NHRP

Natural Hazards Research Platform

Contest 2012

Improving tsunami warnings and real time hazard assessment in New Zealand's ports and harbours

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Organisation: GNS Science
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Improving tsunami warnings and real time hazard assessment in New Zealand's ports and harbours

2012-GNS-03-NHRP Completion Report
(Please note that PhD student research in Research Aims 2.1 and 2.2 will continue until at least Dec 2015. This report contains a progress report for those Aims.)

Programme Leader:
William Power

Affiliation:
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Key message for media: Why are these findings important? 2-3 sentences.

1. A database of simulated events has been compiled that will help to provide more detailed tsunami forecasts for four key ports
2. We have found that even when tsunami come from far away, the specific details of the source earthquake are important for forecasting the impact on ports
3. Detailed physical and numerical modelling of tsunami interacting with port structures is in progress, which is important because there is very limited existing information about how tsunami exert forces on coastal structures, and will lead towards designs with greater resilience.

Abstract:

This report covers research work on improving the resilience of New Zealand's ports and harbours to tsunami. Part of this work concerns the development of improved forecasting tools, so that ports can better prepare for approaching tsunami from distant sources. A second component concerns physical and numerical modelling of tsunami impacts on port structures, with a view to first better anticipating the impacts of future tsunami on existing structures, and later improving the design of new wharves, or recommending modifications to existing wharves, to reduce the damage and disruption to operations in future events.

Four ports were selected for the numerical tsunami modelling component of this work on the basis of their commercial or strategic importance: Marsden Point, Port of Tauranga, Port Taranaki, and Lyttelton Harbour. Tsunami modelling configurations were set up and tested for each of these locations. Historical tide gauge data for

these locations was studied for harbour resonance and used for testing of the numerical models. A database of distant-source tsunami scenarios was developed for sources at regular azimuth angles from New Zealand. The use of these models for tsunami forecasting was assessed, leading to the recognition and evaluation of important sources of uncertainty due to the approximation of real events by the nearest database events. The simulation results have been presented in the form of a 'clickable pdf' chosen as a simple form for the distribution and access of the model results.

Laboratory experiments are underway to measure forces exerted by tsunami on wharf decks. These will consider forces due to both bore-like and wave-like tsunami arrivals. Experiments in the bore-like case are well advanced and producing valuable data. Work is progressing on taking data from experiments such as these and incorporating the effects into integrated structure-foundation computational models (using the OpenSees finite element program) that have been developed to incorporate structural and geotechnical non-linearity. From these estimates of damage states in representatives of realistic wharf structures can be made and used to produce fragility curves.

Keywords: Tsunami, Ports and Harbours

Contents

Introduction / Background:

Ports are vitally important to New Zealand both because of the high proportion of our trade that passes through them, and because of their strategic role in supporting critical enterprises such as the oil and gas industry. Tsunamis have been demonstrated to impact on ports and the vessels using them in situations where overland tsunami inundation is still minimal. In New Zealand these situations are historically typical of large tsunamis from distant sources, such as from South America.

Damage to ports can be very costly, and can to some degree be mitigated with advance knowledge of the likely properties of an approaching tsunami. On the other hand, ports are subject to costs if they are closed as a precaution in events that later turn out to be minor. Both of these are reasons for improving our ability to forecast the impacts, and this is a major motivation for this project.

A second motivation for this project is to be able to implement, over the long term, designs for port structures that are better able to withstand tsunami impacts. For this a programme of physical experiment studying the forces that tsunamis exert on port structures is being developed, and will be integrated with structural numerical modelling to estimate impacts and ultimately improve designs.

Objectives or Research Aims – This section must be completed.

Research Aim 1.1: Analysis of far-field tsunamis in New Zealand ports and harbours

Objective Achieved? Yes

Four harbours were selected for detailed analysis in Research Aims 1.1, 1.2 and 1.3, these were selected on the basis of their commercial and strategic importance to New Zealand. The sites chosen were: Marsden Point, Port of Tauranga, Port Taranaki, and Lyttelton Harbour.

Tide gauge data for each harbour was collected for recent historical events for which high quality data is available, in particular the Chile (2010) and Tohoku Japan (2011) tsunamis, and also the Solomon Islands (2007) and Samoa (2009) tsunamis where

available. This data was used for model comparison under Research Aim 1.2 (below), and studied using spectral analysis to identify resonance properties of the harbours.

