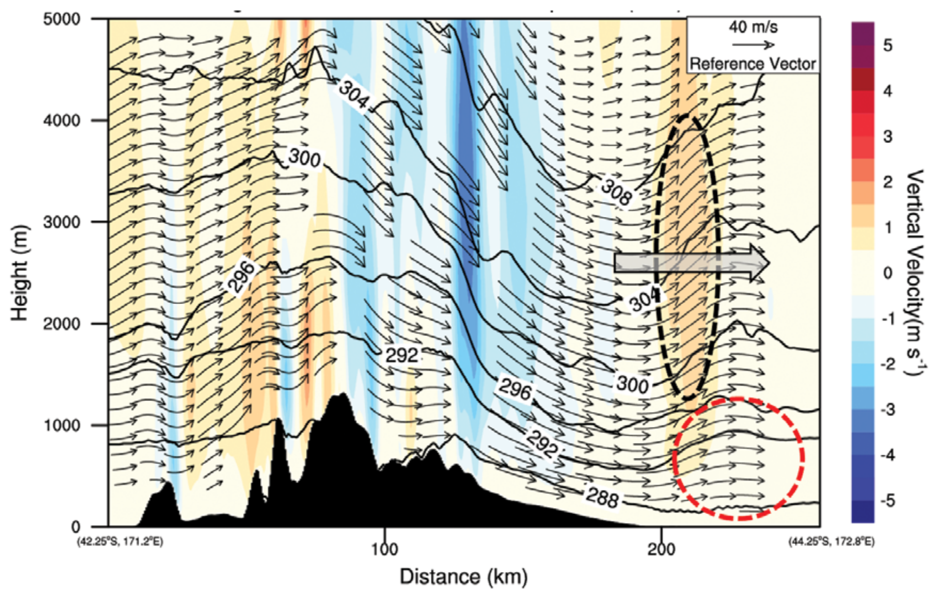


Figure 2: NZCSM simulation of winds (arrows) in the plane of the cross section (indicated Fig. 1), potential temperature (contours), and vertical wind speed (colour filled) of the lowest 5 km of the atmosphere at 8 pm on 10th September. The black ellipse indicates the region of strong upward motion ahead of the extreme surface winds, and its direction travel (grey arrow), and the red ellipse is a region where severe turbulence and atmospheric rotors may be present.

entire NZ land mass and adjacent ocean areas, from the surface to 40 km altitude, out to 36 hours ahead.

The NZCSM, a local configuration of the UK Met Office Unified Model, was developed at NIWA with international collaborators. It is the largest kilometre-scale weather forecast model internationally and can reveal atmospheric flow features caused by the interaction of weather systems with NZ's complex terrain –features not previously seen.

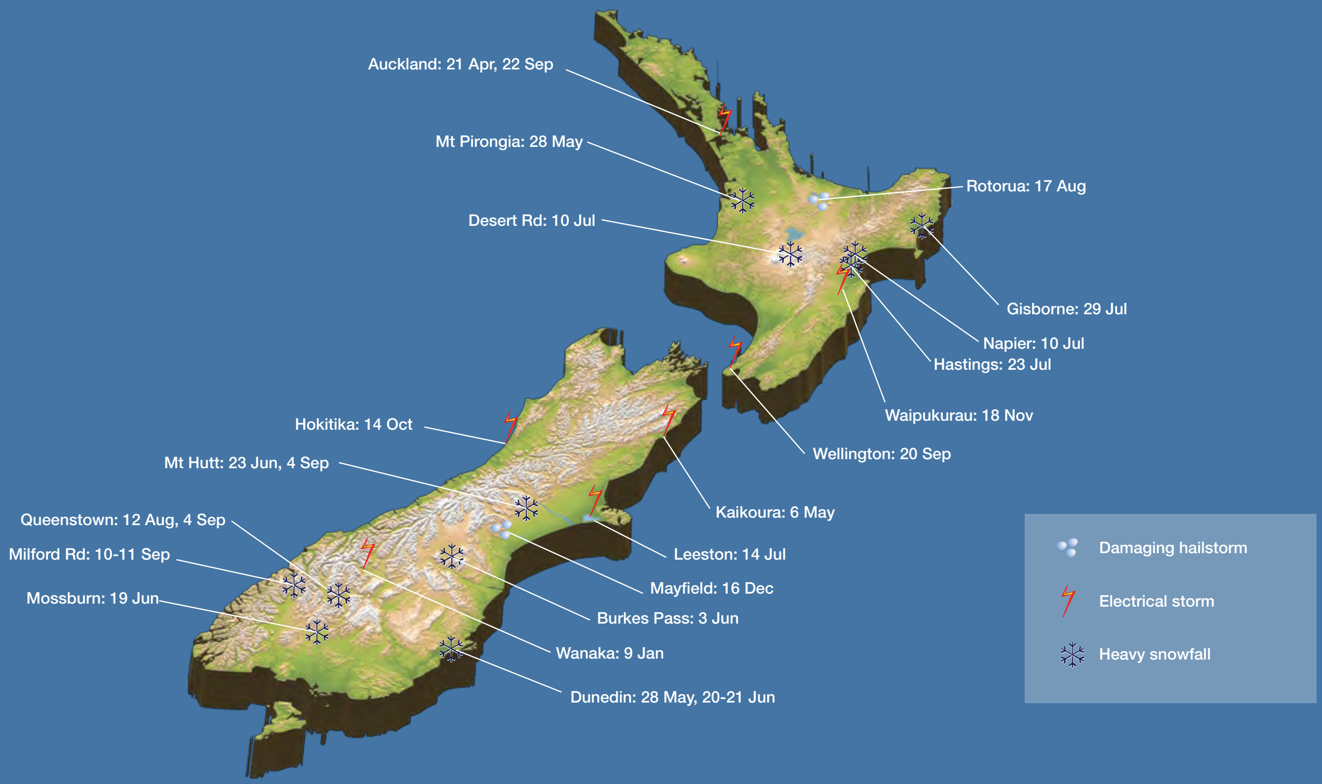
To understand how outputs from the model could better inform decision making in advance of predicted high impact events, NZCSM simulations are being used to investigate the Canterbury windstorm event. Figure 1 shows a spatial composite of the maximum 10 m wind gust simulations for the period 6 am to midnight on 10 September, together with observed maximum gust speeds for the same period. The NZCSM simulations indicate that some regions on the plains are much more susceptible to higher gust speeds (e.g. downstream from major river gorges) than others, perhaps explaining why some areas suffered major damage while others escaped. While the observation network resolution is too sparse to resolve the high wind regions, insurance claim data and the locations of downed power lines can be used to improve our understanding of where damaging winds occurred, and hence verify the accuracy of NZCSM forecasts.

The simulations indicate this event was a downslope wind storm, where energy and momentum in the flow above the mountains is forced down toward the surface. Figure 2 shows the vertical winds (and potential temperature) of the lowest 5 km of the atmosphere along a cross section over the Alps at 8 pm on 10 September (Fig. 1). It indicates very strong mountain waves over the Southern Alps, with alternating zones of strong upward winds (red-orange) and downward winds (blue). Note the very strong downslope and surface winds (up to approximately 40 m/s, or 144 km/h) east of the mountains. The steep black potential temperature lines highlighted in the black ellipse indicate a large amplitude wave response and the strong possibility of wave-breaking and rotors with severe turbulence in the regions within the red ellipse.

In the winter of 2014, the Deepwave experiment (https://www.eol.ucar.edu/field_projects/deepwave) will provide an opportunity to observe mountain waves and determine how well NZCSM is able to model them, and in turn, how well it can forecast the evolution of severe weather over the New Zealand landscape.

Contact Michael.Uddstrom@niwa.co.nz

Snow, Hail & Electrical



Snow

The first significant snow event of the year occurred during 27-29 May, with large snow fall in Otago and Southland, resulting in road and school closures, and bus and flight disruptions in Dunedin and Queenstown.

A second significant event occurred over 3-5 June mainly in Canterbury, resulting in 100 motorists being stranded at Burkes Pass and icy road conditions between Fairlie and Twizel on SH8. A third significant snow event occurred on 14-15 July when snow fell to low levels in Canterbury, Otago, the Kaikoura Ranges, Wellington, Hawkes Bay, Gisborne and the Central Plateau, resulting in the closure of roads due to black ice conditions and power cuts in the Rangitikei district.

On 12 August, a man was killed by an avalanche while climbing in the Remarkables Range near Queenstown. On 4 September a large snow storm resulted in 316 people being stranded on Mt Hutt for the night, and on 10-11 September, SH94 between Te Anau and Milford Sound was closed due to snow. Avalanches affected a 12 km stretch of the road, including a section which was hit by three separate avalanches, leaving a 5 m deep layer of snow over the road.

Hail

A severe thunderstorm hit SH30 near Rotorua on 17 August, with hail creating hazardous driving conditions that resulted in one fatality. On 16 December, a damaging thunderstorm struck part of mid-Canterbury, with hail stones up to 3cm in diameter damaging windows and destroying crops.

Electrical

On 9 January, a thunder storm crossed Canterbury and Otago and lightning strikes caused several scrub fires. In Wanaka, the swimming pool was struck by lightning, giving a mild electric shock to someone in the showers and leading to precautionary pool closures in Wanaka and Arrowtown. The electrical storm lasted more than two hours in Omarama.

September saw nearly 5,000 lightning strikes across New Zealand resulting in fires across Canterbury on 10 September. On 20 September a significant electrical storm hit central New Zealand (800 strikes in Wellington over 3 hours) triggering power outages and the loss of internet services. During a 2 hour period on 14 October, over 5,000 strikes were recorded over the West Coast and East of the Southern Alps resulting in dangerous conditions delaying repair to damaged power lines. On 13 December a century old tree was destroyed by lightning in central Hawkes Bay killing 53 ewes that had taken refuge under it.

Prepared by Christian Zammit, NIWA

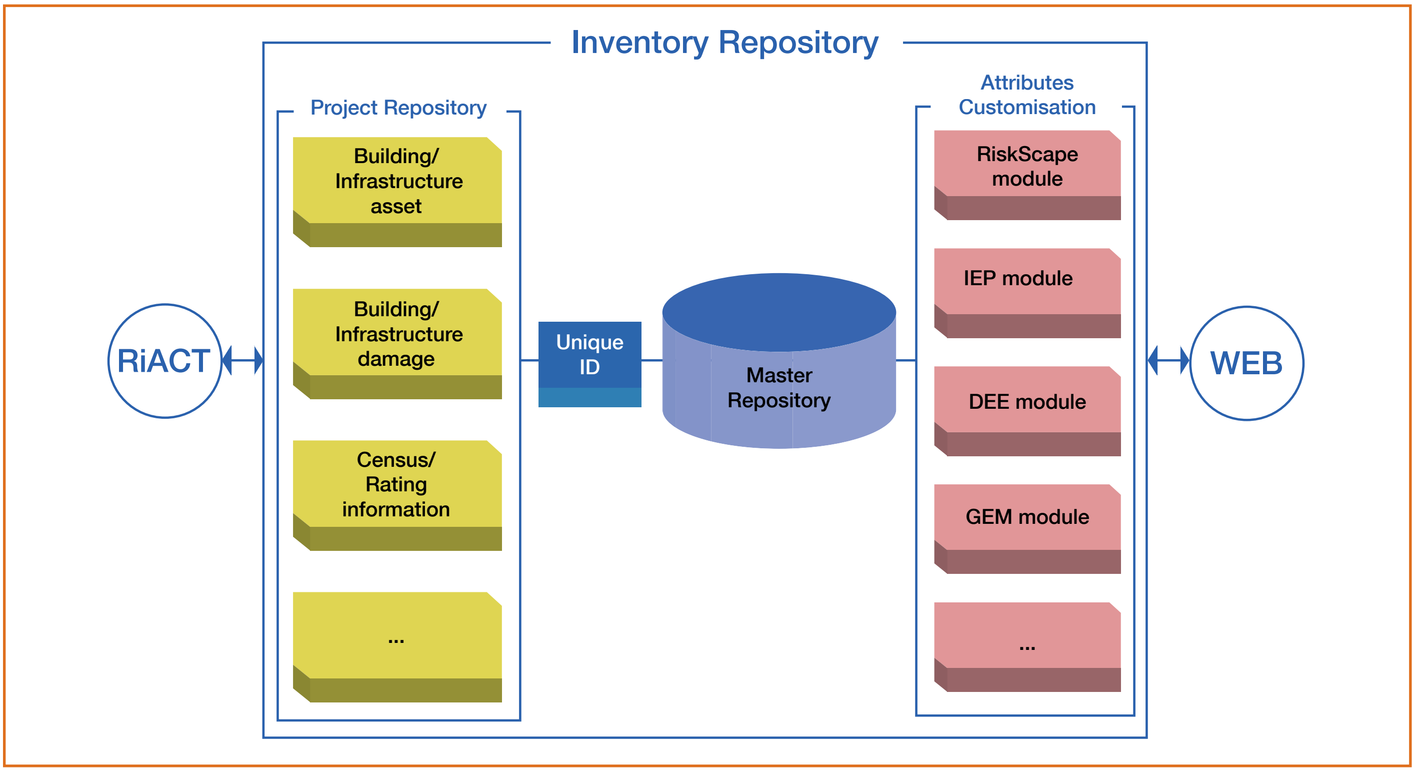
Risk & RiskScape Overview

A key advance during 2013 has been the development of the real-time individual asset attribute collection tool (*RiACT*), inventory repository and asset repository web portal. *RiACT* uses real-time telecommunication, georeference (GPS) and in-built camera capabilities to collect the characteristics and/or damage conditions for each asset (i.e., a building). Observations from the field can be transferred through WiFi or 3G to the Inventory Repository, or conversely, a user can download stored asset information while in the field. *RiACT* is compatible with RiskScape and will significantly enhance the building inspection protocols forming from the recommendations of the Canterbury Earthquakes Royal Commission. It was developed by Sheng-Lin Lin (GNS Science) and based on the Global Earthquake Model (GEM) IDCT Android Tool.

