The Implementation of a Semi-Dynamic Datum in New Zealand – Ten Years On

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Key words: Geodetic, Semi-Dynamic, Datum, Reference Frames

SUMMARY

In 1998 New Zealand implemented a new geocentric datum, New Zealand Geodetic Datum 2000 (NZGD2000). NZGD2000 is defined as a 'semi-dynamic' datum, and accounts for the significant ongoing earth deformation in New Zealand. Published coordinates are defined in terms of their values at the reference epoch of 1 January 2000.

Deformation is provided for by a deformation model which allows positions at other times to be extrapolated from the reference epoch coordinates. The deformation model currently used was generated from repeated GPS survey observations. Currently it only accounts for horizontal deformation with a constant velocity through time. Vertical deformation is assumed to be zero in this model. In addition to the deformation model it has been proposed that the effects of discrete deformation events (eg earthquakes) be modelled by patches and added to the deformation model.

Since the implementation of NZGD2000, the effects of plate motions have resulted in physical movements relative to the datum of up to half a metre across New Zealand. That is, NZGD2000 coordinates at epoch 2000.0 differ from their current day values by up to 0.5m.
Furthermore, in 2009 a large M7.8 earthquake struck the southern portion of the South Island causing a downgrading of the spatial accuracy of the datum in this area necessitating a practical evaluation and implementation of the patch proposal.

It is now 12 years since NZGD2000 was implemented. This presentation discusses the concepts behind NZGD2000, its implementation, what has gone well, lessons learned, and issues that need to be addressed. It also discusses the possible future development of NZGD2000 and possible options for future semi-dynamic and dynamic datums in New Zealand.

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1. INTRODUCTION

New Zealand lies across the obliquely convergent Australian and Pacific plate boundary. To the northeast of New Zealand the Pacific plate is subducted beneath the Australian plate and to the southwest of New Zealand the Australian plate is subducted beneath the Pacific plate. Through central New Zealand the oblique collision of the continental plates has resulted in a combination of strike slip and uplift motion with horizontal motions of 40-55mm/yr along the plate boundary (Walcott 1984). In addition to the plate motions, New Zealand experiences the effects of other deformation events such as large earthquakes, volcanic activity, and more localised effects such as landslides.

After the introduction of the first national geodetic datum in New Zealand, New Zealand Geodetic Datum 1949 (NZGD49), the effects of crustal deformation resulted in a gradual degradation in the accuracy of that datum. This, and the lower survey accuracies achievable when NZGD49 was first defined, resulted in distortions of up to 5m being present in NZGD49 (Bevin and Hall 1995).

In 1998 LINZ implemented a new geocentric datum, New Zealand Geodetic Datum 2000 (NZGD2000) with a reference epoch of 1 January 2000 (2000.0) to address inaccuracies in NZGD49 as well as datum degradation over time due to deformation.

2. NZGD2000 – A SEMI-DYNAMIC DATUM

NZGD2000 is realised in terms of ITRF96 and uses the GRS80 ellipsoid (Grant et al 1999). In a major conceptual departure from the definition of NZGD49 and other international datums, NZGD2000 was defined to be a semi-dynamic datum. A fully dynamic datum is defined by us as one where coordinates of marks change continuously. A semi-dynamic datum in New Zealand has been defined as one where coordinates remain fixed at a reference epoch, however the inclusion of a deformation model enables:
  – Coordinates to be generated at the reference epoch from observations made at a time other than the reference epoch.
  – Coordinates or calculated vectors between points at a time other than the reference epoch to be generated from the reference epoch coordinates.

In NZGD2000 this is achieved by incorporating a national horizontal deformation model (Fig. 1) to model the estimated (predicted) effects of crustal deformation (Office of the Surveyor-General 2003).
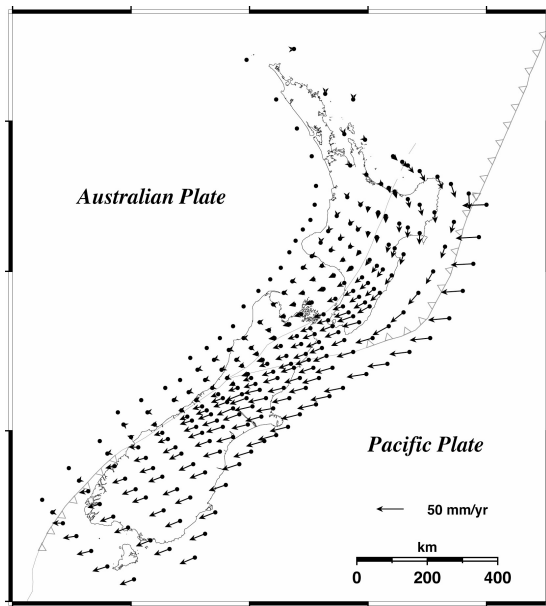
Fig. 1 NZGD2000 deformation model, with horizontal velocities relative to the Australian plate.