In addition, model results from Research Aim 1.2 were used to assess the sensitivity of the harbours to a wide variety of different tsunami sources. In the case of Lyttelton a detailed analysis was made using wavelet analysis to identify the proportion of tsunami energy going into different modes of oscillation as a function of the direction of tsunami approach. For this site detailed modelling comparisons were also made of historical tsunamis in 1866, 1877 and 1960.

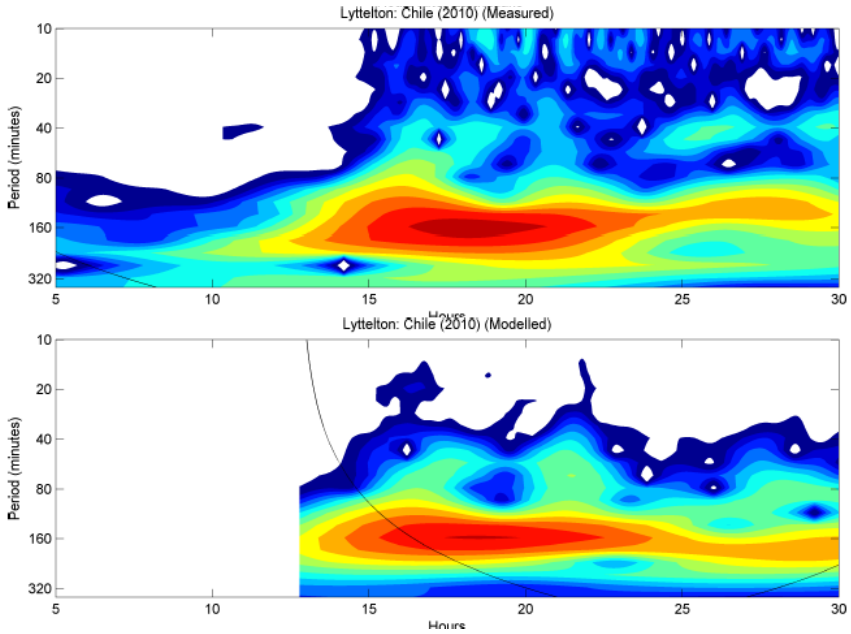

Figure 1. Comparison of modelled and measured tide gauge periodograms for Lyttelton in the Chile 2010 tsunami. The influence of the Pegasus Bay seiche with period ~200 mins is evident.

In Tauranga harbour a unique record exists of tsunami current velocities captured during the 2010 Chile and 2011 Tohoku tsunamis. A detailed analysis paying particular attention to the current speeds recorded on the Port of Tauranga's ADCP current meter located at the entrance to the harbour was performed. Ongoing analysis is focusing on how the tsunami induced current is modulated by tidal currents. Preliminary results suggest there is a strong tidal modulation to the tsunami currents both in terms of speed and direction. We are presently in the process of working with NOAA/PMEL to adapt the MOST tsunami model to work with tide and tsunami forcing in an effort to better understand these processes. Furthermore, the Tauranga current and water level data from the 2011 event has been processed and delivered to the US National Tsunami Hazard Mitigation Program (NTHMP) for use in a tsunami currents benchmarking workshop (http://coastal.usc.edu/currents_workshop/problems.html).

Achievement Measure

Please note that a contract variation was agreed as a result of which the Achievement Measures for Research Aims 1.1 and 1.2 were combined. See the Achievement Measures section for Research Aim 1.2

Research Aim 1.2: Numerical modelling assessment of far field tsunami sources affecting New Zealand ports and harbours

Objective Achieved? Yes

For each of the key study sites of Marsden Point, Port of Tauranga, Port Taranaki, and Lyttelton Harbour (see Research Aim 1.1) a detailed set of topographic and bathymetric tsunami modelling grids were prepared from Nautical Charts and other publically available sources.

These grids were used to establish a tsunami modelling setup within the ComMIT framework developed by NOAA. Tsunami models were run for the historical tsunami events in Solomon Islands (2007), Chile (2010) and Tohoku Japan (2011) and the results compared against collected tide gauge data (see Research Aim 1.1). The levels of agreement varied from excellent to acceptable; in some locations there are features in the bathymetric model that make accurate modelling challenging, such as the very large extent of shallow seafloor offshore of Taranaki.

