Toitu te whenua
Land Information
New Zealand

NEW ZEALAND GEODESY 2003-2006

National Report for the General Assembly of the International Union of Geodesy and Geophysics: Perugia, Italy 2007

Geosciences Standing Committee of the Royal Society of New Zealand

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Contents

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New Zealand Geodesy 2003-2006: National Report for the General Assembly of the International Union of Geodesy and Geophysics. Perugia, Italy, July 2007

1 Introduction

This report presents the geodetic activities in New Zealand for the period 2003–2006. During this period Land Information New Zealand has continued with the expansion of the geodetic networks that comprise the national geodetic datum NZGD2000, installed a continuous GNSS network, and developed a national quasigeoid model. Geodynamic studies have continued in New Zealand, principally by the GNS Science, with major focuses being the GeoHazards and GeoNet projects.

This report has been compiled by the Surveyor-General, Land Information New Zealand, on behalf of the Geosciences Standing Committee of the Royal Society of New Zealand for the General Assembly of the International Union of Geodesy and Geophysics, Perugia, Italy, July 2007. The report is a compilation of material provided by:

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

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2 Geodetic Control Networks

2.1 *New Zealand Control Surveys*

The official New Zealand 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.

Control networks have continued to be developed and surveyed to increase the coverage and retain the accuracy of NZGD2000. The fundamental zero-order network of NZGD2000 is now provided by the PositioNZ continuous GNSS stations (described in Section 2.4).

During this period one second-order mark, 300 third-order marks and 166 fourth-order marks have been added to the respective intermediate geodetic networks. These networks are shown in Figures 1 and 2 for the North and South Islands respectively.

The majority of the emphasis of the geodetic programme has been put into the densification of the fifth-order network that is directly used by cadastral surveyors for the location of property boundaries. The majority of these marks were existing survey marks surveyed in terms of the previous datum, New Zealand Geodetic Datum 1949 (NZGD49). In areas where no suitable marks were available new marks were installed and surveyed.

During this period, 34,915 marks have been added or upgraded in the NZGD2000 fifth-order network. Almost 24,000 of these marks have had their positions readjusted in terms of NZGD2000 using existing control traverses. The remaining 11,000 marks have been surveyed using various GPS techniques. The extent of the fifth-order network is shown in Figures 3 and 4.

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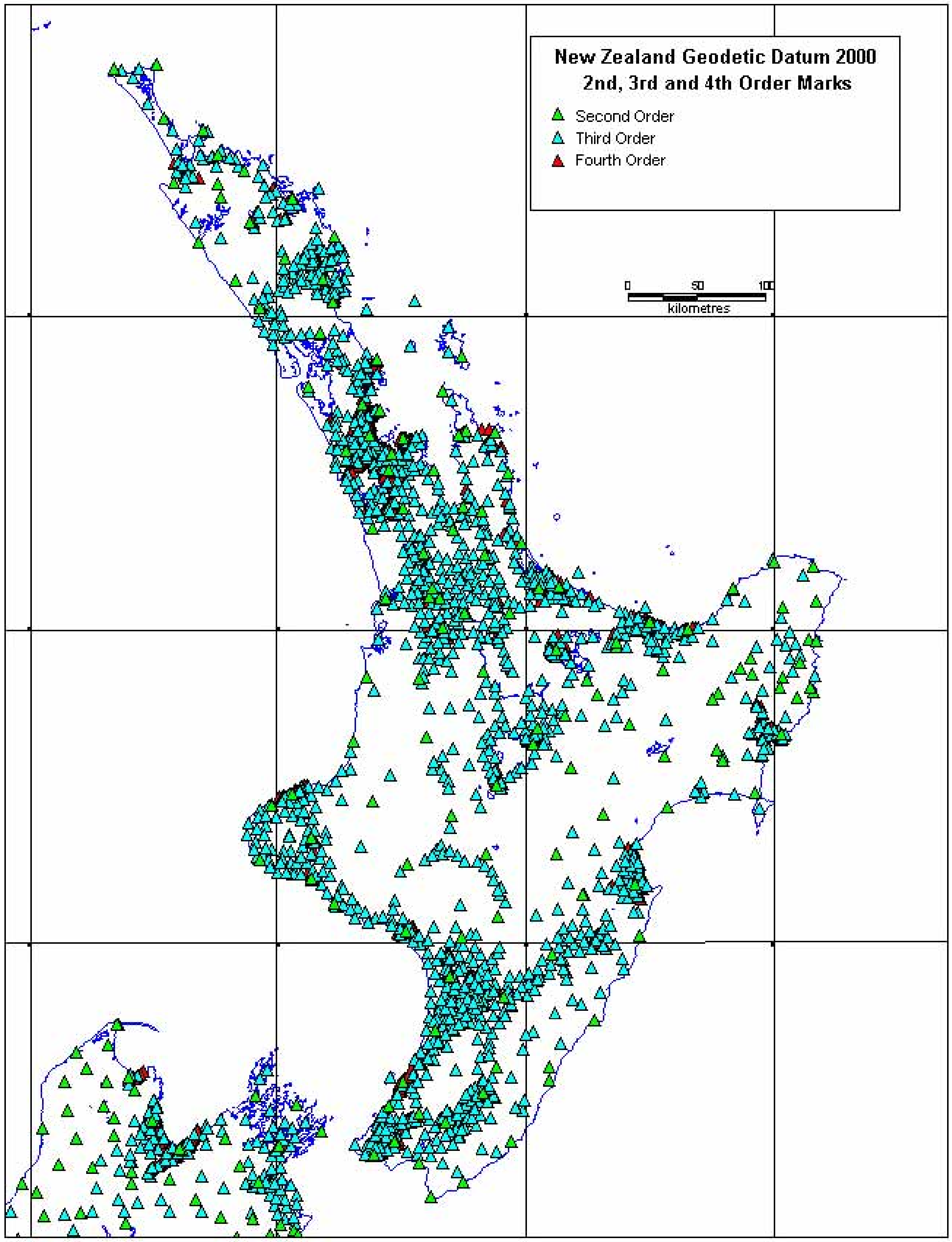

