Toitu te Land whenua Information New Zealand

New Zealand Geodesy 2007-2010

National Report for the XXV General Assembly of the International Union of Geodesy and Geophysics, Melbourne, Australia

Geophysics Committee of the Royal Society of New Zealand

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1 Introduction

This report presents the geodetic activities in New Zealand (NZ) for the period 2007–2010.

During this period the structure of the national geodetic networks has been changed to reflect their purpose. A national vertical datum based on a gravimetric geoid was implemented. The national continuous GPS network, PositioNZ, has been expanded and upgraded, including marks in Antarctica. Absolute gravity observations have also been observed in NZ and the Ross Sea Region of Antarctica.

Geodynamic studies have continued to collect GPS campaign measurements throughout the country and major advances have been made in the interpretation of the resulting data in terms of tectonic models. We have made major progress in developing the continuous GPS network and also significantly increased our use of interferometric synthetic aperture radar (InSAR) methods. Measurements have also been made to characterise two major earthquakes, as well as an additional quake in early 2011.

This report has been compiled by Land Information NZ, on behalf of the NZ Geophysics Committee of the Royal Society of NZ for the General Assembly of the International Union of Geodesy and Geophysics, Melbourne, Australia, June-July 2011. The report is a compilation of material provided by:

- Land Information New Zealand
- GNS Science
- National School of Surveying, University of Otago

2 Geodetic Control Networks

2.1 New Zealand Control Surveys

The official NZ geodetic datum is the New Zealand Geodetic Datum 2000 (NZGD2000). It is a semi-dynamic datum that incorporates a deformation model to enable the currency and accuracy of the datum to be maintained.

During this period, a number of new standards were promulgated by the Surveyor-General. One of the most fundamental changes was to specify six survey control networks, each of which has different characteristics to meet the different requirements of the geodetic system. This contrasts with the previous method of specifying a hierarchy of control networks based on accuracy. Table 1 describes each of these networks.

Control Network	**Description**
National Reference Frame	Connect national datums to international reference frames
Deformation Monitoring Network	Monitor surface deformation at national, regional and local scales
Cadastral Horizontal Control Network	Ensure cadastral surveys can efficiently connect to the official datum
Cadastral Vertical Control Network	Ensure cadastral surveys with height data can efficiently connect to official datums
Basic Geospatial Network	Support government-directed geospatial activities
National Height Network	Protect and maintain existing benchmarks
National Reference Frame	Connect national datums to international reference frames

Table 1 – NZ Geodetic Networks

Where they meet the requirements, existing control marks have been assigned to one or more networks. These marks are shown in Figure 1.

The geodetic programme has continued to focus on the densification of the Order 5 (cadastral horizontal control) network that is directly used by cadastral surveyors for the location of property boundaries. These marks are typically existing cadastral marks, so are also used to provide control for ongoing work to improve the digital representation of NZ's spatial cadastre. There has been a secondary focus on providing additional Order 5 control in primarily urban areas where the existing control was not sufficiently accurate to meet the requirements of the standards.

During this period, 10,000 marks have been added or upgraded in the NZGD2000 Order 5 network. All of these have been surveyed using various GNSS techniques. The extent of the Order 5 network is shown in Figure 1.

