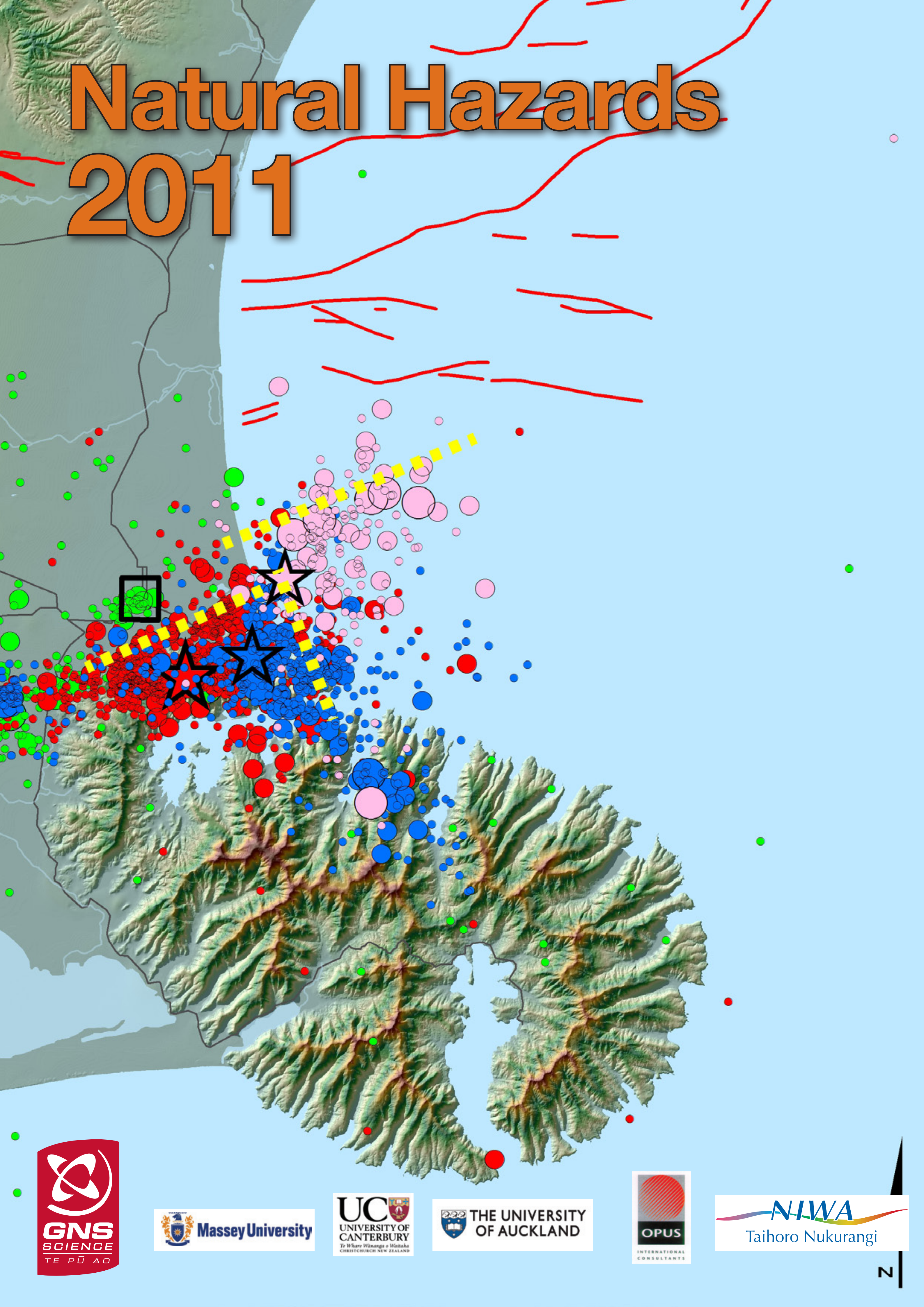
Natural Hazards 2011



GNS SCIENCE TE PŪ AO

Massey University

UC UNIVERSITY OF CANTERBURY

THE UNIVERSITY OF AUCKLAND

OPUS

NIWA Taihoro Nukurangi

2011

New Zealand's amazing natural beauty is one of our most impressive assets, but the natural processes responsible for our dazzling landscapes can give rise to extreme natural hazards events.

2011 will be remembered by New Zealanders as a hugely challenging year. The Canterbury earthquakes have had the single largest impact on New Zealand since World War II, and the consequences will continue to impact communities and businesses for some time to come. Past investment in earthquake-related research paid off for New Zealand in 2011, through emergency preparation and mitigation of risk, so that the effects of the quakes were not as severe as they otherwise might have been. As a country it's important that we continue our natural hazards research to better prepare for the future.

The Natural Hazards Research Platform provides under one umbrella a multi-organisational, multi-themed approach – geological hazards, weather, resilient engineering, risk, and societal resilience – that is paving the way forward for a more resilient New Zealand. The Platform contributed significantly in the immediate response to the earthquakes. For example, their advice to geotechnical experts and the Sumner Community to evacuate at-risk houses after the February 22nd quake likely saved lives when an aftershock on June 13 triggered a rock fall. The Platform has provided consistent support and advice on topics ranging from seismology to economic impacts, to CERA, EQC, private insurers, the Royal Commission of Inquiry on the Canterbury Earthquakes, and many other research users. I would especially like to acknowledge the Platform's Canterbury-based researchers who put their personal circumstances aside to help fellow Cantabrians – they and others from the wider scientific and engineering community have gone above and beyond the call of duty in 2011.

In addition to New Zealand events, other worldwide hazards events of the past year include the Chilean eruption, Japan's Tohoku Earthquake and resulting tsunami, and Cyclone Yasi in North Queensland. These events highlight the need for robust, long-term fundamental and applied research on natural perils, risk assessment and impact studies, to inform policy on sustainable economic development and resilient communities and cities. The Canterbury earthquakes have not reduced New Zealand's vulnerability to other types of natural hazard, and it is pleasing to note that research on other hazards, like work on an improved lahar warning system and on weather modelling to forecast flood peaks well in advance, has also continued this year.

In Budget 2011 the Government supported the efforts of the Platform with an additional $3 million per year for four years to contribute to the Canterbury recovery, as well as to gain knowledge that will be of benefit to the whole of New Zealand.

I congratulate GNS Science and NIWA, and their Platform partners – University of Canterbury, University of Auckland, Massey University and Opus International Consultants – for producing this annual publication, which highlights research and its application to natural hazards events.

Hon Steven Joyce

Minister of Business, Innovation and Employment

Natural Hazards 2011

Features

Communicating Our Research

Cover image: Seismicity map as of the end of December 2011. Central Christchurch (boxed area); earthquakes (stars); aftershocks (dots). Image courtesy Rob Langridge, Will Ries; GNS Science. For more details visit, "aftershock map" at: http://www.naturalhazards.org.nz/NHRP

Platform Manager's Review 2011 - Kelvin Berryman

The Canterbury earthquake sequence represents the largest natural hazard event in New Zealand's written history, with impacts estimated at 8% of national GDP, much more than the relative impact of Hurricane Katrina on the US economy or the recent Tohoku earthquake and tsunami on the Japanese economy. The Natural Hazards Research Platform has made significant contribution to the earthquake response under the auspices of the National Civil Defence declaration followed by CERA, and in providing technical advice to the Royal Commission of Inquiry on the Canterbury Earthquakes. While other aspects of Platform work was not so much in the media glare, there has been excellent progress in research and its applications for weather events and forecasting and in other geological hazards areas, such as tsunami and volcanism.

Our response to the earthquakes and hazard events taking place would have been severely hampered without support. Government made available funding to address issues arising from the earthquake sequence. Results stemming from our findings are summarised in the table (attached). More than $3 million was provided for short term recovery projects to apply existing knowledge and contribute to the early stages of recovery. A longer-term response has been made possible by a further allocation of $12 million distributed over 4 years targeted towards the lessons from the earthquake sequence to be applied across the rest of New Zealand.

Our Platform volcanology programme continues to be strong. We follow up our 2010 article about volcanic eruption impacts on air travel with an update from the 2011 Chilean eruption and contributions made by our researchers; their findings to update emergency management response practices in New Zealand. Floods continue to pose high risk in New Zealand, with five extreme flood events in 2011. NIWA provide an update of their advanced flood forecasting tools made possible by high-powered supercomputing facilities. These plus select articles from the earthquake recovery programme are featured in this edition of Natural Hazards.

The events of 2011 have also revealed the potential economic consequences of infrequent but potentially catastrophic events, and the need for dialogue around acceptable risk and tolerable impact from natural hazard events. In this respect I point you to an article from David Kelly, Deputy Chief Executive of Building & Housing Group, Ministry of Business, Innovation and Employment. We have reproduced this article with amendments courtesy of the Dominion Post. It discusses acceptable risk and tolerable impact in the context of the New Zealand building stock. This excellent piece signals a wider discussion we must consider in the lessons learned from Canterbury.

I hope you enjoy the sample of excellent fundamental and applied research presented in this review, and look forward to extending the contribution that the Natural Hazards Research Platform can make to disaster risk reduction in the coming years.

Recovery Project
Earthquake and Land Stability
CHCH subsurface structure (RC)
Offshore faults (RC)
Earthquake likelihood & seismic coefficients (RC)
Port Hills Rehab & Landuse Planning
Liquefaction impacts on pipe networks (RC)
Greenfields Landuse (RC)
Built Environment & Infrastructure
CBD foundation damage (RC)
Engineering issues for rebuilding (RC)
Performance of fire protection systems
Bridge Performance
Pallet racking systems
Lifelines, hospital services, and housing
Risk & Societal Resilience
Business impact survey program
Risk communications and advice
Internal Migration
Psychosocial intervention and support for schools
Role of public education
Shift in student numbers within the Tertiary sector
Impacts on the tourism sector & other int'l visitors

RC, Royal Commission Technical Reports; CCC, Christchurch City Council; CELG, Canterbury

Technical presentations to the Royal Commission. Clockwise from top: Jason Ingham, University of Auckland; Misko Cubrinovski, University of Canterbury; Seismicity Panel (K. Berryman, G. McVerry, J. Pettinga, T. Webb). Photographs courtesy of The Press.

Project Team	End-Users
GNS, UOC, University of Calgary	MCDEM, CERA, ECAN, EQC, CCC,
NIWA, University of Otago	CERA, EQC, GNS, ECAN, CCC
GNS, VUW	MCDEM, CERA, CCC, Tonkin & Taylor, EQC, DBH
GNS, UOC, UOA, Consultants	CCC, ECAN, CERA
UOC, UOA, GNS, Geotech Consulting	CCC, CERA, CELG
GNS	ECAN
UOC, UOA, Consultants	CCC, EQC
GNS, UOC, BRANZ, UOA	CCC, CERA, EQC, Insurers
UOC, GNS, Fire Protection Assoc., DBH	NZ Fire Service, Fire Protection Assoc, DBH
UOC, UOA	NZ Transport Agency, CCC
GNS, UOC, UOA, Branz, Compusoft Eng	DBH, Branz, Industrial Manufacturers (Dexion)
UOC, GNS, Massey, CCC, Univ Illinois,	ECAN, CELG, Lifelines Utilities, Canterbury DHB, CCC, CERA
UOC, Opus, NZ Centre of SME Res.	CDC, Canterbury Employers' Chamber of Commerce, CERA
UOC, GNS, VUW, ESR, Massey, Risk Strategies	MSI, MCDEM, DBH, CCC, CERA, Engineers, DBH, EAG, Property Council
GNS, Opus, UOC	MSD, MCDEM, Statistics NZ, MSI
Massey, Central Queensland University	Ministry of Health, Ministry of Education, MCDEM, MSD
John Lindsay, GNS, Massey, VUW, UOC	MSI, Civil Defense sector
UOC, Massey	TEC
University of Otago, UOC, Massey	Ministry of Tourism, MFAT, MED

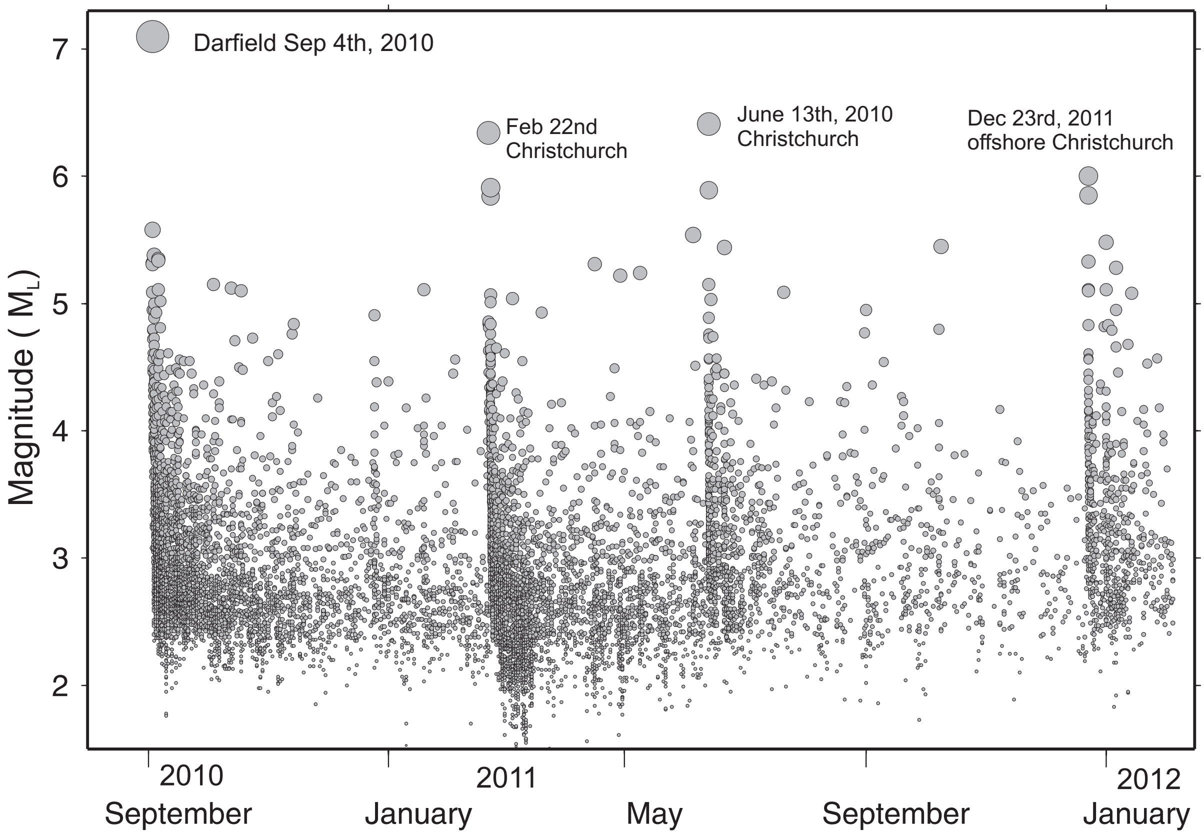
y Engineering Lifelines Group; CDC, Canterbury Development Corp.; EAG, Engineering Advisory Group; ECAN, Environment Canterbury

Earthquake Activity in 2011

The Canterbury earthquake sequence dominated 2011. Outside of Canterbury, there were earthquakes elsewhere in New Zealand of magnitude 5.0 and greater that caused minor damage:

- On April 11, a magnitude 5.2 earthquake centred 10 km west of Porangahau and at a depth of 40 km was felt throughout the lower North Island and caused goods to fall from shelves in Porangahau.
- On July 5, the largest earthquake in 2011 with a magnitude of 6.5, centred 30 km west of Taupo at a depth of 150 km, was felt throughout New Zealand, with the highest felt intensities in the Wellington region, where goods fell from shelves.
- On July 24, a magnitude 5.2 centred 90 km offshore south-west of Whanganui at a depth of 120 km, was felt throughout the lower North Island and in Nelson and Marlborough. Minor damage was reported in Wellington and Levin.
- On September 15, an event of magnitude 6.3 and at a depth of 60 km centred 400 km north-east of East Cape dislodged items from shelves in Gisborne. It was felt mainly on the eastern side of the North Island.
- On December 3, a magnitude 5.7 centred 30 km east of Picton and at a depth of 60 km was felt throughout the lower North Island and upper South Island, with minor chimney damage reported in Wellington, and many reports of items falling from shelves throughout Wellington and Marlborough.

There were eight earthquakes outside the New Zealand region that were reported felt. The most widely felt was a magnitude 6.7 event on April 19 centred 400 km north of Te Araroa at a depth of 90 km. It was felt mainly on the eastern side of the North Island, most strongly in the Wellington region. Reports were also received from the Auckland, Marlborough, Nelson and Christchurch regions.



Time sequence of the 2010-2012 Canterbury earthquakes. Earthquakes located by GeoNet in the Canterbury region between September 2010 and February 2012, plotted as a function of local magnitude.

On July 7, a tsunami alert was issued by the Pacific Tsunami Warning Centre for a shallow magnitude 7.6 centred 1,330 km north-east of Auckland. After assessment by local experts, the alert was dismissed as the threat to New Zealand was considered minor. Felt reports were received for this event from scattered locations along the eastern side of the country from East Cape to Otago.

In 2011, a total of 59 earthquakes of magnitude 5.0 or greater occurred in New Zealand, seven of which were magnitude 6.0 or greater and 19 of which were at depths of greater than 100 km. About 2,460 earthquakes have been reported felt, and all significant damage was caused by the Canterbury aftershock sequence.

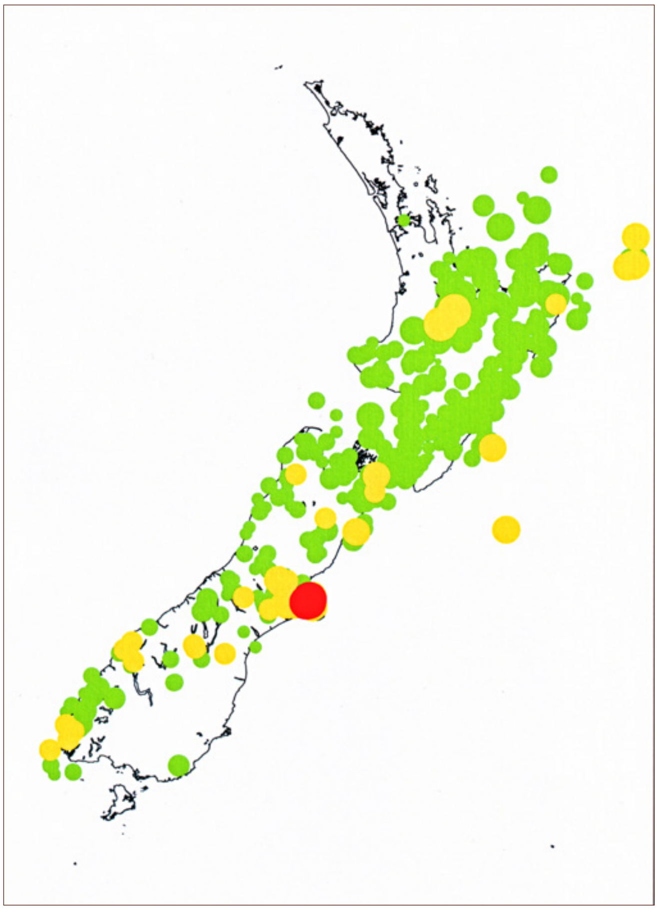
The Canterbury Earthquake Sequence

The devastating 2010-2011 Canterbury earthquake sequence, which began with the magnitude 7.1 Darfield earthquake on 4 September 2010, continued to evolve throughout 2011, with more than 8,700 earthquakes larger than magnitude 2 (see publication cover for map of earthquakes of magnitude 3 and above for the sequence starting in Sept 2010 to Dec 2011). Over a period of many months, the Canterbury earthquake sequence developed from a somewhat weak aftershock sequence following Darfield into a complex, long-lasting series of damaging earthquakes. This sequence will inform how we think about seismic hazard for decades to come. Government funding via the Platform's short term recovery programme allowed us to gather the critical data presented to the Royal Commission of Inquiry on the Canterbury Earthquakes.

