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Information
New Zealand

NEW ZEALAND GEODETIC OPERATIONS 1995-98.

Report for the General Assembly of the International Union of Geodesy and Geophysics: Birmingham, England, August 1999

Geosciences Standing Committee of the Royal Society of New Zealand

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Contents

Introduction

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, Birmingham, England, August 1999. It presents the New Zealand geodetic operations from 1995-1998. The report is a compilation of material provided by:

- Land Information New Zealand;
- Institute of Geological and Nuclear Sciences;
- Surveying Department, Otago University, Dunedin;
- Victoria University, Wellington

NEW ZEALAND GEODETIC OPERATIONS 1995-98: REPORT FOR THE GENERAL ASSEMBLY OF THE INTERNATIONAL UNION OF GEODESY AND GEOPHYSICS. BIRMINGHAM, ENGLAND, AUGUST 1999

1 INTRODUCTION

Since the publication of the last report for the August 1991 General Assembly there have been further changes in the organisation and structure of Government departments.

From 1 July 1996, the national survey mapping and land information functions formerly carried out by the Department of Survey and Land Information (DOSLI), became the responsibly of the new Land Information New Zealand (LINZ) department. The operational mapping and survey functions of the former department were transferred to Terralink New Zealand Limited (a State Owned Enterprise) while the new department retained the policy, regulatory, standards setting, purchase, and service delivery functions of the old department. Under the new structure field surveys and map production are contracted out.

2 NEW DATUMS

2.1 *New Zealand Geodetic Datum 2000 (NZGD2000)*

In August 1998 LINZ approved the development of a new datum for New Zealand (NZGD2000). The new datum will be implemented in early 2000 and has the following characteristics:

- The ellipsoid associated with NZGD2000 will be the Geodetic Reference System 1980 (GRS80 ellipsoid).

- NZGD2000 will be based on The International Terrestrial Reference System (ITRS). The initial realisation will use the International Terrestrial Reference Frame 1996 (ITRF96) which has a geocentric origin and will be defined at epoch 1 January 2000.

- All points coordinated in terms of NZGD2000 will have coordinates defined at epoch 1 January 2000 (2000.0).

- Generalised motions of points in New Zealand with respect to ITRF96 will be modelled to:
    - ensure that observations made at a date other than the reference epoch (2000.0) can be used to generate epoch 2000.0 coordinates; and
    - allow up-to-date coordinates at a date other than epoch 2000.0 to be generated from epoch 2000.0 coordinates.
- Coordinates of geodetic marks in terms of NZGD2000 will not be fixed. Coordinates will be updated as required to account for new observations, earthquakes, or localised mark movement.

A description of the velocity model used to update the new datum is provided in section 4.

2.2 *Ross Sea Region Geodetic Datum 2000 (RSRGD2000)*

LINZ has recommended the development of a new datum in the Ross Dependency of Antarctic to be known as Ross Sea Region Geodetic Datum 2000 (RSRGD2000). The recommended characteristics for this datum are:

- The ellipsoid associated with RSRGD2000 will be the Geodetic Reference System 1980 (GRS80 ellipsoid).
- RSRGD2000 will be based on The International Terrestrial Reference System (ITRS). The initial realisation will use the International Terrestrial Reference Frame 1996 (ITRF96) which has a geocentric origin and will be defined at epoch 1 January 2000.
- The velocity model used to determine the coordinates at 1 January 2000 will be Nuvell-1A.

3 GEODETIC CONTROL NETWORKS TO SUPPORT DATUM DEVELOPMENT

3.1 *Horizontal control surveys in New Zealand*

In 1995 a new control programme was developed to support development of New Zealand Geodetic Datum 2000 (NZGD2000). The new geodetic control network designed as part of this programme allows for six orders of mark referred to as 'Order

2000' marks. Observations were made using the Global Positioning System and therefore provide a national horizontal and ellipsoidal height network. Below is a general description of each order.

- **Zero Order 2000 Marks:** The zero Order 2000 marks (GPS continuious tracking stations) provide the primary connection into the global survey datum. Inter-mark spacing in the global network is between 1000 - 5000 kilometres and in the nation wide network shall be between 100 - 500 kilometres. Marks shall be located on secure stable bedrock sites chosen for use in monitoring and controlling the deformation of the survey datum.

- **1st Order 2000 Marks:** Inter-mark spacing shall be up to 200 kilometres. Marks shall be located to enable use as continuous tracking stations and as base stations for surveying applications. They are ideally located on stable bedrock sites but may also be located on buildings.

- **2nd Order 2000 Marks:** Inter-mark spacing shall be up to 70 kilometres. The marks will be chosen for use in cadastral surveys in wilderness, national park, and back-country areas and as control for 3rd or lower Order 2000 marks.

- **3rd Order 2000 Marks:** Inter-mark spacing shall be up to 20 kilometres. The marks will be chosen for their use in cadastral surveys in rural and intensive rural areas and around urban areas as control for 4th or lower Order 2000 marks.