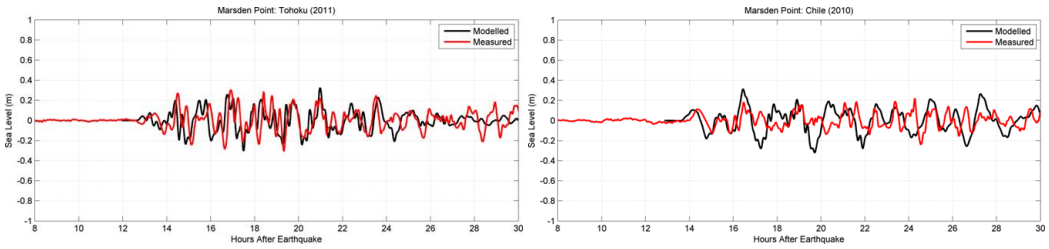

Figure 2. Comparison of Modelled and Measured tide gauge records for Marsden Point

A set of ten distant earthquake tsunami sources was developed. These included events at 15 degree intervals in azimuth from New Zealand, ranging from Chile to Hokkaido. An additional set of three regional sources, on the Solomon Islands, New Hebrides and Kermadec Trench were also modelled. Earthquake source models were developed for each of these locations, at magnitudes of Mw8.7, 9.0, and 9.3. These sets of 39 sources were then run for each of the four chosen port locations.

Results from the modelling were used in two ways. Firstly for further study of the resonance properties of each port (see Research Aim 1.1), and secondly they were processed into outputs suitable for use in providing more specific threat information for port users (see Research Aim 1.3).

The small tsunami generated by the April 1, 2014 Iquique Chile earthquake provided an opportunity to apply the numerical tools developed during the project and a real-time assessment of the projected tsunami effects at Lyttelton was provided to the Lyttelton Port Company. In this case, the modelling suggested that there would be no significant effects from the tsunami; port activities carried on normally avoiding a costly stand-down or unnecessary evacuation.

Achievement Measure
Results of work under Research Aims 1.1 and 1.2 were presented in the following report and papers:

- "Decision Making Tools for the Real-Time Assessment of Far-Field Tsunami Hazards in New Zealand Ports and Harbours. Part 1: Background Information and Preliminary Analysis" prepared for the Hazards Platform.
- Borrero, J.C., Goring, D.G., Greer, S.D. and Power, W.L. (2014) Tsunami Hazards in New Zealand Ports, Pure and Applied Geophysics, 10.1007/s00024-014-0987-4
- Borrero, J.C. and Goring, D.G. (2014) South American Tsunamis in Lyttelton Harbor, New Zealand, Pure and Applied Geophysics, Accepted for publication December 19, 2014.

In addition this work formed the basis for, or a contribution to, several of the publications and other reports listed at the end of this document.

Research Aim 1.3: Devising a rational means for assessing far field tsunami effects in New Zealand

Objective Achieved? Yes

Any real earthquake will never exactly match one of the specific events that have been prepared for in a forecast database. And even if a perfect match existed, the forecast results would need to consider modelling errors – which can be assessed by comparing the model results for historical events with optimised source models developed after the event.

A preliminary breakdown of the different uncertainties present when using a forecast database was made, and compared against those in other forecast methodologies. Some types of error, for instance in magnitude estimates, can be adjusted for using existing scaling techniques, but others require further investigation. Two types of uncertainty were considered in detail – the uncertainty

arising from the approximation of the true source of the earthquake by the nearest source location in the database, and the uncertainty arising due to the approximation of the earthquake by a uniform slip distribution as used in the forecast models.

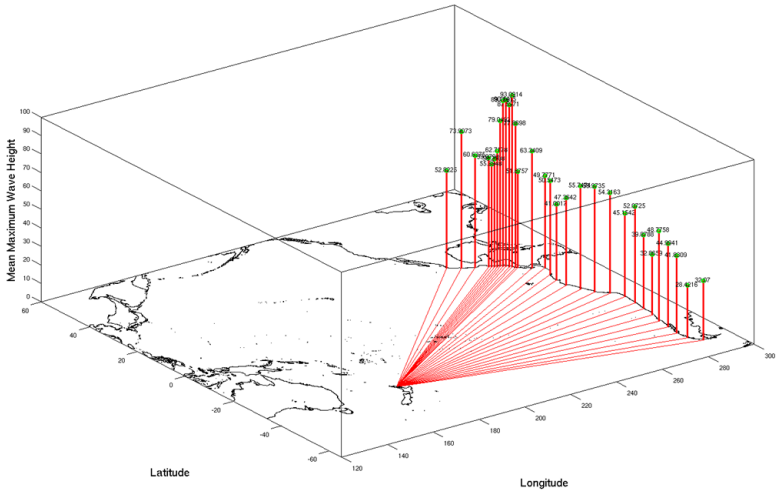

Figure 3. Comparison of tsunami Heights at Marsden Point as a function of source location.

