Toitu te
Land whenua
Information
New Zealand

NEW ZEALAND GEODETIC OPERATIONS 1999-2002

Report for the General Assembly of the International Union of Geodesy and Geophysics: Sapporo, Japan 2003

Geosciences Standing Committee of the Royal Society of New Zealand

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Contents

New Zealand Geodetic Operations 1999-2002: Report for the General Assembly of the International Union of Geodesy and Geophysics. Sapporo, Japan, July 2003

1 Introduction

This report presents geodetic operations in New Zealand for the period 1999–2002. During this period Land Information New Zealand (LINZ) has successfully completed development of its **Land*online*** project, the automation of the survey and title system in New Zealand. This project includes automation of the geodetic system and sees a merging of the geodetic, cadastral survey, and land titles systems in New Zealand. Further development of New Zealand Geodetic Datum 2000 (NZGD2000) and Ross Sea Region Geodetic Datum 2000 (RSRGD2000) has continued during this period (see section 2). Two major projects started in this period are development of a national active control network and national vertical datum. Geodynamic studies have continued in New Zealand, principally by the Institute of Geological and Nuclear Sciences. A major project commenced is the development of the GeoHazards project (see section 3).

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, Sapporo, Japan, July 2003. The report is a compilation of material provided by:

- Land Information New Zealand;
- Institute of Geological and Nuclear Sciences; and
- School of Surveying, Otago University, Dunedin.

2 Geodetic Control Networks to Support Datum Development

2.1 *Introduction*

In 1998 LINZ approved the implementation of New Zealand Geodetic Datum 2000 (NZGD2000) to replace the existing datum, New Zealand Geodetic Datum 1949 (NZGD49) and in 2000 the implementation of Ross Sea Region Geodetic Datum 2000 (RSRGD2000). The characteristics of these two datums are detailed in the previous Geodetic Operations report for the period 1995-1998. Control networks have been developed and surveyed in support of the development of these two new datums.

An impact of the adoption of a new national datum for New Zealand was the need to consider a new national mapping projection in terms of the new datum. In 2001 after wide consultation LINZ adopted a new national mapping projection, New Zealand Transverse Mercator (NZTM). This replaces the New Zealand Map Grid (NZMG) which until this time was used for medium and large scale national mapping purposes.

2.2 *Horizontal Control Surveys in New Zealand*

Along with the resurvey of the old 1st order NZGD49 network (Figure 1) and realisation of NZGD2000, development of the new datum initially focused on the breakdown to the 2nd and 3rd order network across urban and rural areas and higher density 4th order control in urban areas. During this period over 300 2nd order marks, 2000 3rd order marks, and 2500 4th order marks were surveyed in terms of NZGD2000 (Figures 2 and 3). The majority of these marks were existing survey marks surveyed in terms of the old datum, New Zealand Geodetic Datum 1949 (NZGD49) or cadastral marks. In areas where no suitable marks were available new marks were installed and surveyed.