The Risk Theme has also been involved in workshops with key end users such as the National Infrastructure Unit, Stronger Christchurch Infrastructure Rebuild Team (SCIRT), Christchurch City Council, Orion and telecommunication networks. Together, we are devising damage and fragility functions for different lifeline utilities to inform rebuild priorities and repair or replacement strategies. We have developed a Risk Framework with the New Zealand Transport Agency (NZTA) to assist in a national plan of network resilience, and damage projections were developed for KiwiRail using RiskScape.

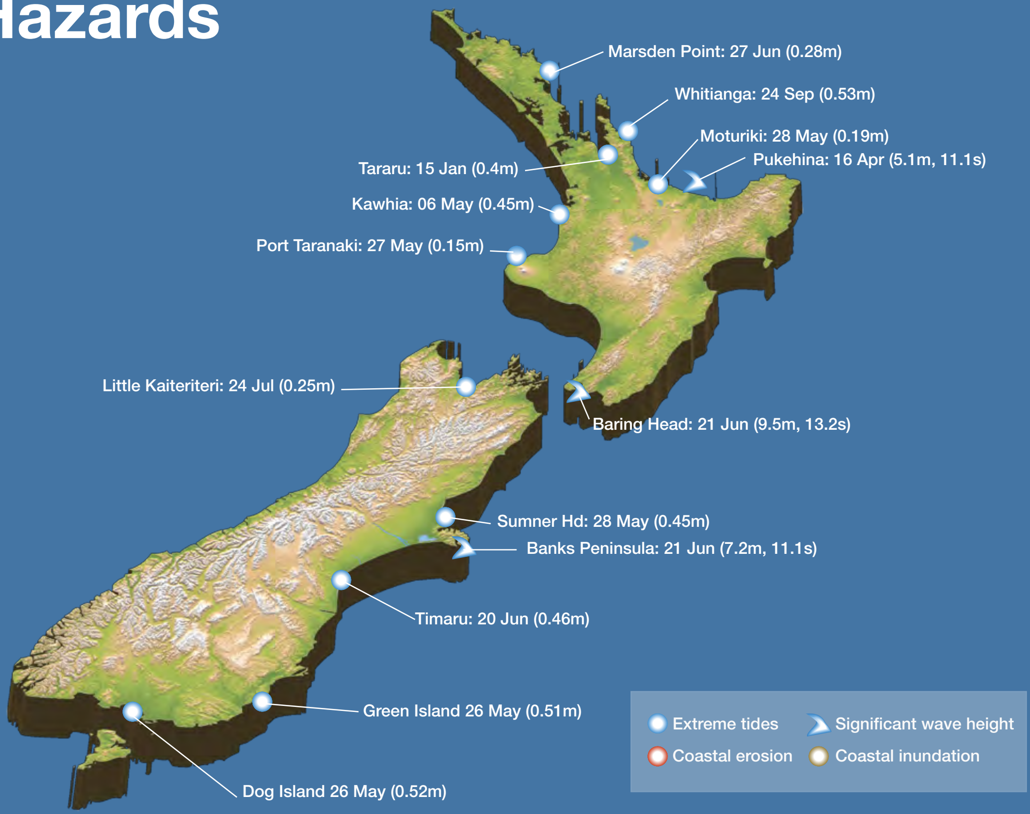
On the international front, Andrew King (Risk Theme Leader) became a member of the Science Advisory Board for GEM. In addition, he and SR Uma (GNS Science) were invited to participate in a UN-initiated building vulnerability workshop in Canberra, where regional fragility functions for earthquake, wind, flood, volcano and tsunami were developed. Members of the Risk Theme also participated in the 2015 Global Assessment Report (GAR) on Disaster Risk Reduction. GAR is a biennial global assessment and comprehensive review of natural hazards risk management. The GAR contributes to the Hyogo Framework for Action (HFA) by monitoring risk patterns, trends and progress in disaster risk reduction while providing strategic policy guidance to the international community.

The Hyogo Framework for Action (2005-2015) is a global initiative in natural hazard risk reduction. A post-2015 Framework will be developed at the UN World Conference in Sendai, Japan; IDCT, Inventory Data Capture.



RiACT and inventory repository structure. IEP, Initial evaluation procedure; DEE, Detailed engineering evaluation; GEM, Global earthquake model

Coastal Hazards



Storm-tide levels (excluding waves) are expressed in metres above the local Mean High Water Perigean-Spring mark set relative to the local annual mean level of the sea for 2013

Waves

A storm on 21 June caused the highest waves to be recorded at two of NIWA's offshore stations for 2013. At 6pm at Baring Head outside Wellington Harbour, the largest wave height was 9.5 m, with the largest individual wave reaching 15.9 m. Waves from this storm caused damage to homes, roads and sea walls on Wellington's south coast. At the Banks Peninsula buoy, significant wave height reached 7.2 m after midnight and the maximum individual wave height was 11.3 m. A storm on 16 April produced the largest significant wave height (5.1 m) recorded at Pukehina in the Bay of Plenty and the maximum individual wave height was 8.2 m. The Baring Head and Pukehina wave buoys were both out of service for some periods during the year (notably Pukehina from 26 June to 26 August). However wave forecast outputs indicate that no events larger than those noted above are likely to have been missed at either site.

Data sources: NIWA, Bay of Plenty Regional Council.

Extreme Tides

The highest storm tide level was recorded at Whitianga on 24 September, measuring 0.53 m above the local Mean High Water Perigean Spring (MHWPS) mark. This occurred about a week after a period of perigean spring tides ('king tides') and was enhanced by a large weather-induced storm that brought strong gales and heavy rain to northern parts of the North Island. On 26 May, a storm led to similarly high tides at Green Island, Otago and Dog Island, Foveaux Strait (0.51 m and 0.52 m above MHWPS, respectively). This storm occurred on a day when 'king tides' were predicted (see web link for 2014 'red-alert' dates).

Coastal Erosion and Inundation

The storm and high tides of 24 September resulted in beach erosion and localised inundation in the communities north of Whangaparaoa. There was also significant erosion at the Orewa foreshore, where a 4 m wide strip of reserve land was lost, leading to beach closures.

Data sources: NIWA, Waikato Regional Council, Environment Canterbury, Port Taranaki, PrimePort (Timaru), Greater Wellington Regional Council. Web link: http://www.niwa.co.nz/our-science/coasts/tools-and-resources/tide-resources

Prepared by Richard Gorman, NIWA

Geological Hazards Overview

Volcanoes

Art Jolly (GNS Science) and Shane Cronin (Massey University) were guest editors on a special issue of *Journal of Volcanology and Geothermal Research* focussed on the Te Maari eruption of 2012. The manuscripts cover physical volcanology, hazard, atmospheric, and volcanic impacts, geochemistry, geodetics, seismic precursors and geophysical reconstruction of eruption processes. It is remarkable that two very small eruptions (on a global scale) have produced such a large collection of high quality papers, with most of the work developed from multi-organisation collaboration.

We continue to make advances in the Auckland Volcanic Field (AVF) in conjunction with EQC and the Auckland Council co-funded DEVORA* project. Collaboration with an Italian research group has resulted in a first ever lava flow emplacement model for the AVF, allowing researchers to develop the first realistic scenarios of eruption timing and lava speeds for emergency management planning. In collaboration with Garry McDonald (Market Economics), we are also investigating the economic aspects of volcanism in Auckland.

New Zealand was strongly represented at the IAVCEI* Scientific Assembly in Kagoshima, Japan. Held every four years, this is the major global meeting for volcano science. Many New Zealanders were session chairs, or gave poster and oral presentations.

Stakeholder engagement continues to be strong with presentations given at the Central Plateau Volcanic Advisory Group. Meetings with tour operators, MCDEM, Regional CDEM, Police and White Island owners were held in October and November where volcanic risk assessment work was presented, as well as a summary of White Island activity over the last two years. This is part of a long-term engagement with key stakeholders for the island to inform them of hazards and risk.

Two international experts on the impacts of volcanic ash on public health, Peter Baxter (University of Cambridge) and Claire Horwell (Durham University) visited New Zealand in November. Together with New Zealand scientists they gave presentations on volcanic health hazards at the National Health Protection Forum and at the Ministry of Health. Our visitors were complimentary about the high quality linkages between science and health practice, and considered the level of collaboration to be globally unique.

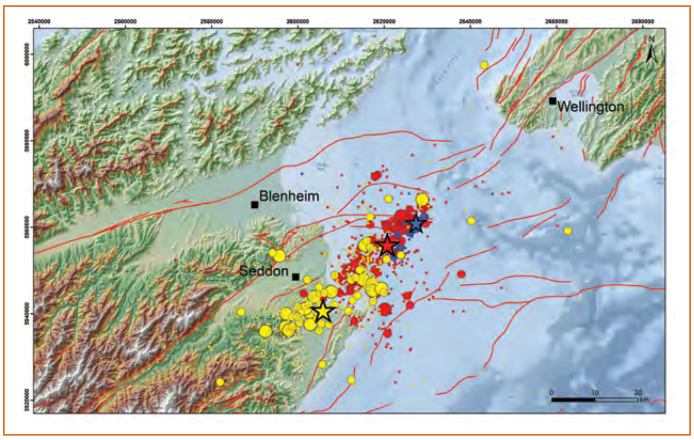
**DEVORA, Determining Volcanic Risk in Auckland; IAVCEI, International Association of Volcanology and Chemistry of the Earth's Interior*

Earthquakes

Following the July-August Cook Strait earthquakes, a major focus was again on responding to damaging earthquakes. Probabilistic earthquake forecasts were rapidly made public via the GeoNet website, and modelling of the earthquake source areas were provided to stakeholders to inform discussion of likely scenarios.

Many presentations were made to the public and to stakeholders, including a well-received public

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



Seismicity map of the Cook Strait region as of 20 September 2013. Epicentres for the 2013 July (blue/red) and August (yellow) Cook Strait/Lake Grassmere earthquakes (stars) and aftershocks greater than magnitude 3 (circles). Active faults (red lines) and urban centres (black dots) are shown. Image courtesy of Rob Langridge, Will Ries, GNS Science.

meeting in Seddon. An update on the Cook Strait earthquakes was given to national hazard and risk assessment managers at the National Crisis Management Centre, Wellington, as well as to the Wellington engineering community. Scientists also gave an invited presentation to the Heritage Working Group, Property Council NZ on Wellington's earthquake hazards and resilience. In attendance were representatives from Lloyd's Insurance Syndicate, Aon Insurance, NZ Heritage Places Trust, Wellington City Council and Property Council NZ.

Following the earthquakes, a field trip was organised for staff and students from the universities of Canterbury and Lincoln to the epicentre. The aim was to build interest in the liquefaction and landslide impacts resulting from these earthquakes. Two students from Canterbury University have since taken on aspects of liquefaction effects as part of their respective M.Sc. and Ph.D. studies.

Scientists have contributed to discussions on various aspects of the NZ building code revisions and progress has been made towards the establishment of a NZ Society for Earthquake Engineering (NZSEE) study group to produce guidelines for seismic isolation. We have supplied additional material for the earthquake section of the NZ Transport Agency bridge manual.

Geological hazard modellers have expanded their development of earthquake models towards developing national models of volcanic, landslide and tsunami hazards. The improvements will be of greater utility to a wide variety of end-users, with the earthquake model acting as the benchmark of what a model should provide to end-users.

Active Landscapes

The Dart River landslide was a key event in 2013, and featured in a New York Times video "How it Happens: Mudslides" (26 March 2014). There is more on the Dart River landslide in this issue.

In a '*Lessons learned from Canterbury*' project, Peter Almond (Lincoln University) and Pilar Villamor (GNS Science) have found evidence of a 1,000 year old paleoliquefaction event at Lincoln similar to the 2010-11 Canterbury earthquakes. Their findings suggest similar shaking levels and confirm spatial recurrence of liquefaction along the same fractures in the soil.

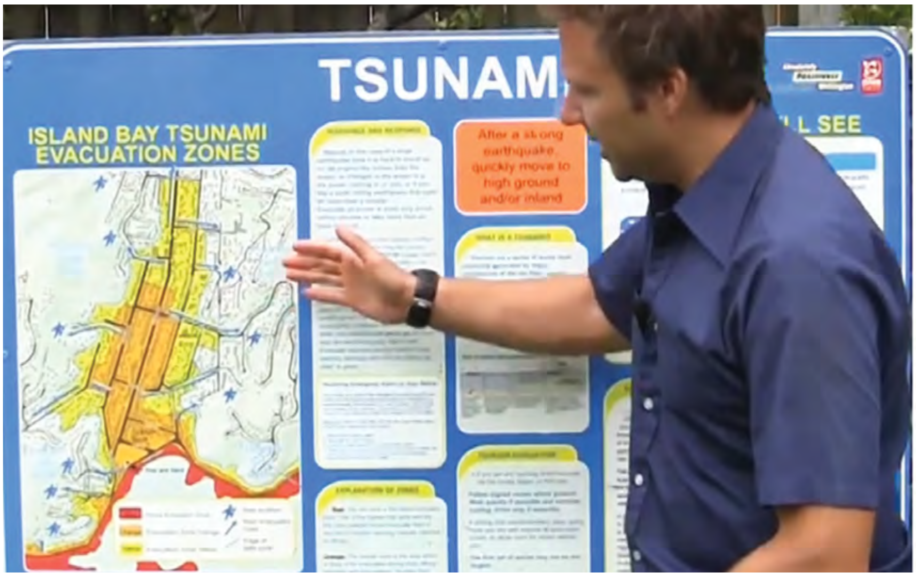
Research in the Port Hills is being used to define rules for land use in Christchurch. A novel '*Landslide Risk Assessment*' for life safety was implemented for the Port Hills and has set a benchmark for New Zealand and international landslide risk assessment. At the annual NZSEE meeting in Auckland, the research group involved was given a special commendation. Led by Chris Massey, there was wide technical involvement across GNS Science, as well as URS, Opus, Geotech Consulting, Christchurch City Council, CERA and international experts. A rockfall and landslide database has been

A GeoNet meeting following the Cook Strait Earthquake. Present are specialists in seismology, slope stability/liquefaction, engineering and social science. Photo: Sara Page, GeoNet

developed for Christchurch City Council to manage, and the data is available to practitioners.