- **4th Order 2000 Marks:** Inter-mark spacing shall be up to 1 kilometre. The marks will be chosen for their use in cadastral surveys in urban areas.

- **5th Order 2000 Marks:** 5th Order 2000 marks are divided into two categories based on method used to coordinate the marks:

  - **5a - Marks** coordinated by observations captured off existing survey control plans. The marks will be existing urban and rural standard traverse marks, or cadastral marks (such as iron tubes and spikes);

  - **5b - Marks** coordinated by observations generated from new field surveys.

During this period 3 zero order stations were installed and were operated (Figure 1). Six repeat surveys were made of the 1st order network (28 stations) for the purpose of development of the Datum 2000 velocity model (Figure 1). In addition a number of offshore stations were incorporated into the regional network (Figure 1). Two hundred and thirty two 2nd order, 1111 3rd order and 1530 4th order 2000 stations were incorporated into the Datum 2000 network (Figures 2 and 3). In addition surveys were made of part of the old geodetic network (New Zealand Geodetic Datum 1949) to ensure a tie between the old network and modern GPS network. The current programme is focused on the development of the 5th order network. Several surveys have been carried out in conjunction with the Institute of Geological and Nuclear Sciences and other geophysical research agencies in support of geodynamic studies.

3.2 *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 Dependency. 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 the Ross Dependency in 1996/97 in conjunction with the US 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) (Figure 4).

In 1997/98 and subsequent years, USGS continued with 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 Transantarctic Mountains (TAMDEF Project). Where practicable, this additional work has been tied into New Zealand's Antarctic survey network and the data has been made available to LINZ for integration into the RSRGD2000 project.

3.3 *Gravity*

In October 1995 an American National Oceanic and Atmospheric Administration (NOAA) absolute gravity meter passed through Christchurch enroute to Antarctica for scientific studies. While in New Zealand the opportunity was taken to make absolute gravity observations at a site selected near Godley Head on Banks Peninsular, Christchurch. Staff from DOSLI and NOAA carried out the survey in October 1995.

The aim of the survey was to make absolute gravity measurements at a site in New Zealand that may serve as origin for a national vertical (orthometric) datum. In addition, a gravity value was transferred from the new site to the New Zealand National Gravity Base Station in the Christchurch Botanical Gardens. The Botanical Gardens site was unsuitable for the absolute gravity observations because of strong groundwater influences and possible local level changes as the water table in the area rises and falls.

Absolute gravity observations were made at the Godley Head site between 15 October 08.15 UT and 19 October 1842 UT. During this period 8628 individual measurements were made. A mean value of the observed gravitational acceleration at the station of 9.804895177 ms^{-2} ±2.8 μGal[1] (approximately ±5mm) was determined.

[1] 1 μGal = 1×10^{-8} ms^{-2}

The error represents the precision of the observations and unmodelled systematic errors may result in a lower accuracy. The Godley Head site was also connected by precise levelling to the level network (and Lyttleton Tidegauge) and by GPS to the geodetic horizontal control network.

During formal studies (1993-1996) by Merrin Pearse at the University of New South Wales, Australia, research was undertaken into the computation of a new national gravimetric geoid model for New Zealand. The research found that the most appropriate global geopotential model for New Zealand was EGM96. Further research showed that in a test region of the lower North Island there exists sufficient gravity data and improvement over a global model to warrant the computation of a gravimetric geoid model. The computation of a national gravimetric geoid model for New Zealand is being investigated by LINZ.

3.4 *National topographic hydrographic surveys*

The restructuring and re-assignment of Regulatory functions from the Hydrographic Service of the Royal New Zealand Navy (RNZN), and the Department of Survey and Land Information, (DOSLI) into a new organisation, Land Information New Zealand, (LINZ) was commenced on 1 July 1996 and is continuing throughout the period. National hydrographic responsibilities are now carried out by the National Topographic Hydrographic Authority, (NTHA) which is part of LINZ. The RNZN is one of several contract providers to the NTHA.

Control for surveys was undertaken in the following areas: Fiordland, Marlborough Sounds, Pelorus Sound, Coastal Region between Port Taranaki and Raglan, Stewart Island. The RNZN use Trimble 4000 SSI GPS receivers to provide geodetic positioning to third order accuracy for hydrographic survey work. No Doppler stations were observed in the period.

All surveys utilised existing tidal stations and therefore no new tidal stations have been established. The NTHA continues to provide analysis of port tidal data for nautical publications on an annual basis. Monthly MSL information for standard ports is supplied to the IGOSS sea level project (ISLPP).

3.5 *Tide gauges*

A collaborative project, between Otago University and the Institute of Geological and Nuclear Sciences (IGNS), has been funded by the Foundation for Research, Science and Technology (FoRST). This project will establish four continuously operated GPS receivers at the four tide gauge sites with the longest records, namely Auckland, Wellington, Lyttleton and Dunedin. The project has been funded for a period of five years beginning in July 1999 and are currently being installed (July 1999).