The earthquake sequence was marked especially by the magnitude 6.2 Christchurch earthquake of 22 February 2011, which resulted in 185 deaths, extensive liquefaction, and more than NZ$11 billion in damages. Ground motions reached 2.2 g in the Heathcote Valley near the epicentre and up to 0.8 g in the central business district. The event was felt from Southland to Bay of Plenty, and aftershocks of magnitude 5.7 and 5.5 followed soon after. Locations less than 5 km from the fault beneath the Port Hills that produced the earthquake were stronger in the Feb 2011 earthquake than for the Darfield earthquake of 2010. Satellite and GPS measurements indicate that the fault rupture was complicated with rupture of several small connected faults, just 3-4 km from the Christchurch city centre. The maximum slip was up to 4 m, at just 4-5 km depth. The extensive damage was caused by a number of factors, including the earthquake's proximity to the city and directional effects. Also, local site conditions contributed, with deep, soft soil conditions and high water table.

Another significant earthquake of magnitude 6.0 occurred on 13 June 2011 near the suburb of Sumner, causing more liquefaction and damage in the eastern suburbs of Christchurch. Ground motions reached 2 g in Sumner. Further activity, including events of magnitude 5.8 and 5.9, occurred offshore from Christchurch on 26 December 2011, 10-15 km east of Christchurch city centre. Total economic losses estimates associated with the Canterbury earthquake sequence as of mid 2012 are approximately NZ$30 billion.

Contact: Stephen Bannister, S.Bannister@gns.cri.nz



Felt earthquakes in 2011 - 2,450 were located.

The red epicentres are from the February 22, June 13 and December 23 events. Green, likely to have been felt; yellow, potential to cause contents damage; red, potential to cause structural damage (Courtesy of GeoNet).

Submarine Faulting Beneath Pegasus Bay

The Canterbury earthquakes of February, June, and December 2011 ruptured a complex network of previously unknown faults hidden beneath North Canterbury.

The aim of the Project was to improve our understanding of the wider faulting and geological context of the earthquakes, and also to determine whether active submarine faults capable of producing large (M6 or more) earthquakes exist beneath Pegasus Bay, off Banks Peninsula. This would help recovery authorities through an on-going assessment of earthquake hazard in the area.

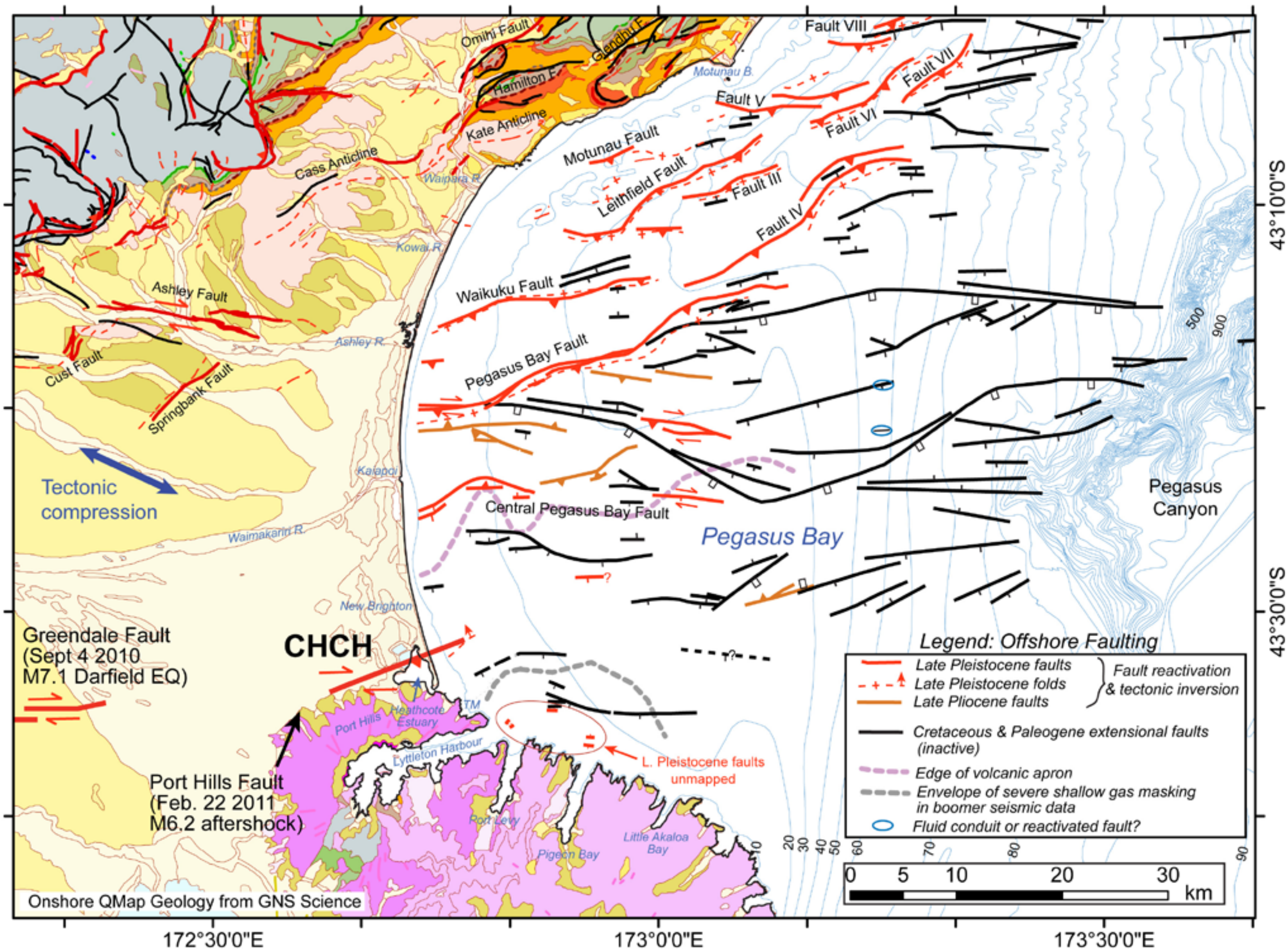
In North Canterbury, part of an ancient fault system (>35 million years) has been reactivated and overprinted by active deformation occurring as part of the Pacific-Australian plate boundary zone. This deformation extends up to 30 km offshore beneath Pegasus Bay, and includes at least 11 major faults, with evidence of renewed activity mainly in the last 1 million years.

The survey took 7 days to complete and was undertaken aboard the *RV Kaharoa*, NIWA's coastal research vessel. Airgun seismic data along 280km of tracks was collected, as well as 430 km of high-frequency seismic data, extending to about 40 km east and north of Christchurch. Additionally, 530 km of complementary open file oil company seismic data were available from the same region.

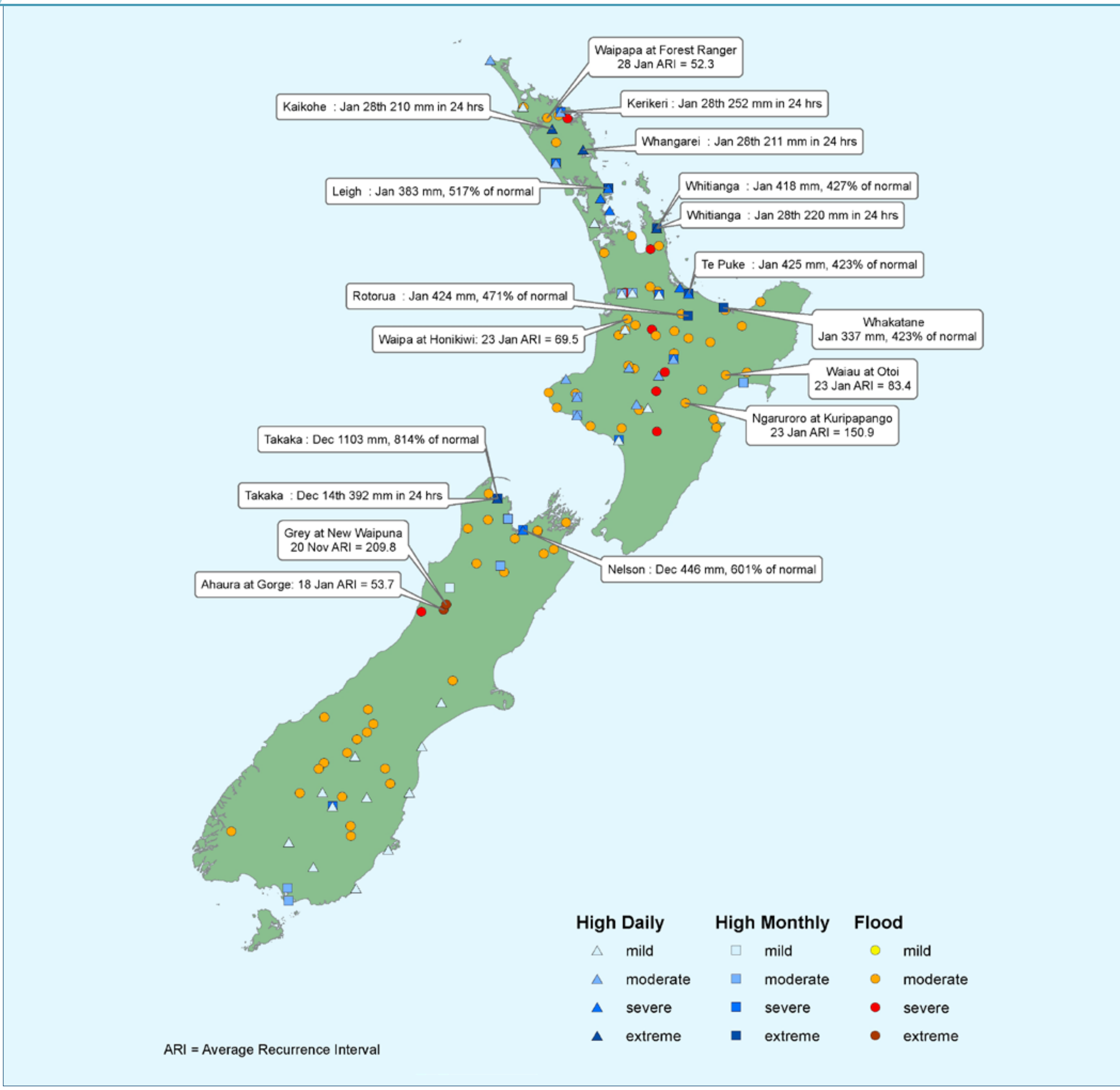
Most of this faulting is concentrated beneath the northern part of the bay, but newly-recognised, very weak deformation appears to extend southward to the northern coast of Banks Peninsula. Most of the active faults are reactivated faults from the older system.

Additional funding for this research has been supported by the Natural Hazards Research Platform for another three years. Article and Image courtesy of NIWA.

Contact: Phil Barnes, philip.barnes@niwa.co.nz



Most of the ancient faulting is concentrated beneath the northern part of the bay, but newly-recognised, very weak deformation appears to extend southward to the northern coast of Banks Peninsula.



Floods and Heavy Rain

In 2011, there were five very extreme rainfall events. A low of tropical origin moved towards New Zealand on 22/23 January, producing significant heavy rainfall, flooding, slips and road closures over much of the North Island. On 28th January, the remnant of Cyclone Wilma moved rapidly across the north-eastern North Island, also causing widespread deluge rainfalls, severe flooding and slips. Otago and Southland experienced very heavy rainfall on 6th February during severe north westerly conditions and an associated frontal passage. On 25th and 26th April, Hawkes Bay was particularly hard hit, as deluge rainfall hit the coastal settlements around Aramoana, causing severe land slips. Residents were evacuated from Te Awanga, east of Hastings, and Aramoana was completely cut off. Extraordinary rainfall totals were observed in the Nelson region on 14th December, resulting in a State of Emergency being declared, and coastal communities in Cable Bay and around Golden Bay being cut off. Heavy rain hit Westland, the Southern Alps and parts of Otago on December 27th and much of the rest of the country on the 28th. Several South Island roads were closed by surface flooding, including SH60 at Takaka, cutting off much of Golden Bay, SH6 at Renwick and at Canvastown, SH6 at the Lower Buller Gorge, SH63 between Arthur's Pass and Otira, SH73 between Otira and Kumara, SH69 from Inangahua to Reefton, SH65 from Murchison to Springs Junction, SH67 from Westport to Mokihinui, and SH7 from Hanmer Springs to Springs Junction.

NIWA's Flood forecast system: Data assimilation, performance and uncertainties

Why flood forecasting?

Floods are New Zealand's most frequent natural hazard. Our aim in designing a flood forecasting system is to give New Zealand communities access to accurate forecasts, reducing the risk to life, and damage to property and cultural assets.

While weather prediction provides advance warning of adverse conditions, we need to translate these predictions of weather to predictions of weather impacts. Given forecasts of heavy rainfall, a flood early-warning system estimates the effects of rainfall on the land and rivers. It forecasts how much rain will be soaked up by the soil, how long it will take the flood waters to rise, the maximum height of flood waters, and the duration of the flood. A flood forecast can also be linked to flood inundation modelling which turns river flood forecasts into maps of local flood depths, water speed, flow paths and length of time of flooding for communities.

Flood forecasts for New Zealand catchments

NIWA is developing its ability to deliver real-time flood forecasts to local and national government agencies and key industries affected by river flood hazards. Hydropower companies could make use of flood forecasts to predict future water levels in hydropower lakes and plan for water releases. Currently we are looking to increase the number of catchments where we provide flood forecasts.

To make flow forecasts, we couple NIWA's weather prediction model, NZLAM[1], to a hydrological model, TopNet. TopNet simulates water movement through sub-catchments using the main flow pathways - surface flow, flow through soils and groundwater. Flows from each sub-catchment are then routed through the channel network. TopNet uses information about the catchment such as land cover and topography. We check that TopNet is working correctly by testing its simulations of floods that we have measured in the past.

Fig 1. Foxton flooding, February 2004 (Courtesy of NIWA).

An example of the flood forecasts we produce is given in Figure 3. This shows the flood of the Grey River during the widespread South Island floods of 15 July 2012. The model, which is run every 3 hours (out to 48 h ahead), provided a good prediction of the flood peak (3800 m^3/s) 24 hours in advance. Because this system uses NZLAM forecasts of rainfall, it is capable of forecasting a flood even before rain has begun falling into the catchment, leading to improved mitigation options.

Data Assimilation: Time lags provide the key

Models such as TopNet are referred to as 'continuous simulation' models, they keep track of the water stored in each part of the catchment, and make flow forecasts every day rather than just during flood events. However, this can lead to errors in the quantity of water stored in the model, due to incorrect rain forecasts. To avoid this problem, we use a method called 'data assimilation' where the predicted flow is compared with the measured flow. If the predicted flow is too low, the amount of water in the model stores is increased and vice versa. The correlations between each model store and the modelled flow are analysed to decide which stores should be increased or decreased.

However, each catchment has a natural 'lag time', i.e. the time taken for water falling as rain to reach main channels. So, if the amount of water in the model stores is increased now, a response might not be seen in the modelled flow until several hours later. This means that data assimilation can cause an 'overshoot' where too much water is added to model stores now, and then later, the predicted flow rises far above what is measured at the gauge. To solve this problem, we use a method which takes the lag time into account, and updates model water stores in the hours previous to an error at the gauge.

How well are we doing?

We have designed an automatic system which compares the observed and modelled peaks, then calculates the flow error and timing error. We can also compare the errors against the forecast timing, forecasts closer to the event are expected to be more accurate. This system allows us to keep track of the model performance. Figure 4 shows how well the forecasts match the measured flows for a catchment that is a mere 44 km^2 in area.

Uncertain times

Flood forecasts will always be subject to errors from sources such as incorrect rainfall forecasts, uncertainty in the hydrological model parameters, and the fact that

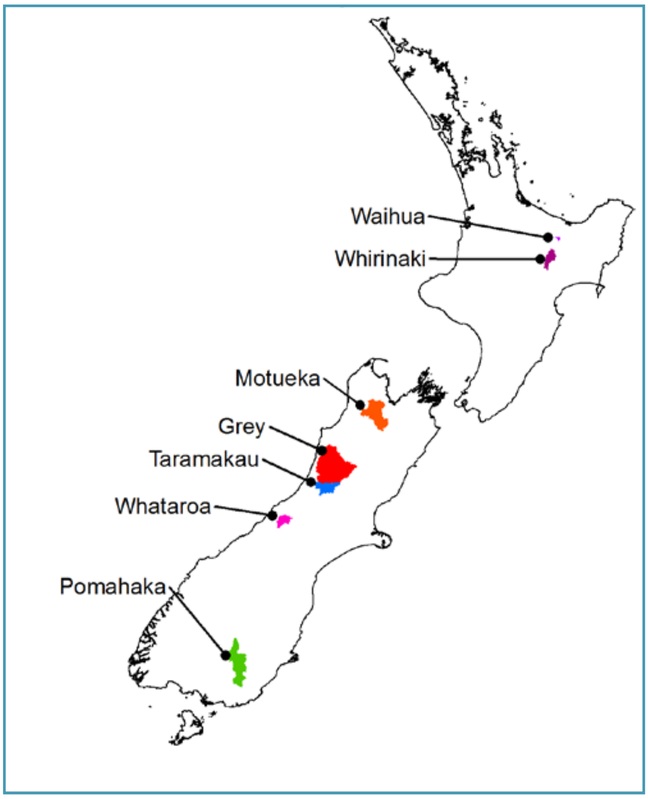


Fig 2. NZ catchments where we currently provide flood forecasts to 48 hour ahead, updated every 3 hours.

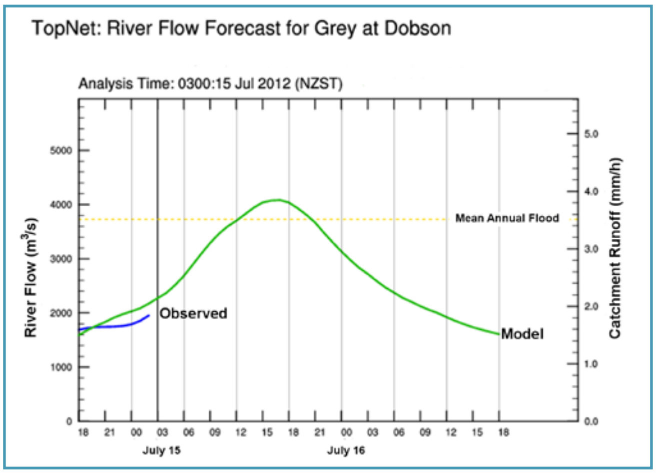


Fig 3. TopNet forecast (using NZLAM rainfall forecasts) for the Grey River during the 15 July 2012 flood showing time at which the forecast was made (vertical bar), observed river flows to that time (blue), and forecast flow (green).

the model is a simplification of the catchment. We are currently developing a method to define the errors associated with flood forecasts, based on previous errors in similar conditions. Where no similar flood events have been measured, the possible forecast error is larger, as we don't know how the catchment will react.