Tsunami

A major output from the tsunami group has been the new National Tsunami Hazard Model developed for MCDEM. Built on Platform-funded research, this landmark work incorporated changes in new understanding (both from New Zealand and overseas) and considers all earthquake sources - local, regional and distant. The updated model creates hazard curves for any section of coast for return periods of 500 and 2,500 years. A roadshow organised by MCDEM travelled to Hastings, Tauranga, Balclutha, Christchurch, Nelson, Auckland, Wellington, and Whangarei to present the national tsunami hazard map and gave local civil defence organisations the opportunity to ask questions of the scientists involved.



Graham Leonard (GNS Science) discusses tsunami preparedness. YouTube video: Julian Thompson, GNS Science.

The tsunami group also shared their findings at the Regional CDEM Group Managers Forum in Wellington where the main topic was use of tsunami hazard modelling in land-use planning.

Discussions were also held with Northland Regional Council on use of evacuation zones in planning decisions. Based on the new model and research findings, a manuscript was accepted for publication in *Pure and Applied Geophysics.*

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

Societal Resilience Overview

This research theme contributes to the creation of well-prepared and resilient communities by identifying success factors that motivate individuals and organisations to prepare, respond, and recover from natural hazard events. The role and value of scientific information in natural hazard risk reduction and resilience has long been recognised in New Zealand. In 2015, three major international endeavours will come together: 1) the Hyogo Framework for Action (2005-2015) on building resilience to disasters; 2) the Sustainable Development Goals; and 3) the 2015 climate agreement under the United Nations Framework Convention on Climate Change. There now needs to be an immediate step change in the use of science in these efforts. Platform researchers and other stakeholders are actively engaged in preparations for the post-2015 international discussions on the successor to the Hyogo Framework for Action, as well as the post-2015 Sustainable Development Goals. Current research is directly feeding into the UN processes, as well as New Zealand efforts to define and build resilient communities.

The Canterbury earthquakes and their aftermath continue to provide a focus for much of the research activity but projects also address other thematic risk issues and hazard-specific problems. Several longitudinal studies are tracking social and economic recovery in Canterbury. These projects inform operation and policy of the recovery agencies and provide a baseline for further research.

Land use planning and policy researchers are providing vital input to support the proposed changes of the Resource Management Act. There is consensus on the need to enhance the use of a "risk-based" approach to land-use planning, focusing more on the consequences of hazards.

Our international linkages are strong. Researchers at GNS Science are working together with the United States Geological Survey (USGS) on earthquake hazard education in New Zealand and Washington State. The Resilient Organisations team were engaged by the Asia-Pacific Economic Cooperation (APEC) to examine workforce issues that emerge following a disaster. Erica Seville (Resilient Organisations) was selected as a member of the Resilience Expert Advisory

UN World Conference on
Disaster Risk Reduction
2015 Sendai Japan

The Hyogo Framework for Action (2005-2015) is a global initiative in natural hazard risk reduction. A post-2015 Framework will be developed at the UN World Conference in Sendai, Japan.

Platform-funded Students

Abi Beatson is a doctoral candidate at Victoria University, Wellington. While conducting her studies she is also working at Opus Research and the Joint Centre for Disaster Research. Abi's thesis is titled '*Social Media, Information Flows and Crisis Mapping: Information Sharing Practices in Response to the Christchurch Earthquakes*.' Her research focuses on crisis mapping - the practice of geo-locating information onto 'live' maps to produce and visualize a birds-eye perspective of the complex and often rapidly changing environment in near real time. This research investigates the value of data produced by social media-based crowd-sourcing techniques in New Zealand; the extent to which it can be used to improve situational awareness for traditional emergency response organisations; and the roles and functions it has with regard to the self-organising capabilities for disaster-effected communities. Abi also serves as a volunteer on the social media response team for the Wellington Regional Emergency Management Office (WREMO).

Group for the Australian Federal Government. Erica is the only non-Australian member on the panel and she will provide advice to the Critical Infrastructure Advisory Committee. David Johnston (Societal Theme Leader) continues to serve as chair of the Scientific Committee of Integrated Research on Disaster Risk Reduction. The IRDR is an integrated research programme co-sponsored by the International Council for Science (ICSU), International Social Science Council (ISSC) and the United Nations International Strategy for Disaster Reduction (UNISDR).

John Vargo (Resilient Organisations) speaking at the *'What if Wednesday'* public seminar series held at University of Canterbury.

Tsunami Activity

On 23 November a sudden surge at Papamoa Beach raised the water level rapidly from low-to high-tide level, knocking a fisherman off his feet and washing-up fishing lines in the process. The raised water level persisted for several minutes before receding. There is no known geological source for this event, though there are two plausible causes. The first is that that this was a small tsunami caused by a submarine landslide; another is that this event is what is known as a 'meteo-tsunami,' that is a tsunami caused by a weather event rather than a geological one. Apart from this isolated event, New Zealand was not affected by significant tsunami in 2013.

For more on meteo-tsunami, see NIWA's *Water & Atmosphere,* April 2014.

Prepared by William Power (GNS Science)

Understanding Factors That Build Iwi Resilience

On 4 September 2010, a Mw 7.1 earthquake struck the central Canterbury region of New Zealand, heralding a series of earthquakes, which included a fatal Mw 6.2 earthquake centred under Christchurch City on 22 February 2011. Census figures indicate that when the series of earthquakes commenced, the Māori demographic (25,725 individuals), constituted 4.1% of the urban population. Although Māori resided in all suburbs, the majority lived in low socioeconomic (low decile) areas, particularly the eastern suburbs. These were also the areas most significantly impacted by the earthquakes, so Māori were disproportionately affected in terms of reduced access to basic necessities. In the aftermath of 22 February, disruption to welfare, health, sanitation and utility services compounded the devastating effects of the earthquakes on the Māori community.

> "We have met with the local Māori community - a beautiful message - there is no you, there is no me, there is only us!... We are collectivised...This disaster has hit everyone and our response is for the people of Christchurch..."
>
> *Marae Investigates* interview with Tā Mark Solomon
> 27 February 2011

Anecdotal evidence suggests that both the Christchurch Māori community, as well as iwi from across New Zealand, responded rapidly to the earthquake. The local iwi, Ngāi Tahu, and other Māori stakeholders drew on various cultural attributes to manage emergent crises and support the well-being of whānau and the wider community. Marae, a key source of support for Māori communities during adversity, were operationalised within Canterbury, the wider South Island and in the North Island, to serve as recovery assistance centres and host temporary evacuees. By all accounts, the response was highly effective and may constitute an exemplar of best practice in natural hazard response and recovery management.

Within the natural hazards response and research sectors, there is increasing recognition of the value of community-led initiatives that facilitate social and environmental recovery. In contrast, cultural approaches to facilitating social resilience have received minimal acknowledgement. Māori cultural

Kenney, C. (2014). Community-led Disaster Risk Management: A Maori Response to Ōtautahi (Christchurch) Earthquakes. *Integrated Risk Science: A Tool for Sustainability* IRDR Conference, 7-9 June 2014, Beijing, China

attributes and the ways in which they may be applied to natural hazards response and resilience have previously been noted in New Zealand but rarely documented. Māori stakeholders in Christchurch have expressed a desire to enhance iwi whānui resilience in response to adversity, and ensure the well-being of future generations. To that end, the Joint Centre for Disaster Research in partnership with the local iwi Te Rūnanga o Ngāi Tahu, are conducting research to identify cultural factors that facilitate community resilience in response to natural hazard events.

In keeping with Te Rūnanga o Ngāi Tahu ethical requirements, a Kaupapa Māori qualitative research methodology Te Whakamāramatanga, which is based on Ngāi Tahu values and practices, has shaped the community-based research. Iwi engagement with the project has been encouraged through tribal networks and purposive recruitment. The earthquake stories and the perspectives of tangata whenua have been gathered. Initial data analysis suggests that the Māori response to the earthquakes and recovery process were highly effective and characterised by collective leadership, values, decision-making and actions. Information arising from the project will facilitate the refinement of iwi and organisational infrastructure and existing hazard mitigation strategies to ensure on-going best practice.

Takahanga Marae at Kaikoura hosted a Red Cross registration centre and provided shelter, food and temporary accommodation for earthquake refugees. Photo: Christine Kenney

Members of the Joint Research Partnership 'Whakaoranga Tūrangawaewae; Whakaoranga Iwi Whānui' (l-r) Mr Henare Rakihia Tau Upoko of Ngāi Tūāhuriri, Sir Mark Solomon Kaiwhakahaere of Te Rūnanga o Ngāi Tahu, Dr Christine Kenney, Principal Investigator Joint Centre for Disaster Research and Ngāi Tahu Kaumatua Mrs Sally Pitama. Photo: Candy Chan

Te Rūnanga o Ngāi Tahu and the Platform anticipate that research findings will inform natural hazards policy development and emergency management planning at the local level. Ngāi Tahu has a statutory governance role in the Christchurch rebuild stipulated in the Canterbury Earthquake Recovery Authority Act (2011), and relational links with central government and local authorities. Information arising from data analysis, tribal knowledge, as well as Māori natural hazards response, recovery and resilience practices is shaping the development of risk reduction and recovery strategies for Christchurch and the Canterbury region, with wider implications for emergency planning across the Māori sector. At the discretion of Te Rūnanga o Ngāi Tahu, research results and recommendations will be disseminated to other iwi and stakeholders to facilitate Māori natural hazards management, preparedness, risk reduction, and recovery planning. More broadly, lessons learned may have relevance for regional and national emergency management planning across New Zealand as well as other small island states and countries with similar cultural value systems and bodies of traditional knowledge.

Contact: Christine Kenney, c.kenney@massey.ac.nz

Resilient Engineering & Infrastructure Overview

Platform engineers continue to provide key advice to stakeholders on infrastructure, interdependencies and structures, and contribute to the improvement of NZ building codes.

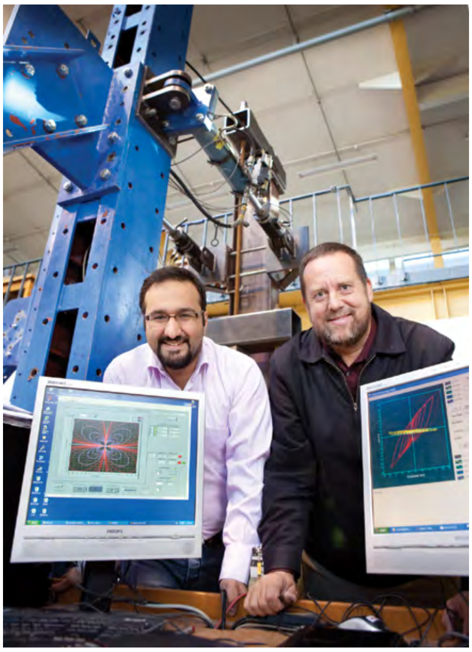
Stefano Pampanin (UC, NZSEE) and David Johnston (Societal Theme leader) co-hosted a USA delegation from the Earthquake Engineering Research Institute (EERI) as part of a study on the New Zealand recovery experience. The visit by EERI was co-sponsored by the World Bank, United Nations Development Programme, and the European Union to share the lessons of recovery with governments around the world.

A new publication has been released on *'Soil Liquefaction during Recent Large-Scale Earthquakes.'* Edited by researchers at University of Auckland and University of Tokyo, the anthology contains selected work funded by the Platform and presented at the NZ-Japan workshop held at University of Auckland. The workshop was attended by engineering practitioners from NZ, Japan and Chile.

Jim Cousins (GNS Science) led a study estimating damage to and restoration of the bulk water supply system into Wellington, which included consequent impacts on people due to prolonged loss of water. Advice was provided to Greater Wellington Regional Council on estimated water shortfall for a variety of large earthquake scenarios, and evaluations of various mitigation measures.

Cook Strait/Lake Grassmere Earthquakes

Platform engineers took part in building inspections following the earthquakes. Researchers at the University of Auckland installed accelerometers in a selection of Wellington buildings to capture building responses during the aftershock sequence, and GNS Science monitored instrumented buildings as part of the GeoNet programme in this area. The New Zealand Society for Earthquake Engineering (NZSEE) website posted earthquake engineering data during this time to assist practitioners. These efforts were additionally supported by EQC, LINZ, BRANZ, and GeoNet.



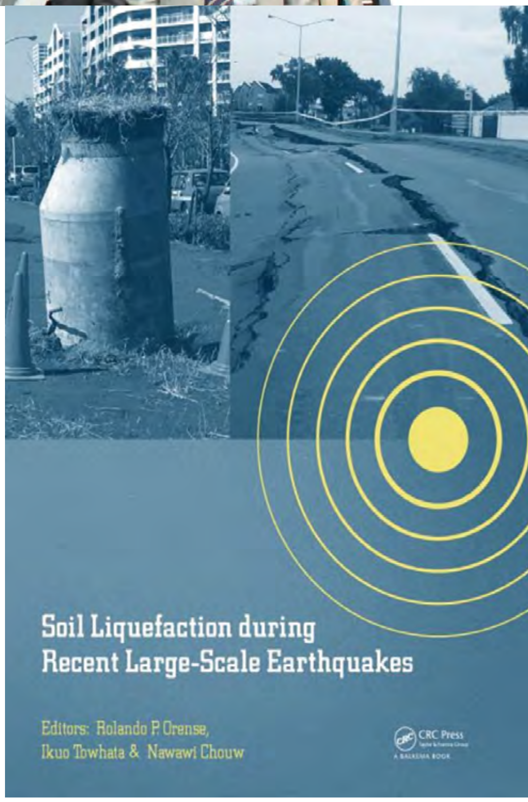
PhD researcher Jamaledin Borzouie (left) and Associate Professor Greg MacRae aim to improve how structural elements perform in strong earthquakes. Photo: University of Canterbury

Bridges

Excellent research continues on New Zealand bridges from soil-structure interactions to improved seismic performance and repair options. Alessandro Palermo's University of Canterbury research group have created and tested bridge prototypes that incorporate low damage design and self-centering capability, a first worldwide. At University of Auckland, Nawawi Chouw's research team investigates how ground motions affect bridge performance. The Auckland-Canterbury Bridge groups are working closely with the NZ Transport Agency (NZTA) to update the current bridge standards, and their contribution to the NZ bridge manual will produce "...some of the most advanced bridge design specifications in the world."(NZTA newsletter, Nov 2013).