Figure 1 North Island second, third and fourth-order NZGD2000 geodetic networks

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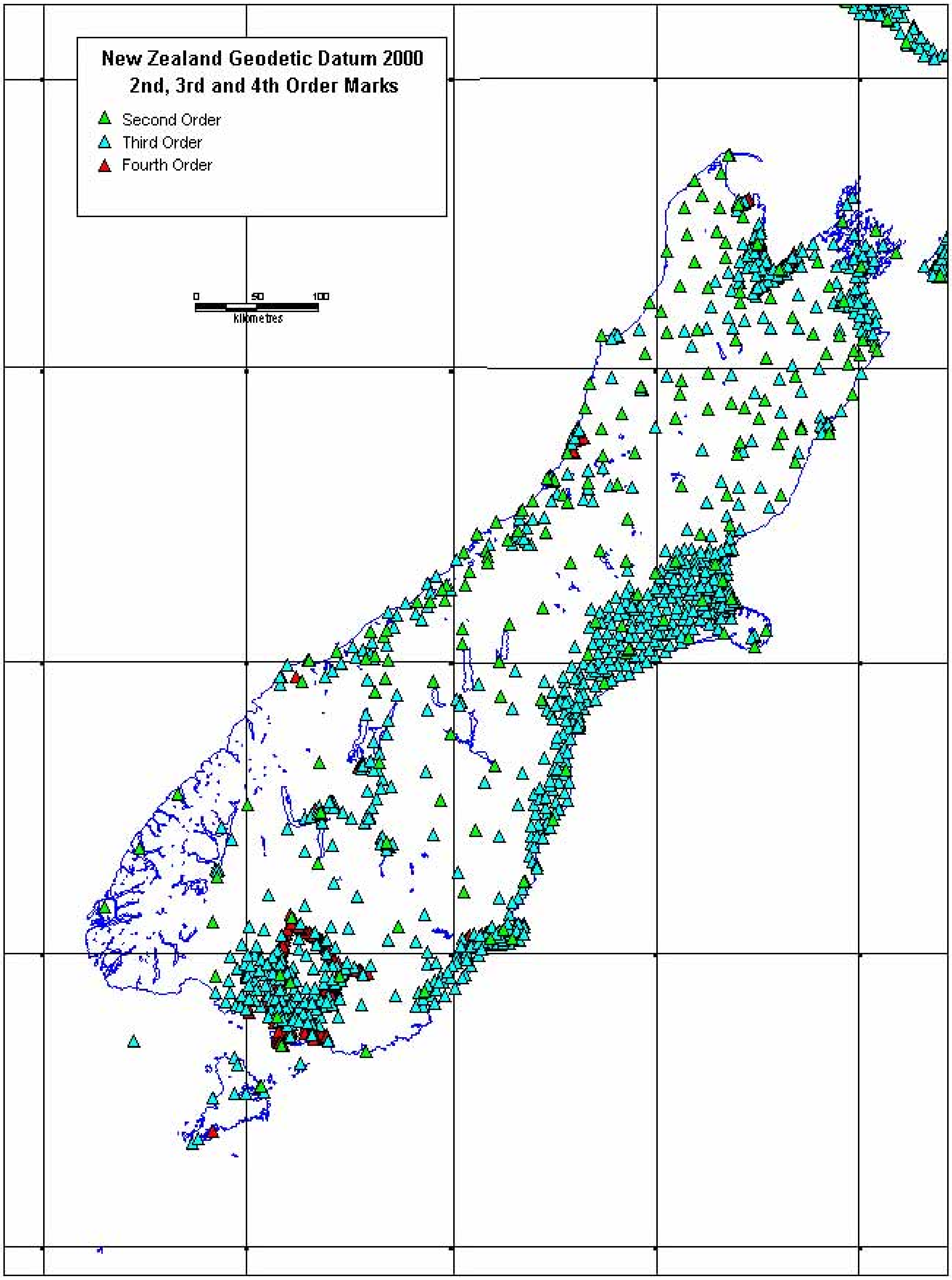

Figure 2 South Island second, third and fourth-order NZGD2000 geodetic networks

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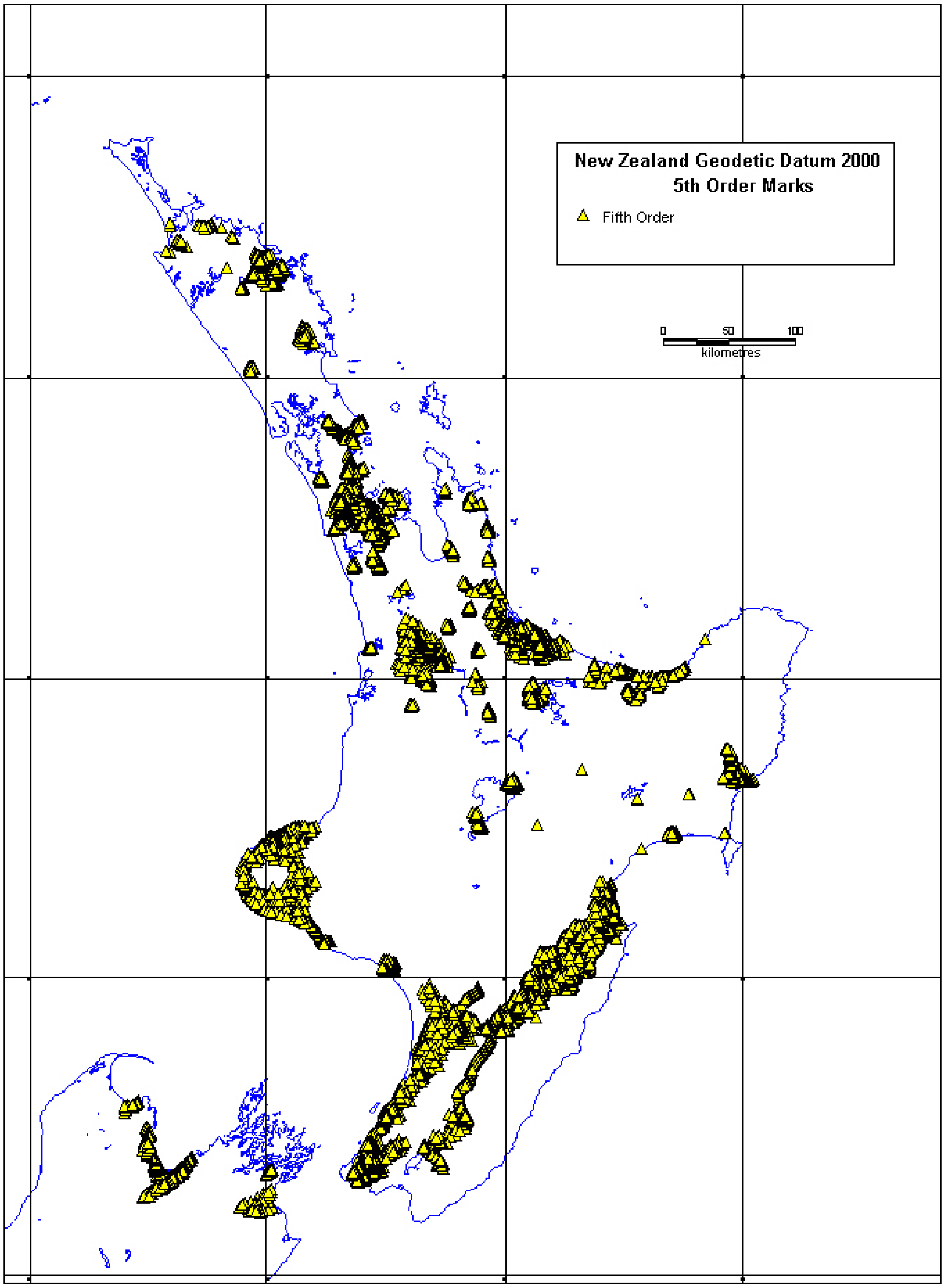