Looking to the future

The TopNet flood forecasting system is under active development at NIWA. This year the development of regional flood forecasting will begin, flow forecasts will be created for every river in a region. To achieve this we will work on improving model calibration methods and faster running speed. We will also develop methods for transferring model parameters between rivers, so that we can provide forecasts for rivers without flow gauges.

Contact: Michael Uddstrom, michael.uddstrom@niwa.co.nz

[1]Natural Hazards 2010. Weather Theme: Data Assimilation – a Key to Hazards Forecast System Accuracy. p32-33. GNS Science Miscellaneous Series 35: ISSN 1177-2441.

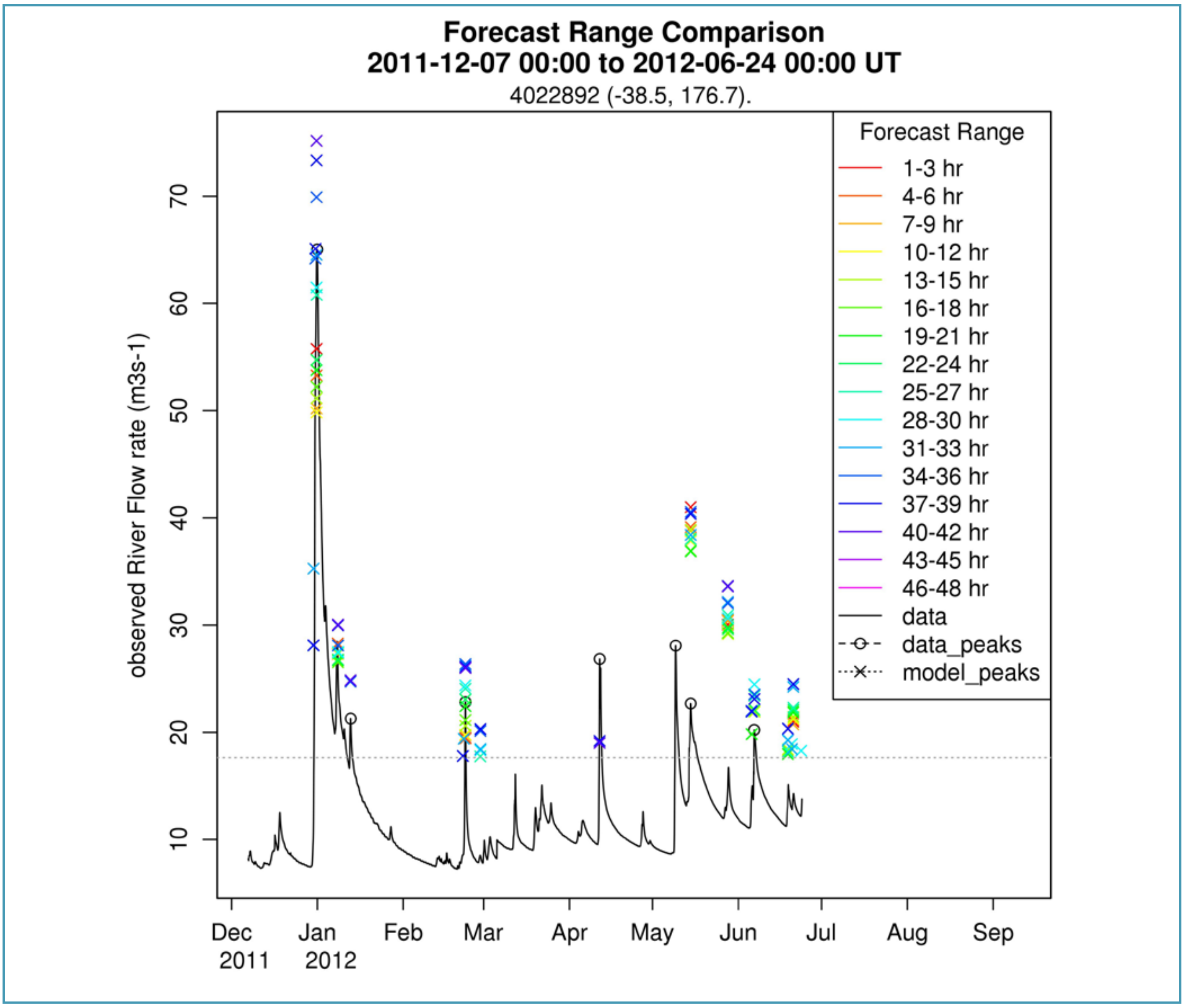


Fig 4. Modelled vs. Observed Flood Peaks on the Whirinaki. Shown in black is the measured flow, shown as coloured crosses are the forecast flood peaks from forecasts every 3 hours between 48 and 3 hours prior to the event.

Volcanic Activity in 2011

No eruptive activity was recorded at any of the active volcanoes during 2011.

During 2011 the extensive monitoring programme undertaken by GeoNet continued on New Zealand's active volcanoes.

The Crater Lake at Ruapehu cycled through two heating episodes during the year, with a sustained cool period from July to October. The first heating cycle peaked in late February when the lake temperature reached 41 °C. During the second cycle in October-December the temperature reached 37 °C. Although activity has been low, gas flux (as measured using an airborne platform) has continued to vary during the year: carbon dioxide (CO_2) ranged from 233 to 2075 tons per day, sulphur dioxide (SO_2) from 4 to 34 tons per day and hydrogen sulphide (H_2S) from 6 to 42 tons per day. Volcanic gas odour was often reported by people on the ski fields during the second heating episode. Volcanic earthquake activity remained at low levels, as did volcanic tremor except for a deep volcanic earthquake in November with very long period waves. Ruapehu remained at Volcanic Alert Level 1 throughout 2011.

The monitoring programme for White Island includes gas and water sampling, ground deformation, soil gas surveys, seismic monitoring, web cameras and equipment servicing. During the year the Crater Lake water level fell to about 16 metres below the overflow, as the temperature rose to over 66 °C. Minor changes were observed in an area of high temperature (118 - 200 °C) steam vents on the southern side of the Main Crater floor. These vents have been changing slowly for some years. The gas flux (measured from the air, from soil gas surveys and from the mini DOAS spectrometer) has remained low for White Island. CO_2 measured by the airborne platform ranged from 928 to 1930 tons per day, while SO_2 ranged from 88 to 237 tons per day. The deformation survey confirmed that the uplift, which had been recorded during the last 2 to 3 years, had stopped. Volcano seismicity remained around typical background levels. The Volcanic Alert Level remained at Level 1 during the year.

Monitoring at Raoul Island has continued, with no anomalous trends having been observed in the temperatures or water levels of the Crater Lakes. The Volcanic Alert Level remains at Level 0.

Anomalous temperatures were reported from the hot pools on Mokoia Island (Rotorua) and water samples were collected. The results showed no changes from previous sampling.

We continued to see evidence on the Rarotonga seismic record of small-scale eruptive activity at Monowai seamount. Activity was confirmed by surface observations in June and August.

Small earthquakes continued to occur at various locations in the Taupo Volcanic Zone, particularly offshore of Matata, south-west of Kawerau and at Waimangu, and along the Haroharo vent lineation within the Okataina Volcanic Centre. Not so many events were located within Taupo Volcano, but activity continued to the south-west of the lake through Turangi to Lake Rotoaira. Events were also recorded on the northern parts of Tongariro and around Ruapehu, in particular to the west of the volcano. No events were recorded under Taranaki, but seismic activity continued to the west of the volcano.

We thank GeoNet for providing data used in this report.

Mt Ruapehu crater lake.

New lahar model reveals mechanism behind their long-range destructiveness

Like flowing concrete, the mechanisms that allow laharic water-particle suspensions to travel over huge distances as violent high-energy flows puzzles geologists, physicists and hazard managers alike.

The first high-resolution record of a volcanic mudflow in motion, obtained during the Ruapehu March 2007 lahar, has now led to a breakthrough in better understanding the mechanisms behind their long-range destructiveness. Massey University-led research revealed how an extremely efficient process of momentum transfer allows lahar flow-energy (and hence maximum destruction potential) to greatly increase over large distances. The new open-system lahar model explains the high energy and deadly catastrophes caused by such flows, even at large distances from volcanoes.

Lahars are a common and extremely deadly hazard at mountain-forming volcanoes that have caused more than 30,000 fatalities worldwide in the 20th century alone. Due to their sudden onset and hazardous nature, direct measurements of lahars are scarce. Existing numerical lahar models are built around the common assumption that they strongly decelerate and dissipate energy closer to their source. These models do not explain high energy lahars capable of causing destruction hundreds of kilometres from their origins, and previous data on moving lahars had always remained too fragmented for quantitative analyses.

In March 2007, the largest lahar in recent New Zealand history occurred at Mount Ruapehu. Our lahar response team was alerted and within fourteen hours began collecting high-resolution, time-series data from more than 20 monitoring sites. This is currently the most detailed lahar record worldwide.

Through a quantitative analysis of the large dataset, recently published in the journal Geology together with a feature story in Earth Magazine, we have described for the first time the internal structure, composition and energy of a lahar wave. We observed that the wave form evolved into three dynamically evolving parts: a frontal bow-wave of river water pushed by the succeeding lahar body to a wavelength of more than 10 km and amplitude of more

Professor Shane Cronin and Dr Gert Lube from Massey University install lahar flow sensors into the channel base of Kali Lengkong, Semeru Volcano, Indonesia. Prior to capturing the March 2007 Ruapehu lahar, novel lahar sensors were thoroughly tested and calibrated in Indonesian rain-triggered lahars.

than 8 metres; a > 8 km-long lahar head that continuously exchanged momentum and matter with the bow-wave; and a several tens of km-long lahar tail carrying the highest concentration of Crater Lake brine and sediment.

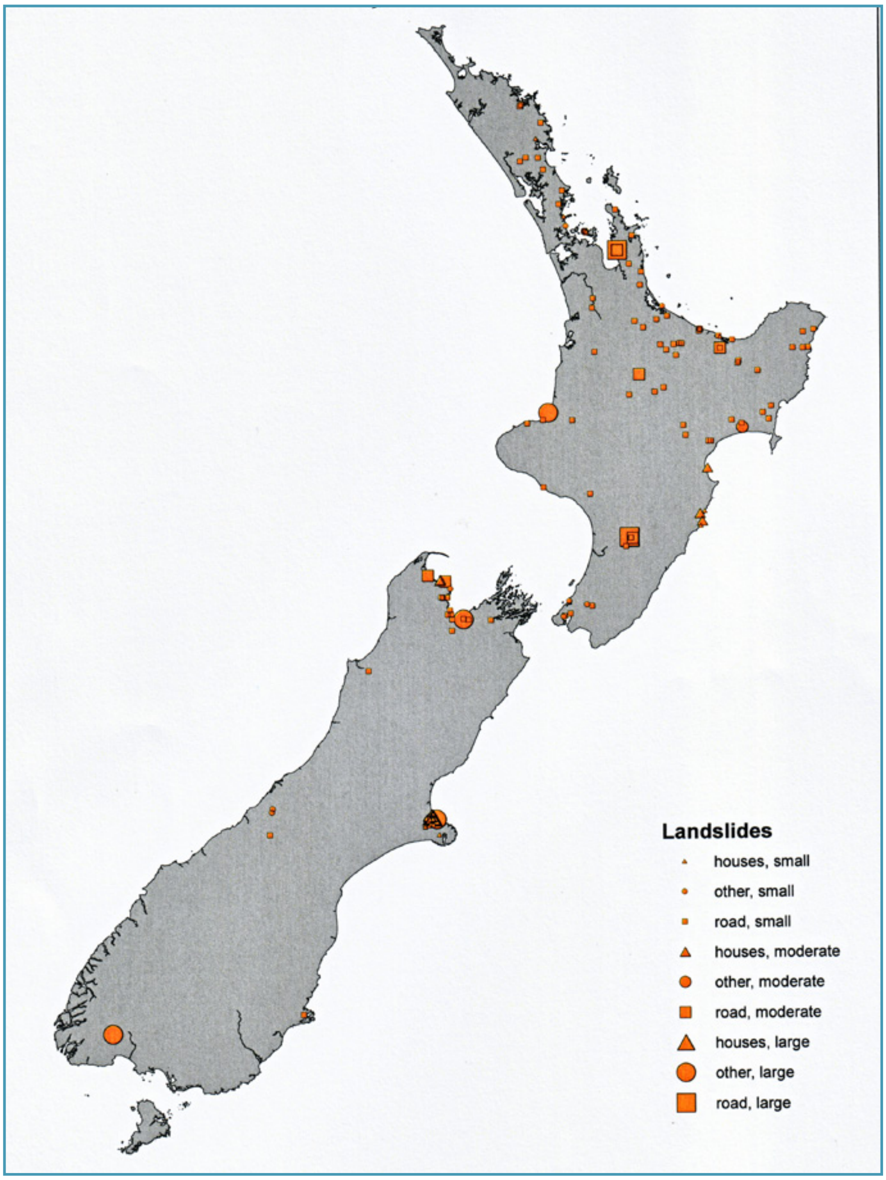
The novel approach of mapping the longitudinal partitioning of mass and energy in the propagating wave revealed that flow energy did not increasingly dissipate beyond the foot of the volcano. Instead, and for more than 100 km of travel, dissipative losses were exceeded by energy gains through incorporation of water and sediment via efficient momentum transfers. These results suggest that it is possible that many lahars, particularly those that enter sufficient stream water (i.e., drain into a river), behave like open systems that gain energy for their long-distance travel.

These findings are the first of their kind and have received international attention. Our results provide the groundwork for a next generation of computational mass flow modelling to evaluate lahar risk at volcanoes around the world.

Contact: Gert Lube, g.lube@massey.ac.nz

Landslide events in 2011

Late January – Cyclone Wilma strikes the upper North Island with slips and other landslides reported from Northland, the Coromandel and Bay of Plenty. Mainly roads affected but some buildings either impacted or evacuated because of landslide threat.



February 22 – a magnitude 6.2 aftershock strikes Christchurch resulting in rock falls and landslides throughout the Port Hills. Three fatalities occurred in the Sumner-Redcliffs area due to cliff collapse and a further two fatalities occurred on walking tracks above Lyttelton. Hundreds of houses were evacuated due to risk of further aftershocks causing more rock falls and boulder roll or cliff collapse in susceptible areas. Several large incipient landslides occurred, some in highly variable rock materials on the flanks of the Lyttelton volcano and some due to loss of strength due to liquefaction at the base of the slopes.

Early May – coastal storm with very heavy rainfall hits Hawke's Bay, badly affecting a narrow coastal strip between Cape Kidnappers and Porangahau. Up to 60 houses evacuated in the coastal settlements of Kairakau, Pourere, Aramoana and Mangakuri. A state of emergency declared in central Hawke's Bay.

June 13 – another magnitude 6.0 aftershock caused further rock-fall and cliff collapse in the Port Hills of Christchurch.

June 18 – slip from the cliff behind Ohope beach kills a teenager. Heavy rain had caused several slips in the area.

July 1 – rock fall south of Rothesay Bay on the North Shore in Auckland killed a women walking on the beach.

August 18 – The first of several slips occurs in the Manawatu Gorge at the Ashhurst end resulting in closure of the gorge road. As a result of this slip and several subsequent slips at this site the road through the Manawatu Gorge did not re-open until early June 2012.

October 25 – years of cumulative movement of a landslide near Pukearuhe results in rupture of the Maui gas pipeline. Emergency shutdown and repairs completed in five days. Loss of gas to northern New Zealand affects many large industrial users with estimated daily losses to the New Zealand economy of up to $175 million per day of outage.

Mid December – record rainfall hits Golden Bay and Nelson. Thousands of slips reported with many homes evacuated. State of emergency declared. Worst affected areas were eastern Golden Bay (Port Ligar, Pohara) and Nelson City. Fears that the Tahunanui slump had reactivated.

We thank GeoNet for providing data used in this report.

Identifying liquefaction hazard in Canterbury for future development

The Canterbury earthquake sequence resulted in extensive ground liquefaction and associated lateral spreading within the CBD and surrounding areas, severely damaging 15,000 residential properties and buildings, and compromising infrastructure such as pipe networks, roads and bridges. In a joint-funded collaboration with Environment Canterbury, we are creating a regional liquefaction susceptibility map that will guide future development of the greater Christchurch area. It covers the region from Southbridge to Leithfield, incorporating the whole of the Greater Christchurch Urban Development Strategy area and a small part of south-eastern Hurunui District. This map will be useful not only for land use planning and building consenting, but also infrastructure asset management and emergency management planning.

The project provides an initial revision of liquefaction hazard information used by councils and the community in decision-making, given the new data and knowledge generated. The revision will provide a consistent approach to regional-scale assessment of liquefaction hazard across the three main territorial authority areas (Christchurch City, Selwyn and Waimakariri Districts).

The project is being undertaken by researchers from GNS Science, University of Canterbury and Lincoln University and a number of Christchurch-based geotechnical consultants. The project team is using geological and geotechnical data collected from the earthquakes of September 2010 and February 2011, along with pre-earthquake information held by research institutes and local authorities. A three-dimensional model of the geological materials underlying the region has been created from this and other data. The model is particularly detailed in the Christchurch urban area, where a large amount of geotechnical information has been collected. The data are being assessed, along with surface geomorphology, soils information and groundwater data to determine areas of differing liquefaction susceptibility. We anticipate that draft results will be available in late 2012.

Contact: Hannah Brackley, H.Brackley@gns.cri.nz

Bridge Performance following the Canterbury earthquakes

Bridges, as critical components of infrastructure, need to be immediately functional after an earthquake to aid response and recovery efforts. Road, highway and railway bridges across the Canterbury region were impacted by both the September 4, 2010 and February 22, 2011 earthquakes. In the days following the February earthquake, engineers from various organisations, including ours, inspected over 800 bridges in the Canterbury region. A range of performance was observed, with many more bridges suffering damage from the February event, particularly in bridge approaches, abutments and piers*. No bridge collapses were reported, but significant damage occurred as a result of liquefaction and lateral spreading, disrupting travel. More important, however, was the concomitant damage to lifelines: bridges are not only linkages in road networks; they serve as "utility structures" where services, such as power cables, sewage and water pipes run through the bridge decking system.

Although the general performance of bridges was satisfactory, geotechnical investigation of soil conditions surrounding affected bridges is required. Advanced structural assessment will allow proper identification of weaknesses in the current design approach and assist mitigation strategies. In consultation with Christchurch City Council and New Zealand Transport Agency, we have developed a project to structurally assess critical bridges in the region: Fitzgerald Bridge, Avondale Bridge, Gayhurst Bridge, Bridge Str. Bridge, Moorhouse/Colombo, Snell Str. Pedestrian Bridge (Christchurch City Council bridges); ANZAC Bridge, Horotane Bridge, Port Hills Bridge (NZTA highway bridges).