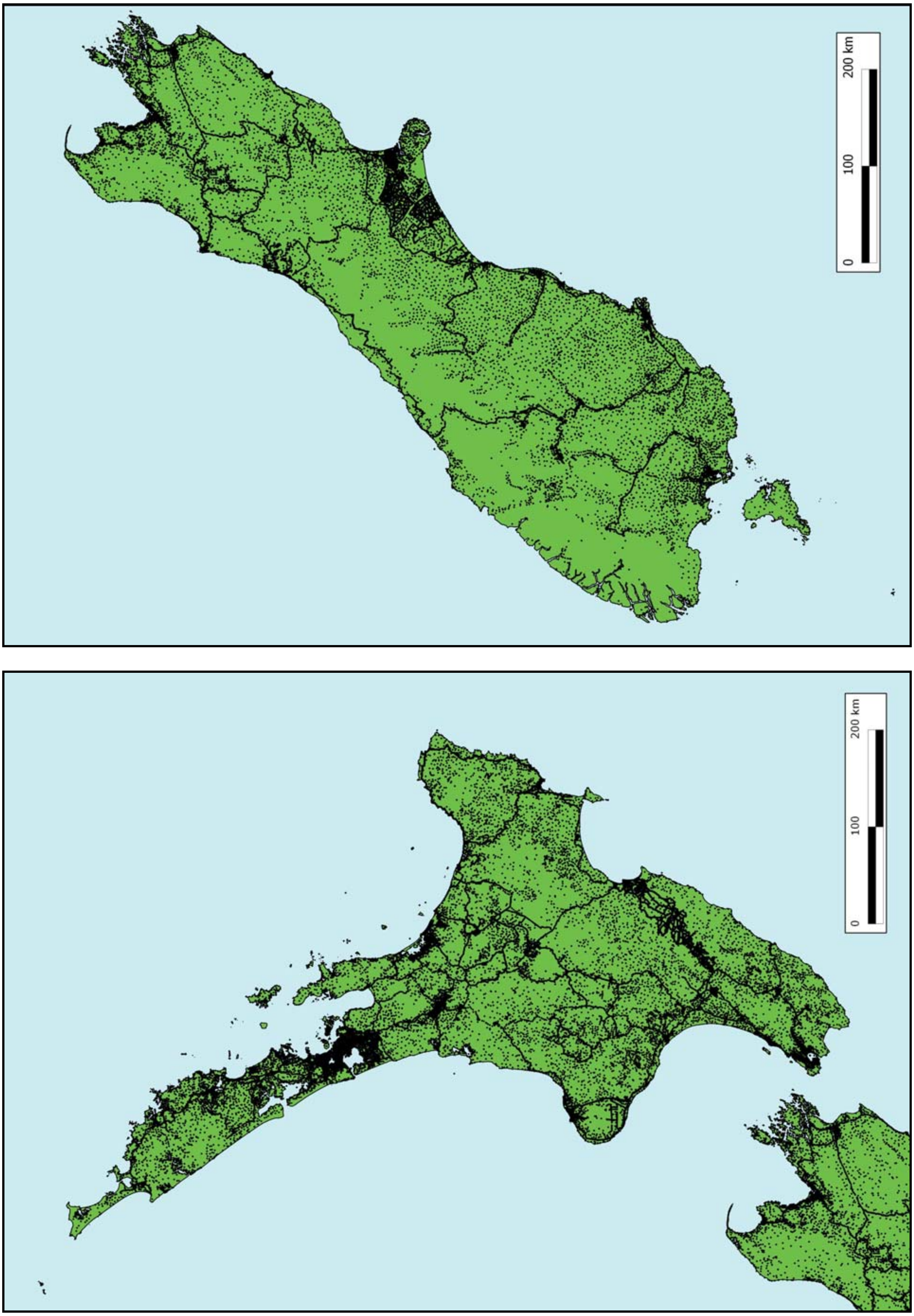

Figure 1 – NZ Control Marks

Approximately 57,000 Order 5 marks, which had been coordinated from historical triangulation and control traverses, did not meet the requirements of the standards and were downgraded to Order 6. These marks are not part of any survey control networks, although they are still valuable to surveyors due to their high density and intervisibility.

2.2 Antarctica Control Surveys

The official New Zealand geodetic datum for use in the Ross Sea Region is the Ross Sea Region Geodetic Datum 2000 (RSRGD2000). To facilitate consistent topographic mapping and the integration of geospatial datasets four projections have been developed throughout the Ross Sea Region:

- McMurdo Sound Lambert Conformal 2000 (MSLC2000)
- Borchgrevink Coast Lambert Conformal 2000 (BCLC2000)
- Pennell Coast Lambert Conformal 2000 (PCLC2000)
- Ross Sea Polar Stereographic 2000 (RSPS2000)