Figure 3 North Island fifth-order NZGD2000 geodetic networks

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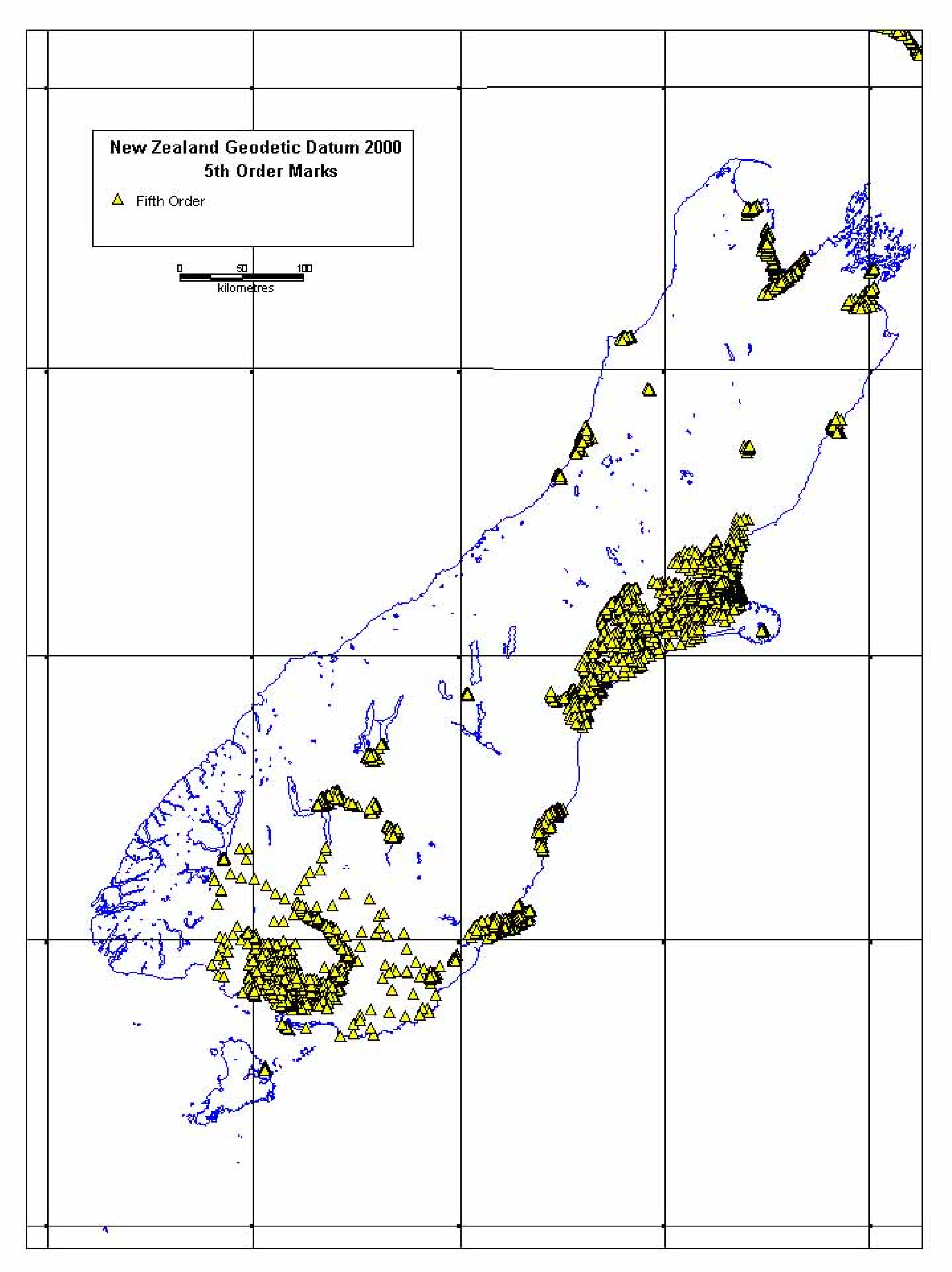

Figure 4 South Island fifth-order NZGD2000 geodetic networks

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2.2 *Ross Sea Region (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). This datum was implemented in 2000 using GPS observations acquired over the previous 5-6 years to support on-going mapping requirements. A significant portion of the data was sourced from a joint United States Geological Survey and Ohio State University scientific project (in which LINZ participated) to study uplift and deformation of the Trans-Antarctic Mountains (TAMDEF).

Since its inception the extent and density of the RSRGD2000 has increased with the addition of new TAMDEF observations and more recently observations from the LINZ Antarctic programme. The RSRGD2000 now comprises approximately 400 marks (of various orders) throughout the Ross Sea Region. The zero to third-order marks are shown in Figure 5.

LINZ also supports the operation of tide-gauges and collocated continuous GNSS receivers at Scott Base (on Ross Island) and at Cape Roberts.