Focus group meeting organised by SR Uma (GNS Science) to address the barriers to uptake of low damage construction. The day included 20 participants from industry, local councils, and research organisations. Photo: SR Uma.

Participants of the NZ-Japan soil liquefaction workshop held at University of Auckland (above), and resulting textbook (right) edited by Rolando Orense (UA), Ikuo Towhata (Univ. Tokyo) and Nawawi Chouw (UA).



Structures

There has been excellent progress in taking ideas from concept to practice. Sliding hinge joint technology was originally developed by Charles Clifton (UA) with HERA.* Further development between UA-UC groups with industry has enabled its inclusion in new construction in Christchurch. The sliding hinge joint helps dissipate energy from earthquakes, protecting columns and beams, and is also more accessible for repairs. In early 2014, Aurecon announced use of the technology for a new building on the Terrace. In 2009, Victoria University of Wellington incorporated an earlier model of sliding hinge technology and base rocking in its Te Puni building.

During the Cook Strait earthquake, the building performed as expected with minor joint movement and no structural damage or residual drift. More ready adoption of these methods into construction would be welcomed. The barriers to the use of low damage technologies is a topic being addressed by SR Uma (GNS Science) and Rajesh Dhakal (UC). A focus group with practitioners and building owners was organised for mid 2014 to discuss and identify solutions for implementation.

This is a sample of the quality work produced over 2013, with valuable contributions from engineers and students at the University of Auckland, University of Canterbury and GNS Science.

HERA, Heavy Engineering Research Association

Platform-funded Students

Mustafa Mashal is studying towards a PhD in Structural and Earthquake Engineering at the University of Canterbury. Mustafa completed a Master of Science degree as a Fulbright Scholar at the State University of New York at Buffalo, and is now participating in '*Advanced Bridge Construction and Design*' with Dr. Alessandro Palermo. The '*Advanced Bridge…*' group recently tested a half-scale, multi-column, precast bridge support for a 16 meter span bridge prototype. The specimen incorporated low-damage seismic design and self-centering capability – a world first. Mustafa is the recipient of the 2013 New Zealand Society for Earthquake Engineering Research Scholarship. For his work in bridges, Mustafa was also awarded a 2013 "Concrete Prize" by the New Zealand Concrete Society.

Mustafa Mashal (left) accepting the 2013 NZSEE scholarship award from NZSEE President Stefano Pampanin (right).

2009 2010 201

GEOLOGICAL HAZARDS

Canterbury earthquake sequence

$17B insur.*
$12B EQC*

Natural Hazards Research Platform

First four years 2009 - 2013

*SOURCE: INSURANCE COUNCIL NEW ZEALAND

WEATHER HAZARDS

INTERNATIONAL EVENTS

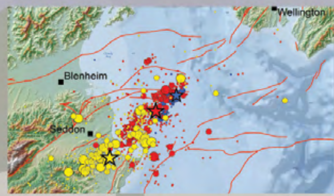
Samoa

Tohoku tsun

GOVERNMENT ANNOUNCEMENTS

NHRP
Oct 2009

2009 2010 201



Cook Strait/Grassmere earthquakes
$31M*

Tongariro eruptions

White Is. unrest

Nelson Floods “State of Emergency”
$16.8M*

Nelson-Tasman flood
$46.2M*

Hobsonville tornado
$8.7M insur.*

Nationwide storm incl. Canterbury wind storm
$74.5M*

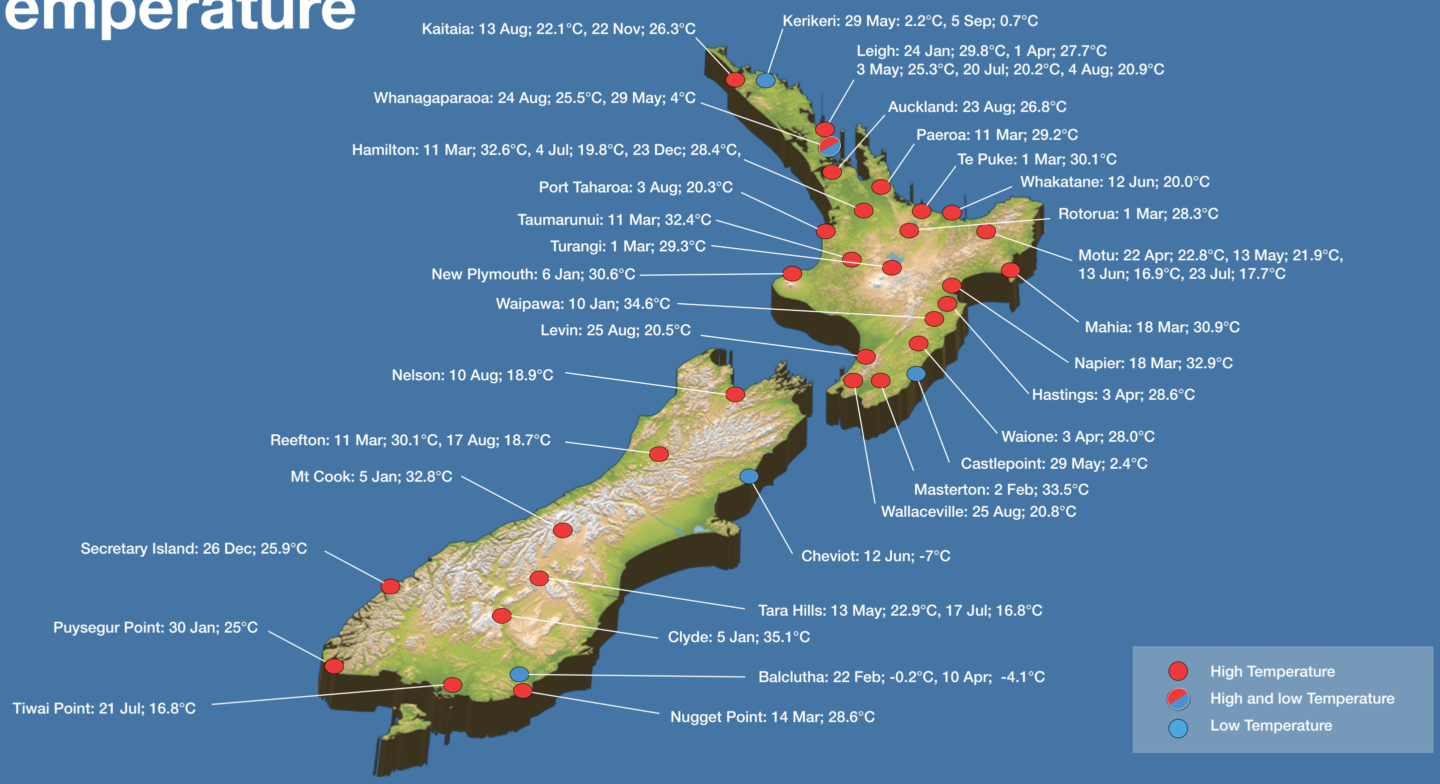
NZ-wide snowstorms

ami

CRI core funding

National Science Challenges announced

Temperature



2013 was a very warm year for New Zealand, with annual mean temperatures above or near average across the entire country. The nation-wide average temperature was 13.4°C (0.8°C above the 1971-2000 annual average), using NIWA's seven-station temperature series, which began in 1908.* According to this series, 2013 was the third-warmest year on record with eight 'warmer than normal' months (March, April, July-December) and no 'cooler than normal' months.

Record breaking mean maximum temperatures were recorded at 16 locations, including Christchurch (Riccarton), where the annual mean maximum temperature of 18.2°C was the highest there since records began in 1863. Highest mean minimum temperature records were set at 18 locations. This may be partly attributed to the country experiencing its warmest winter on record. During this season, more than a third of the locations in New Zealand where long-term measurements have been made (53 out of 146) recorded winter mean minimum temperatures in the top four of their respective temperature records.

Extreme high or low temperatures were not especially prevalent in 2013, with just two locations experiencing their highest maximum temperature on record, and no new extreme minimum air temperature records were established. Occasional cold southerly outbreaks saw lowest or near lowest daily maximum air temperatures recorded in seven locations.

The highest mean annual temperature for 2013 was 16.5°C, recorded at Dargaville. The lowest mean annual temperature for 2013 (excluding high altitude alpine sites) was 8.7°C, recorded at Chateau Mt Ruapehu (central North Island). Whakatane was the sunniest location in 2013, recording 2792 sunshine hours, followed by Tauranga (2515 hours) and Gisborne (2483 hours). Record or near-record high annual sunshine hours were recorded at nine locations across New Zealand, with Balclutha recording well above normal sunshine hours for the year (more than 125% of normal annual sunshine).

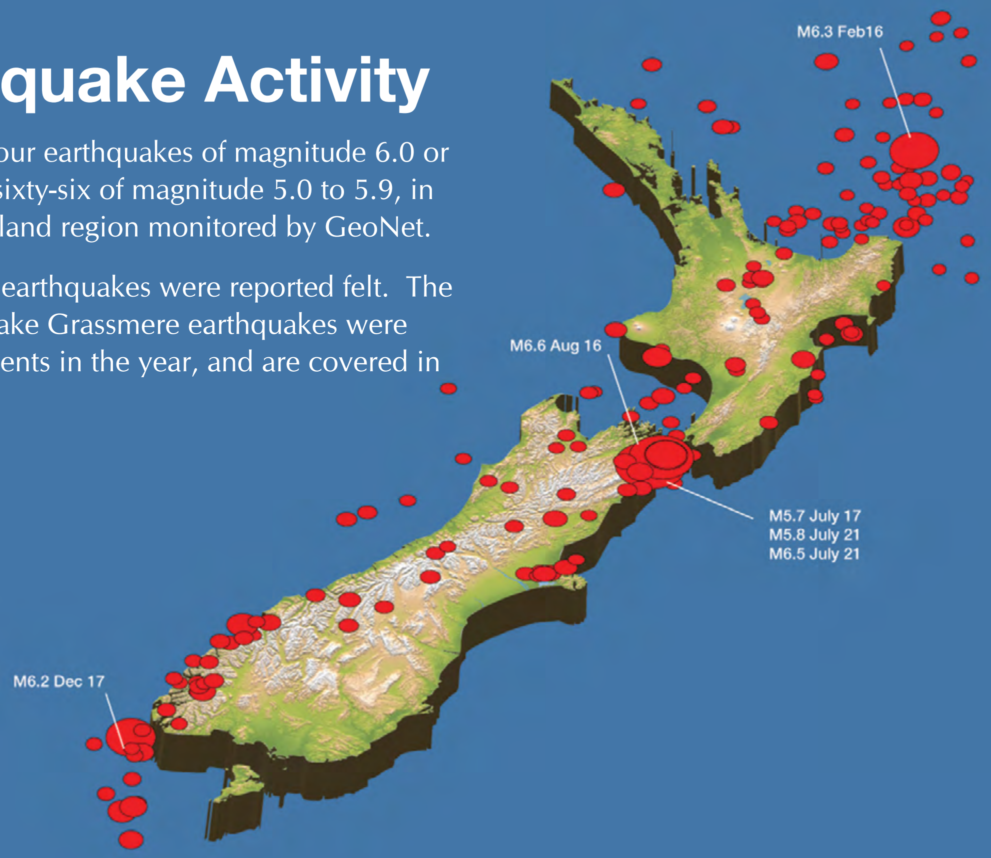
Prepared by Nava Fedaeff, NIWA

**These locations were chosen because they provide broad geographical coverage and long records (with measurements started at all sites by 1908.*

Earthquake Activity

There were four earthquakes of magnitude 6.0 or greater, and sixty-six of magnitude 5.0 to 5.9, in the New Zealand region monitored by GeoNet.

About 2,500 earthquakes were reported felt. The Cook Strait-Lake Grassmere earthquakes were significant events in the year, and are covered in this issue.



Other significant earthquakes were:

1. On 1 January, a shallow magnitude 5.0 centred 30 km north-west of Opunake, was felt from Auckland to Nelson, but most strongly in the Taranaki region. Minor damage was reported in Stratford. A magnitude 4.3 aftershock shortly afterward was also felt strongly.
2. On 16 February, a magnitude 6.3 centred 200 km north of Te Araroa, at a depth of 290 km, was felt from Bay of Plenty to Otago, most strongly in the north-east of the North Island.
3. On 23 February, a magnitude 4.8 centred 40 km south-east of Wairoa at a depth of 70 km was felt in the Gisborne and Hawkes Bay region.
4. On 17 March, a magnitude 3.9 earthquake centred 15 km north-east of Auckland, near Motutapu Island, and at a depth of 6 km was felt strongly throughout the Auckland region. There were several reports of minor damage. Close to 14,000 felt reports were submitted for this event. It was preceded a few minutes earlier by a similarly located magnitude 3.1 that was also widely felt in Auckland.
5. On 4 July, a magnitude 5.3 at a depth of 5 km and centred 25 km north-west of Milford Sound was felt from Southland to the West Coast, most strongly in Queenstown and Oamaru.
6. On 8 July, a shallow magnitude 4.9 centred 25 km north-east of Waipukurau was felt from East Cape to Christchurch.
7. On 29 July, a 9 km deep, magnitude 4.7 centred 20 km north-west of Culverdon in North Canterbury was felt from Taranaki to Otago.
8. On 17 December, a magnitude 6.2 centred 30 km off the south-west coast of Fiordland at a depth of 25 km was felt from Stewart Island to Wellington. No damage was reported.

Two earthquakes centred in the Kermadec Islands region were widely felt in New Zealand. On 12 August, a magnitude 6.1 quake at a depth of 340 km was felt from Auckland to Invercargill, most strongly in Wellington, and on 12 October, a magnitude 6.2 quake at a depth of 150 km was felt from Auckland to Marlborough, mainly along the east coast of the North Island.