NZGD2000 coordinates at the datum reference epoch of 2000.0 are determined by applying the deformation model when generating new coordinates (Fig. 2) following a similar method to that described by Snay (1999). The current deformation model used a constant horizontal deformation velocity through time and assumes zero vertical deformation.
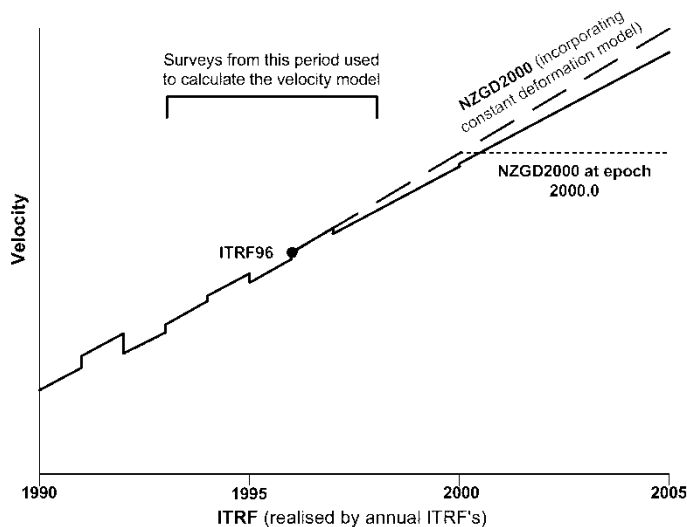

Fig. 2 Relationship between ITRF and NZGD2000.

In the case of localised deformation events such as earthquakes or landslides, it has been proposed that these are modelled independently of the national deformation model, and then

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added to the deformation model as a localised patch (Blick et al 2003; Jordan et al 2005; Winefield et al. 2010).

3. THE IMPLEMENTATION OF NZGD2000 IN NEW ZEALAND

Since NZGD2000 was implemented, over 70,000 geodetic control marks (Fig. 4) have been accurately coordinated in terms of NZGD2000. Many of these marks are used to support cadastral surveys.   Cadastral survey regulations governing surveys of land property boundaries require that cadastral surveys are made in terms of NZGD2000 where practicable.

Following the implementation of NZGD2000 a new national mapping projection, New Zealand Transverse Mercator 2000 (NZTM2000) was developed in terms of the new datum. As GIS users convert their spatial datasets to NZTM2000 it facilitates the integration of their spatial data with LINZ geodetic, cadastral, and topographic data.

In parallel with these developments, LINZ has implemented a national Continuously Operating Reference Station (CORS) network called PositioNZ. Other agencies in New Zealand have also established CORS stations for crustal dynamic studies and to support local survey operations.
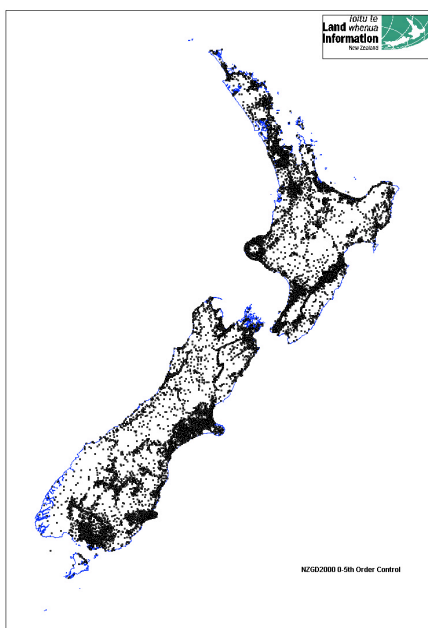

Fig. 4 Location of geodetic marks in New Zealand

The LINZ CORS network consists of 33 sites evenly spaced across mainland New Zealand (Fig. 5), plus two on the Chatham Islands and three sites in Antarctica. Thirty second RINEX data is made freely available via the PositioNZ website[1] and the network is being upgraded to include the delivery of real time 1 second streamed data.