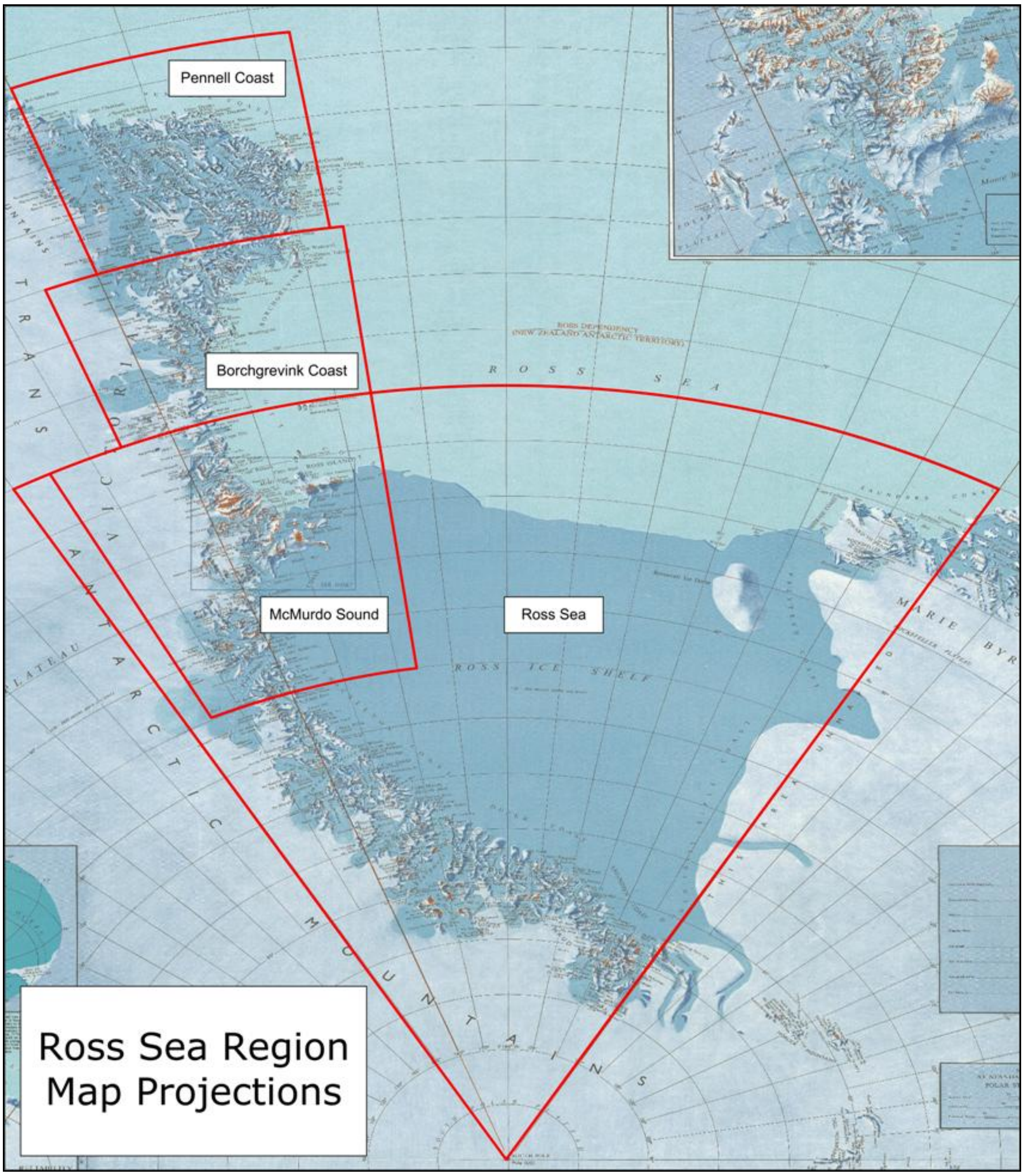

Figure 2 – Ross Sea Region Projections

LINZ has produced vector topographic data at 1:50,000 scale for the Darwin/Hatherton Glacier region of Antarctica. The ALOS PRISM satellite imagery was taken during the 2006/07 season and the survey work for this data was undertaken between 2007 and 2010.

LINZ has set up three GNSS continuously operating reference stations (CORS) at Scott Base, Cape Roberts and Butcher Ridge. The Cape Roberts and Butcher Ridge sites were installed in co-operation with the US Geological Survey, Ohio State University and UNAVCO. LINZ also operates the Cape Roberts tide gauge and supports the operation of the Scott Base tide gauge. These stations and gauges are part of POLENET, The Polar Earth Observing Network.

For the 2009/10 season LINZ supported a POLENET/USGS project, transporting an absolute gravimeter to Ross Island. Absolute gravity was observed at several sites around Ross Island, along with a number of relative ties including to Cape Roberts (see section 2.5).

2.3 New Zealand Vertical Datum

In August 2009 LINZ implemented the New Zealand Vertical Datum 2009 (NZVD2009), the world's first national vertical datum that is based on a gravimetric geoid, New Zealand Quasigeoid 2009 (NZGeoid2009, Figure 3). Heights in terms of the 13 historic precise levelling based datums can be efficiently transformed to NZVD2009 using the NZGeoid2009 to a national accuracy of 0.08 m. The geoid based vertical datum also allows ellipsoidal NZGD2000 heights to be converted to their NZVD2009 normal-orthometric equivalents.

Very little planned precise levelling was carried out during the report period. In late 2010 approximately 400 km of precise levelling was commissioned in the Canterbury Plains to assist with infrastructure recovery following the MW 7.1 earthquake that occurred on 4 September 2010. Together with data from an extensive GNSS heighting survey, this will provide a useful dataset for the verification of future geoid models and gravity surveys in the South Island.

2.4 Geoid modelling

The National School of Surveying at the University of Otago compiled a detailed experimental geoid model of New Zealand utilising the KTH method developed at the Royal Institute of Technology in Stockholm (Abdalla and Tenzer, 2011). Čunderlík et al. (2010b) compiled a quasigeoid model of NZ utilising the boundary element method. This quasigeoid model was compared with the official NZGeoid2009 model for New Zealand showing a similar fit to GPS-levelling data of about 0.07 m. Tenzer et al. (2011a) applied the geopotential-value approach to estimate the average offsets of 18 local vertical datums in New Zealand relative to the adopted geoidal geopotential value W_0 using the GPS-levelling data and the global geopotential model EGM2008.

The National School of Surveying in collaboration with GNS Science compiled the first digital density model of New Zealand. The model has a spatial resolution of 1x1 arc-min and is derived from the digital geological maps QMAP and the national geological database PETLAB (Tenzer et al., 2011b).

Crustal deformation in NZ due to ocean-tide loading (Gladkikh and Tenzer, 2011), atmospheric loading (Tenzer et al., 2011c), and pole motion (Marinovich and Tenzer, 2011) were computed and analysed. Tenzer et al. (2010a) computed and analysed atmospheric gravity corrections.