Christchurch earthquake activity continued at a low level in 2013, with three aftershocks of magnitude 4.6 recorded. One of these, on 18 November, caused a few instances of minor damage.

Prepared by Kevin Fenaughty (GeoNet) and Stephen Bannister (GNS Science)

The 2013 Cook Strait-Lake Grassmere Earthquakes

The Cook Strait and Lake Grassmere earthquakes gave a wake-up call to the Wellington and Marlborough regions for earthquake readiness and response.

The earthquake sequence began with a Mw 5.5 on 19 July, followed by a Mw 5.8 on 21 July and a Mw 6.6 that same evening. The Mw 6.6 Cook Strait earthquake was located offshore, 50 km southwest from Wellington city. Horizontal ground accelerations up to 0.26 g were recorded in the upper South Island and in Wellington.

The shaking duration in central Wellington was short, with moderate shaking (above a 0.02g threshold) lasting 6-7 seconds. On average ground shaking was about 30% of the NZ building code design level.

GNS seismologist Matt Gerstenberger speaking to a crowd of 200 Seddon residents at the Awatere Rugby clubrooms. Photo: Derek Flynn, Fairfax Media New Zealand/Marlborough Express.

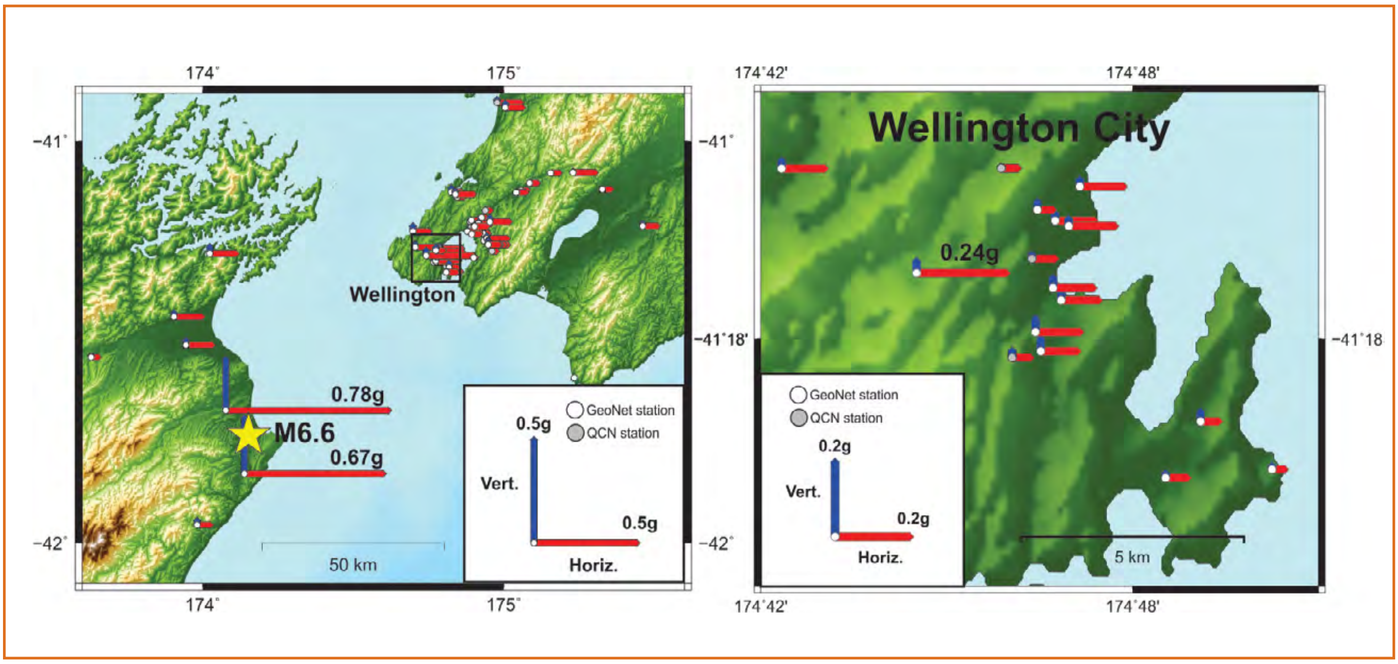
However at some sites close to the harbour foreshore and on areas of reclaimed land, ground shaking was more than 50% of design level. Subsequent engineering inspection found that most buildings were generally unaffected structurally, although damage was observed to around 35 buildings, mainly within the CBD. The NZSEE website hosted earthquake engineering data and links to the GeoNet strong motion waveform data.

We observed ground damage on the Wellington south coast and on the edge of the Kaiwharawhara reclamation. The Container terminal was damaged by liquefaction and lateral spread, and small cracks in paving were also observed, caused by settlement of fill around Te Papa. In Seddon, major cliff collapse occurred between Marfells Beach and Cape Campbell, with smaller landslides on cliffs north of Lake Grassmere, the White Bluffs, and in the banks of the Awatere River. The Bell dam about 10 km southwest of Seddon sustained a crack along its entire width just below the crest, which was likely caused by settlement of the dam fill material.

Modelling of recorded seismic data indicated that the Mw 6.6 earthquake occurred on a near-vertical, right-lateral strike-slip, a NE-SW oriented fault in the crust of the Australian plate, with slip occurring between 5 and 16 km depth, and with a maximum slip of approximately 1 metre at about 12 km depth.

More than 1,700 aftershocks followed, of which 45 were magnitude 4 or greater. To help determine their location, GNS Science deployed temporary seismometers along the coastline of Pegasus Bay. While these studies were underway, Matt Gerstenberger, seismologist (GNS Science) and Sarb Johal, clinical psychologist (Joint Centre for Disaster Research) were invited to Seddon (pop. 4,851) to speak to the locals about the seismicity in the region. It was an informative evening for all, highlighting the benefits of communities working together during hazard events. Their presentations can be viewed on the GNS Science YouTube channel.

The next significant earthquake occurred on 16 August. The Mw 6.6 Lake Grassmere earthquake occurred beneath the coastline of the South Island, southwest of the earlier Cook Strait event. The earthquake was well-recorded by strong motion stations from the GeoNet network, and by the temporary instruments deployed just weeks earlier. Peak ground accelerations of up to 0.7 g were recorded in the northern South Island, while 0.2 g was recorded in Wellington city. The earthquake occurred in the middle of a work/school day, resulting in considerable disruption. For the Wellington CBD, traffic became immediately congested as people attempted to get home, complicated by the halt in commuter train services, all of which restricted access by emergency response vehicles.



Peak ground accelerations for the 16 August M6.6 "Lake Grassmere" earthquake. The larger the bar in the horizontal and vertical direction, the greater the 'felt' impact.

In Seddon, less than 10 km from the fault rupture, nearly every property was damaged, with some buildings damaged extensively. The Lake Grassmere event caused minor reactivations of old landslides and damage at terrace edges. In the Needles Creek area, west of Ward township, severe but localised damage was noted in the form of shallow soil failures and cracking of terrace edges. Following the 16 August earthquake there were 3,000 aftershocks, of which 15 were magnitude 5 or greater.

Estimates are that the two earthquakes have resulted in approximately $50 million in damages ($31.1M in insured claims. Source: Insurance Council of New Zealand).

Stephen Bannister and the Natural Hazards Division (GNS Science).

Contact: S.Bannister@gns.cri.nz

We are grateful to Seddon for their invitation in July. The opportunity to meet with everyone assists us in more readily identifying what information is needed during times of crisis.

Earthquake comparisons.

	22 February 2011	21 July 2013	16 August 2013
Magnitude Mw	6.2	6.6	6.6
Epicentre	30 km W Christchurch CBD	50 km SW Wellington 25 km east of Seddon	70 km SW Wellington 10 km SE Seddon
Max, PGA	2.2 g (0.8 g CBD)	0.26 g upper South Island and 0.26 g Wellington	0.7 g northern South Island; 0.2 g Wellington
Insured losses (source: ICNZ)	$17B insurers $12B EQC	$14.9M	$16.2 M

New Hybrid Modelling Methods Improve Earthquake Rate Forecasts

Working with colleagues from the USA, Europe and Japan in the Collaboratory for the Study of Earthquake Predictability (CSEP), we strive for better forecasts of earthquake rates on time scales of days, months, and years. Models are developed and characterised, adapted to the testing centre requirements so others can use it, and installed by linking the model into the testing centre software. Each of these steps involves a substantial amount of work and models are tested and compared using agreed metrics. Currently, New Zealand has contributed 16 models to the Collaboratory, with considerable outside interest in our new hybrid methods.

> We have more than 10 GNS Science-authored models running in the California earthquake forecast testing centre; 4 models in the Japan testing centre, and 2 models in the European testing centre.

Hybrid earthquake rate models were first used in New Zealand in response to the Canterbury earthquakes where there was a demand for estimates of the expected rates of future earthquakes. Our forecasts supported decisions on refinement of building codes, red-zoning of suburbs, and timing of the Christchurch rebuild. Late in 2011, an international expert panel was convened at GNS Science to discuss short-, medium- and long-term modelling options. The outcome is the Expert Elicitation (EE) hybrid earthquake rate model for Canterbury which provides estimated rates for the next 50 years. Since its

Statistical seismologists Annemarie Christophersen and David Rhoades stand in front of a map of hybrid earthquake rate models for California. Photo: GNS Science

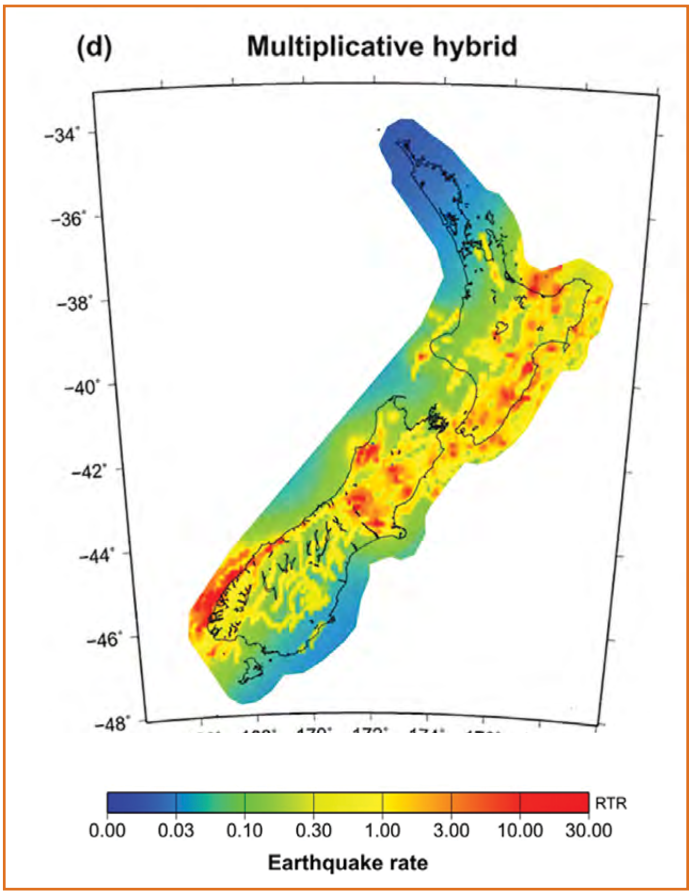
development, the EE model has been retrospectively tested* on the whole of New Zealand using high-quality earthquake records since 1986. The EE model statistically outperforms all of the individual component models.

In our long-term National Seismic Hazard Model, the data from mapped faults and earthquake catalogues are combined following a standard practice established more than 20 years ago. Our new hybrid modelling techniques allow us to consider other ways of combining the same data, or new types of information into the earthquake rate models; for example, the maps of crustal deformation derived from GPS data can now be included. Also, proposed earthquake precursors can be more readily assessed by including them in a hybrid with what we already know about time-varying earthquake occurrence - an improvement over assessing them in isolation. Our methods have proved useful in California, where a five-year prospective test of twelve different long-term earthquake rate models was conducted from 2006-2010.

It is expected that a slew of new hybrid models will be developed in the next few years using our methods. As a result, it is hard to know what earthquake rate models will be in use ten years from now. However, one thing is certain: the models of the future – whether short-, medium- or long-term – will include more types of information, and will be better than the models we use today.

As our models are implemented, New Zealand will be in a better position to cope with future earthquake crises. More dependable forecasts of future earthquake expectation on several timescales will be available, of value to public authorities, planners and the insurance sector.

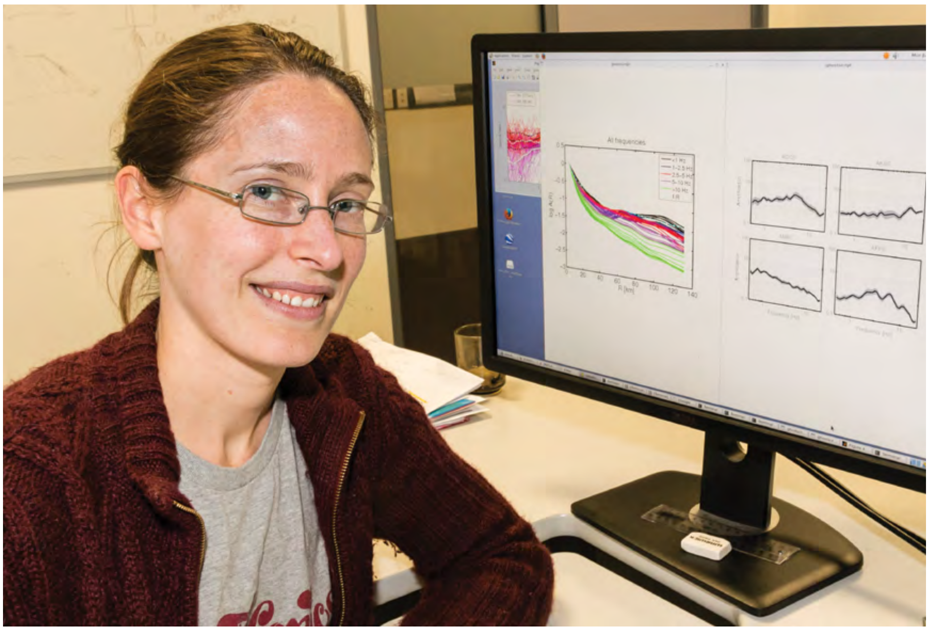
Contact: David Rhoades, D.Rhoades@gns.cri.nz



Statistical testing indicates that the multiplicative hybrid model (shown) is the best for a five-year time window.