Our project is a collaboration between the universities of Canterbury and Auckland and consists of three phases:

1. To review maintenance and retrofit options;
2. Site assessment including characterisation of soil conditions, liquefaction susceptibilities and quantification of any structural damage.
3. Quantitative analyses of existing bridges under a Christchurch earthquake scenario; including susceptibilities of bridge components to liquefaction and lateral spreading. This will allow us to properly assess post-earthquake residual capacity essential for the development of mitigation strategies.

The first phase has already been completed, while the second and the third are still ongoing.

Bridges are a critical component of infrastructure, ensuring access and continuity for all aspects of daily living. Incorporating the lessons from Christchurch into more durable bridge functionality is one step towards a more resilient New Zealand.

Contact: Alessandro Palermo, alessandro.palermo@canterbury.ac.nz

***approach,** part of bridge that carries traffic from the land to the main part of the bridge; **abutment;** structure that supports the ends of a bridge, abutments transmit the load from the bridge to the foundation; **piers,** another form of bridge support.



South column of Moorhouse Overbridge. **Left,** west face; **Middle,** south face; **Right,** north face.

Recovery of Lifelines

The Civil Defence and Emergency Management Act 2002 requires lifeline utilities "to be able to function to the fullest possible extent", even though this may be at a reduced level, during and after an emergency.

Following the Canterbury earthquakes, the "Recovery of Lifelines" project aimed to inform and help meet short-term operational needs by facilitating access to best engineering practices, and to hazards and vulnerability information available from the local and international scientific community. We worked with electricity providers (Orion, Transpower), telecommunications (Chorus), water /wastewater networks (Waimakariri District Council), and transport utilities (New Zealand Transport Agency, Christchurch City Council road and bridges staff). We collected data on the physical damage to the network components; the system performances and operational responses during the emergency management and recovery phase. Weak buried pipes and cables played a major role in the seismic response of water, wastewater, telecommunication and power systems. Here we describe the impact on some of these systems.

Damaged power pole.

Electricity

Both the 4 September 2010 and 22 February 2011 earthquakes challenged the resilience of the high-voltage transmission grid in the Canterbury and northern region of the South Island. The large ground deformation induced by the earthquake largely affected the low and medium voltage distribution networks causing multiple faults in 66 kV and 11 kV underground cables, and induced major power outages and loss of functionality to the power distribution system. Of the 66 kV underground cable network, 50% were damaged, and those supplying Dallington & Brighton zone substations were damaged beyond repair and had to be abandoned. Of the 11 kV underground network, 14% of the cables were damaged. Despite the severe physical impact of the earthquake on the distribution and sub-transmission network, power was restored to 50% of occupied households on the day of the event, 75% after 2 days, 90% within 10 days and 98% after 2 weeks.

Water & Waste Networks

Christchurch water and waste networks suffered extensive damage following the February 22nd earthquake. Approximately 50% of the city was without water in the first days following the earthquake; more than a third of households were without water for over a week. A month on from February 22nd, water services returned to over 95% of occupied units (outside of the cordoned Christchurch CBD), however a "boil order" was in-place for over six weeks due to potential contamination caused by severe damage to the wastewater system. Chlorination, which was not used pre-earthquake, remained a requirement until 7 December 2011. Water conservation orders were in place until 2 April 2012 as a result of damages to key water reservoirs and the loss of numerous groundwater pumping wells and breaks in underground distribution pipes, all related to geotechnical problems.

Road Networks

Roads were extensively damaged by liquefaction following the February earthquake. The ponded water was from both expulsion, associated with liquefaction, but also from ruptures of high-pressure water mains. The latter caused deep blow-out craters in road surfaces, not visible through the ponded waters, and consequently some vehicles were driven into them. Most of the state highways remained open. The local roads in the eastern suburbs of the city were the most affected. Eighty-three sections of 57 roads were closed. Five of the six bridges crossing the lower Avon River were closed and many bridges required weight restrictions. Substantial temporary

traffic management had to be put in place. The temporary traffic management of the highway and local road network faced severe challenges to adapt to the damaged network and to the reorganisation of the city, as businesses and residents relocated following the closure, demolition and rebuild of the CBD.

Knowledge Transfer

In discussion with end-users, the following areas were identified as priorities. The table below is a partial list.

Our advice and support included the following: 1) a review of standards, guidelines and best-practices for repair/retrofitting and designing earthquake-resistant lifelines system; 2) best-practices for documenting and analysing the performance and damage of lifelines during the Canterbury earthquake sequence; 3) procedures for assessing the residual/future functionality of affected components; 4) best-practices for estimating the expected performance and risk of alternative repair and/or reconstruction strategies in case of further earthquakes; 5) procedures for reporting/documenting the lessons learned from the earthquakes before the knowledge is lost. Our advice reached end users and the wider community via consultation, workshops, and publications.

Contact:
Sonia Giovinazzi, Sonia.Giovinazzi@canterbury.ac.nz

Broken underground pipes.

Power
Analysis of seismic performance of underground cables and identification of the multiple causes of the damage to the underground network
Assessment of the residual/future functionality of affected power underground cables
Seismic Scenario Analysis for assessing and comparing alternative solutions to build permanent capacity in the eastern suburbs of Christchurch
Assessing earthquake risk to underground lines versus wind and snow-storm risk to overhead lines
Assessing cable-bridge interactions and coordinating repair activities with road and bridge
Telecommunication
Assessing residual/future functionality of stretched copper cabling
Existing standards/procedures to straighten the cellular network towers out of plumb due to liquefaction
Seismic Scenario Analysis for assessing and comparing alternatives solutions to replace damaged exchanges
Highway and Urban Road
Assessing and accounting, within repair/rebuilding designing procedures, for the increased risk of flooding induced by the ground deformation and subsidence due to repeated earthquakes
Assessing and mitigating the rock-fall risk on roads induced by the earthquakes and following aftershocks
Water and wastewater
Documenting and analysing the seismic performance of different buried pipes typologies (material/age) to identify the less vulnerable solutions for repairing and rebuilding
Identifying techniques and tools to support the prioritisation of repairing/reconstruction activities and to justify costs of earthquake resistant solutions
Defining a method and a tool for automatically mapping and assessing earthquake-induced damage to sewage network, starting from CCTV (closed circuit television) footage

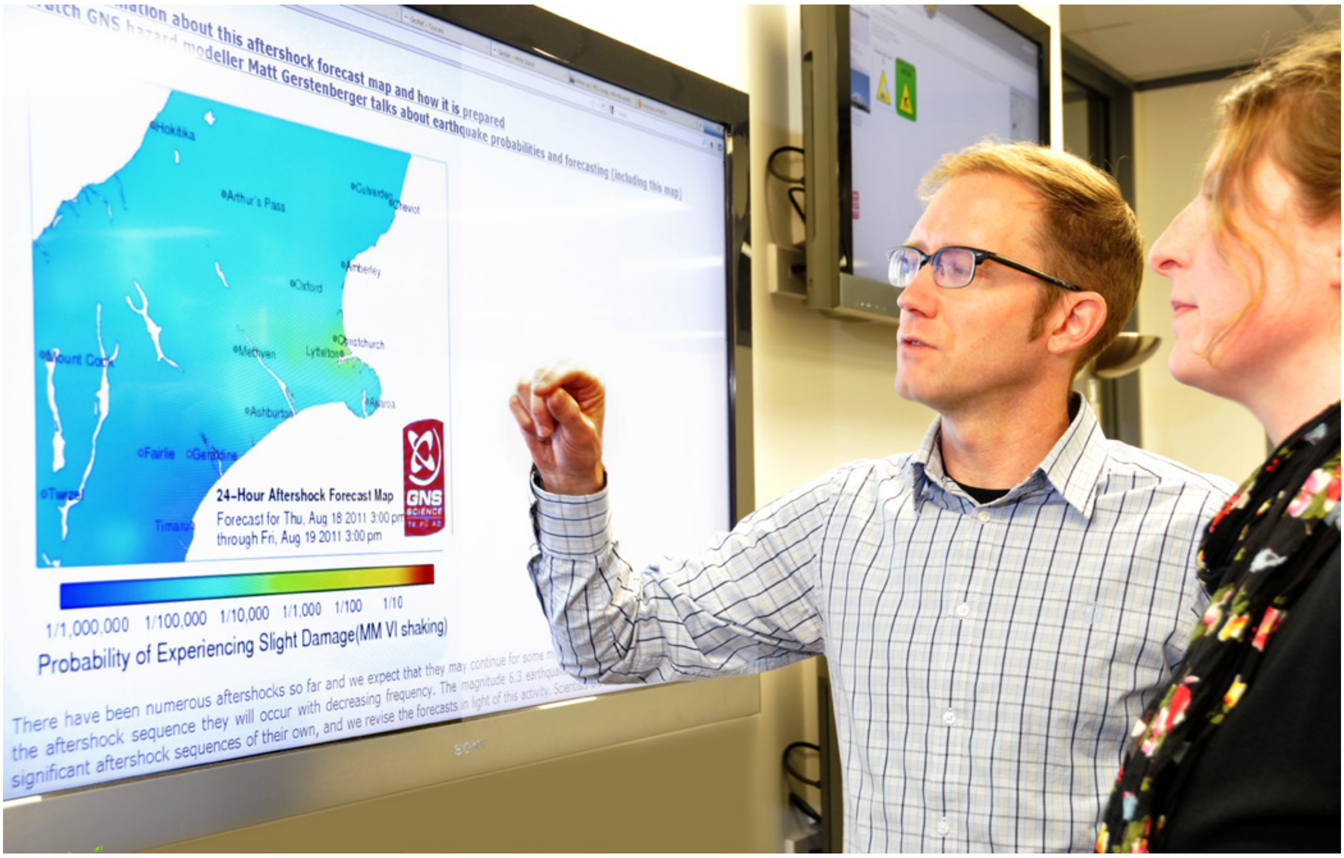
The National Seismic Hazard Model: Revising Canterbury's seismic design levels

The New Zealand **National Seismic Hazard Model (NSHM)** provides estimates of the likelihood of strong earthquake shaking throughout New Zealand. The model has been revised over the years to incorporate advances in seismology and hazards calculations. Updates to the model are important as it underpins our knowledge of regional earthquake hazards, and informs building standards and the insurance sector.

Seismicity in the Canterbury region continues to be very high relative to activity prior to the September 2010 earthquake. The expectation that this will continue has required the development of earthquake hazard estimates that are based on time-varying earthquake rates (e.g., from aftershocks and longer-term earthquake clustering). Over the past year, we have worked on updates for the Canterbury region. This was followed by a 3-day workshop in November 2011, bringing together an international expert panel to update, re-evaluate, and finalise the results. The panel comprised experts from GNS, URS/Risk Frontiers (USA/Australia), universities of Canterbury, Victoria at Wellington, Ulster (UK), Columbia (USA), and Princeton (USA).

The preliminary update consists of an ensemble earthquake hazard model to estimate the ground acceleration value with a 10% probability of being exceeded in the next 50 years. The ensemble model combines several earthquake source models that are based on different concepts and cover a wide range of time, space and magnitude scales. Components include active faults, regional catalogue of historic earthquakes, aftershock statistics and the likelihood of further clustered or triggered large earthquakes.

Contact:
Matt Gerstenberger, M.Gerstenberger@gns.cri.nz

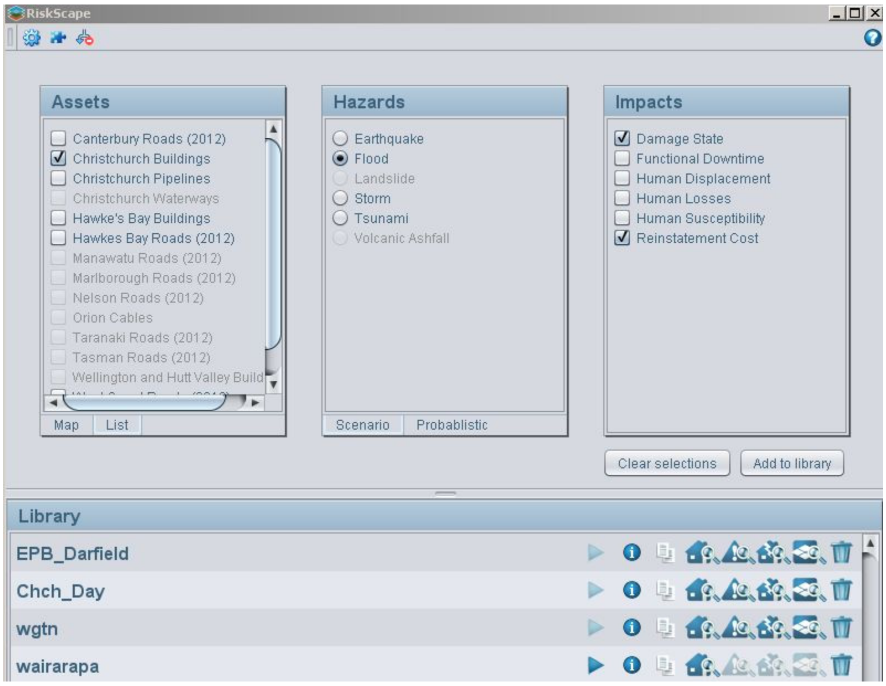


Matt Gerstenberger and Caroline Holden discuss the 24-Hour Aftershock Forecast Map.

Modelling Cumulative Earthquake Losses in Christchurch and Wellington

Forecast levels of future seismicity in Canterbury (see 'Canterbury seismic design levels...') have prompted risk modellers to think beyond modelling isolated events towards the impact of multiple, linked events. Following the Canterbury earthquake sequence, building repair costs for the seven most-damaging events were estimated. Residual values were determined for each asset (i.e., building) following an earthquake and used as input for subsequent events. For a single earthquake, building repair costs ranged from $NZ 1 to 5 billion; all relatively modest. After including the aftershock sequence, damages accumulated to nearly $20 billion. This total reflects 30% of the total initial building stock value of $64 billion. As a comparison, we applied the same methods to the Wellington Region, where seismic hazard is much higher than for Christchurch. For a proposed Wellington fault rupture, damages from the initial earthquake would be expected around $15 billion, doubling to just under $30 billion when taking into account subsequent aftershocks. The proximity of the main shock to the built environment is key to the outcomes and course of the hazard sequence.

While development of the multiple event procedure does a good job with projected losses from the Canterbury sequence, it needs to expand beyond buildings to consider infrastructural damage and reinstatement. The model needs to be expanded to include the peculiar effects of insurance and its influence on the very high level of demolition seen in Christchurch, where buildings that technically could be repaired have been declared a total economic loss and for that reason demolished. Impacts on people have yet to be fully embedded in the modelling, although we have estimated the number of people requiring emergency accommodation after a

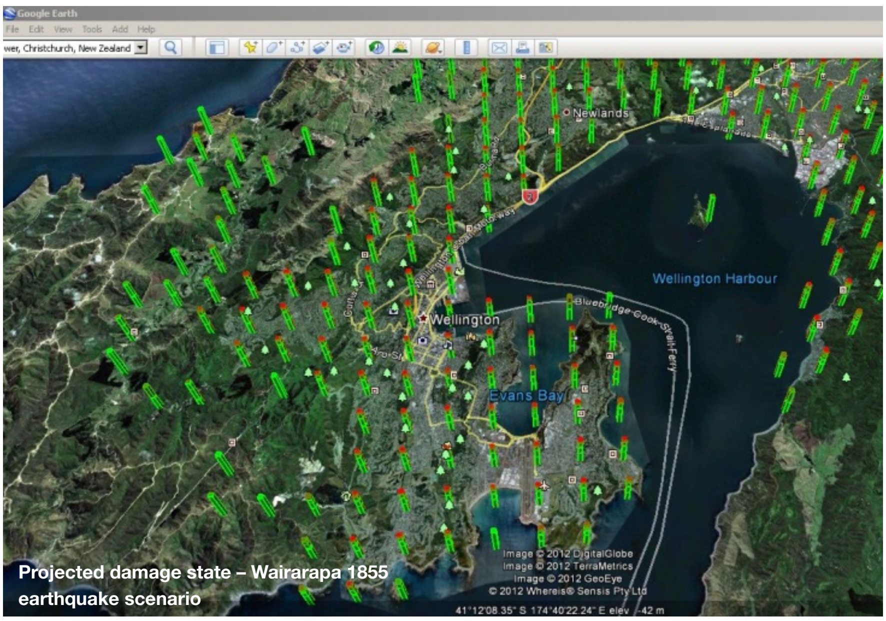


RiskScape user selection control panel

Mw 7.5 Wellington Fault earthquake (manuscript in preparation).

The ability to use a risk-based approach for evaluations of earthquake prone building (EPB) policy (See David Kelly editorial) has become even more important as many EPB policy statements shorten the permitted time for remedial action to be undertaken. The RiskScape engine has, on behalf of the Department of Building and Housing, been applied to indicate the consequences of possible changes to the national EPB regulations. Riskscape is a joint venture between GNS Science and NIWA.

Contact: Andrew King, A.King@gns.cri.nz



Projected damage state – Wairarapa 1855 earthquake scenario

Natural Hazards 2011

A key lesson arising from the trauma, response, and recovery experience in Canterbury has been the need to consider natural hazards in the risk context. The Canterbury experience is driven by earthquake hazard, but the lessons are universal. In the following article, David Kelly asks what acceptable risk means with respect to building standards. The questions that are being asked form a template across other perils –and raise the issue of what constitutes tolerable impacts of natural hazard events in an economic context. I hope this article will stimulate discussion and debate so that research on New Zealand's hazard and risk profile may inform improved policy for cost-effective hazard mitigation on a national basis.

Kelvin Berryman, NHRP Manager,
August 2012.

Public expectations of building safety

David Kelly, *Deputy Chief Executive of the Ministry of Business, Innovation and Employment's Building and Housing Group*

The tragic loss of life caused by the Canterbury earthquakes has raised awareness and concern about building safety standards. This has prompted strong reactions, possibly even over-reactions in some cases. Tenants have walked away from older buildings, and unions reportedly want to make employers provide quake-safe workplaces.

The term "earthquake-prone" is a technical term that is used to describe buildings that are less than one-third of the earthquake strength required for new buildings. Being "earthquake-prone" doesn't necessarily mean that the building should not be occupied, but it does mean that the owner should get immediate expert engineering advice and work out a plan to fix the problems.

Building owners are responsible for ensuring that their buildings are fit for purpose, but this does not necessarily match what the public would regard as safe. Why? Because while the New Zealand Building Code sets minimum standards for earthquake design, every once and a while the level and intensity of ground shaking, such as that experienced in the 22 February 2011 earthquake, will exceed the Code's minimum standards. New Zealand has a sizeable stock of old buildings that do not meet the new building standard (NBS) for earthquake design, and there's no doubt that repair or demolition is long overdue for some of them.

Before the Canterbury earthquakes, there may have been some complacency about getting on with this work. While large, destructive earthquakes can devastate communities, they are fortunately very rare. The likelihood of harm from earthquakes remains low relative to many other risks we face in our everyday lives - and outside of Canterbury, the risk has not changed since the earthquakes.

Since records began in 1843, 483 people are recorded as having died in New Zealand as a result of earthquakes. The vast majority of our earthquake fatalities - 447 people - resulted from the two terrible earthquakes in Christchurch in 2011 and Napier in 1931.

By comparison, more than twice as many people (1125) died on our roads in the three years from 2008-10. The risk for any individual of dying in a road accident is around one in 10,000 each year, compared with a one in a million risk of dying from an earthquake while in a new building.