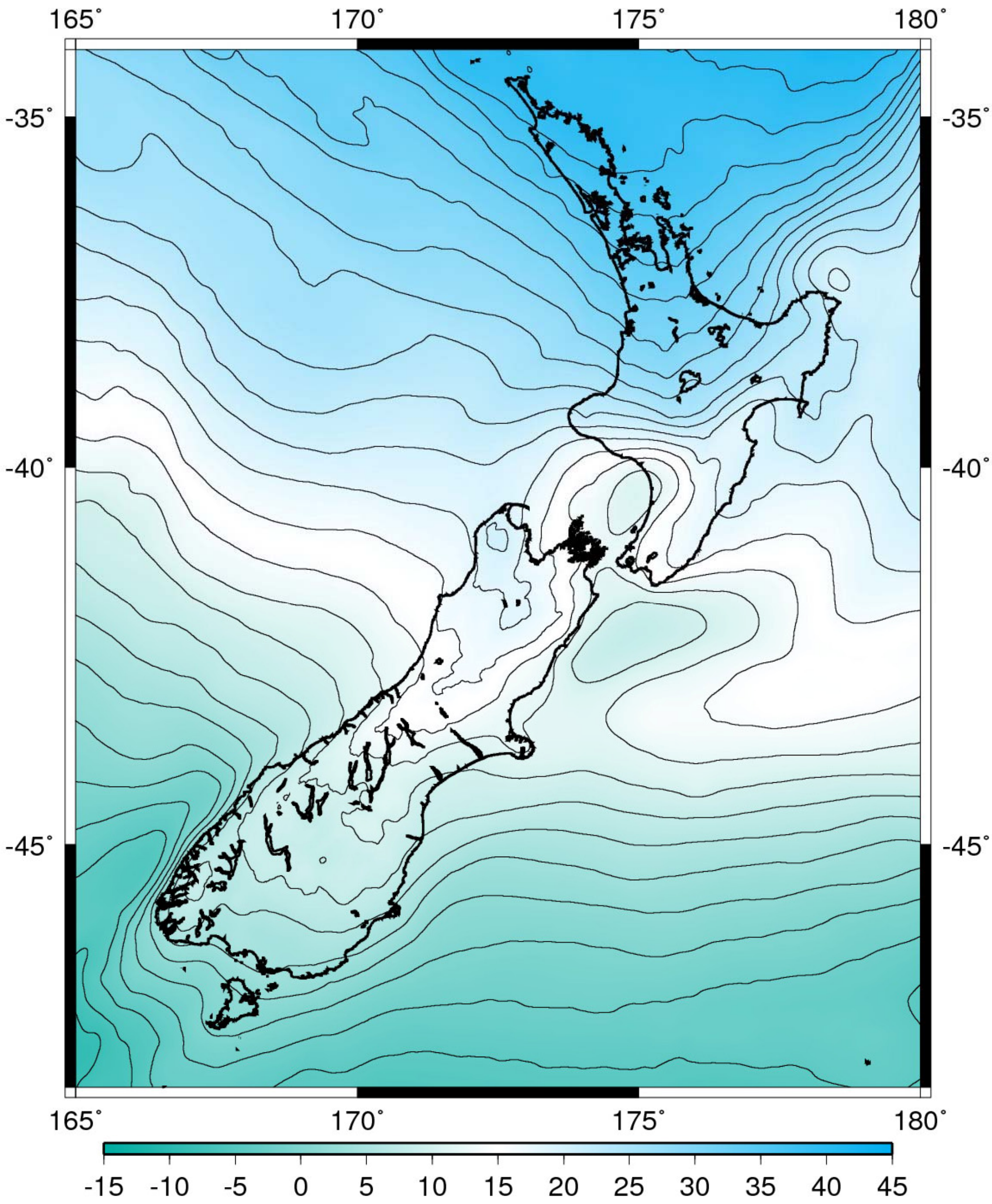

Figure 3 - NZGeoid2009 gravimetric quasigeoid (2 metre contours)

2.5 Absolute Gravity Measurements

Absolute gravity observations were acquired in November 2009 at the Scott Base and Cape Roberts gravity stations in the Ross Sea Region of Antarctica and in December 2009 at the Godley Head gravity station near Christchurch.

The observations were obtained using a FG5 gravimeter owned by the French Institut National des Sciences do l'Univers (INSU) and operated by Géosciences Montpellier, France. All stations had previously been occupied by absolute gravimeters (Scott Base in 2008, Cape Roberts in 1995, Godley Head in 1995 and 2000).

LINZ is planning to establish additional absolute gravity stations across New Zealand to provide a reliable connection to international reference frames and the proposed World Height System.

2.6 National GNSS Network (PositioNZ)

The New Zealand national GNSS network (PositioNZ) is a network of 36 continuously operating GNSS stations (Figure 4) operated in partnership with GNS Science on the New Zealand mainland and the Chatham Islands. The PositioNZ network is a sub-network of the larger GNS Science network (GeoNet) discussed in Section 3.2 (see also Figure 6). It also includes three stations in Antarctica that also form part of the POLENET project.

In late 2010, a PositioNZ upgrade programme has seen the replacement of all receivers with Trimble NetR9 models. GLONASS data will start to be provided from the first quarter of 2011. Five sites have been installed since 2007 (shown in Figure 4):

- Methven (METH), near the centre of the South Island,
- Puysegur Point (PYGR), on the south-west coast of the South Island,
- Kaitaia (KTIA), at the far-north of the North Island,
- Warkworth (WARK), in the north of the North Island which is co-located with VLBI operated by the Auckland University of Technology (see section 3.8), and
- Chatham Island North (CHTI), on the northern part of Chatham Island.

The development of the provision of one-second real-time GNSS has continued, and now all stations are capable of streaming this data. The only exception to this is the very isolated station at Puysegur Point, which will not be upgraded due to cost and lack of demand for the data. This one-second real-time GNSS data is provided in the RTCM v3.1 format using the NTRIP protocol.