In **retrospective testing** we compare the total number of earthquakes expected under each model with the number observed over the test period, as well as determine the overall information gain of one model over another.

Earthquake Ground Motions: Learning from the Canterbury Earthquakes

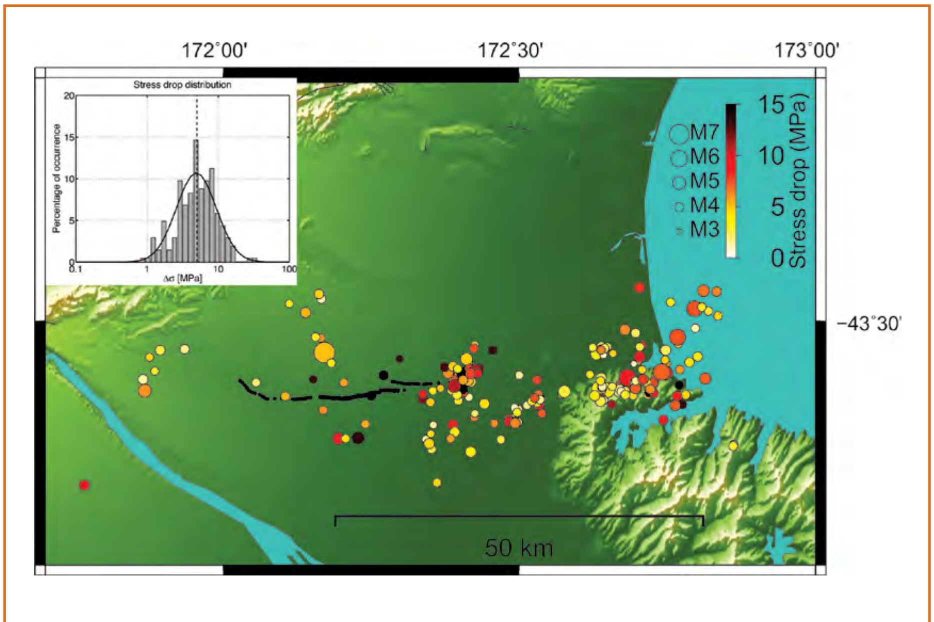


Anna Kaiser, seismologist at GNS Science

Ground motions recorded during the Canterbury earthquake sequence reached some of the highest levels documented worldwide, and the ground shaking varied across the region in terms of its amplitude and frequency. Being able to accurately predict ground motion characteristics for a specific location is necessary to build resilience to earthquake hazards. A number of different factors are thought to explain the observed ground motion characteristics: these include the earthquake source, the wave propagation path and the local ground conditions ('source, path, and site'). The excellent coverage around the epicentre by the GeoNet seismometer network allows us to investigate these factors for Canterbury and improve and update the current ground motion prediction models. In this joint project of GNS Science and University of Canterbury, we are using several methods to quantify the influences on ground motion.

Working with Adrien Oth from the European Centre for Geodynamics and Seismology, we have been able to introduce state of the art approaches to these studies. Our preliminary results suggest that earthquakes in Canterbury tend to release higher than average energy for their size (i.e. they exhibit higher stress drop; see graphic), and this is particularly true for events clustered near the tip of faults that ruptured previously during the sequence. The higher stress drop is thought to be related to the tectonic environment, where rare events, such as the Canterbury earthquake sequence, occur on strong faults within rigid brittle crust. Earthquakes in other historically more active regions of New Zealand might behave differently, and we are testing this in the recent Cook Strait earthquake sequence.

Given that many urban areas of Canterbury are located on deep and/or soft soils, our analysis includes use of models



Stress drop distribution for a subset of earthquakes of the 2010-2012 Canterbury sequence.

representing the 3D response of liquefaction-susceptible soils which we developed as part of this project. In addition, modifications to ground motion prediction equations have been developed and included in the National Seismic Hazard Model to provide more accurate estimates of shaking for structural design and liquefaction assessments.

In the past, traditional hazard assessment has relied on recorded data from strong-motion sensors or seismometers. Now we are able to create accurate simulated data of ground motions for various Canterbury scenarios. This approach utilises the region-specific ground motion characteristics determined above ('source, path, site'). When compared against the recorded data for the large events of the Canterbury sequence, the simulations can accurately estimate ground shaking levels and characteristics at new sites within Canterbury. We can retrospectively assess past performance of structures or landmass under different levels of shaking or simulate ground motions of future scenarios. The use of synthetic approaches is cutting edge and paving the way of the future for seismology.

This project is jointly led by Anna Kaiser (GNS Science) and Brendon Bradley (University Of Canterbury) and includes contributions from colleagues at these institutions and overseas.

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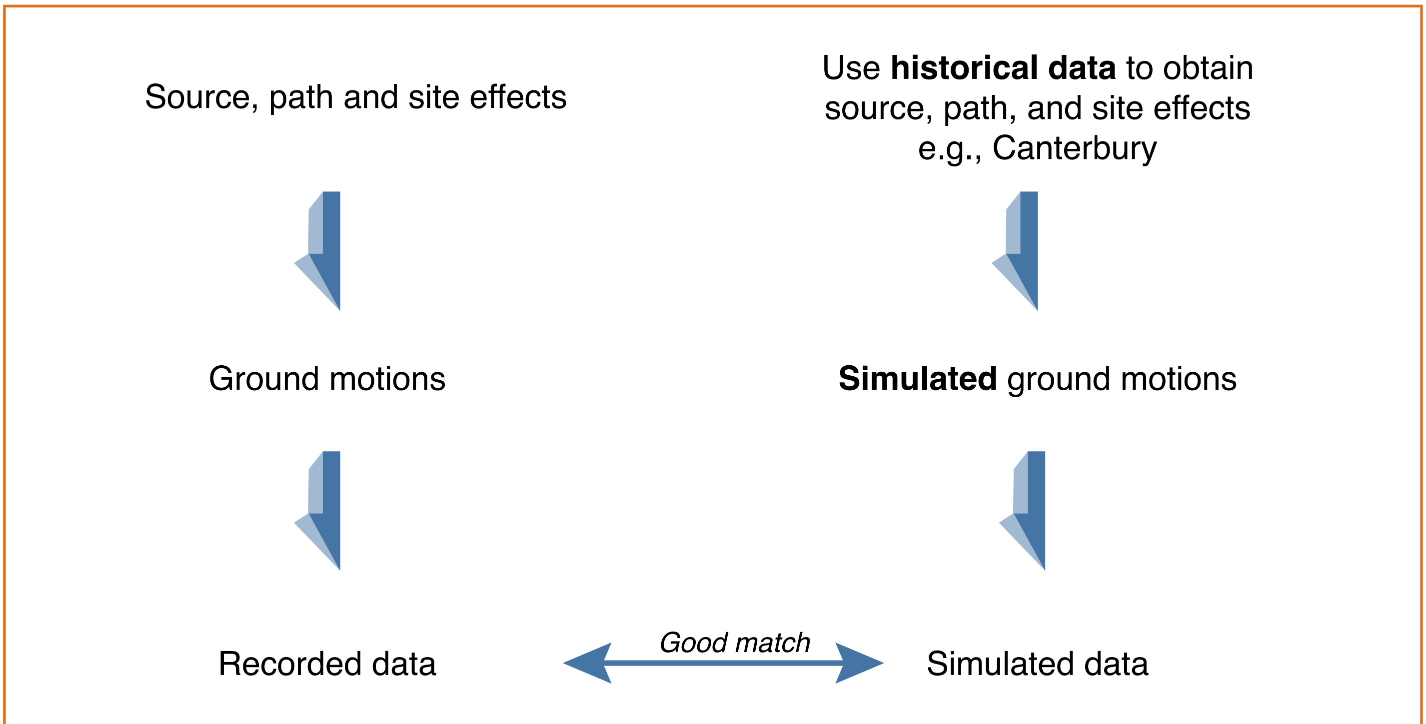
Brendon Bradley, lecturer in earthquake engineering at University of Canterbury



Left: 'Source, path and site' effects influence ground motions which can be measured by strong-motion sensors or seismometers. These effects can vary between different regions or even different nearby locations. Right: We can simulate ground motions for a given earthquake and a given location by drawing on historical data from events like the Canterbury earthquakes.

Volcanic Activity

Photo: Bruce Christenson, GNS Science

Tongariro

Tongariro's activity decreased following the 2012 eruptions. The gas output decayed throughout the year. In August a few small volcano-tectonic earthquakes were detected under the volcano, but these were poorly located and not considered to indicate a notable increase in activity. The main fumaroles in the vent areas from the 2012 eruptions remained hot (ca. 400 °C).

White Island

Several eruptions occurred from August to December 2012, and the high levels of unrest continued through 2013. In early 2013, the lava dome had temperatures of around 200-240°C and the nearby hot lake varied between 60 and 80°C. It appeared that the dome's rubbly lava had extruded slowly and continued to be a source of heat and gases.

In January and February, the lake remained active with "doming-up" of the lake surface by steam and gas, bringing large amounts of sediment to the surface, often with vivid white steam "flashing" from around the base. Gas flux was variable but higher than periods of low activity. As the mud geysering continued, the lake started to dry out and mud and rocks were thrown tens of metres from the vent area. There appeared to be significant amounts of sulphur in the ejected debris. The mud geysering resulted in the formation of a small ash cone on the floor of the lake. Initially very little ash was lofted into the steam plume but towards the end of February, the vent had dried out sufficiently to result in dilute ash emissions. Through March and early April, the volcano continued to alternate between passive degassing and more vigorous ash emissions. Gradually, the lake re-established itself around the ash cone and the activity returned to a relatively quiet state of degassing.

In July, activity stepped up again, with a series of repeated, small volcanic earthquakes occurring every 70 seconds or so. This was interpreted as pressurisation (and then de- pressurisation) of the hydrothermal system under the volcano. In late July, mud and steam geysering in the crater lake re-started, although this episode only lasted a few days before the lake became quiet again.

On 20 August, a steam eruption occurred suddenly at 10.23 am and lasted for about 10 minutes. The eruption threw mud and rocks a short distance from the vent and minor ash was lofted into the plume which rose about 4 km high. Gas emissions were high immediately after the event, then dropped down to background levels.

Fiona Atkinson & Karen Britten monitor Ruapehu gas flux onboard a specially-equipped plane funded by GeoNet. Photo: Julian Thompson, GNS Science.

Further eruptive activity occurred through October, with small eruptions on 4, 8 and 11 October. The last eruption in the sequence was the largest, with mud and blocks deposited on the crater floor to about 350 m from the vent. Monitoring equipment was damaged, suggesting the activity was energetic, and this event had the most impact of any eruption since early 2012. Thereafter, the activity returned to lower levels until the end of the year.

Ruapehu

In late 2012, the temperature of Ruapehu Crater Lake appeared to be "stuck" at a low temperature (less than 25°C). It stayed low from February 2012 to March 2013, whereas normally it starts to warm within a couple of months of reaching a minimum temperature. This led to concerns in early 2013 that there might be a blockage preventing gas and heat from transferring into the lake from the hydrothermal system. However, in April 2013, the lake temperature started to increase to a maximum of 40°C before dropping again to a low of less than 20°C in August. Towards the end of the year, the lake temperature was again rising, reaching 30°C by year end. This cycling represents typical Crater Lake behaviour.

We thank Geonet for providing data used in this report.

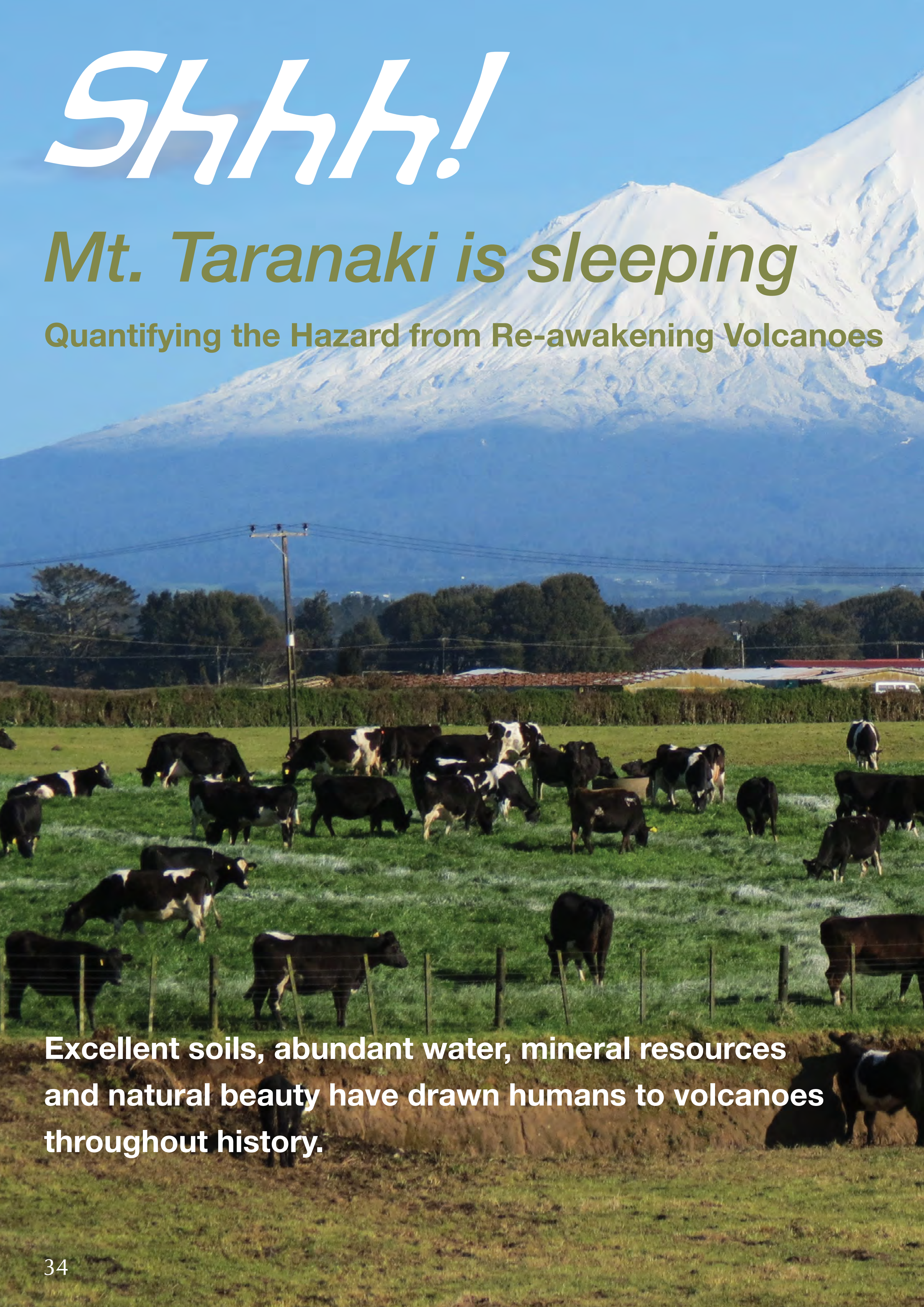
Prepared by Gill Jolly (GNS Science)

Richard Johnson maintaining monitoring equipment at White Island. Photo: Steven Sherburn, GNS.