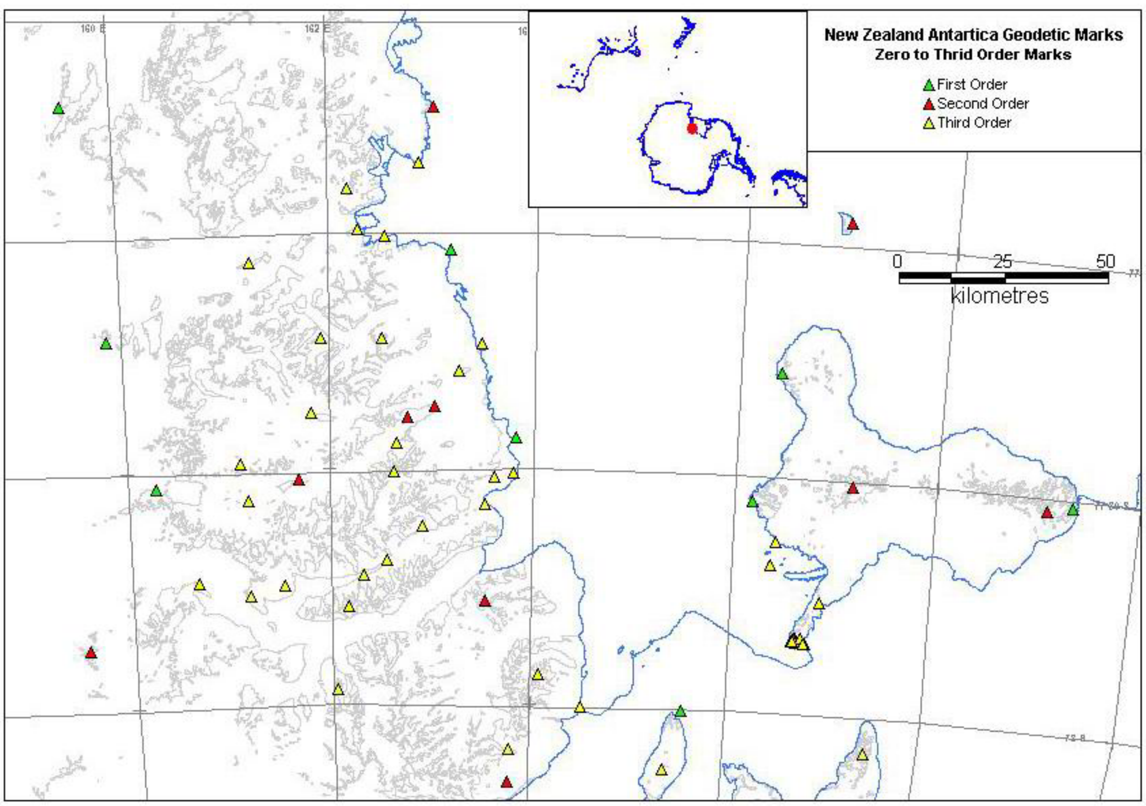

Figure 5 RSRGD2000 first, second and third-order geodetic networks

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2.3 *New Zealand Vertical Datum and Geoid Model*

During this period Land Information New Zealand has computed a gravimetric quasigeoid model for the New Zealand continental shelf region (NZGeoid05) in conjunction with the Western Australian Centre for Geodesy at the Curtin University of Technology, Perth, Australia (Figure 6). When used in conjunction with a datum offset the NZGeoid05 can be used to transform ellipsoidal heights in terms of NZGD2000 into the each of the 13 normal-orthometric precise-levelling datums that are currently used for heighting in New Zealand.

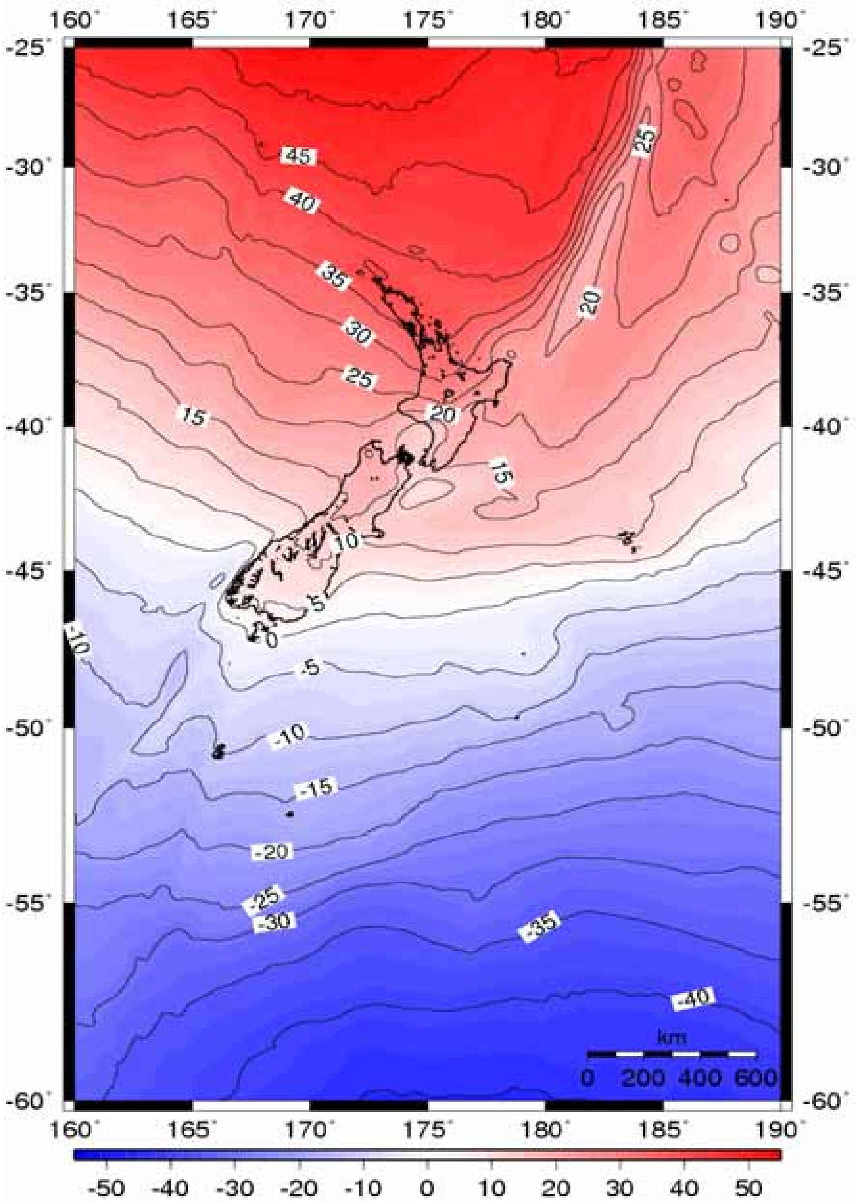

Figure 6 The NZGeoid05 gravimetric quasigeoid (metres)

Precise levelling activities for the purpose of vertical datum development have been limited to a small number of observations to relate the tide-gauge origins of the normal-

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orthometric height systems to NZGD2000 and a 90 km line in the northern South Island. This is because a new vertical datum is under development which will use a gravimetric geoid and GNSS derived ellipsoidal heights to transfer heights rather than the conventional practise of adjusting precise-levelling observations in relation to tide-gauge derived estimates of sea level. This approach is discussed more fully in Amos *et al*. (2005) and Amos and Featherstone (2003).