The PositioNZ network also provides thirty-second RINEX data for each station via the LINZ web site (www.linz.govt.nz/positionz). Further enhancements that are being developed include an online GPS processing service and the provision of one-second RINEX data captured from the real-time streams.

2.7 National Standard Port Sea Level Data

LINZ, as NZ's National Hydrographic Authority, collects and analyses sea level data for the production of official tide-related nautical information, including daily tide predictions and tidal levels for 16 standard ports (Figure 5).

The sea level data recorded at these standard ports is supplied at no cost by the port companies and regional councils that are the owner/operators of the equipment at these sites. Sea level measurements are made with a variety of technologies including downward looking radar and acoustic devices, underwater pressure sensors and stilling well/float with encoder. All measurements are recorded digitally mainly at intervals of one or five minutes. Calibration checks continue to remain the responsibility of the tide station operators.

LINZ retains all sea level data in a database and contributes information to international data archives such as the University of Hawaii Sea Level Center and the Permanent Service for Mean Sea Level on a regular basis.

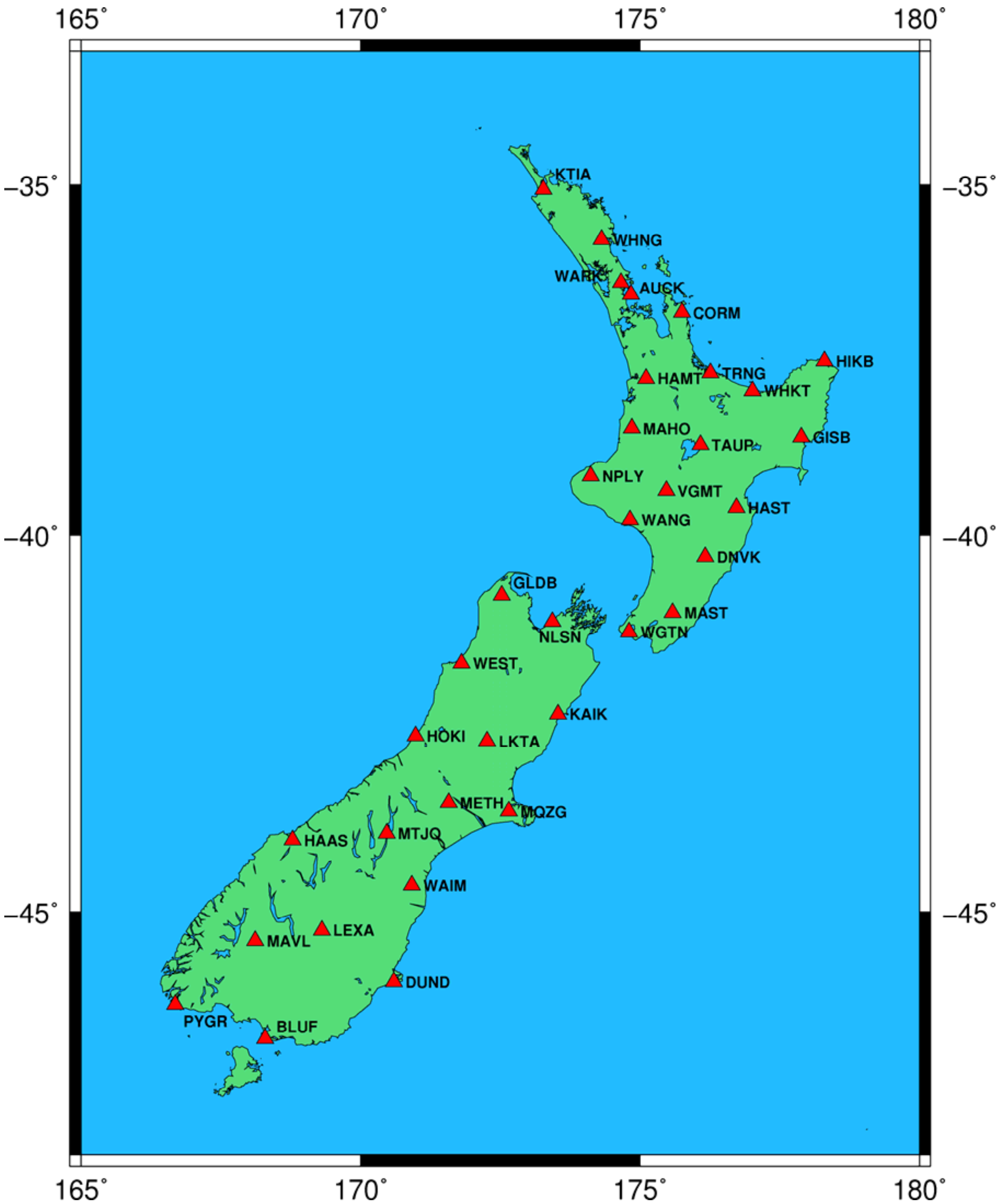

Figure 4 –NZ national GNSS network – PositioNZ

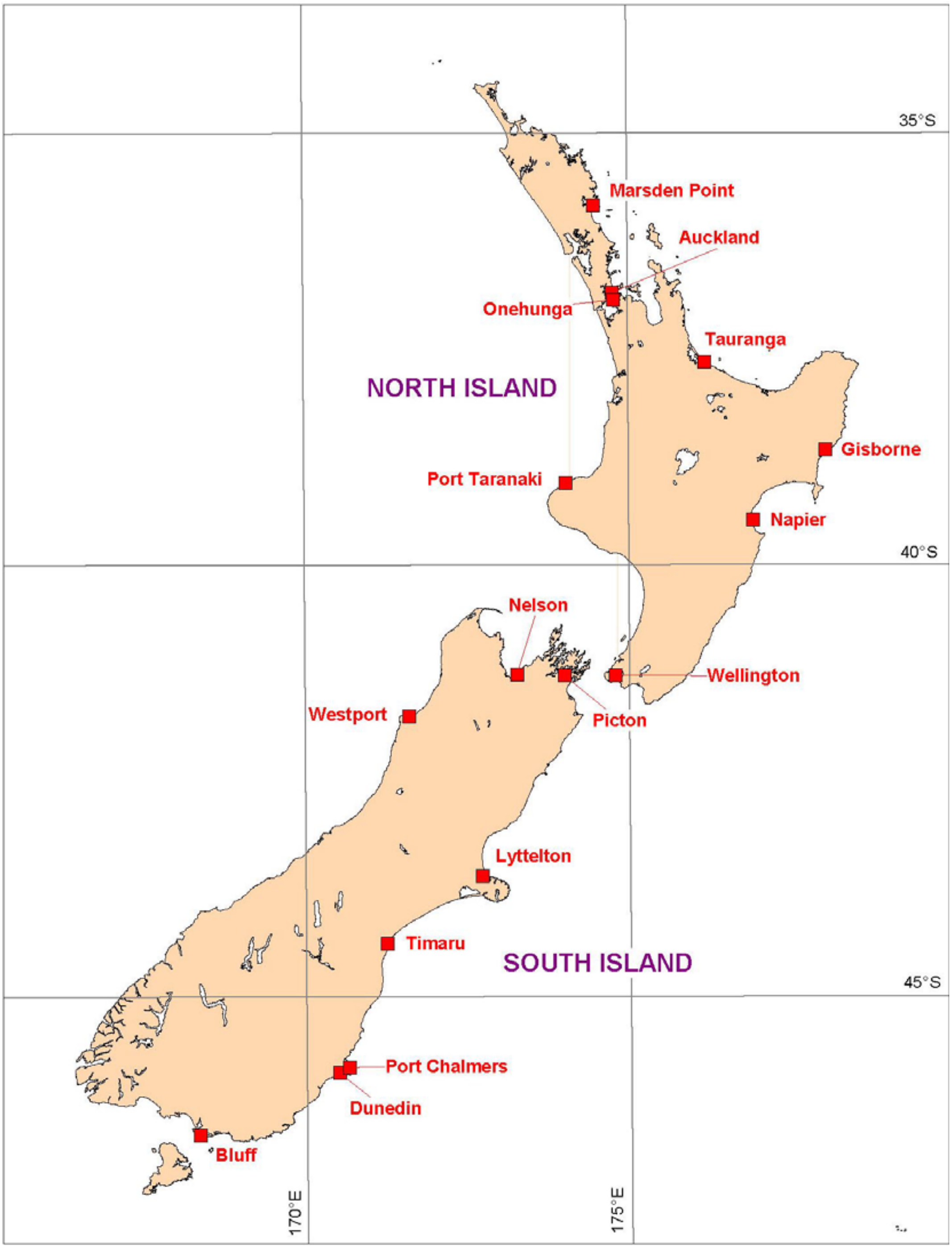

Figure 5 –New Zealand standard ports

3 Geodynamic Studies

3.1 Introduction

Geodetic methods are used to measure the deformation of the Earth's crust in the New Zealand region. This is motivated by the country's location on the boundary of the colliding Australian and Pacific tectonic plates. It is this collision that gives rise to the landforms of New Zealand and