It was found that sensitivity to location was always present, but greatest when New Zealand is in or near the main energy beam of the tsunami. In such situations a mismatch in location of only 200km could be enough to change results by nearly a factor of two. A similar range in outcomes was also found as a result of systematically varying slip distributions, so that slip was concentrated within limited regions of the overall rupture. Results from these studies were presented at the NZ Geosciences conference, and will form the basis of a paper in preparation. This part of the work would benefit from further study into the randomised generation of realistic slip distributions.

It was decided to use the collected set of distant-source tsunami simulations (see Research Aim 1.2) to construct a clickable pdf document for each port in a similar format to the existing New Zealand threat-level database. Several forms of graphical information summarising information of value to port users were considered, and a subset of key properties: maximum current speeds, maximum and minimum water levels, and simulated tide-gauge records, were used to form the basis of the forecast summaries in the pdfs.

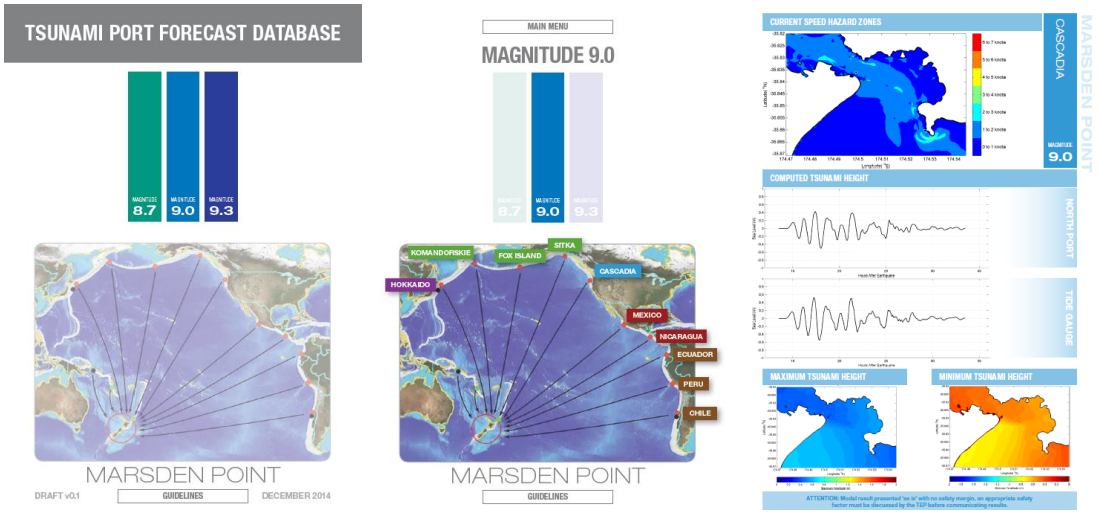

Figure 4. Example pages from the clickable pdf document for Marsden Point

The forecast results are presented in the pdf directly as modelled, the assessment of uncertainties is currently assumed to be made by the Tsunami Experts Panel, as these uncertainties are highly event dependent, and the adoption of a uniform 'catch-all' uncertainty without expert assessment would lead to frequent over-response. The port forecasts and their interpretation and anticipated use will be presented and discussed at the next Tsunami Experts Panel meeting.

Achievement Measure

The set of forecast pdfs to be presented at the next Tsunami Experts Panel meeting represent the Achievement Measure for this Research Aim.

Research Aim 2.1: Physical modelling of tsunami loading on wharf structures

Objective Achieved? On Track

The scope of this project is to study wharf-type structures that may be subjected to tsunami loading using wave flumes in the Fluid Mechanics Laboratory at the University of Auckland. Two series of experiments are planned in order to simulate tsunami bore and tsunami wave induced forces on wharf decks. A dam break flow was generated using an automatic sluice gate, representative of the tsunami bore. Also, a solitary wave was generated using a wavemaker, representative of the tsunami wave.