2.4 *National GNSS Network (PositioNZ)*

The implementation of a national GNSS network (PositioNZ) in partnership with GNS Science was completed in mid-2005 with the installation of 30 continuously-tracking GPS stations (Figure 7). The PositioNZ network is a sub-network of the larger GNS Science network discussed in Section 3.2.

More recently, a PositioNZ upgrade programme has seen the replacement of all receivers to Trimble NetRS models. In addition two more sites are planned for the network by the end of 2007 (Puysegur Point, on the south-west coast of the South Island; and Kaitia, at the far-north of the North Island).

The PositioNZ network currently 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 (scheduled for completion at the end of 2007) and the provision of one-second data from for real-time positioning applications. Ten sites are currently streaming one-second real-time GPS data for testing purposes.

2.5 *National Standard Port Sea Level Data*

LINZ is New Zealand's national regulatory authority responsible for the production of nautical charts and publications. LINZ continues to contract out most of the collection and processing of hydrographic survey and chart production to LINZ accredited providers. The analysis of sea level data and production of official tide predictions, an activity that was formerly contracted out, is now carried out within LINZ.

At present, sea level data recorded at 17 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. Data is recorded digitally at all but one of these sites and the quality of these data is much improved compared to earlier analogue systems. Calibration checks continue to remain the responsibility of the tide station operators.

A standard for sea level information has been developed (presently in draft form) to define what official sea level information LINZ must provide to meet its national and international responsibilities and to provide the minimum requirements for that information. The use of this standard will ensure that official sea level information is timely and accurate and that a complete record of sea level information is maintained for each tidal station.

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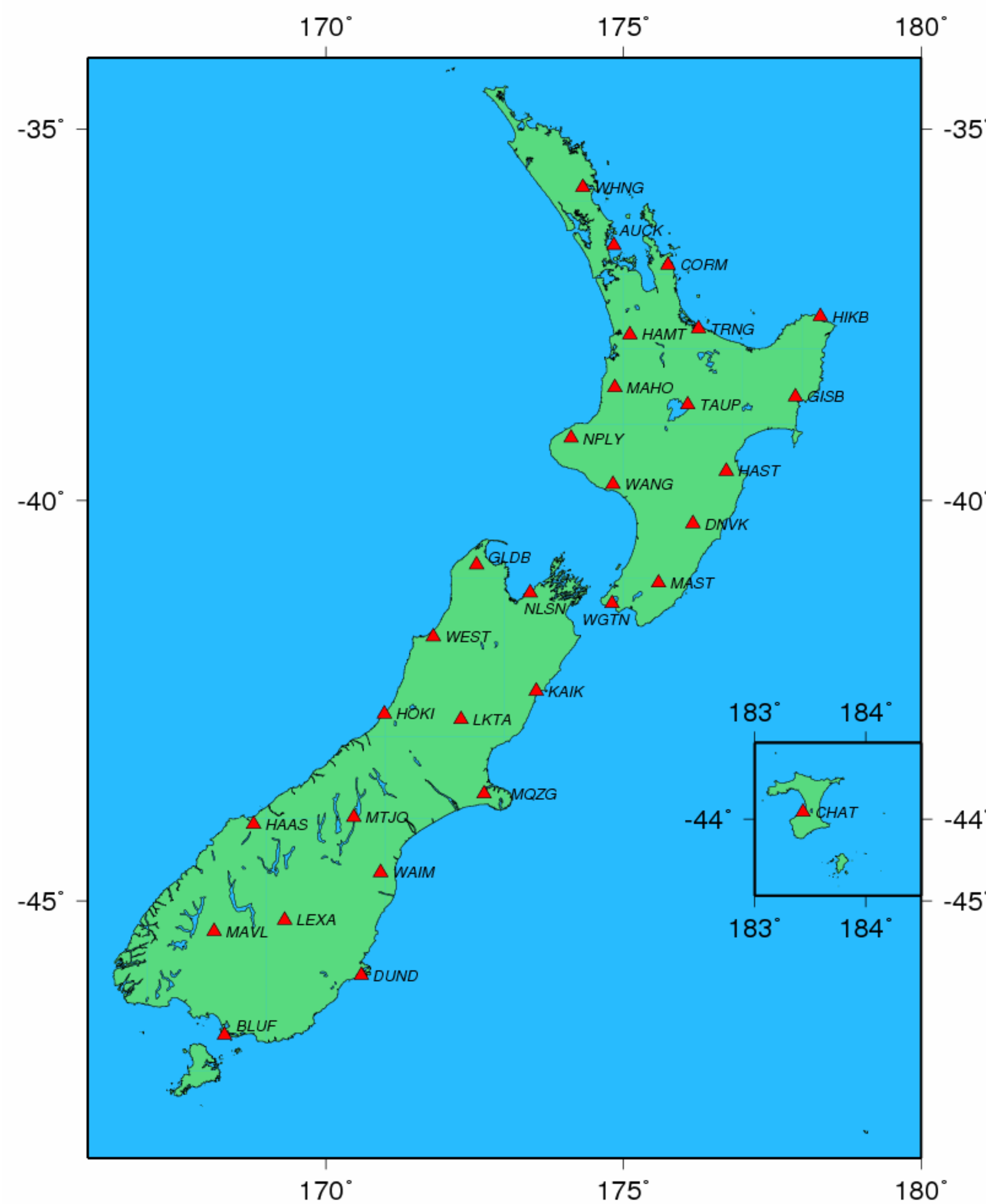

Figure 7 NZGD2000 zero-order stations (PositioNZ GNSS stations)

2.6 *Absolute Gravity Measurements*

No absolute gravity observations have been made in New Zealand during the 2003-2006 reporting period.

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3 Geodynamic Studies

3.1 *Introduction*

In New Zealand, geodynamic studies using geodetic methods are principally undertaken by GNS Science (GNS) and Otago University (OU). In the period 2003-2006 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; and we have made major progress in developing a continuous GPS (CGPS) network.

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.

3.2 *Continuous GPS network*

The New Zealand continuous GPS network at May 2002 consisted of 16 stations. Since then, 25 new nationally distributed CGPS stations have been installed and operated by GNS under contract to Land Information New Zealand (LINZ). A further 49 CGPS stations have been installed as part of the GeoNet project, 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. A further two CGPS stations have been added to the Southern Alps network. Including the pre-existing stations, there were 92 CGPS stations operating in New Zealand as at 31 May 2007 (Figure 8). This number is continuing to grow as more GeoNet stations are installed.