New Zealand has been monitoring sea levels since the last decade of the 19th Century and has some of the longest and most reliable tide gauge records in the southern hemisphere. Two of the most significant limitations of using tide gauges to monitor global sea level rise, are the predominantly northern hemisphere spatial distribution of tide gauges and the extremely small number of long term records (with particularly few in the southern hemisphere). Additionally, most global analysis have only used sites which have records that are of high data integrity, are not in close proximity to tectonically active plate boundaries and cover more than a 50 years period.

New Zealand has a history of tectonic activity. Sea level records therefore, are possibly contaminated by localised vertical movements at individual tide gauges, and it has only been in recent years, with the advent of GPS, that it has become both possible and realistic to accurately measure this movement. These receivers will be run in conjunction with the current permanent IGS stations located at Auckland and the Chatham Island as well as other permanent receivers located at Wellington, Hokitika, Christchurch and Dunedin. Each receiver will be located as close as possible to the structure on which each tide gauge is mounted.

Victoria University Wellington (VUW) has operated a tide gauge at Cape Roberts since 1990. This has provided a valuable, (possibly the longest such record in Antarctica) of sea level and tidal monitoring in the Ross Sea region. Until 1997 annual ties were made between the gauge and a reference bench mark by DOSLI. This tide gauge has operated successfully with the exception of 18 months loss of data due to hardware problems.

The operation of this site provides an important reference data set for development of tidal models and determination of sea level for future hydrographic charting in the Ross Sea as proposed by LINZ. An assessment of the data from this site will be carried out and a formal agreement arranged between VUW and LINZ for the ongoing maintenance and operation of the gauge and supply of data.

4 GEODYNAMIC STUDIES

Geodynamic studies in New Zealand are principally undertaken by the Institute of Geological and Nuclear Sciences (GNS). Various aspects of this work would not have been possible without material support and the collaboration from the following organisations: UNAVCO, Lamont-Doherty Earth Observatory, Oxford University, Univesität der Bundeswehr München, NASA/JPL, University of Hawaii, LINZ, Australian Survey and Land Information Group, University of Otago, and Victoria University of Wellington.

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 location that gives rise to the landforms of New Zealand and the associated earthquake and volcanic hazards. All geodetic measurements are now carried out using the Global Positioning System (GPS). Stations surveyed are usually a combination of older terrestrial points to take advantage of 50 to100-year old data for deformation research, and new, readily accessible points, to take full advantage of GPS technology. During 1995-1998, GPS observations were made at points represented in Figures 5 and 6.

4.1 *Tectonic plate motion*

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, Macquarie, Chatham, Antipodes, Auckland and Campbell Islands, and on-shore sites at Whangaparaoa, Napier, New Plymouth, Hokitika, Christchurch and Invercargill. Results show higher plate convergence rates compared with the global models, but incorporation of data from Australia and the SW Pacific is necessary to yield statistically well-determined rates and poles of plate rotation.

4.2 *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 300 sites throughout New Zealand have been combined using sophisticated mathematical techniques to produce velocity and strain maps of the whole country. These techniques employ bi-cubic spline interpolation on a curved surface. The maps show how fast any point is moving, and this information is being used by LINZ to define a new geodetic datum for the country that takes into account point velocities. The strain maps will be used in a reassessment of earthquake hazard in New Zealand. The deformation results from various regions within the country have been used to address specific tectonic problems. The velocity model is being incorporated into New Zealand Geodetic Datum 2000.

4.3 *Rifting of the central North Island Taupo Volcanic Zone*

The region of extension and volcanism in the central North Island arises from geochemical and mineralogical transitions as the subducting Pacific plate encounters higher temperatures and pressures at depth below the Australian plate. An analysis of the horizontal extension occurring in the Taupo Volcanic Zone in relation to its surroundings comprised the first deformation results for New Zealand from GPS surveys. This confirmed extensional rates of 8±4 mm/yr, and the surveys provided the basis for more detailed future work. They have been complemented by a compilation of historical precise levelling surveys to measure vertical deformation. Locally, the vertical deformation rates reveal the widespread effects of subsidence associated with extraction of geothermal energy. Simple models show that the horizontal deformation is even more widespread and can easily be mistakenly interpreted as a tectonic effect. These investigations are continuing using terrestrial and GPS data, together with the levelling data.

4.4 *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 comparison of a 1995 GPS survey with several historical terrestrial surveys shows that for a period in the middle of the century the plate interface was unlocked beneath the Raukumara peninsula in the easternmost part of the North Island. Data from surveys further south, involving about 50 points completed in 1997 and 1998 have been processed and detailed deformation analysis is in progress. This is an interesting area because of the M=7.8 earthquake that occurred there in 1931. Terrestrial data from these GPS points were acquired just after the earthquake, and from surveys in the 1870s.