Concerns about earthquake risk are high because the consequences of a major earthquake are so devastating. We must take sensible steps to protect our buildings from life-threatening collapse in earthquakes. But we must also keep the investment required in proportion to the risk.

How earthquake resistant should our buildings be? The February 22 earthquake was approximately a one in 2500-year event (GNS Science). If we combine the low likelihood of such an event with the massive cost and resources to strengthen our entire building stock it quickly becomes unrealistic. The odds are none of us will ever experience such a devastating earthquake again.

Therefore, we need to strike a reasonable balance between protecting people from harm in earthquakes and the economic cost of strengthening buildings.

Current seismic resistance standards for new building design are based on a one in 500-year earthquake, taking account of the building's location in New Zealand. This is why, for example, Wellington buildings are required to be stronger than buildings in Auckland, as Wellington has higher seismic hazard. The standard also requires high-importance buildings like hospitals to be designed to resist stronger earthquake shaking that will occur with lower likelihood.

It is estimated that less than 5 per cent of New Zealand's commercial and multi-storey residential buildings are "earthquake-prone", and for these the Councils can require the owners of these buildings to reduce or remove the dangers, including by strengthening or demolition. There are other buildings across New Zealand that, while they may not be deemed to be "earthquake-prone", present significant safety risks. Some of these can be improved with relatively low-cost fixes like removing parapets or chimneys, or tying back facades to buildings. But in some cases strengthening work may be uneconomic. Building owners need to decide for themselves how to manage their buildings, aided by expert engineering advice on the individual circumstances and risks in each case.

Importantly we need to recognise that there is no such thing

as a fully earthquake-resistant building - all buildings are prone to damage or collapse if the earthquake is strong enough, as Christchurch has shown us.

The lessons of the Canterbury earthquakes are now being considered by the Canterbury Earthquakes Royal Commission. At the same time, Building and Housing is conducting its own review of policy and practice in this area. Building and Housing's review will help the Government respond quickly to the Royal Commission's findings. It already seems clear that, given the massive scale of the Christchurch quake, most the city's buildings actually performed relatively well in terms of protecting life.

A total of 133 of the 185 people who tragically lost their lives were in one of two large buildings, CTV and PGC, which collapsed due to the intense ground shaking and critical structural weaknesses. Most of the other fatalities resulted from falling debris, striking people who were outside buildings. While the property damage was great, the occupants of most Christchurch buildings - even the older structures - got out of them alive.

For the future, it is clear that there needs to be much better public understanding about what constitutes a safe building, and on how individual buildings will perform in earthquakes. We do not have good information nationally about the seismic performance of our buildings and where they are located. Wellington is one of the few local authorities with good data on the seismic performance of buildings in its region, and it has published a list of "earthquake-prone" buildings on its website.

Work is already under way on how to collect better information about the seismic performance of our buildings and to make this information more readily available to the public.

In the meantime, Building and Housing has prepared guidance for engineers, specifically aimed at the Canterbury rebuild, and it will soon release general guidance for building owners on earthquake risk. This will give them useful practical advice to help them make decisions. (*This is an edited version of an article that originally appeared in the Dominion Post.*)

Contact: Susan Owens, Susan.Owens@dbh.govt.nz

Earthquake Communications Manager, Building and Housing Group, Ministry of Business, Innovation and Employment

Societal theme: How people interpret risk

The Platform is aligned with the National CDEM Strategy and with other strategies of government agencies responsible for reduction, readiness, response and recovery from natural hazard events and processes. Our research can directly assist the CDEM sector in developing appropriately targeted plans to improve procedures, and crisis management methodologies.

The societal theme of the Natural Hazards Research Platform examines the risk to which New Zealand is exposed and how well society is prepared for and responds to natural hazard events. Within this theme, policy and planning research helps build knowledge around "good practices" and increases the uptake of hazard knowledge by policy makers, land use planners, communities and iwi through the adoption of appropriate land use practices and public policy. Community resilience projects explore the relationship between risk perception, risk acceptance, evaluation of personal competencies, capabilities, and preparedness at a community, organisational and individual level. A further set of projects looks at effective warnings systems and emergency management arrangements.

A key issue emerging from current events is understanding how people interpret risks and respond based on their interpretations. This knowledge is vital to any strategy for defining acceptable risk. Acceptable risk in the context of building safety always involves interactions between natural (physical and engineering) and human (behavioural) factors. Decision-making under conditions of uncertainty is inadequately described by traditional models of 'rational choice'. Instead, attention needs to be paid to how people's interpretations of risks are shaped by their own experience, personal feelings and values, cultural beliefs and interpersonal and societal dynamics. Furthermore, recent research has shown that lack of access to and/or framing of risk information have contributed to much of the misunderstanding around issues such as seismic risk and rock fall hazards. Following the 2010-2011 Canterbury earthquake sequence, seismic performance codes are being revised. In order to determine levels of acceptable risk an integrated understanding of engineering performance, risk language and public perception of risk is required. This will need to bring together the knowledge of engineers, land-use planners and the behavioural sciences, closely linked with affected individual and communities and various government departments and agencies.

Contact: David Johnston, David.Johnston@gns.cri.nz

Development of Design Guide for improved performance of industrial pallet racking systems

The September 2010 and February 2011 earthquakes tested all racking (storage) systems in the Christchurch area. These racks generally fall under two categories: (i) racks as high as 5 m used in public settings (i.e., super markets, handyman stores) where generally lighter contents are stored at lower level and heavier contents at the top; and (ii) racks as high as 10 m used in restricted-access industrial settings where heavy pallets are stored at all levels.

From the damage survey, it was observed that the racks used in places with public access performed relatively well. However, many racks used in industrial settings suffered failure leading to damaged contents and huge economic loss. The failure of such systems could be attributed to various reasons including inadequate design, inappropriate operational conditions, improper installation and lack of maintenance.

Industrial racking manufacturers and design engineers raised their concerns: A Guide providing design recommendations was available for racks used in public areas, but there was no equivalent Guide for racks in industrial settings; this was further complicated in that the available guidance was not enforced by a regulatory authority.

A seismic focus group involving design engineers, racking manufacturers and suppliers from New Zealand and overseas, City Council representatives, and representatives from Department of Building and Housing was formed to address various aspects, including development of design recommendations, enforcement of policies within the pallet racking industry and to steer the development of a revised Guide in alignment with design principles of NZS 1170.5:2004 loading standards. Our team comprised of researchers from GNS Science, BRANZ, the University of Canterbury, University of Auckland and Compusoft Engineering provided technical input towards the revised recommendations for the design of storage racking systems in areas with and without public access.

Our revised guide emphasises the need to carry out regular, detailed inspection of racking systems. A framework to practise the safety check guidelines should be in place within industrial storage facilities. Failure of racking systems incurs heavy economic loss due to damaged contents and business interruption. More importantly, life-safety hazard is high for the employees due to the collapse of racks and falling pallets. Managers/Owners should be aware or their responsibilities to employees under the Health and Safety in Employment Act 1992.

Contact: S.R. Uma, S.Uma@gns.cri.nz

Performance of masonry buildings in the 22 February 2011 Christchurch earthquake

As a team composed of local and international researchers, we documented the observed earthquake damage to masonry buildings, focusing on failure patterns and collapse mechanisms. Observations and data were collected on approximately 1200 buildings of unreinforced masonry (clay brick/stone) and reinforced concrete masonry, as well as 1100 residential dwellings with external masonry veneer cladding. In addition, we assessed retrofit techniques that were implemented within Christchurch URM buildings prior to the February 22nd earthquake. Here we discuss some of our findings.

Unreinforced Masonry (URM)

Whilst in September 2010 most earthquake shaking damage was limited to URM buildings, in February 2011 all types of buildings sustained damage. In addition, two large aftershocks occurred on 13th June 2011, further damaging already weakened structures. An example of observed progressive building damage is shown in Figure 1.

The Feb 22nd earthquake subjected URM buildings to greater widespread damage. The construction of clay brick walls may be solid or contain a cavity (an air gap between in inner and outer layer of bricks), features that are not easily determined by external inspection. However, with the extensive damage caused by the February earthquake, we were able to establish that 50% of all URM buildings surveyed had cavity construction, which was much higher than we expected. Cavity walls are more vulnerable because they act as a single layer of bricks. The metal ties that connect the two layers can corrode over time and this was observed in some of the older buildings.

Retrofit and temporary shoring techniques improved building response and prevented collapse. Common retrofits observed in Christchurch URM buildings were steel moment frames, which increased the lateral capacity of a building; steel strong-backs, which helped prevent out-of-plane failure of URM walls; and application of shotcrete, which increased wall strength.

External masonry veneer

We inspected just under 1100 residential dwellings with external masonry veneer cladding throughout the wider Christchurch area: 24% were constructed using the older nail-on veneer tie system (before 1996); 76% were constructed using screw fixed ties to comply with the 1996 standards revision, and 30% of all inspected houses were of two storey construction. Of the inspected dwellings, 27% had some evidence of liquefaction, ground settlement or lateral spreading. In areas where some form of liquefaction or lateral spreading had occurred, the cause of damage for 40% of the dwellings was attributed to ground movement only and 28% of dwellings had damage that was attributed to shaking damage only.

Whilst it may be too late to save many of Christchurch's historic clay brick and stone URM buildings, lessons learnt can be applied to masonry buildings throughout the rest of New Zealand and around the world.

Contact: Jason Ingham, J.Ingham@auckland.ac.nz

Fig 2. Internal view of steel moment frame retrofit

Figure 1. Progressive damage to a URM building (**left,** minor damage after 4 Sept 2010; **middle,** 22 Feb 2011; **right,** collapse of the wall after 13 June 2011.

Active Link Fractures in Eccentrically Braced Steel Frames

The construction of modern steel buildings in Christchurch has become more common in the last twenty years and especially since 2000. Their performance during the Christchurch earthquakes has provided the first opportunity to examine the effectiveness of the current seismic design provisions. Our international research team studies the earthquake performance of existing and new forms of steel construction and here we discuss one type - that of eccentrically braced frames (EBFs).

Eccentrically braced frames are steel-framed building systems designed to resist earthquake in which the braces do not meet the beam at the same location (Figure 1). The region of beam between the braces is called the Active Link. During a severe earthquake, the system is designed for the active link to deform in a controlled manner, limiting the spread of damage across the building (Figure 2). This is analogous to the crumple zones in cars which are designed to take the damage from an impact and protect the main part of the car and its occupants. Under normal conditions, the EBF is a very rigid system that prevents excessive building movement, such as in windy conditions. During a severe earthquake, the EBF undergoes controlled damage in the active links without endangering the stability of the building or damage in other components of the system. This combination of beneficial properties means EBFs are now the most commonly used seismic resisting system in New Zealand's multi-storey buildings, incorporated into the design for a majority of steel-framed buildings and also into a significant number of reinforced concrete-framed buildings.

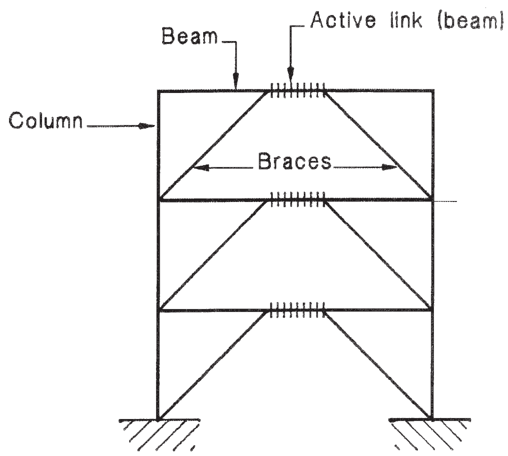


Fig 1. V-braced EBF. Courtesy of NZS 3404

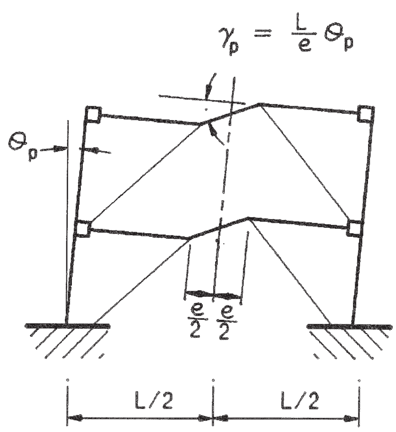


Fig. 2. Following a severe earthquake, the active link deforms in a controlled manner.

Steel structures generally performed very well following the 2010 and 2011 earthquakes, even following the February 2011 earthquake when ground accelerations exceeded their design basis by a factor of more than 1.8. The notable exceptions to this good performance are two link fractures discovered: one in a steel framed building with composite floors comprising concrete slab on steel deck on steel beams; the other in a precast concrete gravity frame system comprising precast floor with topping on precast beams and columns.

Although steel structures performed well following the Christchurch earthquake sequence, it is instructive to note that even robust systems such as EBFs can be susceptible to unexpected modes of failure when forces are large. It is expected that on-going investigations into practices and material properties will shed light on the failures identified and develop solutions to prevent their occurrence in future structures.

Contact: Charles Clifton, C.Clifton@auckland.ac.nz

Fig. 3. Parking garage with fractured link at lower level EBF due to poor detailing. Courtesy of Greg MacRae, UOC.

Volcanic ash and aviation: Lessons from Chile

In June 2011 a sprawling ash plume from the Chilean volcano Puyehue-Cordón Caulle, caused disruptions to flights across the southern hemisphere. This followed soon after the 2010 eruption of the Eyjafjallajökull volcano in Iceland, which caused mayhem across the skies of Europe and triggered an article here last year describing the very real risk from ash fall in New Zealand.

The International Volcanic Ash Impacts Working Group (IVAI) is a collaboration co-led by University of Canterbury and GNS Science. We work closely with colleagues at US Geological Survey, British Geological Survey and various universities to continually update and coordinate ash impact research. GNS Science is also responsible for volcanic advice to MetService's Volcanic Ash Advisory Centre in Wellington.

The Puyehue-Cordón Caulle volcano is a complex of eruption vents on the eastern edge of the Lake District of Chile, and is close to the border of Argentina. San Carlos de Bariloche, a ski resort town in Argentina, was the largest town to receive significant (centimetres) ash fall. Chilean volcanoes often have significant impact in Argentina because of the prevailing westerly wind directions, similar to those in New Zealand. In the past, Puyehue-Cordón Caulle has erupted a range of magma from rhyolite (very explosive, similar to Taupo) to basalt (producing small scoria cones and lava, like the Auckland Volcanic Field). The 2011 eruptions were at the explosive rhyolite-dacite end. Rhyolite and dacite are explosive because they tend to be cooler and more sticky, so gas that wants to escape from the magma at the earth's surface tends to explode out breaking the liquid rock into tiny fragments that cool to ash.

Following the eruption at Puyehue-Cordón Caulle, we evaluated the situation in Chile and Argentina to better frame what might occur in New Zealand. As part of the IVAI, we prepared resources to share with international groups to understand and prepare for ash fall. We also developed materials for critical infrastructure preparedness in New Zealand, and have advised other sectors, such as health services, regarding ash fall.

Ash and aircraft

The Chilean eruption sent ash 15 km into the atmosphere. These are the heights of jet-stream winds and preferred altitude for aircraft. The main risk to New Zealand was of ash being taken up by aircraft engines, and to a lesser extent abrasion from ash on the outside of aircraft (the latter being a longer-term cumulative effect). When ash is taken up by jet engines it can cause abrasion, blockage,

Ash cleanup in June 2011 in Villa la Angostura, Argentina (Photo courtesy of Argentinean team member Gustavo Villarosa)

and also melt and deposit on the extremely hot engine parts. It effectively melts back to volcanic glass and stops combustion in the engine. Avoidance is the best strategy, as it is still unclear exactly how much ash causes damage, or over how long a period. Following the Icelandic eruption, there has been ongoing work internationally to improve the ability to detect and forecast ash concentrations and set thresholds for what is safe.

Dense, near source ash plumes are sometimes visible to pilots in clear, daytime skies. However, ash clouds cannot be seen by pilots at night, and more dilute/distal plumes are often not visible, even in daylight. The ash plume that reached New Zealand travelled east from Chile, over Argentina and the Atlantic, south of Australia and onto New Zealand via the westerly winds of the southern hemisphere. By the time the ash reached New Zealand it was high in the atmosphere (See accompanying NIWA article).

Advice to the aviation industry

There are nine Volcanic Ash Advisory Centres that provide broad, regional coverage. The Metservice in Wellington hosts the VAAC for New Zealand and the South Pacific. The Darwin VAAC covers Australia and most of Southeast Asia. Because coverage is broad, airlines receive advanced notice from the VAAC and they can choose to avoid the ash (by flying under it in this case) or cancel flights. Changing flight paths around the ash is difficult because the plume can be very wide.

The ash itself

The ash that reached New Zealand was very fine, like flour, with most of the coarse material released over Chile and Argentina. Fine ash stays suspended by high elevation winds and can travel far. Little or no detectable ash touched ground in New Zealand, which was similar to the situation in southern and eastern Europe from Eyjafjallajökull.

Explosive eruptions can have large bursts of activity after days or weeks of lesser activity, so there was the potential for more waves over time. It was also difficult to estimate how long the volcanic eruption would continue, and reports of plumes into July 2011 caused concern of further flight cancellations in New Zealand. However, watching the activity at the source in Chile allow us to give advanced warning days before any new ash reached New Zealand. (Note: As of April 2012, new small plumes reaching hundreds of metres into the air have been reported from Puyehue-Cordón Caulle.)

Looking to the future….

New Zealand has many volcanoes that can produce volcanic ash, so Chile has provided a timely reminder. Our active volcanoes are monitored by the GeoNet project and we work with the NZ VAAC and CAA during local eruptions to assess the risk from ash clouds.

Our ash impacts research team has an ongoing programme studying eruption impacts in South America – including Ecuador, Guatemala, Chile and Argentina. This work is being carried out in 2012 to evaluate effects of ash on urban infrastructure, agriculture and public health and overall emergency management of the eruption crisis. We expect it will inform New Zealand practices for some time to come.

Contact: Graham Leonard, G.Leonard@gns.cri.nz

Brown ash plume above Puyehue-Cordón Caulle. (NASA image by Jeff Schmaltz, Modis Rapid Response Team, NASA-GSFC.)