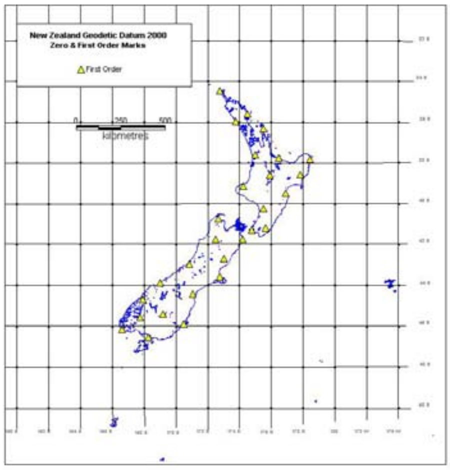

Figure 1. Zero and 1st Order 2000 Geodetic Network

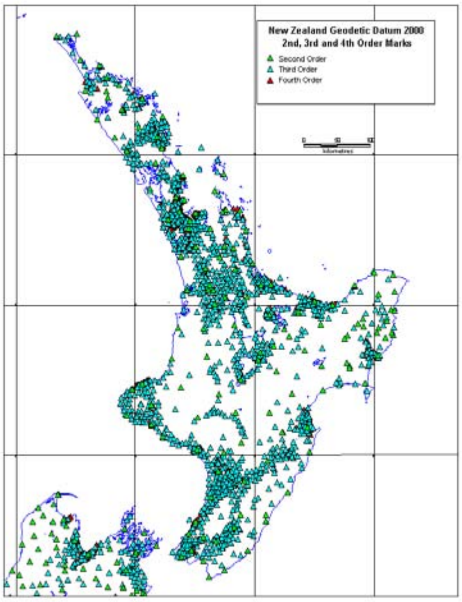

Figure 2. North Island 2nd, 3rd, and 4th Order 2000 Geodetic Network

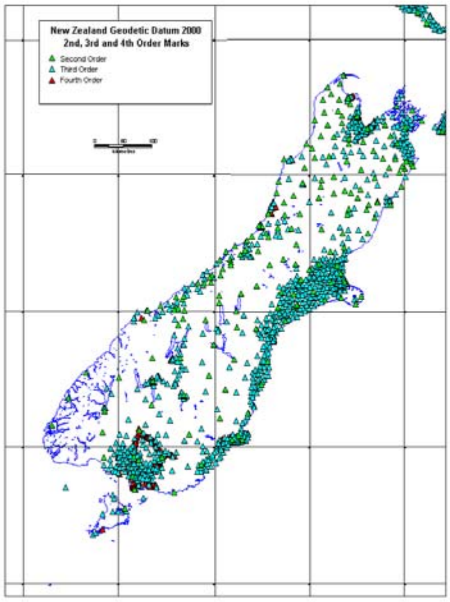

Figure 3. South Island 2nd, 3rd, and 4th Order 2000 Geodetic Network

In 2000 work commenced on the provision of 5th order (cadastral control) in support of the automated survey and title system **Land*online*** and the development of Survey Conversion Areas (SCAs). These are the areas where the Digital Cadastral Database (DCDB) has been enhanced with the capture of survey dimensions to create a Survey-accurate Digital Cadastre (SDC). The aim of this work is to provide reliable NZGD2000 control at an adequate density to support **Land*online*** projects and cadastral surveyors. The density of NZGD2000 control in SCA areas is:

- Urban areas: 95% of boundary marks shall be no more than 200m from a geodetic control mark
- Peri-urban areas: 95% of boundary marks shall be no more than 600m from a geodetic control mark
- Rural areas: 95% of boundary marks shall be no more than 2000m from a geodetic control mark.

This provides control at a spacing of approximately 300m, 800m and 3km respectively, although in many areas the control will be at a greater density.

During this period over 60,000 5th order marks have been added to the geodetic database. The majority, over 50,000 marks, are readjusted former control traverse marks, however some 10,000 existing cadastral survey or new marks have been surveyed in terms of NZGD2000 and added to the database (Figures 4 and 5).