The GPS points at the southern end of the North Island, in the Wellington-Wairarapa region, comprise one of the densest geophysical GPS networks anywhere in the world. These points have now been surveyed up to 5 times. Parameters of elastic models of plate subduction have been obtained by formal inversion of the surface deformation. The plate interface in this region appears to be completely locked down to a depth of about 30 km over a 70-km width. These results are consistent with interpretations of the pattern of recent earthquakes, and provide, for the first time, evidence that earthquakes of magnitude 8 have the potential to occur beneath Wellington. This may represent New Zealand's greatest earthquake risk.

4.5 *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 two of the fastest moving faults in the world are the Alpine and Hope faults, but what happens at their intersection is not understood.

GPS surveys have now been conducted through much of the northern 2/3 of the South Island, taking advantage of comparisons where possible with older terrestrial surveying data to measure deformation. Most of the plate-collision deformation is occurring on land, but simple models of geological faults slipping at depth cannot explain all aspects of the observed distribution of contemporary deformation.

4.6 *Time variability of contemporary deformation*

The question of whether deformation rates are constant by making continuous GPS measurements at a few sites is starting to be addressed. Data have been processed from four continuously operating stations that have been running on Chatham Island, and at Auckland, Wellington, and Dunedin, since 1995, and one station established at Hokitika in 1998. This represents the beginning of a project to continuously process data from many such stations, which will in future allow a real-time evaluation of deformation throughout New Zealand as well as support meteorological and weather forecasting applications of GPS.

The Chatham Island (CHAT) and Auckland (AUCK) data are distributed via the International GPS Geodynamics Service. Several groups are using these data worldwide for improving GPS orbit calculations in the southern hemisphere and for tectonic plate motion studies. The continuous sites are also vital to support New Zealand's regional GPS measurement campaigns.

A special class of temporally varying deformation is that which accompanies moderate and large crustal earthquakes. During this reporting period analysis of surveying data from the deformation zone of the 1994 Arthur's Pass earthquake has contributed to the derivation of geophysical parameters for that event.

4.7 *Multi-disciplinary research*

The mathematical technique used for generating the contemporary deformation maps described above, 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 further investigation. When compared with analogous maps of seismic moment release we have a powerful tool for understanding completeness of the different data sets and for assessing earthquake potential.

4.8 *INSAR studies of co-seismic deformation*

The Arthur's Pass earthquake of June 18th 1994 is the largest earthquake to occur in central New Zealand for the last 25 years. Because of the size of the earthquake, the general lack of vegetation in the epicentral region and the availability of a suitable pre-earthquake imagery, this earthquake represents the best opportunity for an INSAR study in the New Zealand region to date. In collaboration with Didier Massonnet and Nadine Pourthie CNES Division "Qualite et Traitement de l'Imagerie Spatiale Toulouse France we have developed an INSAR image of the earthquake and major aftershocks, which is a first for the southern hemisphere. The results tend to confirm the predominantly reverse nature of the earthquake inferred from geodetic and seismological studies.