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[1] www.linz.govt.nz/positionz

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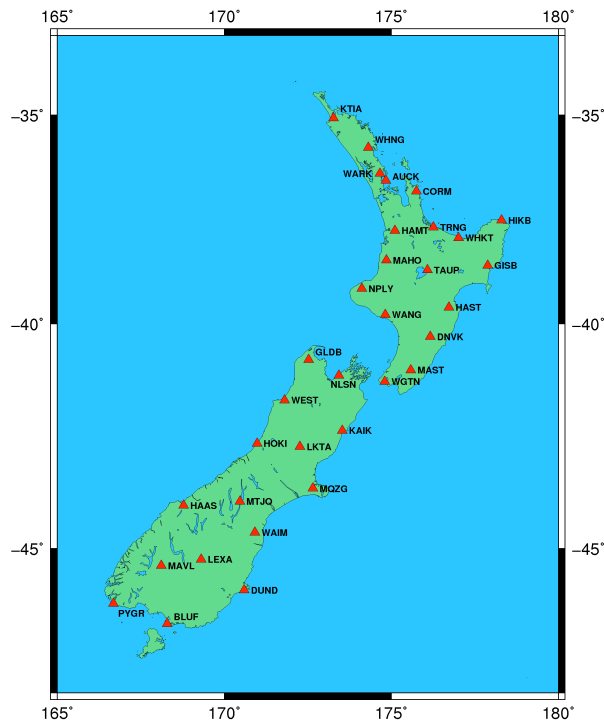Sydney, Australia, 11-16 April 2010

Fig 5: LINZ's CORS network (PositioNZ)

4. WHAT HAS GONE WELL WITH THE IMPLEMENTATION OF NZGD2000

The implementation of a semi-dynamic datum with the inclusion of a deformation model is a major departure form normal geodetic datums. The following are considered to have gone well.

4.1 User Acceptance

From a geodetic perspective use of a semi-dynamic datum is relatively easy to implement and manage. For low accuracy users (at the metre level), the datum appears static and the deformation model can be ignored, facilitating its ease of use. For LINZ geodetic applications processes have been developed to enable use of the deformation model and conversions of NZGD2000 coordinates between the previous datum (NZGD49) and other reference systems.

Users of the datum have readily accepted the concept of a semi-dynamic datum and there has been little if any adverse reaction to its implementation. In part this was due to a comprehensive advertising and publication campaign aimed a keeping users fully informed of the datum and the implications for users.

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4.2 Implementation of the Deformation Model

The deformation model was developed to support the accuracy requirements of the geodetic system. In fulfilling this requirement, it also provided a useful tool for other users to enable their surveys to accommodate the effects of crustal deformation and thus maintain their consistency. For geodetic users, accounting for deformation is relatively straight-forward, however for non-geodetic users it can be complex and present an annoyance.

In terms of managing the accuracy of geodetic data the inclusion of the deformation model has been successful and NZGD2000 coordinates at epoch 2000.0 are generated and delivered to users through the geodetic database. Although using rather sparse data in some areas (Beavan 1998), the development of the deformation model and its implementation has gone well.

4.3 Maintaining the Accuracy of Datum

One of the fundamental aims of NZGD2000 was to maintain a relative accuracy of 5cm across New Zealand. With deformation due to plate tectonics amounting to movements of that magnitude/year, adoption of a static datum would have meant that the relative accuracy tolerance would have been exceeded after only one year.

Incorporation of the deformation model has meant that after 10 years the relative accuracy tolerance is, in general, still being met. However analysis is showing (Amos 2006) that due to small errors in the deformation model this tolerance will soon be exceeded and work is currently being undertaken preliminary to a revision and formal update of the deformation model.

5. ISSUES WITH THE IMPLEMENTATION OF NZGD2000

As with implementing any new system, a number of limitations have been recognised and have, or are in the process of, being addressed.

5.1 Managing the Deformation Model

The surveys used to determine the initial deformation model in NZGD2000 are now over 15 years old. As time passes, errors in the determination of the velocities used in the deformation model have led to increasing errors in the calculated coordinates of marks in terms of the reference epoch, 2000.0. Research has indicated that in parts of New Zealand the existing deformation model is already unable to predict the current positions of geodetic marks at their required accuracy level (Amos 2006). In effect, the datum is still steadily degrading with time, but at a much slower rate than if no deformation model had been used.