the associated earthquake and volcanic hazards. Virtually all our geodetic measurements are now carried out using GPS and other space-based methods. We continue to observe some points established during older terrestrial surveys but the majority of the GPS points are at new, more easily accessible sites. For deformation research we now use repeated and continuous GPS measurements almost exclusively, rather than a mix of GPS and older terrestrial measurements.

In New Zealand, geodynamic studies using geodetic methods are principally undertaken by GNS Science (GNS) and Otago University (OU). In the period 2007-2010 we have continued to collect GPS campaign measurements throughout the country; we have made major advances in interpreting the resulting data in terms of tectonic models; we have made major progress in developing the continuous GPS (cGPS) network; we have significantly increased our use of interferometric synthetic aperture radar (InSAR) methods; and we have made measurements to characterize two major earthquakes, as well as an additional quake in early 2011.

3.2 Continuous GPS network

The New Zealand continuous GPS network at 31 May 2007 consisted of 92 stations. At 31 May 2011 it consists of 183 stations (Figure 6). The increase is mainly due to the GeoNet project (www.geonet.org.nz), which is operated by GNS on behalf of the Earthquake Commission (EQC), a government-owned geohazards insurance company. The GeoNet stations are concentrated on the east coast of the North Island above the Hikurangi subduction interface, and in the Taupo Volcanic Zone, a region of back-arc rifting and volcanism in the central North Island. In 2010 the GeoNet project received renewed funding for an additional 5 years from 2011-2016, and 30 new cGPS stations in the northern South Island are planned over that period.