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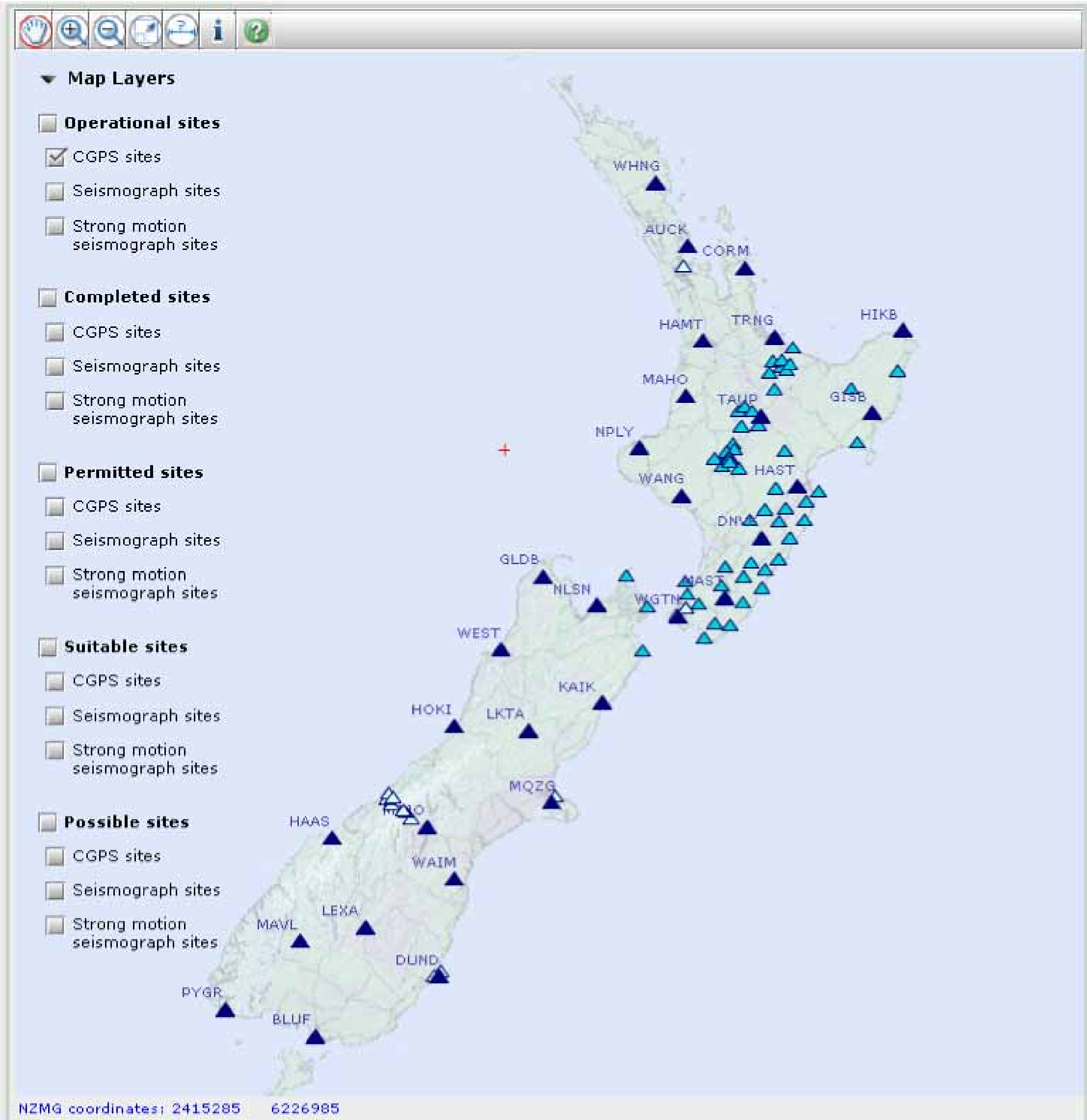

Figure 8 Continuous GPS network of 92 stations, as at May 2007. Sites labelled are those that form the LINZ PositioNZ network

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 generally available up to the present. We are looking forward to the availability of L-band (~ 25 cm) data from recently launched and planned satellites to make further progress in this work.

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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 are so far too short for robust conclusions to be drawn from the data.

3.5 *Tectonic plate motion and plate-boundary earthquakes*

We participate with Ohio State University in GPS observations at several Pacific islands. The M_W 7.9 Tonga earthquake of 3 May 2006 was detected at some of our sites, and a preliminary estimate of the fault plane of the earthquake has been determined using GPS and teleseismic data. Our preliminary results are that the earthquake was a steeply dipping rupture within the upper part of the descending Pacific Plate, rather than an interplate rupture at the subduction interface. Such studies have a bearing on the likelihood of large tsunamigenic earthquakes at plate boundaries like Tonga-Kermedec, where the prevailing wisdom is that huge tsunamigenic earthquakes are unlikely to occur.

The M_W 8.1 Macquarie earthquake of 23 December 2004 was detected at continuous GPS sites throughout New Zealand. We are still working to see whether the small displacements observed can give us information about which fault plane ruptured in the earthquake.

The M_W 7.2 Fiordland earthquake of 21 August 2003 was captured by a network of about a dozen campaign GPS sites that had been observed 2.5 years before the earthquake and were re-observed a few weeks afterwards. Initial interpretations were that the rupture was on the subduction interface, but later work has suggested that the rupture was in fact within the subducting Australian Plate. We continue to work on this so-far unresolved issue. The interpretation is complicated by the fact that the earthquake was close to the coast so that all our data are to one side of the epicentre. Use of these data to help design a way to incorporate coseismic deformation into the NZ geodetic datum is described elsewhere in this report.

3.6 *NZ-wide deformation, dynamic datum, 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 finite-element model techniques to produce velocity and strain-rate maps of the whole country (see our 2003 report for examples). An earlier version of these deformation models was used in LINZ's semi-dynamic datum, NZGD2000. During the last couple of years we have done some work on the integrity of NZGD2000, both in terms of the accuracy of the deformation model, and the accuracy of ITRF96 on which NZGD2000 is based. This has led us to suggest that NZGD2000 will need to be updated within a few years if its design accuracy is to be maintained.