In addition, since NZGD2000 was implemented, New Zealand has been struck by several significant earthquakes. The largest, the Fiordland earthquake (Fig. 6) of 15 July 2009 with a magnitude of 7.8, resulted in ground deformation of up to 0.8m (Fig. 7) over the bottom half of the South Island (Winefield et al. 2010). Fortunately this earthquake occurred in a National Park and thus an area of low population and development in New Zealand. Methods to

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manage such movements have been proposed by Blick et al [2003] and managing the effects of the earthquake are being studied. It is proposed that a patch will be added to the deformation model so that the effects of the earthquake can be accommodated (Winefield et al. 2010). Further monitoring of ground movements is planned to accommodate any further post-seismic movements from the earthquake.
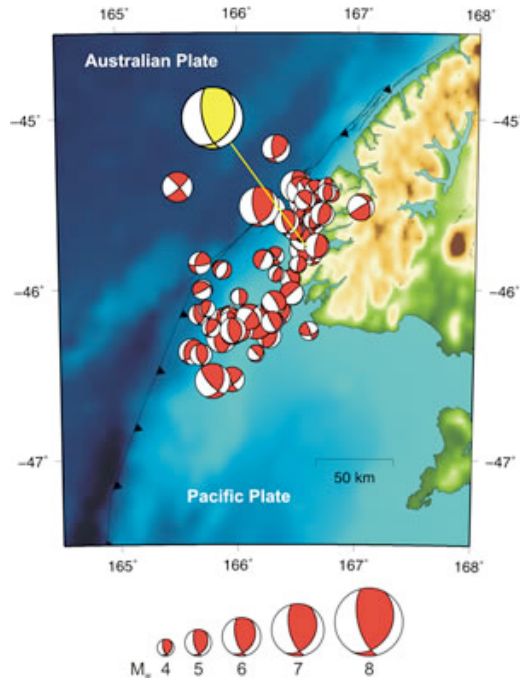

Fig 6. Epicenter of the 2009 Fiordland earthquake (from Winefield et al. 2010).
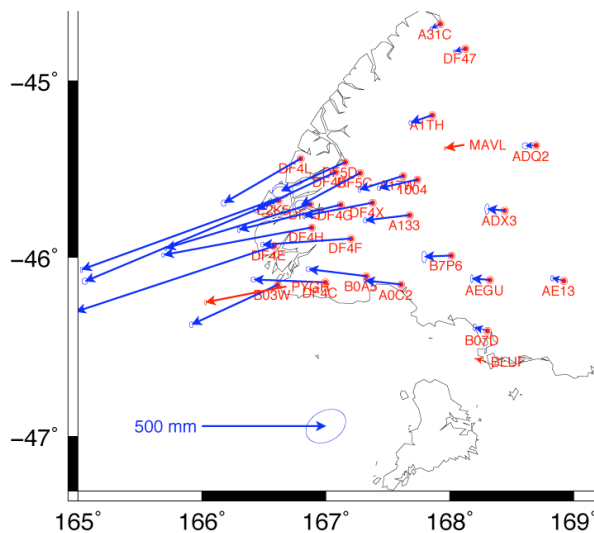

Fig 7. Observed horizontal displacements from the 2009 Fiordland earthquake (Winefield et al. 2010).

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5.2 Managing Changing Coordinates – CORS Real Time Network

The issues with a semi-dynamic datum and the LINZ CORS network revolve around the coordinates and velocities of the CORS sites; more specifically, the management of coordinates at different epochs. In terms of coordinates, only NZGD2000 epoch 2000.0 coordinates are made readily available. However, a coordinate at epoch 2000.0 may not always satisfy the user's needs.

To provide post-processing and one second data services, LINZ requires the capability to easily generate and publish coordinates at epochs other than 2000.0. The online post-processing service requires a coordinate that accurately represents the position of the CORS site at the epoch the GPS observations are being processed. The real-time one second GPS data service will also need coordinates for base stations that accurately reflect the true position of the site – real time. Providing 'current' or non-2000.0 coordinates of the CORS sites is not necessarily a trivial exercise. Three options are described by Beavan (2006) and are currently being evaluated:

1. Publish a weekly position based on GNSS observations at each CORS station.
2. Predict positions from a model fitted to the CORS time series, with the model allowing for some or all of: straight line; seasonal (annual, semi-annual) terms; steps (coseismic and/or equipment changes); aseismic tectonic deformation events. The model would need to be updated on a fairly regular basis.
3. Predict positions from a simpler model (eg the current deformation model) involving the NZGD2000 coordinates of the site and the NZGD2000 deformation model.

Option 1 has the clear advantage of providing the best 'current' coordinate; however, it does have the disadvantage requiring the storage of coordinates for each week. It also raises the question "what reference frame are the coordinates in terms of?" Clearly not NZGD2000 as that has a deformation model incorporated in it. Option 2 enables coordinates to be generated at any epoch; however, the model is complex and will need to be maintained and the reference frame of these coordinates is not the national datum but rather something else – perhaps one of the International Terrestrial Reference Frames (ITRF's). Option 3 also enables positions to be generated at any epoch, but uses the existing deformation model. The coordinates are in terms of the national datum but with the decreasing accuracy of the deformation model with time (Beavan and Blick 2005), errors will be introduced when extrapolating epochs into the future unless the deformation is kept up to date.