A typical wharf deck model was constructed, which is a 1:90 scale of a prototype wharf. The wharf deck is equipped with a series of pressure transducers to measure the uplift pressure applied to the soffit of the deck. The pressure records will be used

to investigate the pressure distribution on the soffit of the deck, and to calculate the uplift force (through integration of the measured pressures over area).

To date, experiments were conducted to investigate the tsunami bore propagation in the flume. Different combinations of the bore heights and velocity were generated, representative of various bore strengths. The bore-induced pressure profile on the deck was measured using the pressure sensors, in a horizontal array at the centre and sides of the model wharf deck.

Achievement Measure
Journal and conference papers detailing research outcomes are due Dec 2015.

Research Aim 2.2: Development of wharf fragility models for tsunami loading

Objective Achieved? On Track

Using a database of New Zealand specific wharf designs, a group of generic wharf models have been developed that are representative of New Zealand characteristics. As the country is dominated by pile supported wharves, these are the focus of this research. A modelling process has been developed to represent the effect of tsunami loading on wharf structures. Using the OpenSees finite element program integrated structure-foundation computational models have been developed that incorporate structural and geotechnical non-linearity.

Initial modelling using tsunami loading characteristics derived from international design codes has been undertaken. These are simplified approaches, and as they have been developed for a range of structural forms, their applicability for wharves is questionable. This is the main motivation behind the modelling carried out in research aim 2.1. Loading characteristics from research aim 2.1 will be used as inputs for this computational modelling, with this to be completed in 2015.

The framework for the development of fragility models has been developed, and will be used to compare the outputs from code-defined and physical modelling loading.

Achievement Measure
Journal and conference papers detailing research outcomes are due Dec 2015

Conclusions & Recommendations:

This multi-institution collaborative project has advanced New Zealand's capability to mitigate the impacts of tsunamis on ports.

Numerical modelling grids for estimating tsunami impacts have been developed for four key ports: Marsden Point, Port of Tauranga, Port Taranaki, and Lyttelton Harbour. Historical tide gauge data for these locations was studied for harbour resonance and used for testing of the numerical models. A database of distant-source tsunami scenarios was developed for sources at regular azimuth angles from New Zealand. The use of these models for tsunami forecasting was assessed, leading to the recognition and evaluation of important sources of uncertainty due to the approximation of real events by the nearest database events. The simulation results have been presented in the form of a 'clickable pdf' chosen as a simple form for the distribution and access of the model results.

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We recommend that further work be undertaken to:

1. Develop the capability for real time forecasting of tsunamis in ports by using the Tweb framework to generate tsunami source models in real time from DART buoy data. This will remove, or greatly reduce, many of the uncertainties present in the use of forecast databases.
2. Develop tsunami modelling grids for a greater set of New Zealand ports and harbours. And develop methods to assist port managers in the practical use of the model outputs.
3. Expand the use and application of laboratory derived tsunami impact data to model a wider variety of port structures, and to develop similar techniques for estimating tsunami impacts on infrastructure in general.
4. Consider the role of the overall large-scale design of ports, such as the location and orientation of breakwaters, with a view to recommending configurations that minimise destructive tsunami properties within the port.

Outputs from this Project:

Manuscripts

Borrero, J.C., Goring, D.G., Greer, S.D. and Power, W.L. (2014) Tsunami Hazards in New Zealand Ports, Pure and Applied Geophysics, 10.1007/s00024-014-0987-4

Borrero, J.C. and Goring, D.G. (2014) South American Tsunamis in Lyttelton Harbor, New Zealand, Pure and Applied Geophysics, Accepted for publication December 19, 2014.

Lynett, P.J., Borrero, J.C., Son, S., Wilson, R.I., and Miller, K. (2014) Assessment of the tsunami-induced current hazard, Geophysical Research Letters, Volume 41(6), p. 2048–2055, 28 March 2014, DOI 10.1002/2013GL058680

Borrero, J.C., Greer, S.D., Goring, D.G., Arcas D. and Moore, C., in prep. Tsunami Current in Tauranga Harbour New Zealand. Expected submission early 2015.

Power, W.L., Borrero, J.C., and Greer, S.D., in prep. Comparison of tsunami forecast techniques for Ports and Harbours. Expected submission mid 2015.

Technical Reports

Goring, D. G., (2013) Pegasus Bay seiche along northern Banks Peninsula, Mulgor Technical Report.