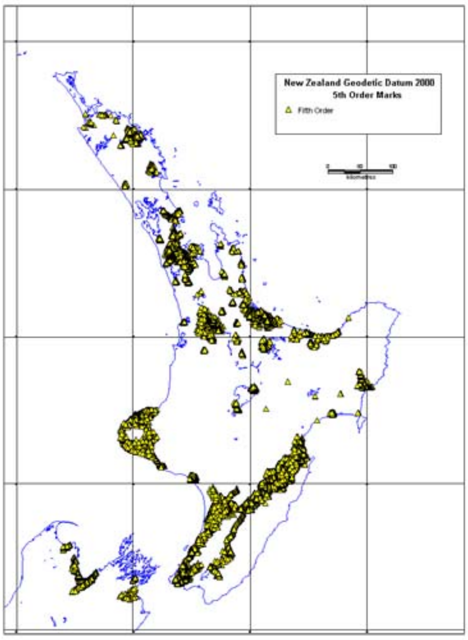

Figure 4. North Island 5th Order 2000 Geodetic Network

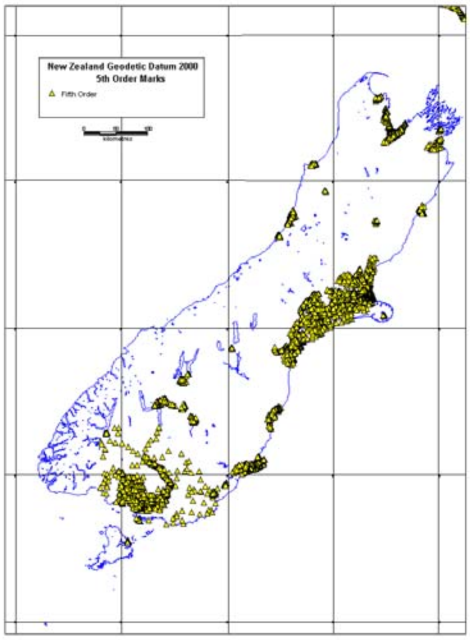

Figure 5. South Island 5th Order 2000 Geodetic Network

In 2001 LINZ commenced development of an active control network (**PositioNZ**) in partnership with the Institute of Geological and Nuclear Sciences (GNS). **PositioNZ** stations are the highest accuracy points in the New Zealand Geodetic Datum 2000 (this is covered more fully in section 2.5).

2.3 *Control Surveys in Antarctica*

With the trend towards the use of GPS and development of GIS systems and the need for managing and correlating spatially dependent data, there was a recognised need for consistency of spatial referencing of data in the Ross Sea Region. The use of GPS for scientific and other activities accelerated the need for a consistent and uniform spatial referencing system in the area.

A major GPS control survey was carried out in the Ross Sea Region of Antarctica in 1996/97 in conjunction with the United States Geological Survey (USGS) with the aim of developing a new Ross Sea Region Geodetic Datum. This network formed a primary network (1st and 2nd Order 2000 stations) to connect all horizontal and vertical datums in the Ross Dependency together in terms of the ITRS (International Terrestrial Reference System).

During this period LINZ has continued to work with the USGS on their field surveys as part of their ongoing mapping requirements and as part of a joint USGS and Ohio State University (OSU) scientific project to study uplift and deformation of the Trans-Antarctic Mountains (TAMDEF Project).

Where practicable, this additional work has been tied into New Zealand's Antarctic survey network and the data integration into the RSRGD2000 project. Data from this project continues be used to extend the RSRGD2000 (Figure 6).

New Zealand also supports operation of a tide gauge and GPS continuous tracking receiver at Cape Roberts.

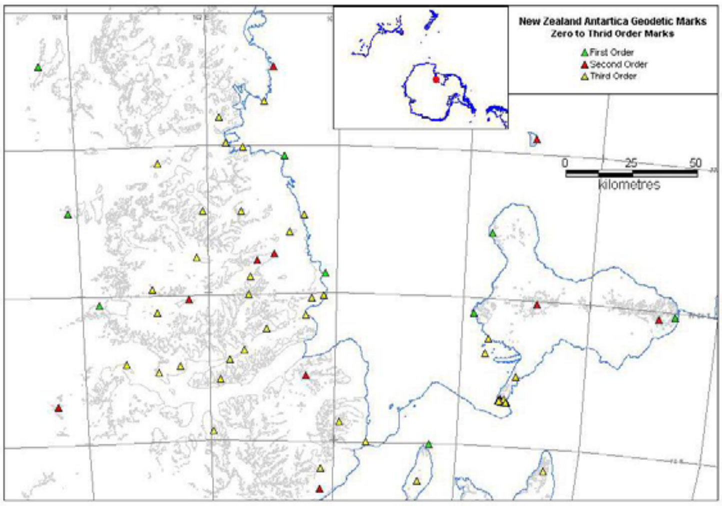

Figure 6. Ross Sea Region Geodetic Network

2.4 *Development of a National Vertical Datum and Geoid Model*

Unlike NZGD49, which is a two dimensional (horizontal) datum, NZGD2000 is a three dimensional (horizontal and vertical) datum. In terms of the NZGD49 datum, heights of marks were determined in terms of separate vertical datums based on a number of tide gauges at Standard Ports around New Zealand. All newly surveyed NZGD2000 geodetic marks have ellipsoidal heights generated in terms of the GRS80 ellipsoid.

During this period LINZ has implemented a project to better define a national vertical datum in New Zealand [*Amos and Featherstone 2003*]. This project aims to define an accurate New Zealand geoid model to enable orthometric heights to be generated from NZGD2000 ellipsoidal heights. A complementary aim is to determine the relationship between the 13 separate existing vertical datums.

The emphasis of the work to date has been on the computation of a gravimetric geoid for the New Zealand region, which will then be used to unify the 13 principal local vertical datums. NZGD2000 is the "official" ellipsoidal height system and the geoid will allow these heights to be transformed into any of the local levelling datums and will also be used to define an official orthometric height datum. An accurate geoid model will also permit the transfer of heights between the local datums.