Shhh!

Mt. Taranaki is sleeping

Quantifying the Hazard from Re-awakening Volcanoes



Excellent soils, abundant water, mineral resources and natural beauty have drawn humans to volcanoes throughout history.

Many volcanoes are constantly active, with 'business as usual' eruptions expected by the people that live around them. But even these regular performers produce the odd unwelcome surprise. A massive eruption of Mt Merapi (Indonesia) in late 2010 killed over 380 people, despite evacuation of almost 250,000 people. This scale of eruption had not been experienced since the early 1890s, long enough for the memories (and fear) of such events to fade.

Photo: Brad Scott, GNS Science


Lake Richmond has been silently witnessing eruptions of Mt Taranaki for at least 10,000 years, with volcanic ash falls becoming preserved at the lake bottom. Photo: Massey University

In New Zealand, eruptions are much less frequent. Decades (Mt Ruapehu), centuries (Mt Taranaki), or even millennia (Taupo) may occur without eruption, encouraging complacency. Such volcanoes can 're-awaken' at any time. Taranaki is a perfect example. Despite it not having erupted since the mid 1800s, its proximity to dairy, natural gas and oil production, means that an understanding of its hazards is crucial.

> "the new data and modelling increase the estimate of an eruption in 2014 from 1.6 to 3.1 percent."

To assess hazard we must first define "when" an eruption will occur. Over the past several years we have developed a highly detailed record of Mt Taranaki eruptions. By examining soil sequences and drill-core sections from lakes and swamps around the volcano, volcanic ash layers have been counted, chemically fingerprinted and dated. From novel statistical and geochemical approaches developed by us, we estimate the volcano has erupted over 160 times in the last 36,000 years.

From past work we know that Taranaki's activity occurs on a regular cycle, with periods of rapid-versus slow-recurring eruptions. We also know that both the size of the eruptions and their magma chemistry changes between different parts of these eruption cycles. This strongly affects the type of eruption, and the consequent hazards faced: slow-moving lava flows versus explosions and widespread ash.

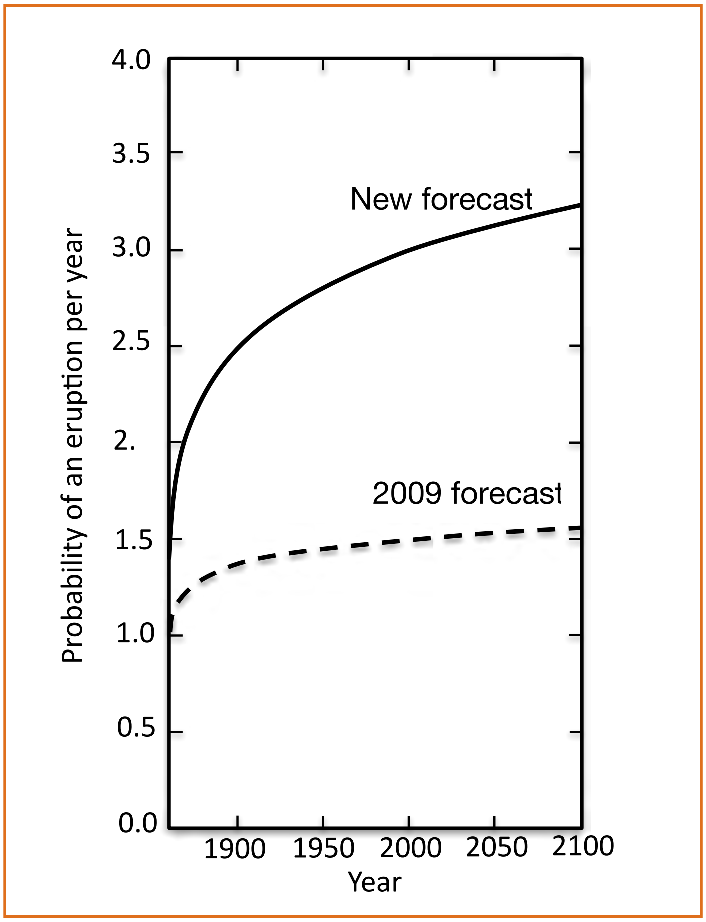
In our latest research involving PhD student Rebecca Green (see profile), we have used our understanding of the chemical cycling at Mt. Taranaki to better forecast the 'rest period' before the next eruption. The specifics of this process rest on the chemistry of some of the smallest components of magma: the iron-titanium bearing oxides known as titanomagnetites. In general, if aluminium content varies in the titanomagnetite of a given ash deposit, we know that several different magma batches were mixed deep within the volcano before eruption, correlating with longer rest times and larger eruptions;. If titanium content varies, it tells us that the magma has rested within a few kilometres of the surface, resulting in more frequent yet smaller eruptions.

The only bad news about these advances is that the improvement in our understanding of the volcanic processes has led to an increase in the forecasted probability of Taranaki erupting: the new data and modelling increase the estimate of an eruption in 2014 from 1.6 to 3.1 percent.

There is still much more to be uncovered about magmatic processes driving eruptions. These ongoing studies lead the way for international volcanology and can be applied to other settings, such as Mt. Merapi.

Major contributors to this research have been: Shane Cronin, Mark Bebbington, Ian Smith, Richard Price, Michael Turner, Thomas Platz, Ting Wang, Bob Stewart, Vince Neall, Rebecca Green and Magret Damaschke.

Contact: Shane Cronin, s.j.cronin@massey.ac.nz

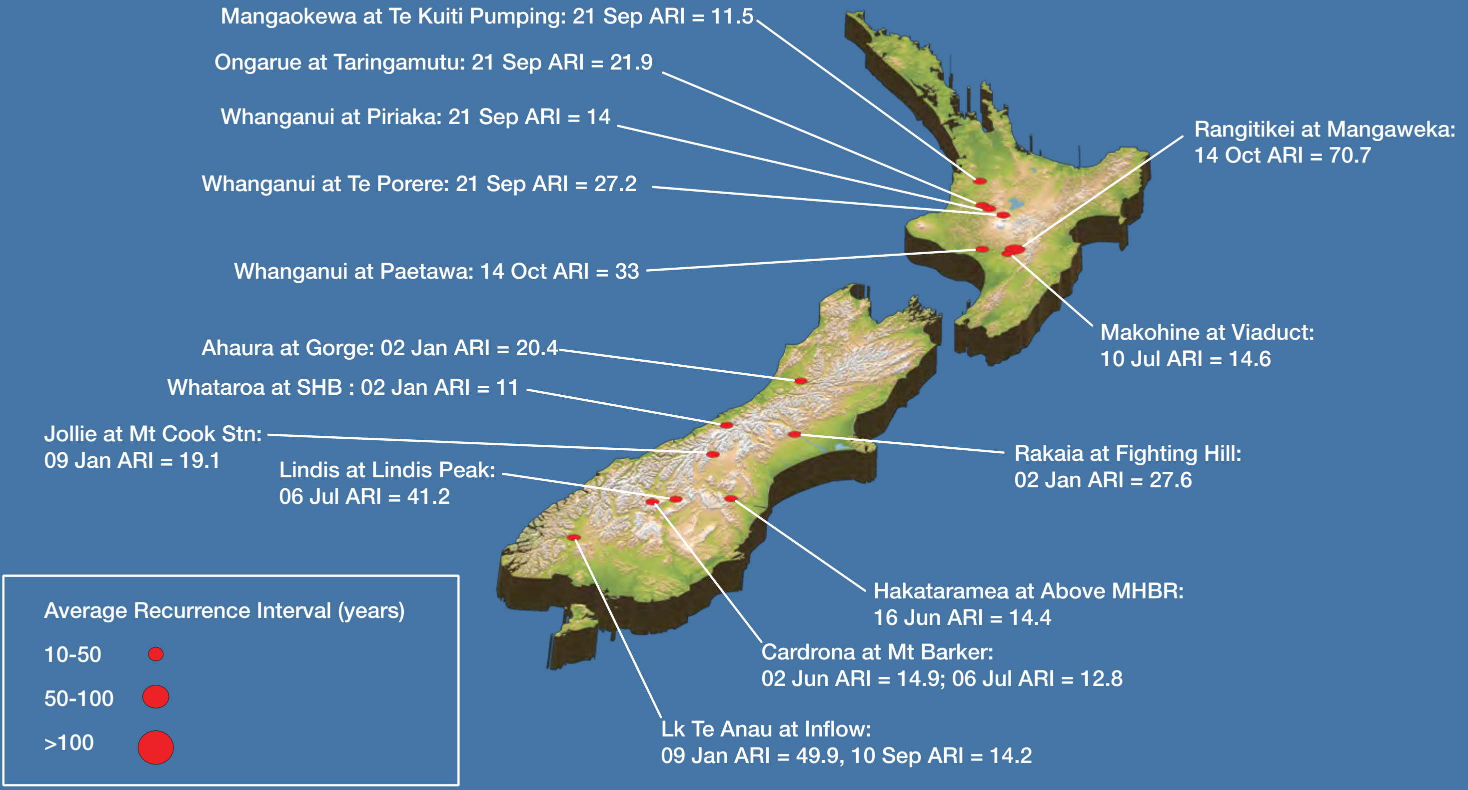


Estimates of eruption likelihood since the last known eruption at Mt. Taranaki (in probability of event per year). The new model with geochemical control is shown by the solid line and our former 2009 hazard model is the dashed line. The likelihood of an eruption increases over time of resting.

Platform-funded Students

Rebecca Green is studying towards a PhD in Statistics at Massey University. Rebecca's research focuses on probability models for long-term volcanic hazard. Besides showing how to incorporate geochemical data into eruption forecasting, she has developed a statistical method for correlating tephra layers in space and time. These findings have opened the door to methods of estimating eruption volumes from point thickness measurements. Rebecca's thesis is supervised by Mark Bebbington, Shane Cronin and Geoff Jones at Massey University.

Floods and Heavy Rain



Two especially notable flooding events occurred during 2013. The first occurred on 21 April in the Tasman region, and the second on 15 and 16 October, which affected Whanganui.

On 21 April, torrential rain caused flooding in the Nelson and Tasman regions, particularly in Richmond and Stoke. This rainstorm was one of the most intense ever measured in New Zealand, and ever recorded in the Nelson and Tasman regions. The maximum 1-hour rainfall total during the storm was 101 mm/h in the Roding catchment near Richmond, a rainfall total which has a 500-year return period in this area. The most extreme 1-hour rainfall ever measured in New Zealand is 134 mm/h in the Cropp River catchment on the west coast of the South Island, a catchment which holds many of New Zealand's extreme rainfall records. The highest 24-hour rainfall total recorded during the 21 April storm was 216 mm, recorded at the Tasman District Council office in Richmond. Rainfall data here were sourced from Tasman District Council.

On 14 October, the Rangitikei and Whanganui Rivers had flood events of 70 and 33 year return periods, respectively. This led to 100 houses and 50 businesses in Whanganui being evacuated as the Whanganui River burst its banks (15-16 October). A local state of emergency was declared by the Whanganui Mayor, and floodwaters were considered contaminated due to sewerage system overflows in some places. Residents of the small Turakina Beach settlement were isolated by 3 metre deep floodwaters which closed the only road out of the township. Flooding and slips affected numerous roads in the western North Island.

Floods described as '1 in a 100 year' or a '100 year return period' have a 1% chance of happening in any given year.

Source: Climate Database, Water Resources Archive and National Climate Centre Monthly and Annual Summaries (all NIWA), and Regional Council data sources. Note: flood magnitudes are derived from real-time unaudited data that has had visual checks to remove data spikes and other obvious errors.

Prepared by Roddy Henderson , NIWA

Landslide Activity

Dart River landslide. Photo: GNS Science.

GNS Science recorded over 140 landslides that impacted roads, houses and other infrastructure in 2013. The majority of these landslides were triggered by heavy rain, however two significant earthquakes near Cook Straight also triggered cliff collapse, rockfall and landslide. Three people were killed by landslides during 2013.

Two significant rainstorm-triggered landslides occurred on 21 April in the Nelson-Tasman area, and on 15-16 October in the lower North Island, particularly the Whanganui-Ohakune area. Torrential rain caused numerous slips and flooding in one of the most intense rainstorms measured in New Zealand and recorded for the Nelson-Tasman region.

Significant landslip also occurred in the Nelson-Tasman region. In a storm of 15-17 June, a woman was killed at Otuwhero Bay, Kaiteriteri, when her house was destroyed by a landslide. Another house in the Marahau Valley had to be evacuated when a slip came to rest behind it. Wellington and Wairarapa also experienced slips during this storm.