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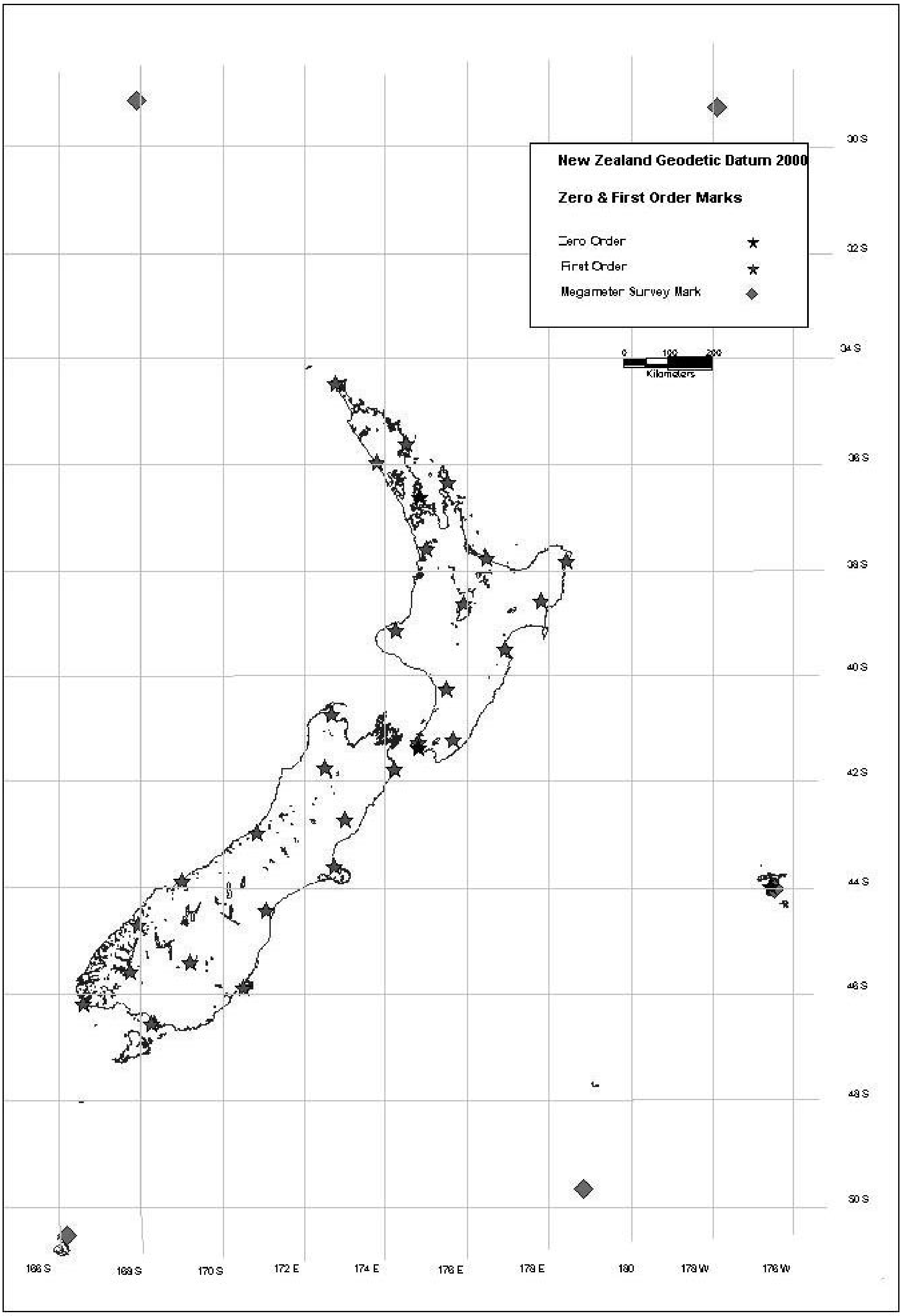