The geoid will be computed by essentially improving a global geoid model with terrestrial, marine and satellite derived gravity observations over the New Zealand region. There are a number of issues that need to be resolved with each of the data sources to ensure that they are all integrated optimally to produce the highest accuracy geoid. The computed model will be verified using a network of points throughout the country that have both ellipsoidal and orthometric heights and also with stations that have deflections of the vertical determined at them.

The work programme for this project includes: observation of GPS positions on additional levelling points in the North Island, cross-over adjustment of marine gravity observations, and potentially the collection of additional gravity data along the New Zealand coast by airborne techniques. A preliminary geoid model has been computed and a final model is expected in 2005.

LINZ has also commenced a programme to upgrade the benchmark network at selected Standard Ports as part of the wider National Vertical Datum project. The upgrade will include re-selection and geodetic/precise levelling to benchmarks established to first order standards, with the primary aim of ensuring the effects of subsidence/local land movement are minimised (at present, most benchmarks are located on reclaimed land). See also section 2.6.

2.5 *Development of a National Active Control Network*

In 2001 LINZ commenced development of an active control network (**PositioNZ**) in partnership with the Institute of Geological and Nuclear Sciences (GNS). **PositioNZ** stations are the highest accuracy (Zero Order) stations in the New Zealand Geodetic Datum 2000.

The completed network will consist of approximately 30 continuously tracking GPS stations across New Zealand and the Chatham Islands. By July 2003 15 stations will be operational in the North Island, four in the South Island and one on the Chatham Islands (Figure 7). The Active Control Network is expected to be fully operational by 2005/06.

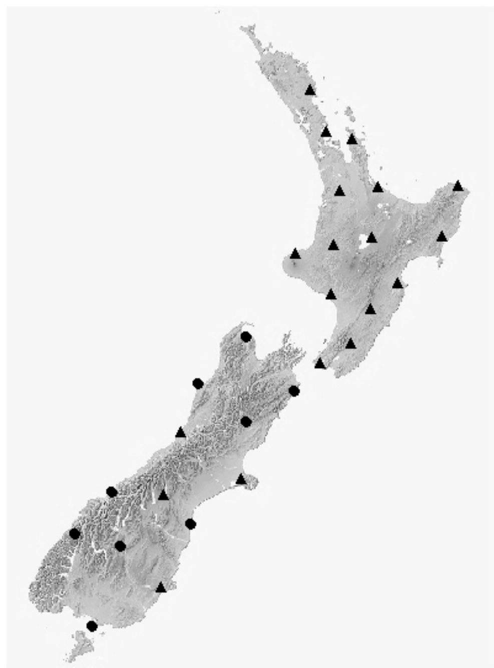

Figure 7. Active control network (Chatham Island excluded). Triangles represent operating stations as at July 2003 and circles planned stations.

The primary objectives of this network are to:

- facilitate improved efficiency in the survey and maintenance of geodetic control and use of GPS survey methods
- ensure NZGD2000 is rigorously linked to the global geodetic system
- enable cadastral and other surveys to be more easily tied to geodetic control
- monitor the dynamics of NZGD2000 and contribute to the refinement of a national velocity model
- coordinate the investment by several government and private sector agencies in GPS networks
- locally monitor the integrity of the GPS system.

Currently thirty-second RINEX data for the operational sites is freely available from the LINZ web site at *www.linz.govt.nz/positionz*. This data can be used with data collected from roving GPS receivers for post-processing of the data to derive positions in terms of NZGD2000.

Further enhancements being considered for this project include the ability to submit GPS data through the Internet for automated post-processing of the data and the ability to use one-second data for real time positioning applications.

2.6 *National Standard Port Sea Level Data*

LINZ is the New Zealand national regulatory authority responsible for the production of official nautical charts and publication. LINZ contracts out most of the collection and processing of hydrographic surveys, chart production and analysis of tidal data used for the production of tidal predictions in the National Tide Tables to LINZ accredited providers.

At present, tidal data at the 16 New Zealand Standard Ports is supplied at no cost by the Port Companies and District Councils who are the owner/operators of the majority of the tide gauges at these sites. Data is received “as is” with little or no control over the frequency or quality of the observations.