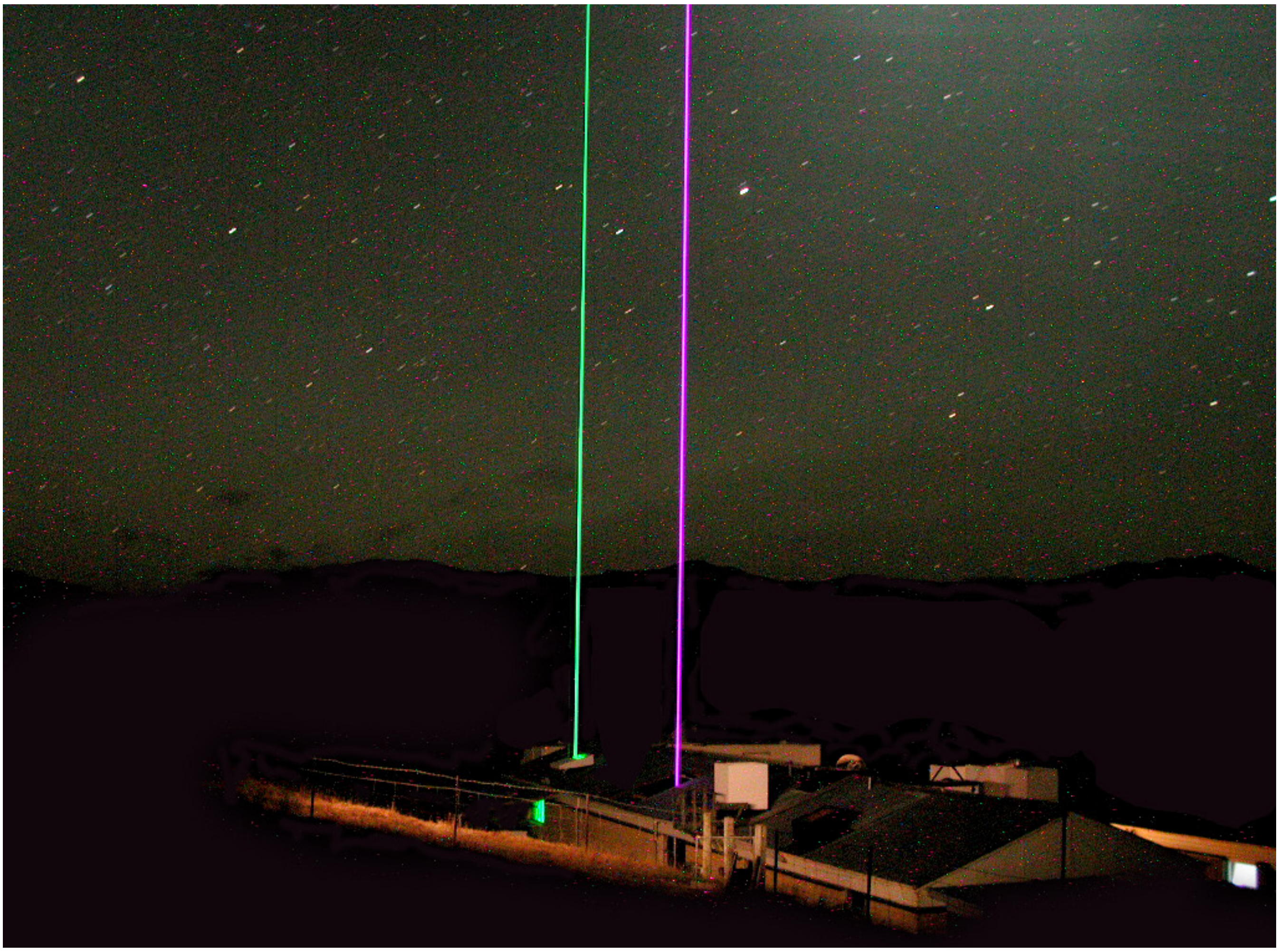
Volcanic ash measured at NIWA's Atmospheric Research Station

In the weeks following the eruption of Puyehue-Cordón Caulle, NIWA scientists measured the height of the volcanic ash clouds as they approached and passed over Lauder, in Central Otago. Lauder's high tech instruments can profile the volcanic ash clouds from bottom to top, and give clues as to their composition.

The scientists used LIDAR, a light detection and ranging instrument, to emit a laser beam vertically upwards towards the clouds, measuring the amount of light scattered off the aerosols (small particles) and clouds. The concentrations of particles at different heights can then be calculated from the amount of laser light reflected back to a telescope, and the height of the 'echo' from the time delay, measured to a billionth of a second.

LIDAR works like RADAR, but instead of using radio waves, it emits beams of pulsed laser-light vertically and is sensitive enough to measure particles up to about 30 kilometres.

Lauder's observations of the volcanic ash suspended in the atmosphere confirmed that international modelling effort to forecast the arrival was accurate for the Central Otago location, data that was critical to aviation authorities. The first cloud plume was over Lauder approximately a week after the eruption, and was 8.5-10 kilometres in altitude. The ash layer was about 2 kilometres thick, and slowly moved up in altitude to reach 10 kilometres by the next day. Further ash plumes arrived in waves and were situated above 8 kilometres.

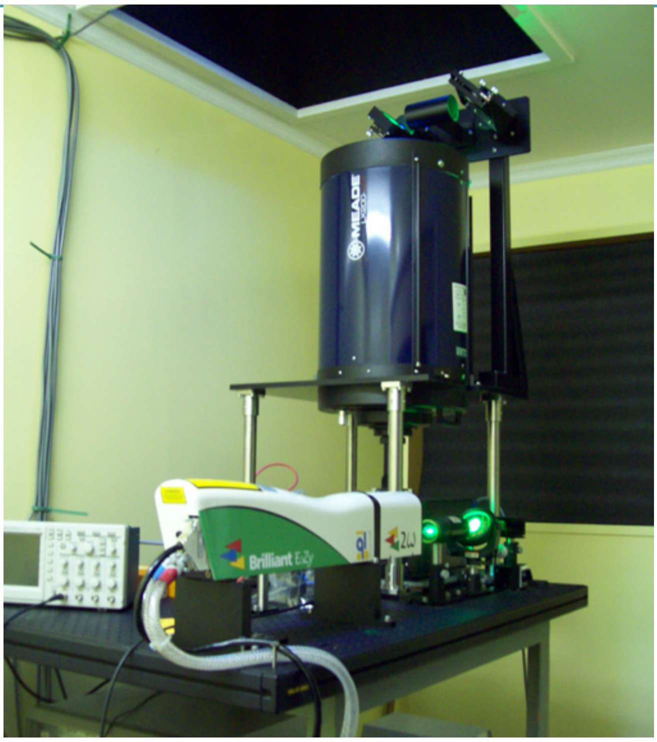


LIDAR was run continuously for a month, measuring profiles of aerosol and cloud every five minutes. The purple beam is from separate LIDAR (laser radar) studies measuring ozone above NIWA's atmospheric research station at Lauder, Central Otago. (studies unrelated to volcanic ash).

Background:

Situated 35 kilometres from Alexandra in the South Island, NIWA's Atmospheric Research Station at Lauder is well known throughout the international research community. The clear skies and isolation makes it perfect for observing atmospheric chemistry and radiation. Lauder specialises in measuring CFCs, Ozone, UV light levels and greenhouse gases and has a wide range of world class instruments. *Article and Image courtesy of NIWA.*

Contact: Ben Liley, Ben.Liley@niwa.co.nz



All aerosol measurements were made with the instrument shown at right, which emits the green beam seen in previous photo.

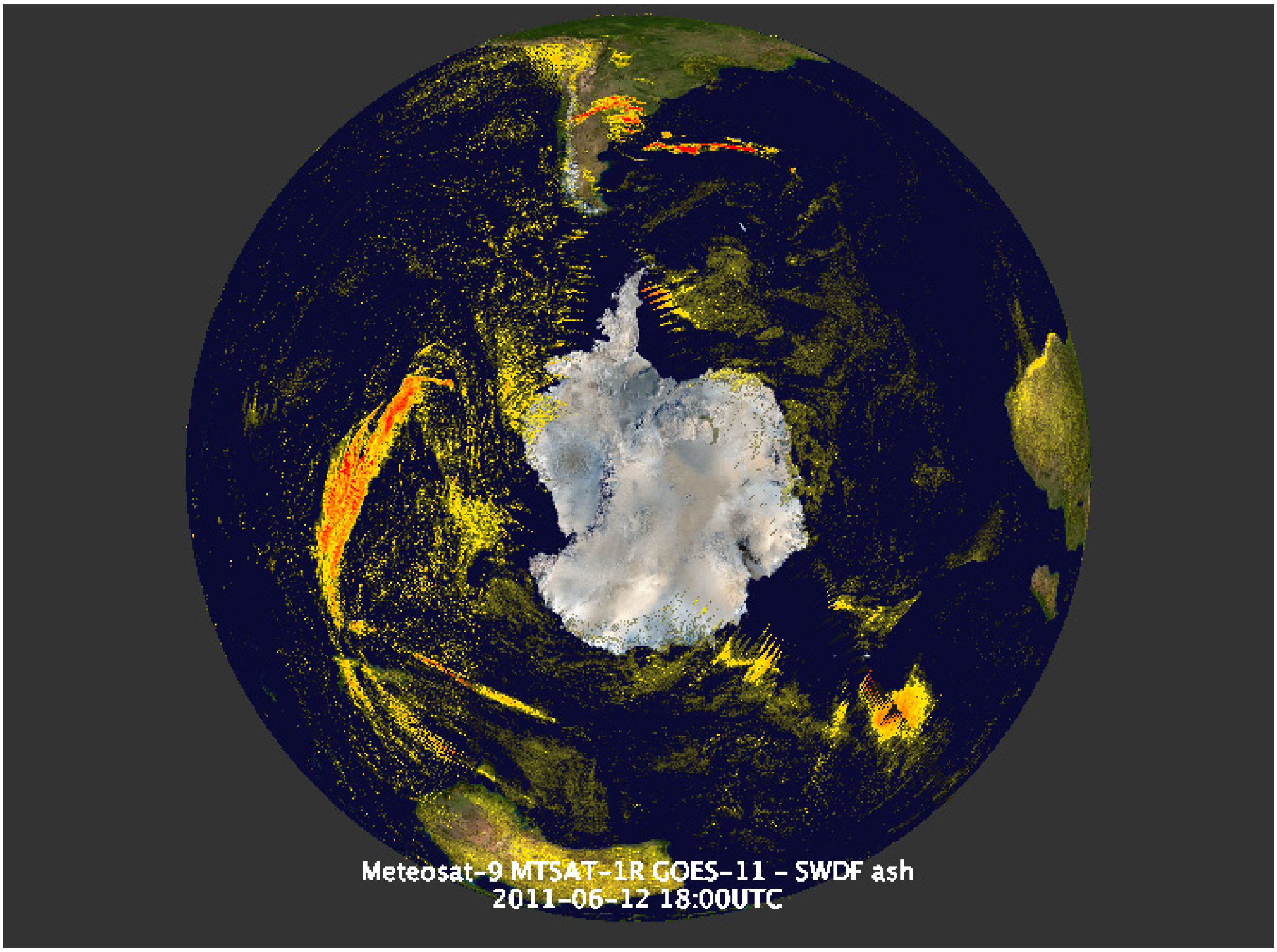


Image courtesy of HansPeter Roesli, data copyright EUMETSAT. Composite satellite image of the South Pole from June 12th, 2011. Antarctica is the white land mass, with NZ located to its lower left in this image. South America appears at the top, Australia at the bottom. Ash south of Australia and over New Zealand is depicted as patches of yellow through orange. Higher concentrations are in red. Newly erupted ash is visible over Chile. The large green-yellow patches over Australia are likely local non-volcanic dust.

Social research to support policy and operational activities

The Canterbury earthquakes have provided extreme challenges for government departments in both policy and operational activities. Research has shown that recovery depends not just on people's abilities to cope with the physical impacts but how individuals, communities and organisations support the complex and protracted processes of community recovery. Agencies and departments such as Canterbury Recovery Authority (CERA), Ministry of Civil Defence & Emergency Management (CDEM), Department of Building and Housing, Tertiary Education Commission, Ministry of Education, Ministry of Economic Development, Statistics NZ, and Ministry of Health have partnered on projects covering topics as diverse as risk communication, roles of public education, shifts in tertiary populations, psychosocial impacts, internal migration, and business impacts and recovery.

Following the earthquakes, Platform researchers formed a Psychosocial Recovery Advisory Group to help support organisations involved in the recovery process. The advisory group reviewed and summarised evidence-based research findings for a range of organisations and provided a definition of psychosocial recovery. In partnership with the New Zealand Psychological Society, a special issue of the New Zealand Journal of Psychology was released that presented research and a range of professional experiences related to the changing condition of the population of Canterbury in the aftermath of the last earthquakes.

In collaboration with the TEC, the Platform facilitated a research project (largely completed by the end of 2011) concerned with the effects of the earthquake on the tertiary sector in Christchurch. This involved three distinct projects: A comparative analysis of the impacts of the Loma Prieta and Northridge earthquakes on both local (general) population counts and on tertiary enrolments, also the effects of the Kobe earthquake and Hurricane Katrina on general and tertiary student populations in the impacted regions. The aim was to use these earlier, international urban disasters to provide a broad sense of the range of possible impacts, and of the relation between disaster scale and the tertiary enrolment impacts. A second project looked at the lessons learned on the UC and CPIT campuses after the 4th September and 22nd February events, while the third drew these together with a US emergency response model to create a set of emergency response guidelines for New Zealand tertiary education organisations, with the aim of informing policy in this area.

Research and advice on public education has attracted considerable interest. A recent workshop entitled "Building an Evidence Base for Public Education Post the Canterbury Earthquakes" highlighted that public education for emergency management goes beyond the CDEM sector. Harmonisation with other sectors which directly and indirectly contribute to public understanding of risks and their mitigation, such as health and education, is critical to future success, as is ongoing evaluations measuring the influence and effects of public education programmes. Also the differences between public education and crisis communications need to be recognised in the research and practice. Communicating with the public is framed by the context in which the information is being used and shared.

After the 22nd February event, a position for a local social scientist liaison was established. Based on the science desk during the emergency response, this role is now part of the community wellbeing team working with CERA.

Contact: David Johnston, david.johnston@gns.cri.nz

The GNS based social science team. The social science team also includes researchers from University of Canterbury, Opus, and a wider network of collaborators.

The Canterbury Series of Earthquakes: Recovery and Resilience of Industry and Geographic Sectors

The Canterbury series of earthquakes shows how organisations can be vulnerable to hazard events. The earthquakes have also highlighted that recovery is complex and involves collaborative efforts between multiple stakeholders such as the affected organisations, CERA, local councils and the community.

Organisations[1] in the greater Christchurch area have shown remarkable resilience in the aftermath of the earthquakes. Research undertaken by the Resilient Organisations Research Programme[2] found that an organisation's resilience is made up of two key dimensions; *planning* and *adaptive capacity*. Following the earthquakes, organisations in Canterbury have demonstrated exceptional adaptive capabilities. Some of these adaptive capabilities, illustrated in Figure 1, are discussed here.

Figure 1: Organisational adaptive capabilities

Some organisations whose pre-earthquake premises were within the CBD red zone or are marked for demolition have changed the way they do business to suit the post-disaster conditions: some retail organisations have started to conduct their business door-to-door. In this way, not only have they forged closer ties with their pre-earthquake clients; they have also broadened their customer base.

Other organisations have used this time to investigate and implement other ways of doing business as an addition to the way they did business pre-earthquake; such as trading online in addition to customers being able to visit the physical store.

New collaborations have also sprung up between organisations. For example, competitors are now sharing premises, in some cases with no expectation of one organisation having to pay rent to the other. This means that not only can both organisations carry on trading but that they are also benefitting from having a larger combined customer base.

In another case, several organisations that used to be neighbours have formed an informal association that meets regularly to share intelligence and to support each other in these trying times.

Some hospitality organisations started to craft each day's menu around produce that was available after the earthquakes, at a time when their regular supplier was unable to deliver. They report that they regard this as a business opportunity that has brought their innovation skills to the fore; not just in the food they serve but also in the way they run the business. They have noticed that this has led to their getting new customers they might otherwise not have attracted prior to the earthquakes. The organisation reports that they are going to make these changes a permanent part of the way the establishment operates.

A further way some organisations have adapted is by starting to purchase more of their stock from local suppliers. Organisations have recognised that it would be difficult, if not impossible, for them to recover if the organisations around them, or in the region, do not recover at the same pace or at all.

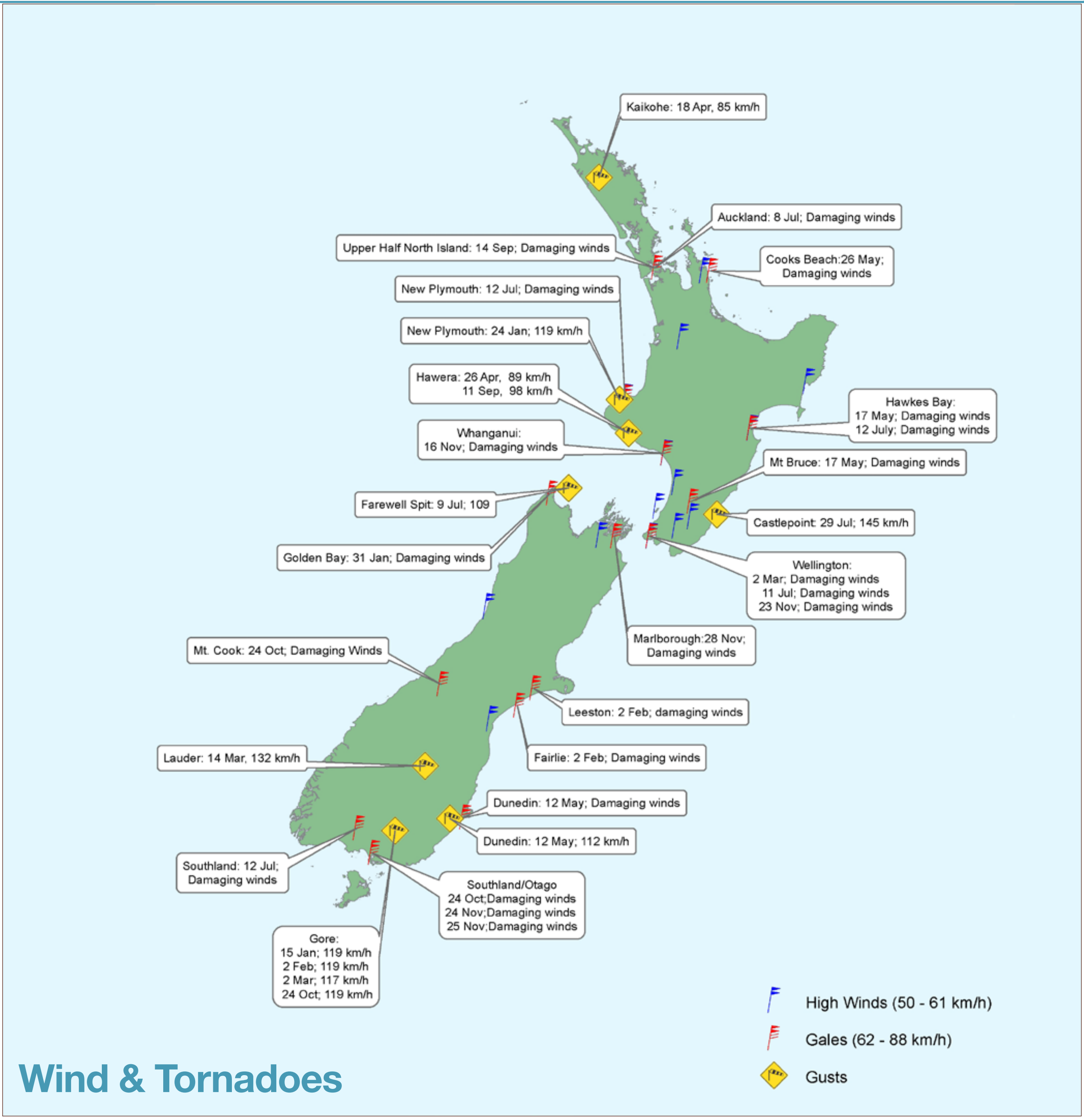
Lastly, adaptation has also been in the form of businesses wanting to build back better. For example, building and business owners from the Central City are looking for reconstruction of a downtown Christchurch that will not only engage the public but that will galvanise the area and make it viable again.