On 10 September, two Canadian tourists were killed when their campervan was hit by a debris flow on Haast Pass, and washed into the Haast River. There were about ten debris flows in Haast Pass in the same storm between the Gates of Haast bridge and the Haast Pass summit, including a major slip at Diana Falls. The slip closed the road for 9 days and affected the road for the rest of the year as stabilisation was attempted.

On 15-16 October, flooding and slips affected numerous roads in the western North Island, with the Ohakune to Whanganui areas hardest hit. Farmers in the hill country inland from Whanganui reported extensive damage to roads and property. Landslides were also reported in Taranaki and Manawatu from this storm. We thank Geonet for providing data used in this report.

Prepared by Sally Dellow and Brenda Rosser (GNS Science)

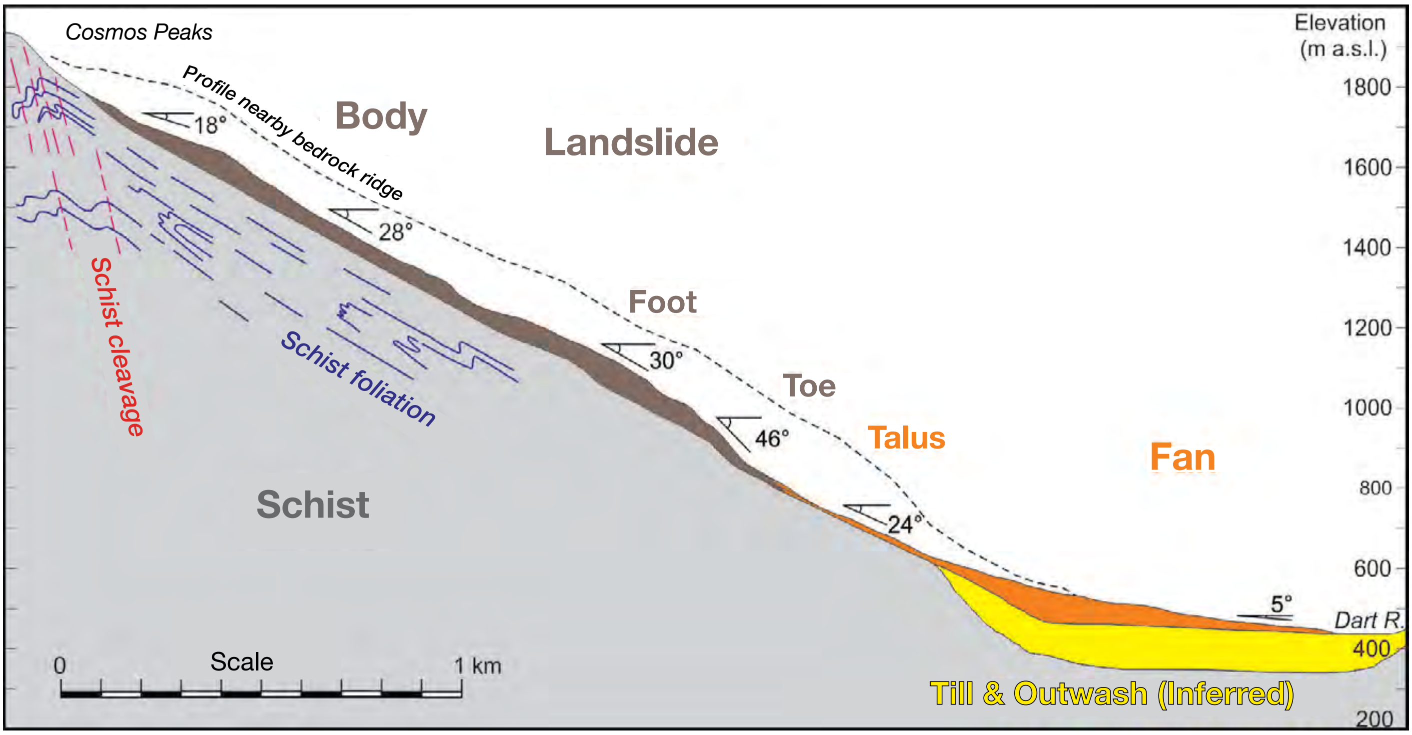
The Dart River Landslide

In early January 2013, heavy rain in the Southern Alps reactivated a massive landslide in remote Dart River valley. To Maori, the area is known as Te Koroka and the slip as Te Horo; the area is culturally significant as a source of pounamu and has the status of tōpuni.

Maori shared stories about Te Koroka and Te Horo with Captain James Cook. In the last decade the 50,000,000 cubic metre landslide has become increasingly active. Debris-flow activity from the landslide toe increased during 2013, covering a fan below with fresh debris and sometimes blocking Dart River. Debris flows consisting of wet concrete-like slurries (boulder-sized to fine-silt) traveled downslope from Te Horo and across the sloping fan, burying anything in its path. Debris flows over the last year have delivered more sediment to Dart River that it has been able to carry away, resulting in the fan partly blocking the river.

In January 2013, a small lake (0.13 square km) formed upstream of Te Koroka /Slip Stream. More debris flows over the year caused the lake to reach 1.48 square km by January 2014. A large debris flow on 4 January 2014 delivered nearly a million cubic metres of sediment to the fan and was sufficient to dam the flooded Dart River. For the rest of the month the debris flow pulsed continuously, up to several times each hour, switching to new channels across the fan, and intermittently raising the dam crest and lake. The growing fan pushed the Dart River channel against a terrace edge on the opposite side of the river, eroding the steep, forested bank. A section of the popular Rees-Dart walking track fell into the river and another part was submerged in the lake.

The continuing event presents a rare and unprecedented opportunity to study the dynamics of debris-flow initiation and deposition, and the impacts of a very large sediment pulse on a river. Using aerial photography and satellite imagery, GNS scientists Simon Cox, Mauri McSaveney and Mark Rattenbury have updated the erosion and sedimentation history for 2011 to 2014. Debris-flow source areas,



Profile (cross-section) of Slip Stream landslide and fan

fan deposits and the lake extent were mapped for successive years. The maps show the different parts of the landslide that were active at different times, and the debris-flow source area on the landslide that is progressively enlarging upslope over time. The maps also show how the fan has grown in size, restricting and temporarily blocking flow in the Dart River at its toe.

The upper part of the landslide is intensely fractured, and the slope area at 1200–1470 m provides a source for future debris flows. Until such a time as sediment delivery from the landslide reduces radically, the periodic debris flows and associated events are likely to continue.

At this writing, landslide-related debris flows do not appear to add any additional danger to users of the lower Dart River in areas below the dam, though the Te Koroka /Slip Stream area itself is hazardous. A catastrophic lake-outburst flood is unlikely. However, Dart River visitors downstream of Te Koroka /Slip Stream need to check with the local information centre at Glenorchy for updates on the situation.

Contact: Simon Cox, s.cox@gns.cri.nz

Photos: GNS Science

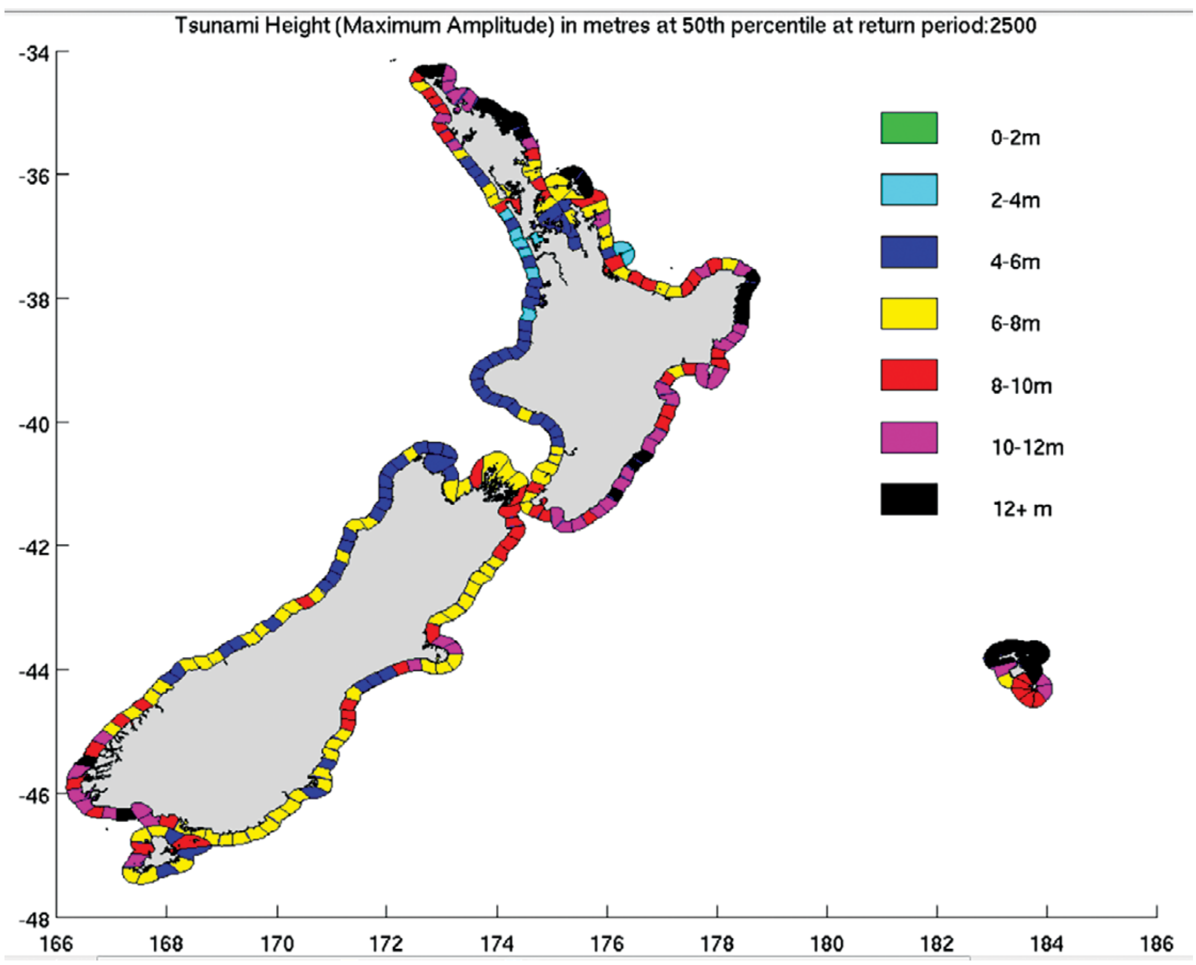
Review of Tsunami Hazard in New Zealand

A report summarising New Zealand's tsunami hazard was prepared in 2013 for the Ministry of Civil Defence and Emergency Management. The *'Review of Tsunami Hazard in New Zealand (2013 Update),'* examines all likely sources of tsunami that could affect New Zealand. The review builds on the previous 2005 report and summarises the current state of knowledge and highlights new research. A substantially revised probabilistic hazard model has been constructed for this report, which for the first time estimates the tsunami hazard for all parts of the New Zealand coastline.

The review focusses on quantifying tsunami hazard caused by earthquakes – the likely size of resulting tsunami over specified timescales, along with estimates of uncertainty. The hazard posed by tsunami generated by landslides and volcanic activity has also been carefully considered. It is not yet possible to quantify the hazard from these sources, though research towards this goal is being undertaken.

The 2011 Tohoku tsunami in Japan illustrated some of the key changes in scientific knowledge. The tsunamis of the Indian Ocean (2004) and South Pacific (2009), followed by Tohoku were produced by earthquakes substantially larger than considered likely to occur at those locations. These earthquakes contradicted previous geophysical assumptions about the maximum magnitudes of earthquakes that could be created on tectonic plate boundaries.

There are now far fewer restrictions on possible maximum magnitudes than previously thought, and the new probabilistic model attempts to account for this. It is now known that there was a similar tsunami in Japan in AD 869, indicating that the interval between the largest earthquakes there is over a thousand years. The tectonic plates in Japan are converging twice as fast as those around New Zealand, which suggests that the interval between the largest earthquakes on our local plate interfaces could



be in excess of 2,000 years. The important implication here is that our brief historical record of 200 years can, on its own, provide very little guidance in estimating the magnitude of the largest earthquakes that New Zealand may experience.

To improve estimates of the earthquake potential of subduction plate interfaces around New Zealand, where one plate is pushed below another, we must study the evidence of prehistoric tsunami and earthquakes (paleotsunami and paleoearthquakes) in the geological record, and work with the global community to find new, statistically valid, geophysical methods for estimating earthquake potential.

The movement between the tectonic plates in the Tohoku tsunami was very non-uniform—in some areas the plates moved more than 50 metres whereas in many other areas the movement was much less, typically around 5 to 10 metres. This 'non-uniform slip' has important implications for tsunami, as the distribution of movement between the plates affects the motion of the seabed, which determines the size of tsunami. The probabilistic model in the report attempts to incorporate the effects of this phenomenon to a first level of approximation - this is at the cutting-edge of current science and the analysis represents a first attempt at tackling this important problem.

The greater uncertainty that now exists regarding the maximum size of earthquakes on plate boundaries has led to an increase in the estimated hazard from tsunami triggered by local and regional sources. While the overall levels of estimated tsunami hazard did not change greatly from the 2005 report, the estimated hazard generally increased in those areas most exposed to tsunami from local subduction zones – notably the east-facing coasts of the North Island, and the southwest corner of the South Island.

Contact: William Power, W.Power@gns.cri.nz

Platform-funded Students

Seyedreza ("Reza")Shafiei Amraei is studying towards a PhD in Civil Engineering at the University of Auckland with Professor Bruce Melville. Reza is investigating the impact of tsunami on inland structures - the forces induced on coastal structures by tsunami waves, the effects of wave-borne debris on coastal structures, and numerical modelling of tsunami-building interactions. Reza recently presented his work at the *35th International Association for Hydro-Environment Engineering & Research* in Chengdu, China.

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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