LINZ has identified cases where unreliable predictions have been produced from source tidal data supplied by some commercial/third party operators. There is risk that if such predictions were accepted as the “official” tide predictions, that decisions surrounding navigation of vessels might be based on this information which may result in a vessel incident.

To mitigate the above risk, a set of standards outlining the minimum requirement for Sea Level Data has been developed. Research undertaken during this process has highlighted the fragmented nature of existing information about tide/sea level standards and the document serves to combine the relevant information in one place.

2.7 *Absolute Gravity Measurements*

Absolute gravity was measured at several sites in New Zealand using an absolute gravity meter (see section 3.9). This included the establishment of a calibration line at Christchurch.

3 Geodynamic Studies

3.1 *Introduction*

In New Zealand, geodynamic studies using geodetic methods are principally undertaken by the Institute of Geological and Nuclear Sciences (GNS) and Otago University. In the period 1999-2002 most of this work has been done by New Zealand institutions without overseas support. This is in contrast to the period 1995-1998 when many of our Global Positioning System (GPS) studies were supported in part by overseas sources, and were in cooperation with overseas investigators. However, one exciting new collaborative project has been developed in the reporting period, involving Otago University, GNS, Massachusetts Institute of Technology (MIT) and the University of Colorado. This project aims to measure the uplift rate of the Southern Alps using continuous GPS. As well as this, a number of scientific studies using New Zealand data have been advanced through collaborative work between New Zealand and overseas investigators, including United States, United Kingdon, Australian, Japanese and German workers.

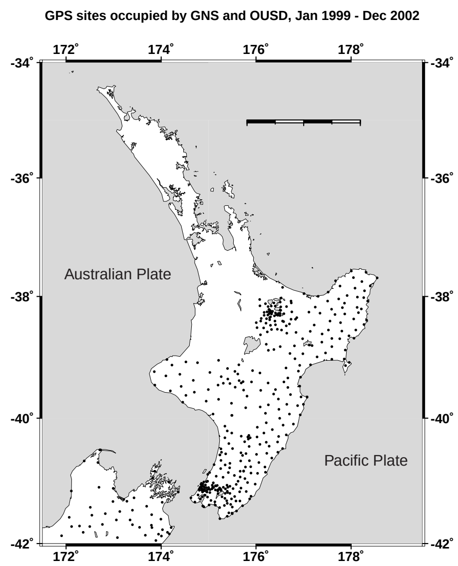

Figure 8. GPS sites occupied in the North Island. (Note. Higher density of sites is along the plate boundary)

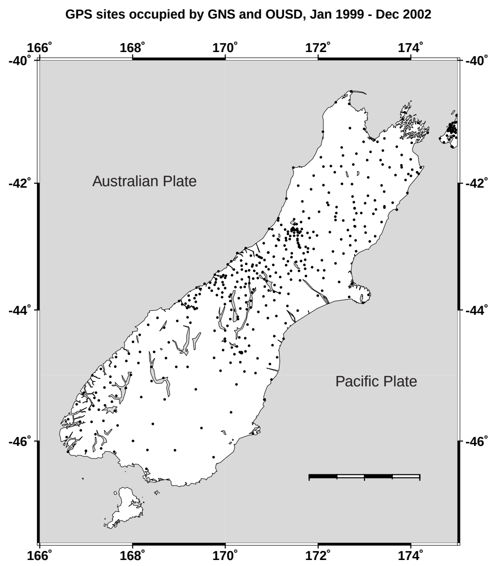

Figure 9. GPS sites occupied in the South Island. (Note. Higher density of sites is along the plate boundary)

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 GPS measurements almost exclusively, rather than a mix of GPS and older terrestrial measurements. This is because we now have at least two repeat GPS campaigns over all the deforming parts of the country, with five or more repeat measurements at some stations. During 1999-2002, GPS observations were made at points shown in Figures 8 and 9.

3.2 *Continuous GPS Network*

At the end of 1998 the New Zealand continuous GPS network comprised just five stations. The network grew slowly over the next two years through a variety of small initiatives. Amongst these, four stations were added at New Zealand's long-term tide gauges in 1999-2000, and five were added in 2000 as part of the Southern Alps project mentioned above.