Goring, D. G., (2013) Effects of tsunami source region on resonance in Lyttelton Harbour, Mulgor Technical Report.

Goring, D. G., (2013) Wavelet analysis of MOST results for Tohoku tsunami at Lyttelton, Mulgor Technical Report.

Borrero, J.C., Goring, D.G., Greer, S.D., Power, W.L., and Barberopoulou, A. (2013) Decision Making Tools for the Real-Time Assessment of Far-Field Tsunami Hazards in New Zealand Ports and Harbours. Part 1: Background Information and Preliminary Analysis. eCoast report for the Hazards Platform.

Borrero, J.C. (2014) Real-time Modeling and Assessment of Tsunami Waves in Lyttelton Port Generated by the April 1, 2014 Earthquake in Northern Chile, technical report prepared for Lyttelton Port Company, April 12, 2014.

Goring, D. G., (2014) Effects of tsunami source region on response at Marsden Point, Mulgor Technical Report.

Goring, D. G, (2014) Effects of tsunami source region on response at Port Taranaki, Mulgor Technical Report.

Full length Conference paper

Borrero, J.C., Goring, D.G., Greer, S.D., Power, W.L. and Barberopoulou, A. (2013) Understanding Tsunami Hazards in New

Zealand Pots and Harbours, Proceedings of Coasts and Ports Conference, Manly, Australia, September, 2013.

Conference oral presentations

Borrero, J.C., Wotherspoon, L., Power, W.L., Goring, D.G., Barberopoulou, A., Melville, B. and Shamseldin, A. (2012), Tsunami Hazard Assessment in New Zealand Ports and Harbors, Abstract NH32A-07 presented at 2012 Fall Meeting, AGU, San Francisco, Calif., 3-7 Dec.

Lynett, P.J., Borrero, J.C., Son, S., Wilson, R.I., and Miller, K. (2012), Assessment of Nearshore Hazard due to Tsunami-Induced Currents, Abstract NH54A-01 presented at 2012 Fall Meeting, AGU, San Francisco, Calif., 3-7 Dec.

Borrero, J.C. (2013) Tsunamis: Recent Lessons Learned and Future Research Directions, Keynote Address Presented at New Zealand Coastal Society Annual Conference, Hokitika, New Zealand, 19-22 November.

Shafiei, S. R. (2014). Experimental Study of Tsunami Bore Impact on a Coastal Structure. *2014 Earthquake Engineering Research Symposium*. Auckland, New Zealand.

Shafiei, S. R. (2014). Tsunami research at the University of Auckland. 2014 Annual Conference of the Geoscience Society of New Zealand. New Plymouth, New Zealand.

Borrero, J.C., Goring, D.G., Greer, S.D., Power, W.L. (2014) Modeling tools for the real-time evaluation and historical reconstruction of tsunami events in New Zealand, presented at New Zealand Coastal Society Annual Conference, Raglan, New Zealand, 18-21 November.

Goring, D. G., and Borrero, J.C. (2014) The influence of source region on tsunami in Lyttelton Harbour, NZ Coastal Society Conference, Raglan, New Zealand, 18-21 November.

Power, W.L., Borrero, J.C., Greer, S.D., and Goring, D.G. (2014) Developing robust tsunami forecasts for ports and harbours, Presented at New Zealand Geosciences Conference, New Plymouth, New Zealand, 24-28 November.

Borrero, J.C., Goring, D.G., Greer, S.D., Power, W.L. (2014) Modeling tools for the real-time evaluation and historical reconstruction of tsunami events in New Zealand, Abstract S14A-02 presented at 2014 Fall Meeting, AGU, San Francisco, Calif., 15-19 Dec.

Conference posters

Borrero, J.C., Goring, D.G., Greer, S.D., Power, W.L. (2014) Modeling tools for the real-time evaluation and historical reconstruction of tsunami events in New Zealand, Presented at New Zealand Geosciences Conference, New Plymouth, New Zealand, 24-28 November.

Borrero, J.C., Goring, D.G., Greer, S.D., Power, W.L. (2014) Modeling tools for the real-time evaluation and historical reconstruction of tsunami events in New Zealand, Presented at New Zealand Coastal Society Annual Conference, Raglan, New Zealand, 18-21 November.

End user contacts

Port representatives; Port CEO's conference 19-20 November 2013 Dunedin