Figure 1. Zero and 1st Order 2000 Geodetic Network

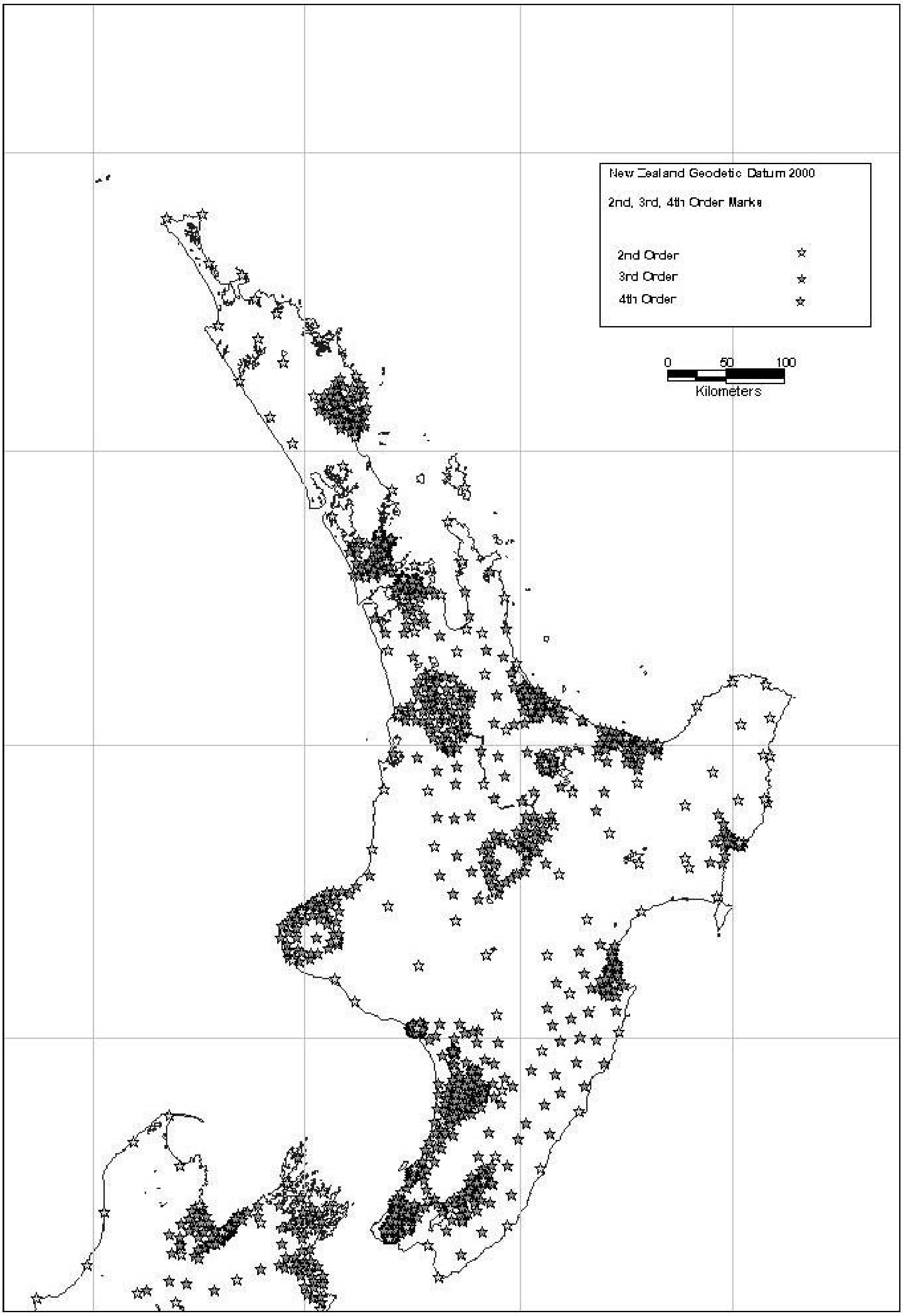

Figure 2. North Island 2nd, 3rd, and 4th Order 2000 Geodetic Network

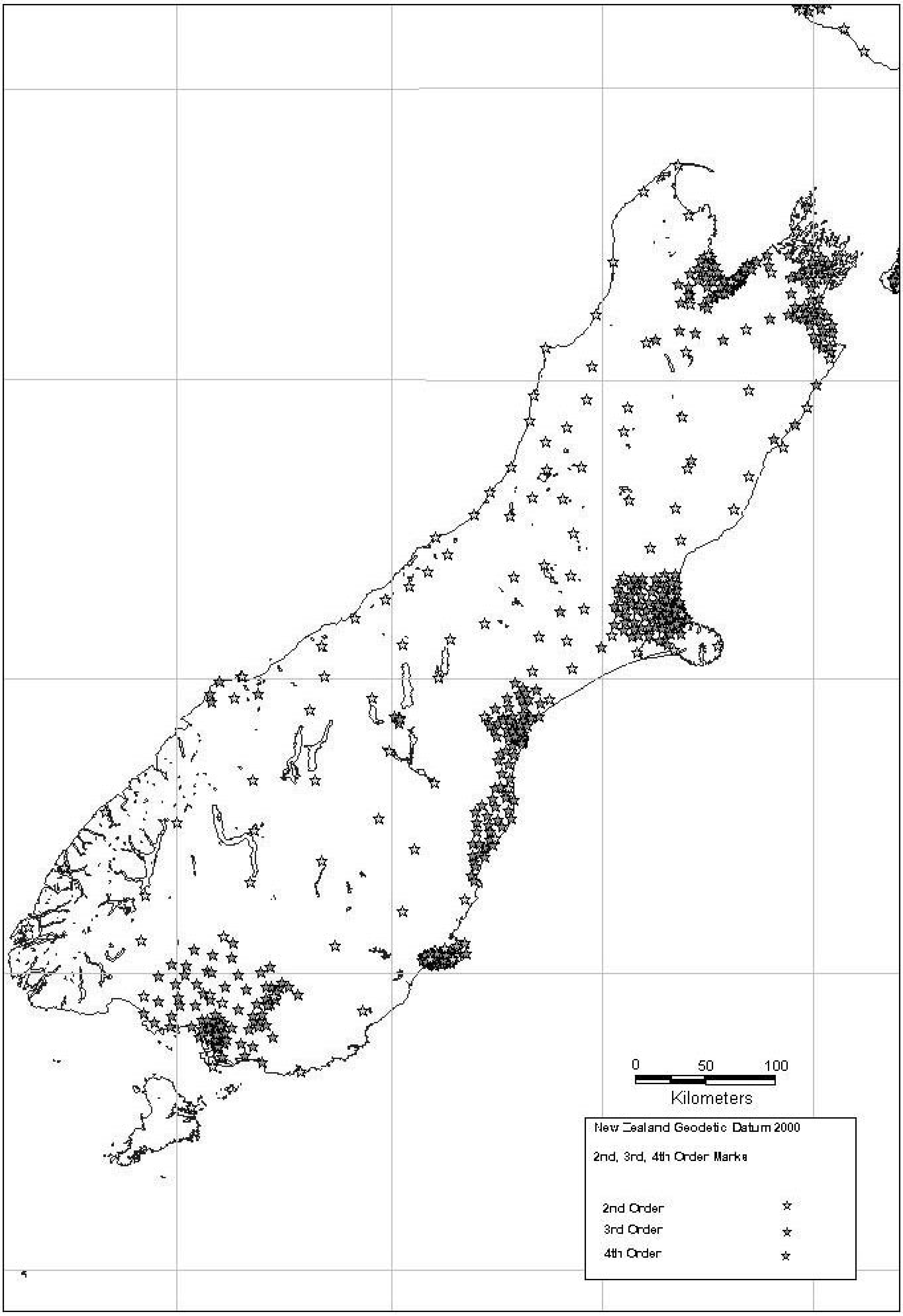