This extended study, into the determinants of recovery for organisations, is currently ongoing. The insights from this study will provide information for this and future organisational recovery work.

Contact: John Vargo, John.Vargo@canterbury.ac.nz

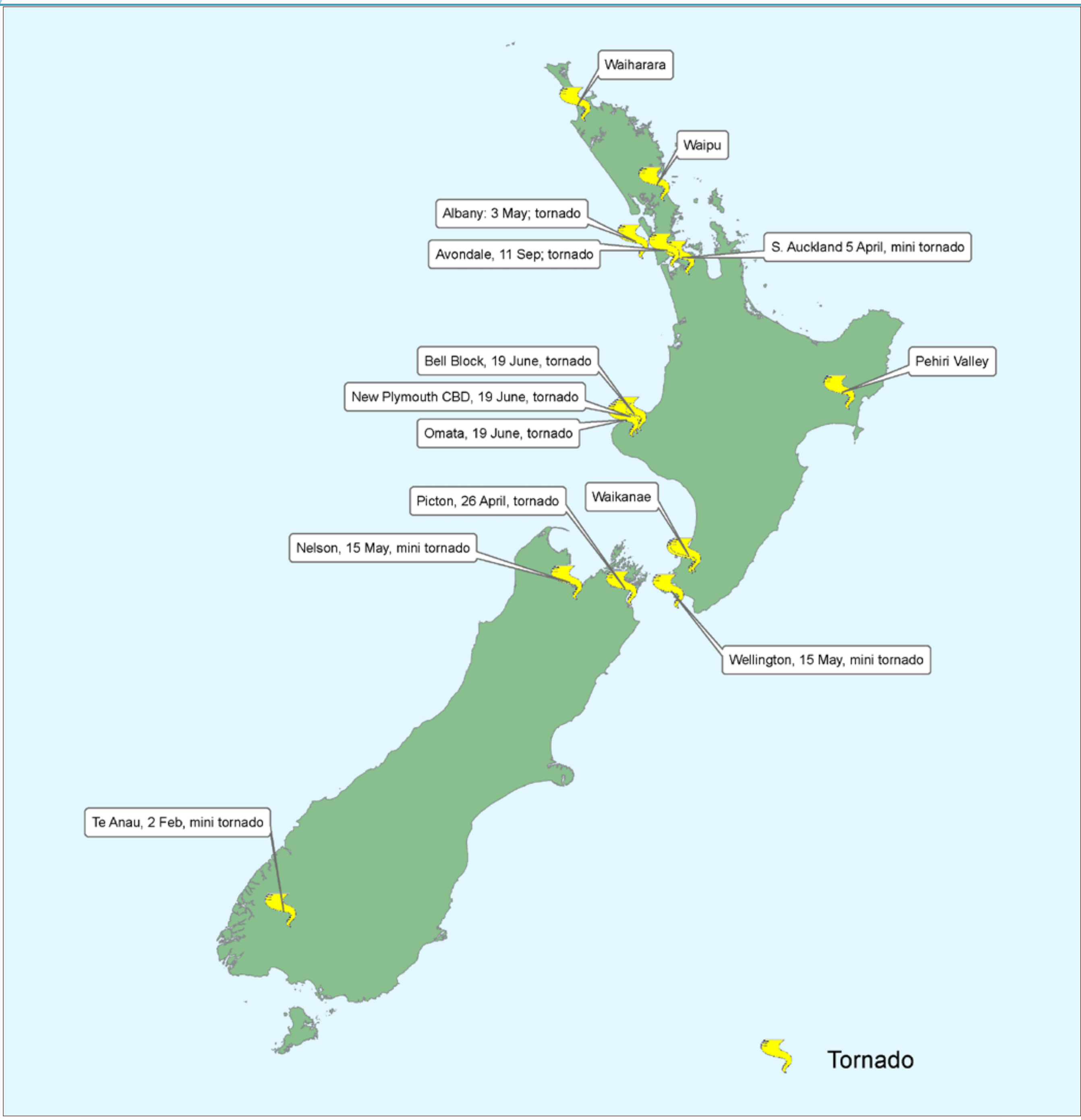
1 The organisations that make up the sample group are from the following industry and geographic sectors: Information and Communication Technology (ICT), Hospitality, Fast Moving Consumer Goods (FMCG), Critical Infrastructure, Trucking, Building Suppliers, Christchurch CBD, Kaiapoi Town Centre and Lyttelton Town Centre

2 The Resilient Organisations Research Programme is made up of researchers based at the University of Canterbury and the University of Auckland.



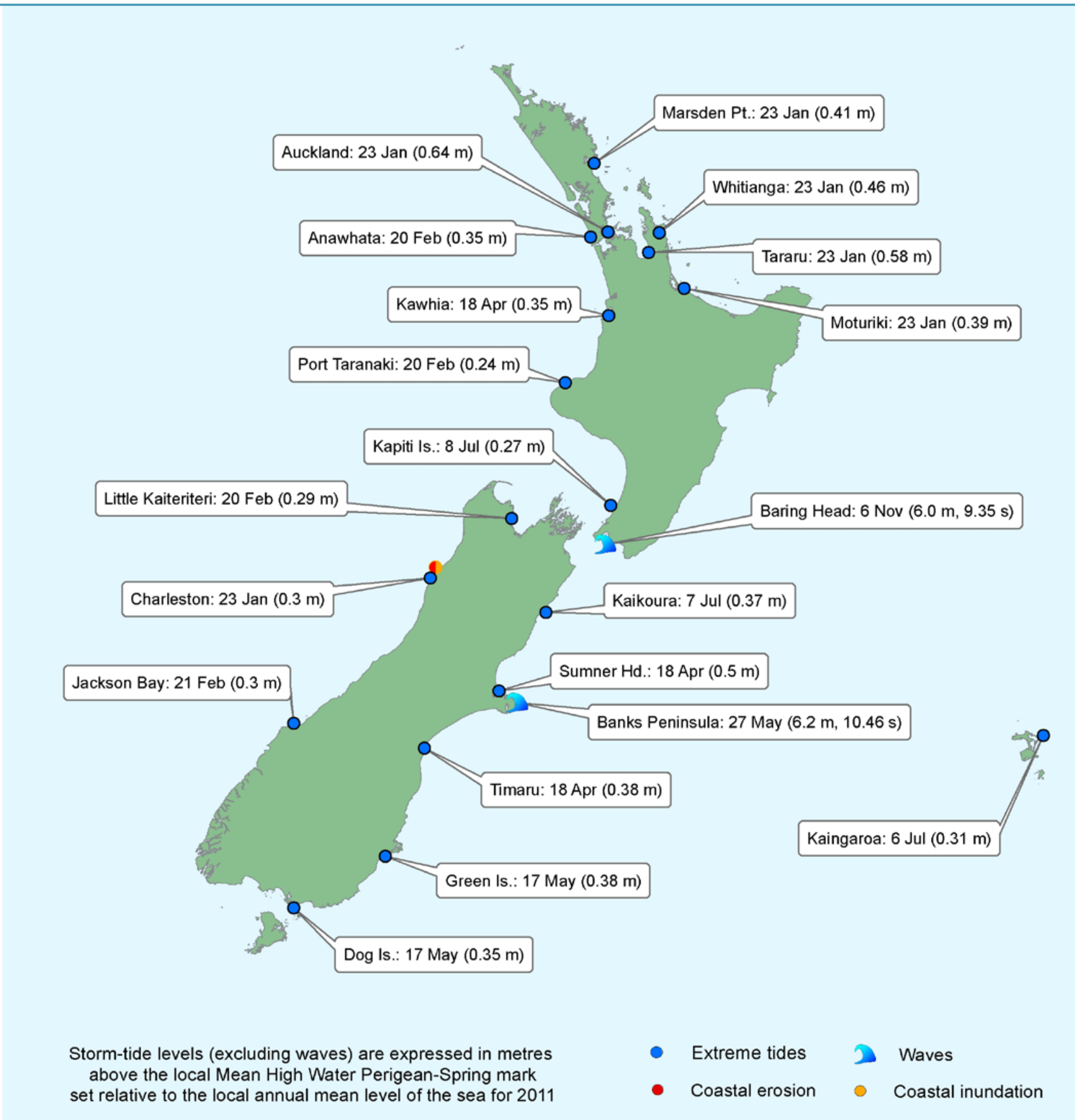
The Albany tornado of 3rd May occurred between 2:45 and 3:30 pm, killed one person and caused millions of dollars of damage, and was the most significant wind hazard that occurred in 2011. The maximum wind speed was estimated to be close to 200 km/h, it lifted cars into the air, and caused considerable damage to property and trees over a 15 km swathe from Albany to Pt. Chevalier. Auckland also experienced small damaging tornadoes on, 5th April (South Auckland[1]) and 11th September (Avondale to Te Atatu South). Other locations to experience damaging tornadoes were Te Anau (2nd February[2]), Picton (26th April), Nelson, Wellington, and Kapiti coast (15th May[2]), New Plymouth CBD (with a track parallel to and within 100 m to that of the tornado of 4 July 2007), Bell Block, and Omata (19th June), Waikanae (9th July, 2 injuries), Waipu (22nd July), Waiharara, (north of Kaitaia, 11th August), and the Pehiri Valley (inland from Gisborne on 14th September). Also, 2011 was a very windy year, particularly the first 5 months which were much windier than normal, and Otago and Southland had their second windiest July since records began in 1941. The highest recorded wind gust was 189 km/h at Cape Turnagain, Wairarapa on 12th July, with the next highest being 184 km/h at Southwest Cape, Stewart Island on 12th May and 24th October. Aside from the tornado events, damaging

1 Described as a mini-tornado.



and disruptive winds due to gales and thunderstorms occurred on at least twenty-five other days, including :

- 31st January, severe wind gusts lifted roofing iron, uprooted trees, demolished farm sheds, and tore apart tunnel houses in Golden Bay and felled power lines between Collingwood and Puramahoi.
- 26th April, disruption throughout much of the country, with severe winds and damage reported from the Waikato to the West Coast.
- 8th – 13th and 22nd July, severe winds within a strong broad westerly flow caused damage and disruption through the entire length of the country. Apart from building damage, ferry, rail, power, and roads were all affected at various locations. Along the west coast of the North Island from Kapiti to Taranaki very large numbers of sea birds were killed.
- 24th October, severe winds brought down power poles and trees, smashed windows and lifted roofing iron in inland Otago and Southland and tourists had to be evacuated from a backpackers' hostel in Mt Cook Village, after it suffered structural damage. The mast of the NIWA climate station at Mt Cook was destroyed after gusts to 180km/h were recorded.



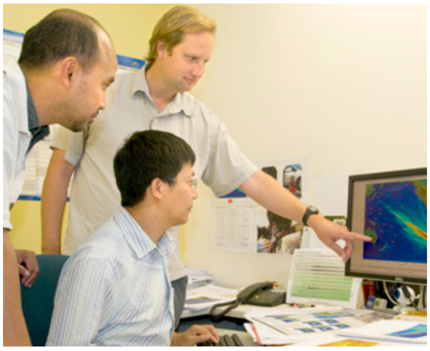
Coastal hazards

The two highest storm-tide levels in 2011 occurred on 23 January, reaching 0.64 m and 0.58 m above the local Mean High Water Perigean-Spring (MHWPS) mark at Auckland (Waitemata Harbour) and Tararu (Firth of Thames). This event resulted from the combined effects of a king tide and a deep-low causing strong northerly winds to 'pile' water onto the NE coast of the North Island. Low-lying areas of Auckland were flooded e.g., Tamaki Drive, Herald Island, Maraetai and the north-western Motorway. It was higher than the previous record level in 1936, although very similar when subsequent sea-level rise is taken into account. The event that produced the third highest storm-tide level was on 18 April reaching 0.5 m above MHWPS at Sumner Head. This occurred when a king tide coincided with a strong southerly wind flow up the east coast of the South Island. At the offshore sites monitored by NIWA, the highest waves were recorded off Banks Peninsula during a storm on the 16th of August (largest significant wave height 6.75 m, largest individual wave 12.3 m), and at Baring Head on 11th July (largest significant wave height 5.87 m, largest individual wave 12.9 m).

Tsunami Summary 2011

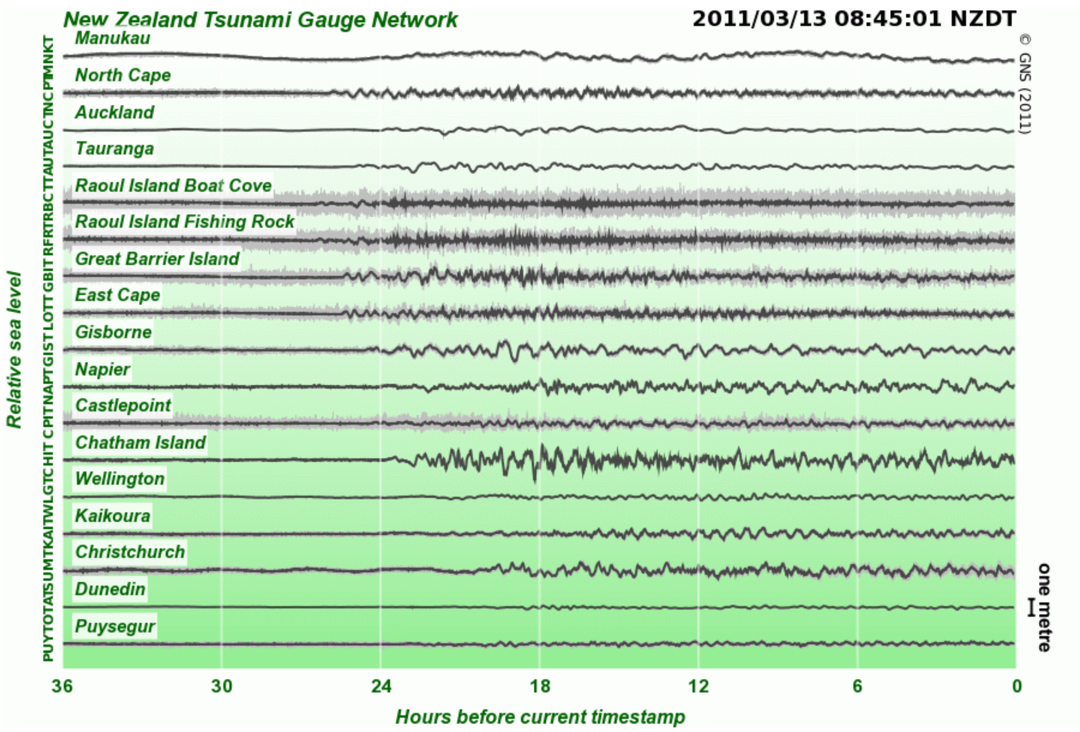
The most significant tsunami to affect New Zealand in 2011 was caused by the Tohoku earthquake in Japan. This magnitude 9.0 earthquake occurred on the 11th of March, and the subsequent tsunami had devastating effects on the northeast coast of Honshu Island. In places the tsunami run-up reached 40 metres above sea level. The tsunami caused the majority of the nearly 20,000 casualties as well as a very serious nuclear accident at Fukushima.

The effects on New Zealand were much less serious, though they still represented by far the most major tsunami to affect this country in 2011. Initial waves reached New Zealand approximately 13 hours after the earthquake, and the maximum recorded amplitudes were up to around one metre (and trough

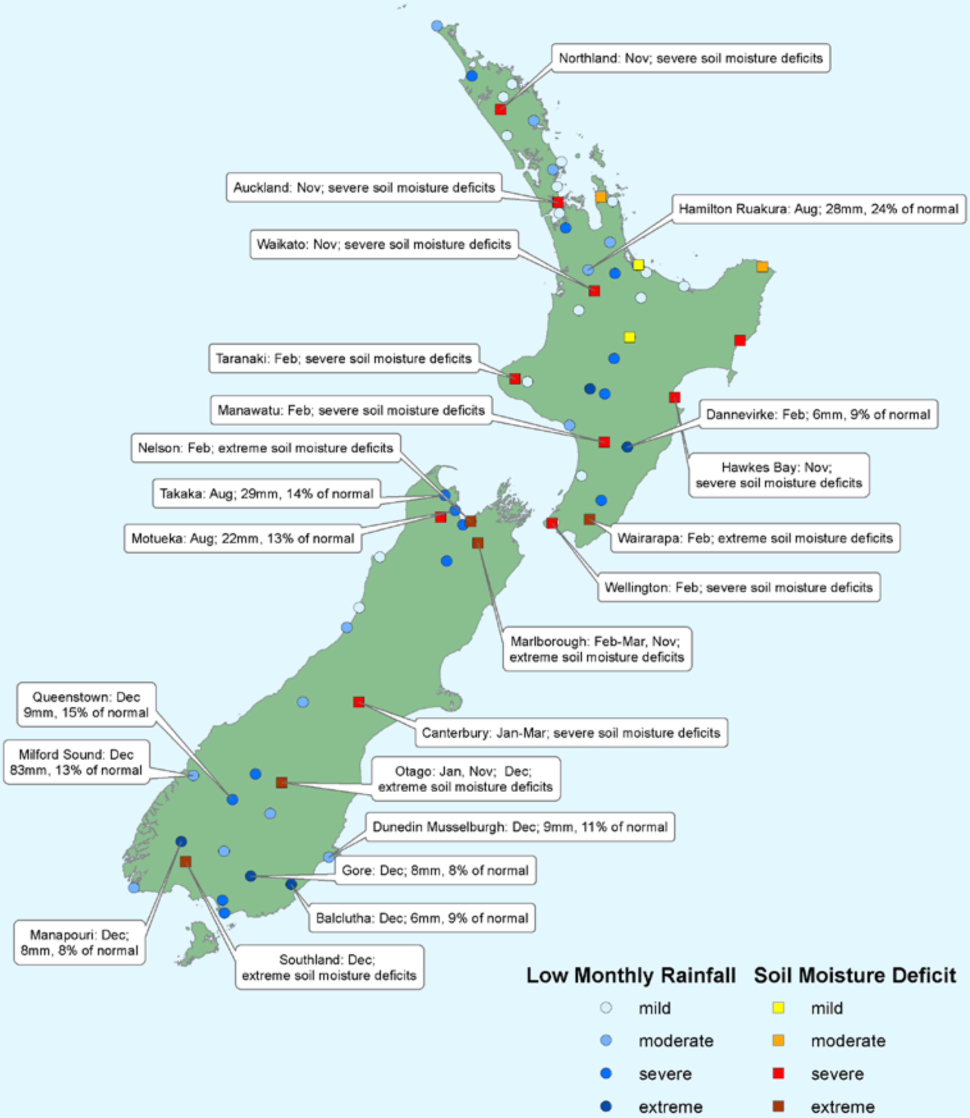


to crest wave-heights nearly twice that). Particularly noteworthy was the long duration of the tsunami, which continued for several days; in some locations the largest waves occurred nearly two days after the first arrivals, such a long delay has important implications for how we should respond to future distant-source tsunami.

The tsunami was widely observed around the country. An online survey conducted by Geonet received 52 reports nationwide, though these tended to be concentrated around the northeast coast of the North Island. Notable observations include one from Orewa where the "water level varied between the low tide and high tide marks over a period of about 8 minutes" corresponding to a surge height of about 2.2 metres, and from Baddeleys Beach in Millons Bay where the water's edge was estimated to have moved back and forth by approximately 650m in response to the tsunami. There was minor damage caused to small boats and marine facilities in various locations, and inundation damage to houses in Port Charles at the northern tip of the Coromandel Peninsula.