3.3 Interferometric synthetic aperture radar (InSAR) techniques

In addition to studying deformation using GPS, we have, since 1999, been experimenting with the use of interferometric synthetic-aperture radar (InSAR). Because of widespread vegetation and steep terrain, the technique is more of a challenge in New Zealand than in some other parts of the world, particularly at the C-band (~5 cm) wavelengths we had been using up to 2007. Since 2007 we have made major use of the Japanese ALOS/PALSAR L-band (~24 cm) satellite for monitoring deformation in the Taupo Volcanic Zone, and for measuring and interpreting coseismic and postseismic deformation from earthquakes in the Fiordland and Canterbury regions. Shorter wavelength C-band data from the European Envisat satellite and X-band data from the Italian Cosmo-SkyMed satellite have also been useful in the coseismic studies, and for testing InSAR's capabilities at monitoring deformation in the volcanic field on which the city of Auckland is built (Samsonov et al., 2010a).

3.4 Volcano deformation

The GeoNet project has installed a substantial number of cGPS stations to measure deformation on and around Mt Ruapehu, which last erupted in 1995 and 1996. GeoNet has also instrumented two calderas, Taupo and Okataina, which are located between Mt Ruapehu and the Bay of Plenty coast to the north. GPS time series from these sites have shown a number of interesting signals, only some of which have been written up and published at this stage (e.g., Hole et al., 2007; Peltier et al., 2009a).

3.5 Tectonic plate motion and plate-boundary earthquakes

A magnitude MW 7.8 earthquake on the Puysegur subduction interface beneath the Fiordland region of SW New Zealand occurred on 15 July 2009. The earthquake was mostly offshore but was well enough recorded by campaign and continuous GPS and ALOS interferometry to provide good detail of the earthquake source parameters (Beavan et al., 2010a).

GNS participates with Ohio State University in GPS observations at several Pacific islands. The MW 8 Tonga-Samoa earthquake and tsunami of 29 September 2009 was well recorded by cGPS sites and campaign GPS sites in the region. The GPS data, together with tsunami wave recordings, gave the surprising result that the event consisted of two nearly simultaneous magnitude 8 earthquakes, one within the downgoing Pacific Plate and the other on the subduction interface between the Pacific Plate and the over-riding Tonga microplate (Beavan et al., 2010b).

A MW 7.1 earthquake occurred on a previously unknown fault beneath the Canterbury Plains on 4 September 2010. Only a few high-accuracy campaign GPS sites were located close to the earthquake source. However, the combination of those sites, medium- and far-field high accuracy sites and a substantial number of lower accuracy sites installed for land survey purposes, together with ALOS and Envisat InSAR data, have allowed the complex earthquake source to be well characterized (Beavan et al., 2010c).

A major MW 6.3 aftershock of the September event occurred on 22 February 2011 almost beneath Christchurch, New Zealand’s second-largest city. This caused more than 180 fatalities and massive destruction in the city. The source of this earthquake has also been well characterized geodetically using GPS and InSAR data. Both the September and February earthquakes have had major impact on the geodetic infrastructure in the region, in addition to their other effects.

3.6 NZ-wide deformation and tectonic modelling of New Zealand

Tectonic plate motion results in deformation within most of the New Zealand landmass, at rates up to 50 mm/yr. Repeated GPS observations from more than 800 sites throughout New Zealand have been combined using two methods: (1) finite-element model techniques to produce velocity and strain-rate maps of the whole country, and (2) elastic block models to understand the kinematics of the plate boundary deformation zone. This work was reported in our 2003-2006 report; since then we have applied these results to better understand the coupling between the downgoing Pacific Plate and the overriding Australian Plate at the Hikurangi subduction zone along the east coast of the North Island (Wallace et al., 2009a), and to better understand how fault systems interact across Cook Strait between the North and South islands.

The continuous network across the Southern Alps (Figure 6) has continued to operate well and has produced estimates of vertical rate of up to 6 mm/yr that have now been published (Beavan et al., 2010d).

3.7 Slow slip events at Hikurangi subduction interface

Considerable additional work has been completed and published on slow slip events on the Hikurangi subduction interface (e.g., McCaffrey et al., 2007; Wallace and Beavan, 2010). Our increased understanding of coupling on the subduction interface, and the role of slow slip events in releasing that coupling, has been incorporated into the latest version of the New Zealand National Seismic Hazard Model.

3.8 VLBI

An initiative led by Auckland University of Technology (AUT) to build several radio telescopes suitable for VLBI in New Zealand has been making progress. Though the primary purpose is for astrophysical research, the radiotelescopes are also intended to be useful for geodetic purposes. A first radiotelescope has been installed at Warkworth (WARK in Figure 6) and has had an initial tie to the cGPS network via a cGPS site installed nearby. Some initial geodetic baseline measurements have been carried out.

3.9 Sea level science

A great deal of work has been done in developing a regional picture of sea level in New Zealand. With the possible exception of Wellington, it has become clear that there is little or no variation in relative sea level change around the New Zealand coast. On average, relative sea level change at all sites, as determined from records spanning at least 50 years, is +1.7 ±0.1 mm/yr. Recent analyses show no evidence of any acceleration in the rate of sea level rise.