Since then, two major initiatives promise to increase the network to well over 100 stations. LINZ and GNS are installing a nationwide network (**PositioNZ** network) of 30 stations with an intersite spacing averaging about 150 km (see section 2.5 above).

An even larger project (GeoNet) has been funded since mid-2001 by the Earthquake Commission, a government-owned geohazards insurance company. The GeoNet project aims to substantially upgrade seismic (broadband, short-period and strong-motion), volcanic and geodetic monitoring in New Zealand, and includes some 80 new continuous GPS stations in its initial stages. Installation of these stations begins in 2003.

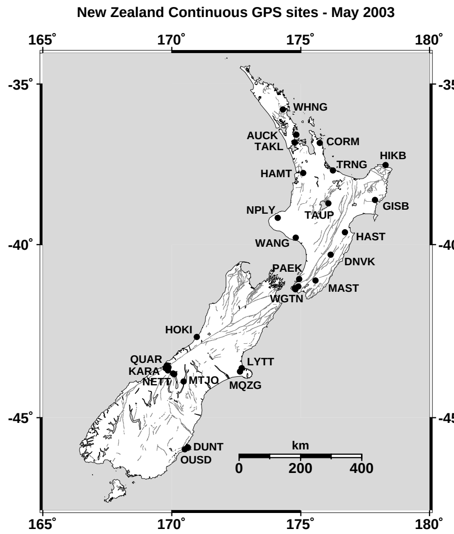

Figure 10. New Zealand Continuous GPS sites – May 2003.

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 New Zealand's widespread vegetation and steep terrain, the technique is more challenging than in some other parts of the world. However, we have demonstrated that repeat-pass orbital InSAR is effective for the Auckland and central North Island volcanoes, as well measuring geothermal deformation in Taupo and Rotorua.

In 2000, we participated in the NASA PACRIM-2 airborne radar campaign, and obtained high resolution topographic data of the Ruapehu and Tongariro volcanoes. These observations have been invaluable for a number of diverse studies (see bibliography), as well as a source of accurate data to remove topographic noise from the InSAR data.

3.4 *Volcano Deformation*

A number of small-scale pilot experiments have taken place for GPS monitoring of deformation at Mt Ruapehu, which last erupted in 1995 and 1996. The GeoNet project aims to develop a more rigorous and routine monitoring programme at this and other volcanoes.

3.5 *Tectonic Plate Motion*

Geologically based global models of plate motion do not include seabed and earthquake data from the New Zealand region. To address the question of whether the Pacific Plate is truly rigid, and to measure its contemporary motion with respect to the Australian Plate, GNS have established and measured a GPS network comprising off-shore sites at Raoul, Norfolk, Chatham, Auckland and Campbell Islands, as well as a number of onshore sites. We also participate with the University of Hawaii in GPS observations at several Pacific islands. Working with Australian, Japanese and United States colleagues we have used these and other GPS data to accurately estimate the present-day rates of motion between the Pacific, Australian and North American plates, and have compared these rates with 3-million-year average rates determined from the geologically-based NUVEL-1A model.

Results show that present-day Pacific-Australia motion is generally quite similar to NUVEL-1A, but implies an Alpine fault slip rate a few millimetres per year faster than NUVEL-1A. Present-day Pacific-North America motion is several millimetres per year faster than NUVEL-1A, as has also been found by other workers. The results also demonstrate a high degree of internal rigidity of all three plates. An interesting exception is that the submerged continental boundary zones offshore of southern California and offshore of the eastern South Island of New Zealand are each deforming more rapidly than expected, by a few millimetres per year. This probably implies the existence of additional, previously unsuspected, offshore faults.

3.6 *NZ-wide Deformation and Development of a Dynamic Datum*

The 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 600 sites throughout New Zealand have been combined using finite-element model techniques to produce velocity and strain-rate maps of the whole country.

These techniques employ bicubic spline interpolation within a grid defined on a curved surface, and make a best fit to the observed velocities while minimising strain rates within each grid cell.

The velocity map (Figure 11) shows how fast any point is moving, and an earlier version of this map has been used by LINZ to define a new geodetic datum for the country (NZGD2000) that takes point velocities into account. Strain-rate maps derived from the velocity map are beginning to be used in a reassessment of earthquake hazard in New Zealand, while the deformation results from various regions within the country have been used to address specific tectonic problems.