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The nationwide campaign GPS data have been interpreted in terms of elastic block models for both the North and South islands, in which we solve for both the long-term motions of independent geological crustal blocks and the elastic interactions between the blocks. The elastic interactions are due to the fact that geological faults bounding the blocks are "locked" or "coupled" during the times between large earthquakes on the faults. This results in strain-energy being stored in the surrounding rocks, with the resulting deformation recorded by GPS sites on the Earth's surface.

The observed motions of the blocks has led to a dynamic (mechanical) explanation in which much of the long-term rotational motion of the eastern North Island and the back-arc extension in the Taupo Volcanic Zone are the result of torques induced by the entry of the continental rocks of the Chatham Rise into the Hikurangi subduction zone. This causes the subduction rate to decrease or even cease at this point, while the subduction continues at its pre-existing rate further north. The resulting torque is what causes the rotation of the eastern North Island, and is what maintains (and perhaps even initiated) the Taupo back-arc extension.

This model has been applied to many other instances of forearc rotation and back-arc extension around the world, and is found to be remarkably successful. See the series of paper in the bibliography with L Wallace as first author.

Progress has been made on understanding the dynamics of the oblique continental convergence between the Pacific and Australian plates in the central South Island. We have moved towards the ability to model both long-term motion and the earthquake cycle in a single model. We have also used the GPS data to put bounds on the maximum width of mantle flow beneath the Southern Alps. See the papers in the bibliography with lead authors M Gerbault and S Ellis.

The continuous network across the Southern Alps has continued to operate well and has produced preliminary estimates of vertical rate of up to 6 mm/yr. A fuller discussion of this network is provided in Section 3.10.

3.7 *Slow slip events at Hikurangi subduction interface*

Our 2003 report mentioned the first slow slip event recorded in New Zealand, in October 2002. Since then a large number of other events have been recorded both in New Zealand (see bibliography) and overseas – mainly in Japan, western Canada/U.S. Pacific Northwest, and Mexico. Despite considerable work, the nature of these events is not fully clear, though it does seem certain that they are part of the mechanism of transition between frictional and elastic behaviour at shallower depths, and steady shearing at deeper depths. Temperature, rock type, and the presence of fluids all play some role in the transitional behaviour.

3.8 *VLBI*

An initiative led by Auckland University of Technology (AUT) to build several radio telescopes suitable for VLBI in New Zealand is looking promising. Though the primary

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purpose of the telescopes is for astrophysical research, it is intended that some of their time will be used for geodetic purposes and they are being designed with this in mind.

3.9 *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 and CHAT. 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. There has been agreement with the IGS for several other New Zealand sites to be added to the IGS network; the paperwork for this should be completed shortly.

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. Some additional information on the New Zealand "CGPS at tide-gauge" work is given in Section 3.11.

3.10 *Southern Alps Geodetic Experiment (SAGENZ)*

The Southern Alps Geodetic Experiment (SAGENZ) is a collaborative project operated and funded by Otago University, the Institute of GNS Science, the Massachusetts Institute of Technology, and the University of Colorado at Boulder. The objective of this on going project is to measure both the rate and distribution of the mountain uplift. This actively deforming region exhibits oblique strike-slip motion between the Pacific and Australian tectonic plates. We now have up to 7 ½ years of high quality GPS data from 14 sites in a profile that spans the approximately 70km wide deformation zone (Figure 9).

Of the 14 sites, 8 are operated as permanent sites (CGPS). To increase the distribution of the network, the remaining 6 sites are operated in a semi-continuous mode with 6 month occupations. Current estimates of the uplift rates are up to ~4 mm/year in the central portion of the network (Figure 9), although the rates at a couple of sites with shorter time series (BNET, HORN) are higher at ~6 mm/year. Seasonal variations with amplitudes of 7-8 mm have also been recorded at several of the sites, especially those located in the high mountains.

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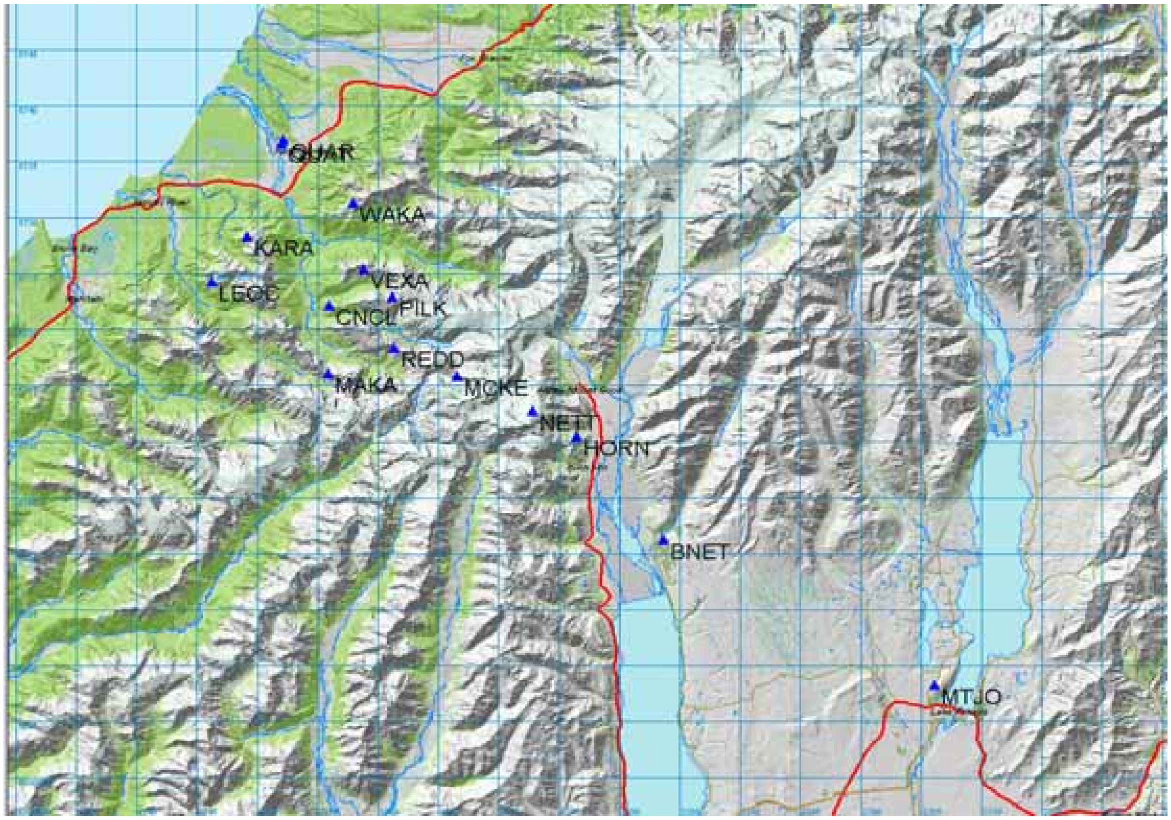

Figure 9: The SAGENZ 14 site GPS network.