Screenshot from the Geonet website approximately one day after the arrival of the first waves, showing the previous 36 hours of sea level variations from all operational sites. The dark part of the trace shows the average sea level height over a one minute period, whilst the grey part shows the maximum and minimum values.

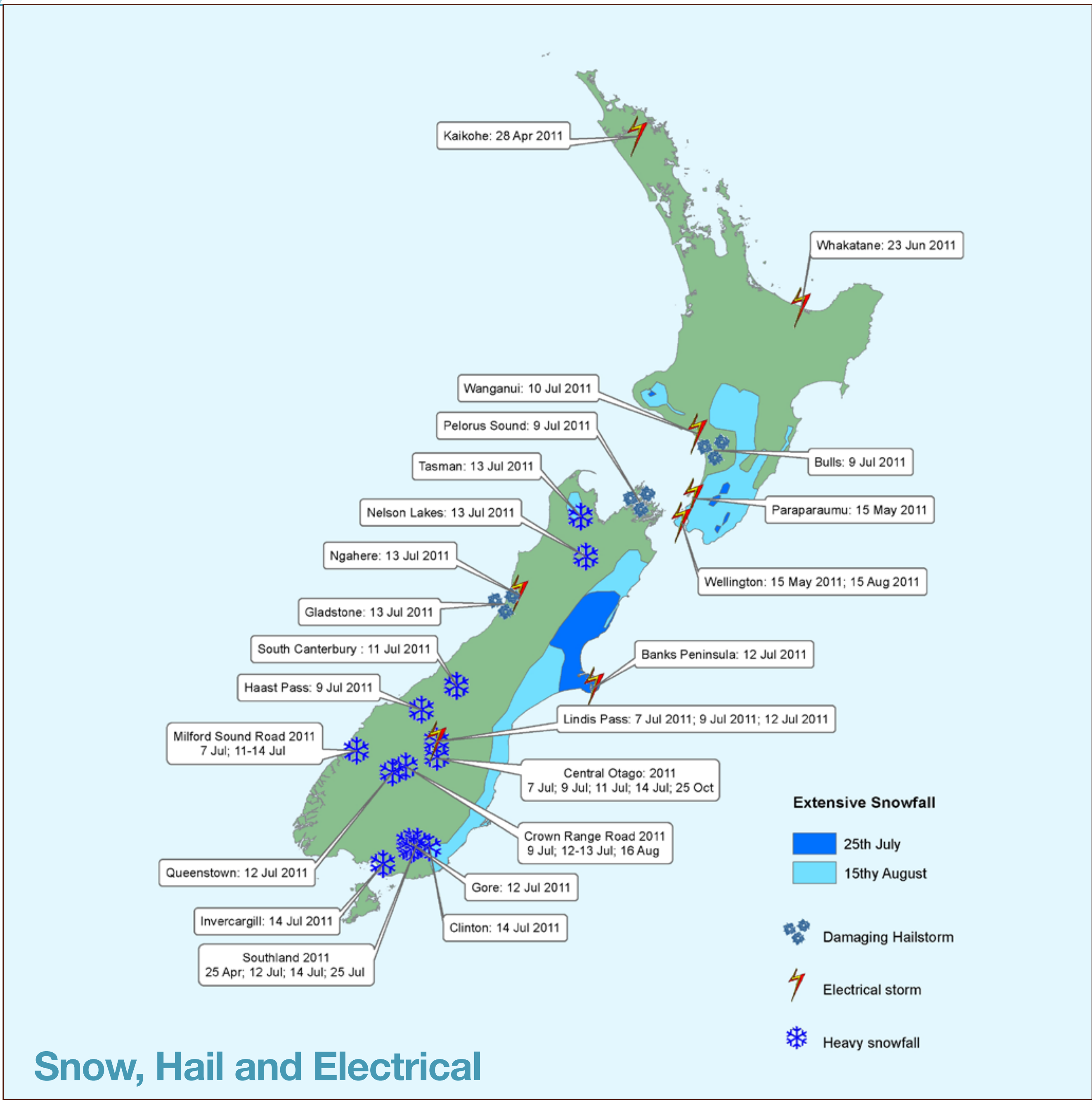


Low rainfall and drought

Annual rainfall totals for 2011 were generally above normal, with six months generally wetter than normal, and two months drier than normal. There were large geographical differences between very wet regions and areas of extreme dryness. The lowest annual rainfall was 395 mm at Clyde.

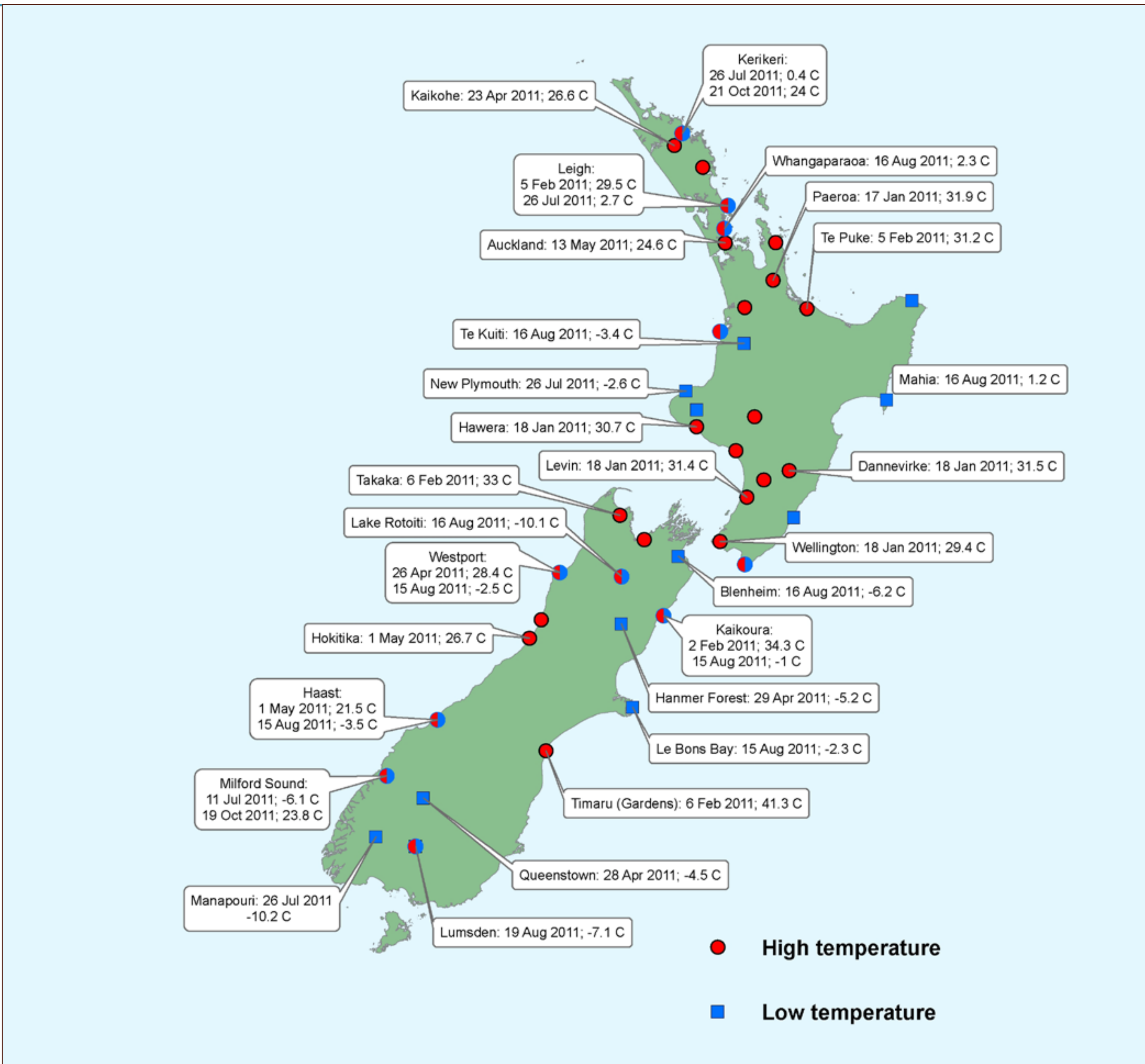
At the beginning of 2011, significant soil moisture deficits (more than 110 mm of deficit) affected much of the North Island, as well as parts of Canterbury and Central Otago, but significant rain in January recharged soil moisture levels across the North Island. While soil moisture deficits redeveloped in February for much of the North Island and Canterbury, by the end of March they were present only in Tasman, Marlborough and parts of Canterbury. By the end of November, significant soil moisture deficits had developed in regions north of Taupo, and also in the eastern North Island, Marlborough, and Central Otago. Above normal rainfall totals in December throughout the North Island improved soil moisture levels there, but by the end of the year, deficits had become extreme (deficit of more than 130 mm) in Central Otago and Southland. No state of drought was declared in 2011.

Source: NIWA National Climate Centre



The two most significant snowfall events of the year, characterised by snow falling down to sea level, occurred during 24-26 July and 14-17 August across both Islands resulting disruption of essential services (e.g. road closure, mail delivery, power distribution, airport and hospital access). The July event resulted in the closure of several roads across the North Island (Desert Road, Napier-Taupo and Napier-Taihape Roads) and parts of the SH1 in the South Island (Dunedin-Gore, Oamaru-Dunedin, and Cheviot-Waipara). During the period 14-17 August heavy snowfall was observed to unusually low levels across the South Island as well as across the North Island (flurries were observed in Auckland and Northland) resulting in many eastern and alpine South Island roads, as well as lower North Island roads being affected by snow or ice. SH 94 from Fiordland National Park to Milford Sound was closed by snow over the periods 29 to 30 July and 6 to 16 August, and from 10 to 11 September due to avalanche risk.

Two major hail events occurred during July. On 9 July, in Bulls hail the size of marbles caused bullet-sized holes in windows, and 2cm hailstones were observed in Pelorus Sound. Four major electrical storms struck between April and October. On 28 April lightning struck a Transpower line near Kaikohe in the Far North resulting in loss of power to more than 30,000 customers. On 15 May, almost 6000 lightning strikes were reported around New Zealand and over the period 10-13 July electrical storms took down the wireless internet network and blew fuses in Wanganui On 25 October, transmission lines between Clyde and Twizel were struck resulting in power cuts across Central Otago.



Temperature

Mean annual temperatures were above average (by between 0.5°C and 1.2°C) in the northeast of the North Island, and over the north of the South Island. The nation-wide average temperature for 2011 was 12.8°C, 0.3°C above the 1971–2000 annual average, using NIWA's seven-station temperature series which begins in 1909, and the 17th warmest year since 1909. May 2011 was the warmest May on record, and June 2011 was the third-warmest on record, according to the seven-station temperature series

Record-breaking high temperatures were experienced over much of the North Island on 18-19 January, as an ex-tropical cyclone delivered tropical air to the country. The country was affected by exceptional heat for the first half of February, with many sites recording temperatures in excess of 30°C on 5-6 February. Timaru recorded 41.3°C on 6 February, a new all-time high, since records began in 1885. High temperatures continued into April and May, especially for the West Coast of the South Island. Overall, it was the warmest year on record for Kerikeri and Te Puke (15.9°C and 14.7°C, respectively), and Whangarei recorded the highest mean annual temperature (16.3°C).

Two extreme cold spells affected New Zealand during 24-26 July and 15-16 August. The lowest temperature of the year was -10.2°C, recorded at Manapouri on 26 July, setting a new all-time record. Numerous August (as well as all-time) low temperature records were broken between 14-17 August.

Nelson was the sunniest location in 2011, recording 2487 hours, followed by Tekapo (2463 hours) and Whakatane (2380 hours). Source: NIWA National Climate Centre

The Hazard Platform Strategic Advisory Group

The Canterbury earthquakes have changed perceptions of hazard occurrence and management in all sectors that have an interest in the work of the Platform. The Strategic Advisory Group, as representatives of these interests, has had a considerable challenge to keep abreast of the needs and opportunities that have arisen over the past year.

Following the Canterbury earthquake sequence, the SAG has worked with Platform management to set priorities as part of Government's earthquake response. The special place of Canterbury at this time has been recognised in the SAG and three additional members have been invited: Roger Sutton from CERA along with representatives from Environment Canterbury and Christchurch City Council. Their presence will help ensure that decisions made in connection with the Canterbury recovery will be well-informed.

The SAG also contributed to the Platform's contestable round. Members of the SAG assessed applications and the Group was represented at the final two-day meeting for input on recommendations. The SAG is required, by the rules of the Platform, to endorse the recommendations of the Platform Management, and this was done.

The SAG also recognises the contributions of the Platform manager, Kelvin Berryman, in Christchurch's recovery. As well as his "day job", Kelvin has a regular presence at CERA and is unsparing in his efforts to communicate and explain publicly the science of the earthquakes. The country owes Kelvin, and others who have worked unstintingly since September 2010, a debt of gratitude.

The Platform is about all natural hazards, not just earthquakes, and it is important that we recognise the contributions made across all themes. The opportunity provided by the Canterbury earthquakes is to make New Zealand more knowledgeable of its natural hazards, and more resilient against them.

Lastly, I wish to acknowledge that SAG member Dr. Neil Gordon (MetService) has retired. His well-considered and balanced approach will be missed.

David Middleton, Chair of the Strategic Advisory Group

Hazard Platform Technical Advisory Group

The primary mission of the Technical Advisory Group is to assist the Natural Hazards Research Platform by assessing the technical excellence of the research funded through the Platform and ensuring that the proposed research is of international standard – both informed by and contributing to global research efforts.

The Technical Advisory Group was assembled in the second half of 2011 and has already played a major role in assessing proposals for funding in the 'New Zealand Natural Hazards' and 'Lessons learned from Christchurch' themes by providing thoughtful scores and insightful comments on a myriad of excellent proposals.

Emphasising the international perspectives offered by TAG members, none of the team live in New Zealand but all have strong connections with New Zealand natural hazards research. All of the Group are internationally acknowledged experts in their respective disciplines which span natural hazards science from geophysics and meteorology through engineering, to sociology and regional planning:

- Emeritus Professor Russell Blong, Aon Benfield Ltd, Australia (Chair)
- Professor Stephanie E. Chang, University of British Columbia, Canada
- Professor Michael K. Lindell, Texas A & M University, USA
- Dr William L. Ellsworth, US Geological Survey
- Professor Stephen Sparks FRS, University of Bristol
- Professor Jim Hall, University of Oxford, UK
- Dr George Pankiewicz, UK Met Office
- Professor Thomas O'Rourke, Cornell University, USA
- William Holmes, Rutherford and Chekene PLC, San Francisco, USA
- Professor Willy Aspinall, University of Bristol, UK

The secondary mission of the Technical Advisory Group is to review the natural hazards science strategy, offering our views on how New Zealand natural hazards science should look in, say, five years time. We intend to re-examine the five inter-linked Platform themes – geological hazard models; predicting weather, flood and coastal hazards; developing regional and national risk evaluation models; social resilience: social, cultural, economic and planning factor; and resilient buildings and infrastructure - from global and New Zealand-centric views to consider whether these remain the most appropriate, to reflect on the balances between disciplinary and inter-disciplinary strengths, and between established and new directions.

Professor Russell Blong, Chair of the Technical Advisory Group

Communicating our Research

Geological Hazards / Geotechnical

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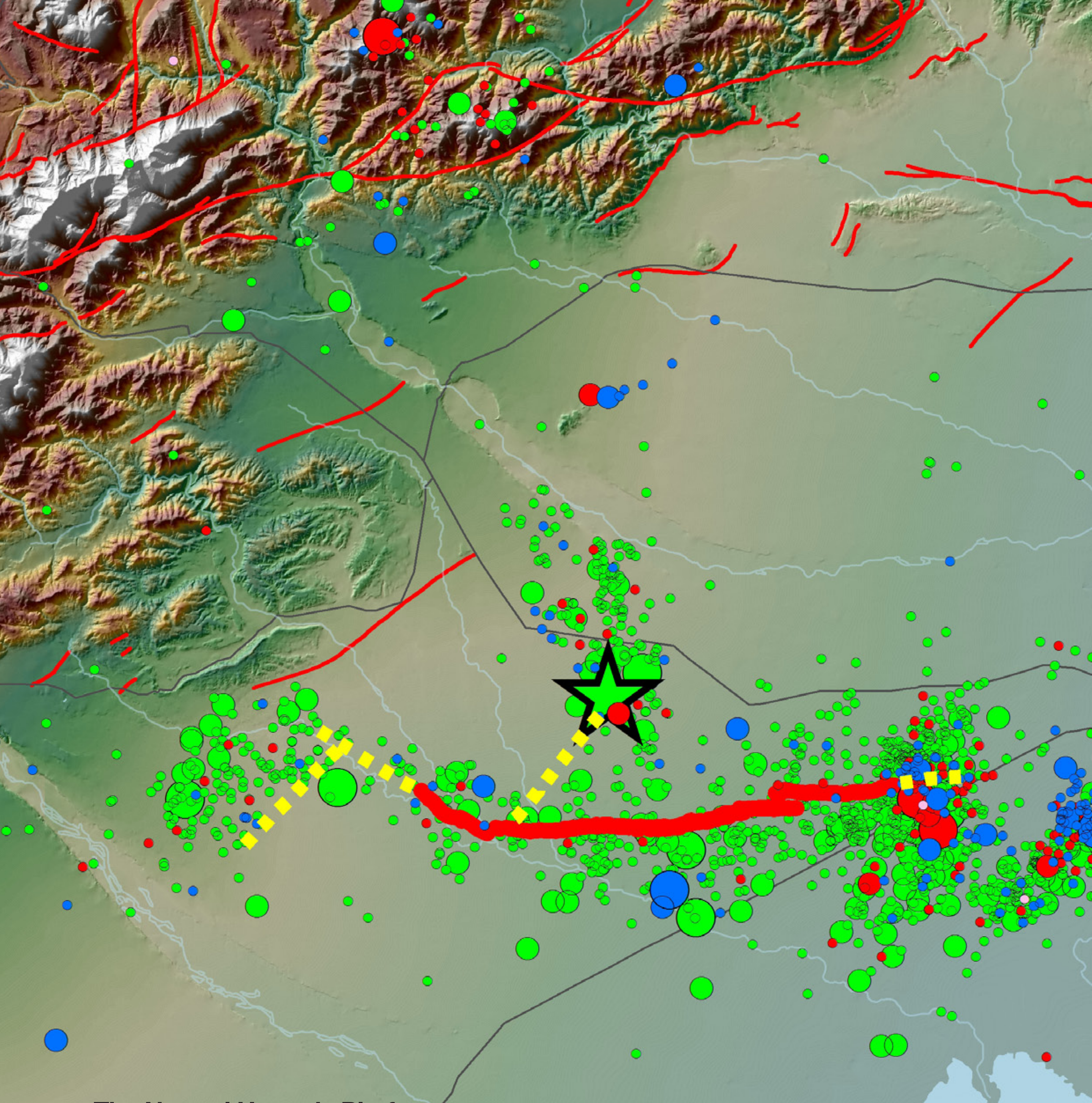

The Natural Hazards Platform

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.

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GNS Science - Te Pu Ao
Ph +64 4 5701444
Fax +64 4 5704600
PO Box 30368, Lower Hutt 5040
www.gns.cri.nz

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