Figure 3. South Island 2nd, 3rd, and 4th Order 2000 Geodetic Network

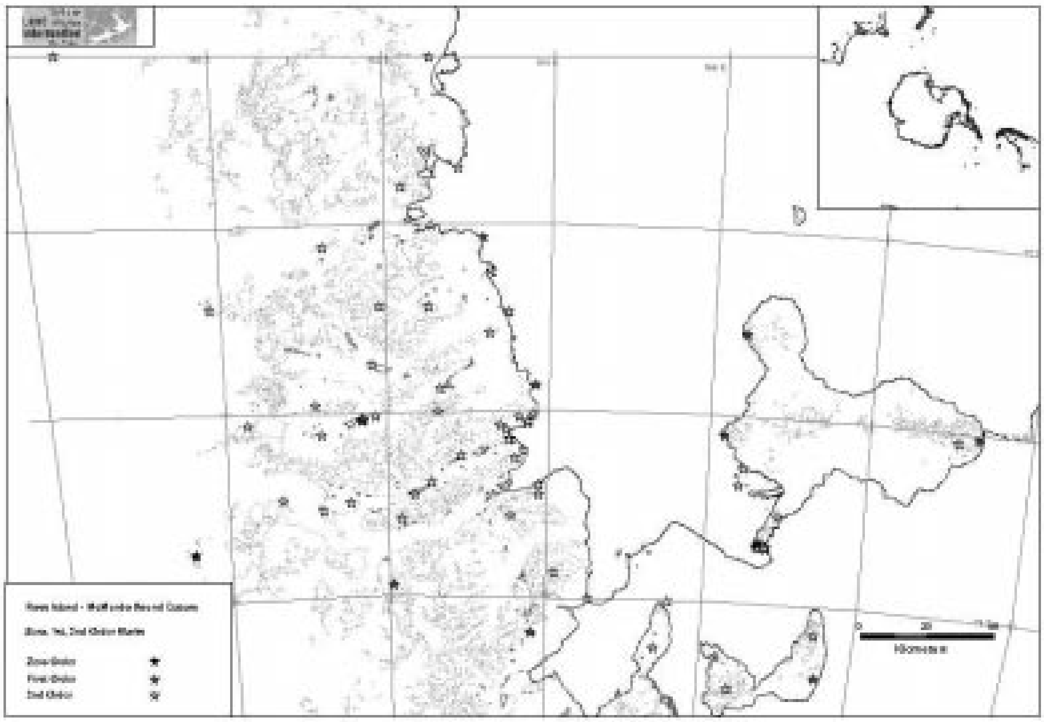

Figure 4. Ross Dependency Geodetic Network

GPS sites occupied by GNS and colleagues, Jan 1996 - May 1999