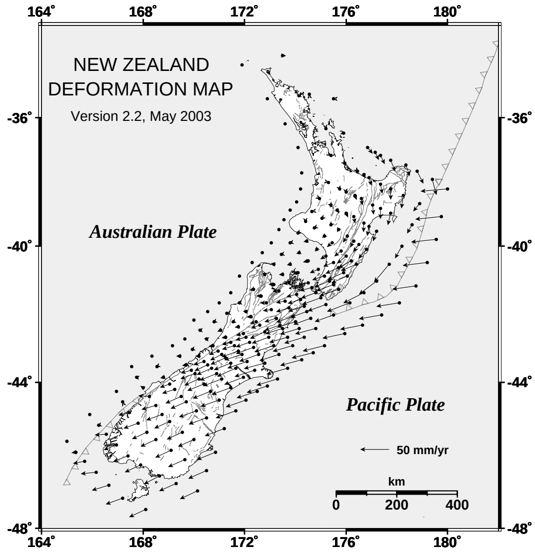

Figure 11. New Zealand deformation map.

3.7 *Effects of Plate Subduction Beneath the East Coast of the North Island*

Deformation of the eastern part of the North Island arises from the frictional stresses of the Pacific Plate subducting beneath the Australian plate. A number of GPS surveys between 1999 and 2002 have greatly improved our understanding of the plate interactions along this margin.

In the Wellington region at the southern end of the North Island repeated GPS surveys have demonstrated that the plate interface is nearly fully coupled, meaning that most of the Pacific-Australia plate motion in this region is likely to be released in earthquakes. There is historical and paleoseismic evidence of great earthquakes that release the margin-parallel component of plate motion along major on-land strike-slip faults such as the Wellington and Wairarapa faults. However, there is presently no similar evidence that great earthquakes have occurred on the subduction interface. The inferences from geodetic observations are therefore particularly important in assessing seismic hazard from such events.

Further north it is believed that the subduction interface is less strongly coupled. A clue to the mechanism of weak coupling may have been detected recently. Two continuous GPS stations in northeastern New Zealand recorded a slow deformation event of 20-25 mm magnitude over a 10-day period in October 2002. This event appears similar to events observed in recent years in subduction zones in western

Canada, Japan and Mexico. The New Zealand event can be interpreted as resulting from about 20cm of slip on the subduction interface.

3.8 *Continental Collision in the South Island*

In the South Island the tectonic plate boundary comprises old continental crust of the Chatham Rise to the east colliding with the Challenger Plateau to the west. These more buoyant crustal fragments resist subduction and result in the uplifted Southern Alps, with the plate boundary being on-shore and represented by the Marlborough and Alpine faults. In fact, the junction of the Alpine and Hope faults is one of few places in the world where two faults intersect that are each moving at 20+ mm/yr, but the mechanisms operating at the intersection are not clearly understood.

The southern third of the South Island was the last section of the South Island deformation network to be surveyed. This final first-epoch survey was carried out in February 2001 as part of Otago University's Southern Alps Program and GNS's deformation program. The survey included existing LINZ marks covering much of Otago and Southland, but also established over 30 new marks in the Fiordland block between Puysegur Point on the southwest corner of New Zealand to Haast Pass. Fiordland is different geologically from the rest of the South Island and this work will provide insight as to whether the behaviour of the continental collision zone of this block, from a geodetic perspective, is similar or different compared to regions to the east or north. This survey will be repeated in the mid decade.

3.9 *Southern Alps Geodetic Experiment – NZ (SAGENZ)*

In February 2000, Otago University (OU), the Institute of Geological and Nuclear Sciences (GNS), the Massachusetts Institute of Technology (MIT), the University of Colorado at Boulder (CU) and UNAVCO established a network of CGPS sites across the central Southern Alps between Karangarua (West Coast) and Mount John (East Coast) (see Figure 12).