3.10 Global international cooperation

As well as studying deformation problems related to New Zealand, we participate in a number of global international efforts. Most important of these is the provision of GPS data to the International GPS Service (IGS) from stations AUCK (near Auckland) and CHAT (Chatham Island). From there the data are used by a number of analysis centres in the calculation of precise GPS orbits. Data from the New Zealand IGS stations have also been used by a number of investigators in plate motion studies. During the reporting period, several other New Zealand sites have been added to the IGS network. These are NIUM (Niue Island), CHTI (a second, more geologically stable, site on Chatham Island), WGTN (Wellington), MQZG (near Christchurch) and DUND (near Dunedin).

We are also contributing to the TIGA pilot project which aims to use continuous GPS to measure vertical tectonic motion at tide gauge sites in order to correct long-term sea level records for ground motion – this is an important issue for global sea-level rise.

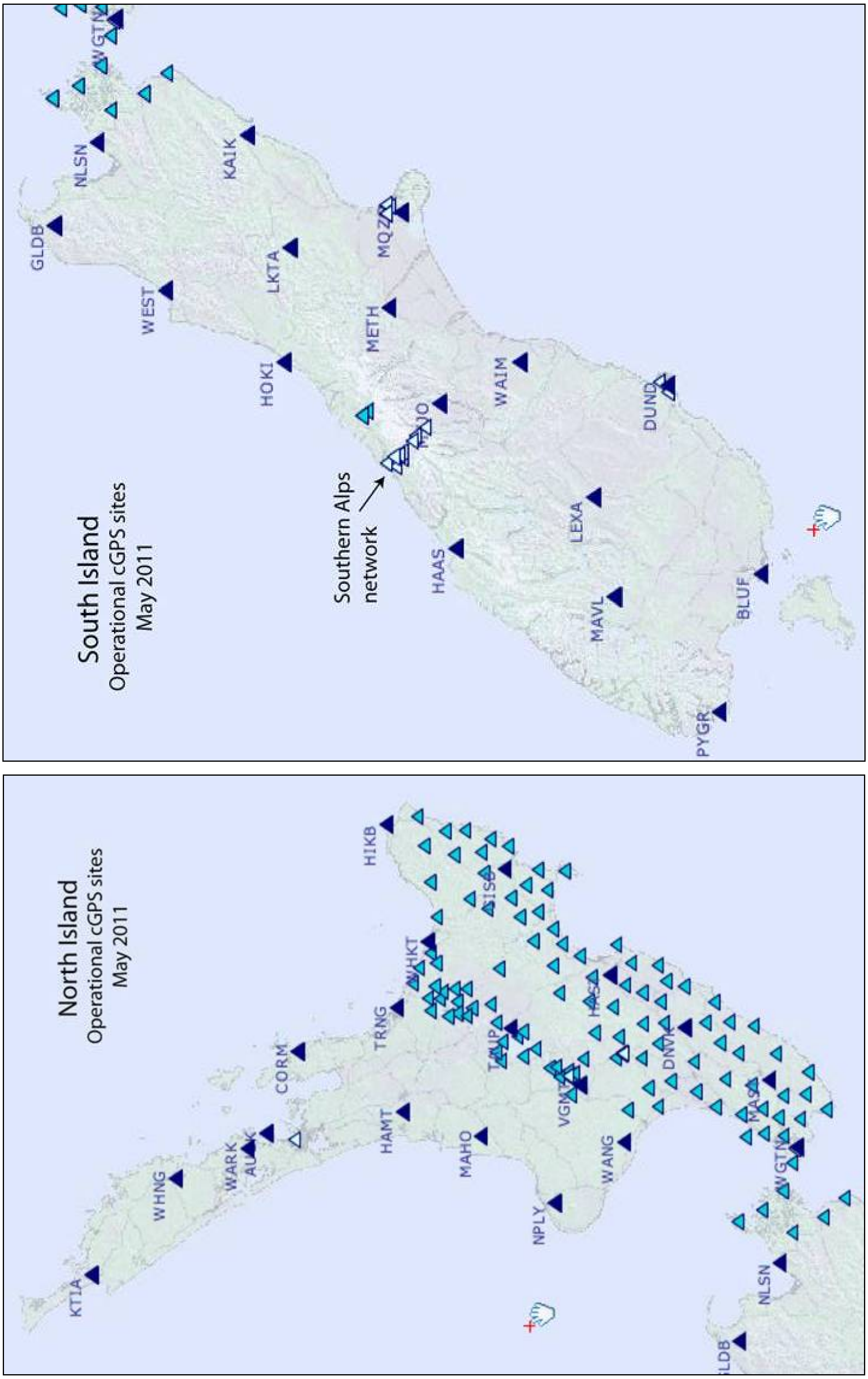

Figure 6 – Continuous GPS network of 183 stations, as at May 2011. Dark blue sites with labels are those that form the LINZ PositioNZ network, and light blue sites form the GeoNet tectonic and volcanic networks. Five offshore sites are not shown (2 on Chatham Island, 1 each on Niue, Samoa and Vava'u). 8 landslide monitoring sites are included in the 183.

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