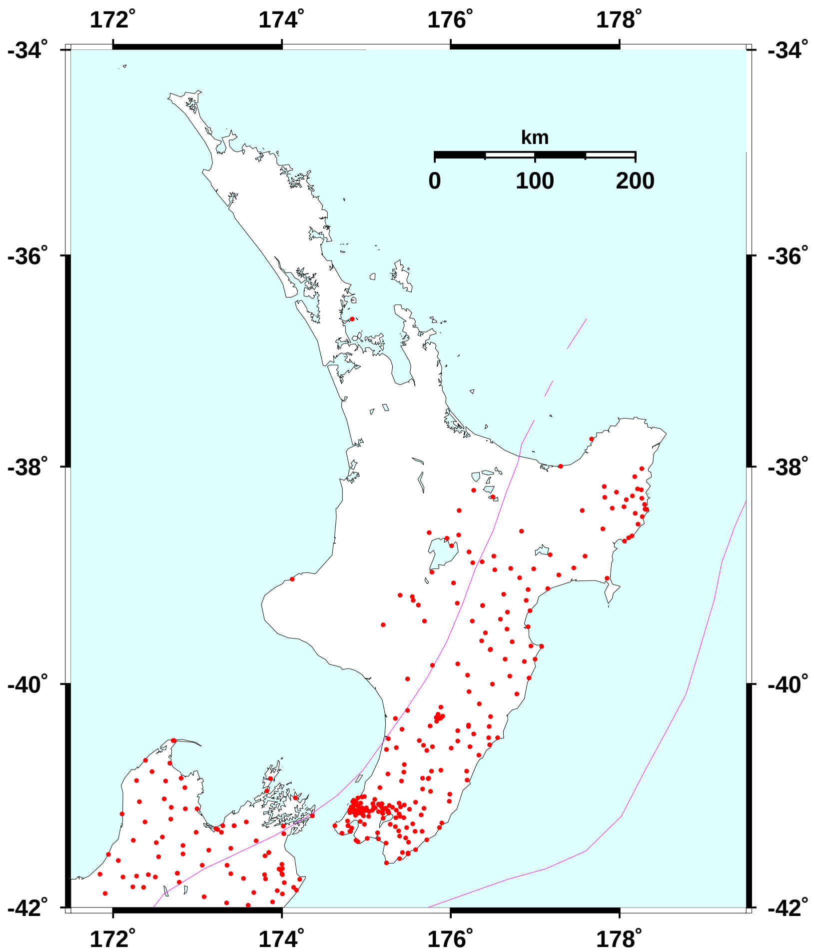

Figure 5. North Island GPS Sites Occupied for Crustal Dynamic Studies

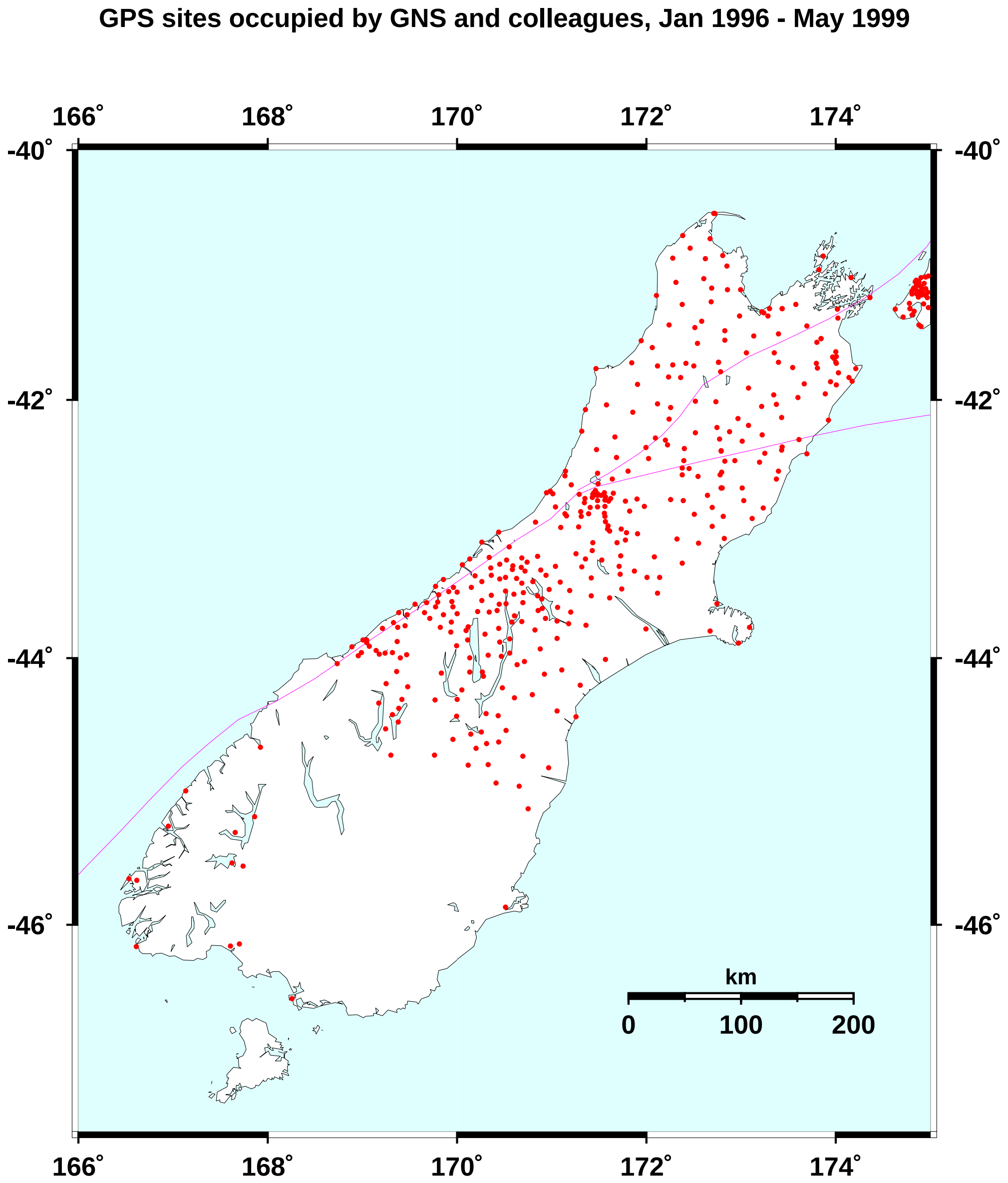

Figure 6. South Island GPS Sites Occupied for Crustal Dynamic Studies