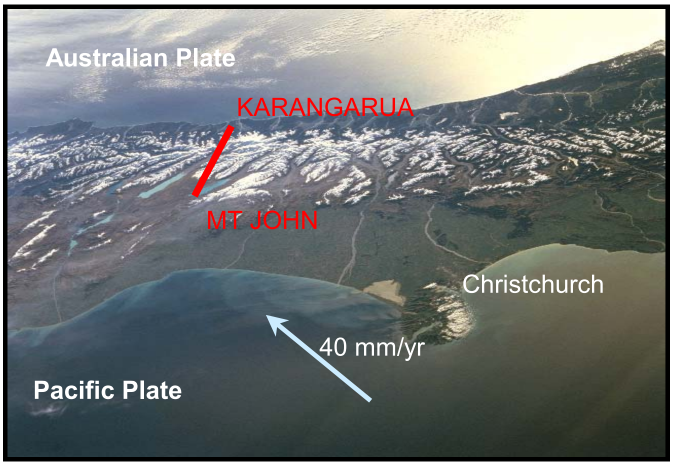

Figure 12: Southern Alps Geodetic Experiment – New Zealand profile from Karangarua to Mount John

This collaborative project aims to measure both the rates and distribution of the vertical uplift of the mountains in a region where high uplift rates are expected. In the central South Island, GPS has been used since 1994 to measure the horizontal deformation associated with the Australian – Pacific plate boundary, but little is known of the contemporary vertical velocities. Long-term geological evidence, largely the result of work carried out in the 1970s by the late Harold Wellman, suggests a vertical rate of approximately 10 mm/year.

The network consists of six CGPS sites (a seventh was established in December 2002), and a further three semi-CGPS sites that are deployed for six months at a time in order to increase the distribution of marks. Results after three years of data collection (February 2000–December 2002) indicate uplift rates of up to 7-8 mm/year, with a maximum rate midway between the Alpine Fault and the Main Divide of the Southern Alps.

At the start of the project, the force of gravity was measured at several of the sites using an absolute gravity meter. By re-measuring gravity at these sites after a suitable time interval (eg 5 years), we expect to be able to estimate the change in gravity as a result of the vertical uplift. In many mountain belts, as the mountains rise there is a corresponding deepening of the crustal "root" beneath the mountain. By measuring the force of gravity as well as the uplift of the mountains, we can measure the extent to which this is happening in the Southern Alps. In particular, we will be able to determine the extent to which vertical uplift is a result of tectonic plate collisions and how much can be attributed to rapid erosion.

3.10 *Tide Gauges*

A collaborative project, between Otago University and the Institute of Geological and Nuclear Sciences (GNS), has been funded by the Foundation for Research, Science and Technology (FoRST). This project has establish four continuously operated GPS receivers at the four tide gauge sites with the longest records, namely Auckland, Wellington, Lyttleton and Dunedin. CGPS data has been collected at these sites from July 1999 (Dunedin), December 1999 (Wellington), February 2000 (Lyttelton) and July 2001 (Auckland).

Precise levelling has been carried out at each site to establish the stability of both the tide gauge and CGPS antenna. This has been by connecting to both existing benchmarks and new marks established in bedrock close to each site (Dunedin and Lyttelton) and through a method of regular precise GPS levelling at Wellington. Each tide gauge CGPS is also paired with a nearby by CGPS and the baseline components are monitored to provide insight to the regional stability of each site.

The tide gauge data collected in New Zealand is being submitted for processing by TIGA – an International GPS Service Pilot Project addressing GPS Tide Gauge Benchmark Monitoring. The objective of this project is to deal with issues involving the GPS height component in routine global computations. The project will also establish and maintain geodetic ties to tide gauge systems and will be an important contribution to climate change studies.

3.11 *Multi-disciplinary Research*

The mathematical technique used for generating the contemporary deformation maps can also use geological measurements of deformation, such as fault slip rates, tectonic uplift rates, and paleomagnetic rotations, to produce maps of deformation over geological time scales. This has been done for the North Island. There are important differences from geodetically derived strain rates, and those differences provide the basis for ongoing investigation.

Many geophysical surveys have been conducted across the central South Island during the past few years, including seismic reflection, seismic refraction and magnetotelluric profiles. The three-dimensional seismic velocity and electrical conductivity structures beneath the central South Island have been determined from these and other observations. Considerable recent effort has gone into joint interpretation of these data along with the geodetic data, including the use of a variety of finite-element models.

Substantially more GPS stations have been installed in the vicinity of the intersection of the fast-moving Alpine and Hope faults. A start has been made on combining velocity results from these stations with geological and paleoseismological data, as a means to understanding the mechanisms in play at the fault intersection.

3.12 *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 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. 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.

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