3.11 *Continuous GPS at Tide-Gauges*

GPS is being used to monitor four long record tide-gauge sites since the start of 2000. Each GPS site is located in the vicinity of the tide-gauge although better sites have been chosen to maximise sky visibility and stability. A precise-levelling tie has been carried out between the GPS monument and the tide-gauge. In addition, the long term stability of each GPS site is monitored using a nearby GPS receiver, which is typically within 10km of the continuous GPS/tide-gauge site.

Monitoring of the local site stability at each location is also carried out by precise-levelling to a set of benchmarks, many of which have been installed for this project. Depending upon the location of the benchmark, most sites are showing good stability, although some sites have rates up to ±0.5 mm/year based on 7-8 years of data. Subsidence rates of up to -0.3 - -0.4 mm/year are clearly evident on benchmarks with historical records going back more than 30 years.

This work is funded by FRST as part of GNS Science plate tectonics programme.

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3.12 *Fiordland Co-seismic and Post-seismic deformation*

In August 2003, a M_w 7.2 earthquake caused horizontal displacements of up to 18cm in Fiordland (Figure 10). Such an earthquake will potentially destroy and/or distort the geodetic infrastructure. The NZGD2000 largely models the secular plate tectonic motion at the national level but does not account for regional and local deformation events (cf. Section 2.1; Blick, 2003). Such events can be caused by earthquakes (co-seismic, post-seismic and slow earthquakes), volcanic activity and more localised deformation, e.g., landslides.

Land Information New Zealand and Otago University have been investigating the modelling of both sudden deformation e.g. co-seismic displacements, catastrophic landslides; and longer-term deformation, e.g., post-seismic displacements, slow earthquakes and slow and imperceptible land movement (Jordan 2005; Jordan *et al.* 2007), with the view of incorporating such models into NZGD2000.

Following the Secretary Island earthquake, GPS was used to measure the co-seismic displacements in August 2003 at 11 sites surrounding the epicentre. Since then, 4 post seismic surveys have been carried out in January 2004, January 2005, January 2006 and December 2006 and techniques developed to incorporate their results into the geodetic datum (Jordan, 2005, Denys *et al.*, 2007)

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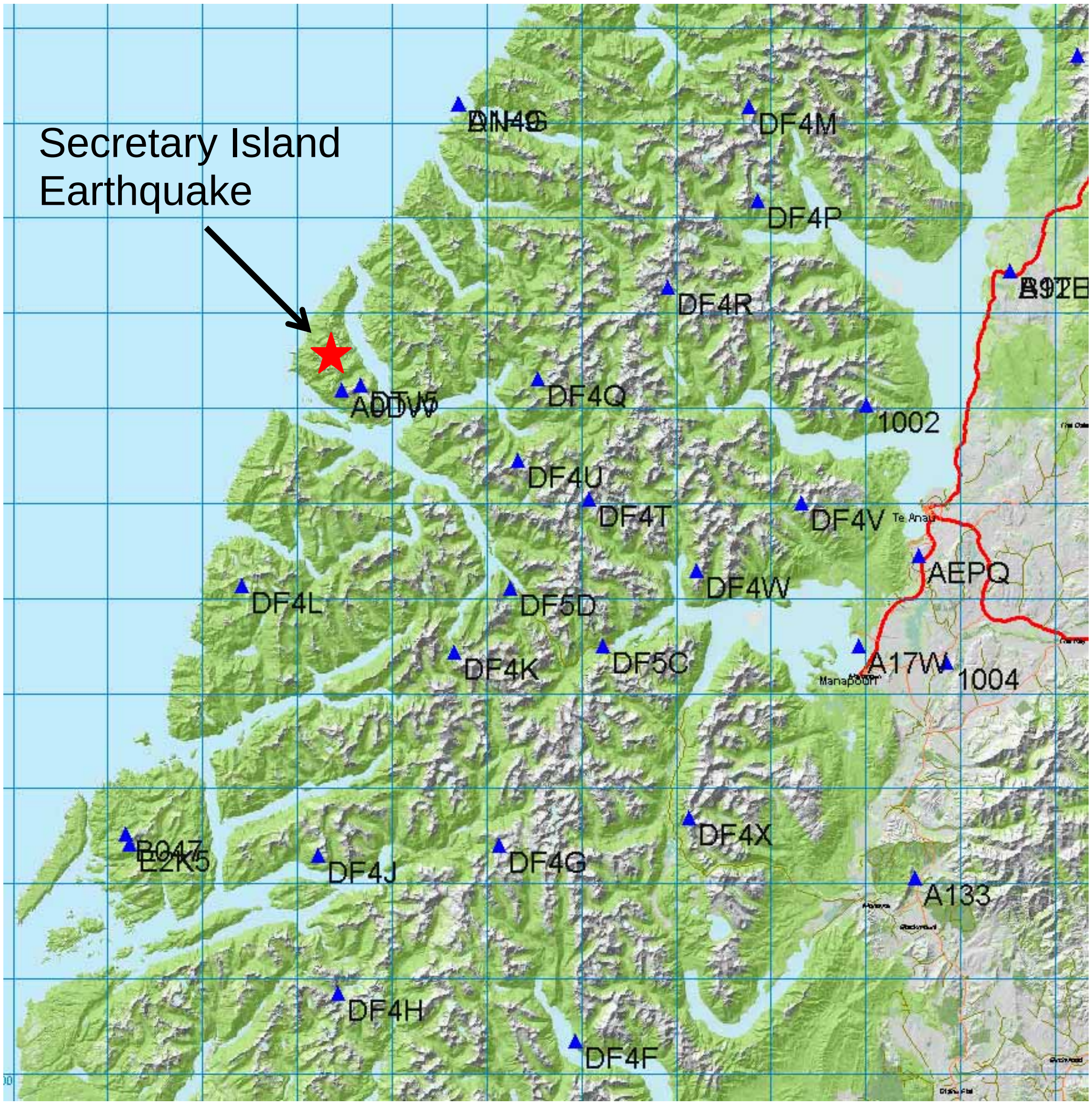

Figure 10 Part of the Fiordland deformation network centred on the Secretary Island earthquake

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