5.3 Managing Changing Coordinates – Surveys With Long Base Lines

The New Zealand cadastral system is based on a fundamental legal premise common to most cadastral systems around the world that undisturbed survey marks form the primary evidence for property boundary definition. Boundary positions must be referenced to cadastral witness marks which are in turn tied to geodetic marks by survey observations. Accordingly, the New Zealand cadastral system is founded on a large number of physical survey marks and survey observations (Blick et al. 2009).

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When using theodolite and electronic distance measuring equipment, connections to geodetic control marks are generally within 1-2 km of the survey area. For most practical purposes the effect of crustal deformation over these relatively short distances can almost always be ignored. More recently however, greater use is being made of GNSS systems and ties to geodetic control marks can include much longer lines, including lines to CORS stations in excess of 100km. With the greater survey accuracy achievable using such technology over long lines, the effects of crustal deformation must now be considered in circumstances such as:

1. When locating or setting out marks using GNSS over long distances at an epoch other than 2000.0.
2. When incorporating data of varying epochs into the survey. For example, if closing onto epoch 2000.0 coordinates using non-epoch 2000.0 observations.

To overcome these issues, all observations (or coordinates) need to be transformed into a common epoch; either epoch 2000.0 or the epoch of the survey.

Epoch 2000.0 coordinates are generated by LINZ geodetic staff using in-house developed least squares adjustment software incorporating the deformation model. This software is also made available to allow external users to generate NZGD2000 coordinates at epoch 2000.0. However, for a user to successfully use the software requires a thorough understanding of the principles involved in applying the deformation model. For these users (a majority) the management of the dynamics can become a complex issue and annoyance. Ways of simplifying this process need to be sought.

5.4 Managing the Spatial Alignment of the Cadastral System

As well as managing the spatial accuracy of the CORS network underpinning the geodetic system, LINZ also manages the accuracy of the cadastral system (Blick et al. 2009).

One of the key drivers for the move to NZGD2000 was the automation of New Zealand's survey and titles systems. It was recognised that if the full benefits of automation were to be realised, cadastral boundaries would need to be accurately positioned in terms of a single coordinate system (Haanen et al 2002). All cadastral boundaries in New Zealand now have geodetic coordinates – although some are more accurate than others. For about 70% of New Zealand's land parcels, actual survey observations have been integrated using least squares to form a seamless network, generating coordinates for each boundary point (Rowe 2003). These coordinates are 'survey' accurate (to a few centimetres), relative to the local geodetic control. For the other 30%, mostly in rural areas, the cadastre has generally been digitised off paper-based cadastral maps, and errors of metres are common – they may be up to 50m in remote rural areas. This "geodetic cadastre" is managed in a system called Landonline.

While applying the deformation model and updating geodetic data is a relatively trivial task using tools developed to undertake these tasks, updating the cadastral data and boundary marks connected to this control is a more complex task due to the sheer volume of marks concerned.

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Currently, when geodetic marks have their coordinates updated, there is no efficient process to update the nearby cadastral coordinates by least squares adjustment. Consequently, LINZ is actively looking at efficient methods of updating large numbers of cadastral coordinates, so that the cadastre can maintain its accuracy after a significant geodetic update.

The impact of this issue on users is that cadastral surveyors potentially need to consider how coordinates were created when assessing whether their survey is consistent with the underlying work. For example, if the coordinates for geodetic marks have been updated, but adjacent cadastral marks have not, some discrepancies between the surveyor's observations and the existing coordinates would be expected.

5.5 Misalignment of Readjusted Historic Geodetic Control with new Surveyed Geodetic Control

The development of NZGD2000 necessitated the upgrading of geodetic control to NZGD2000 status (Blick et al. 2009). This was achieved in two ways:
1. Survey using GNSS of existing and new control; and
2. Readjustment of existing control using historical observations

It has become clear that there can be a misalignment between the surveyed and readjusted control such that if a cadastral surveyor uses a mixture of both control types they can fail to meet their cadastral survey accuracy requirements. The solution to the problem has been to downgrade the accuracy of doubtful readjusted geodetic control so that its stated accuracy more accurately reflects its true accuracy. This is necessitating the provision of a larger amount of newly surveyed control than was originally envisaged.

6. FUTURE DEVELOPMENTS OF NZGD2000

NZGD2000 is now 12 years old however continued development of it continues to ensure that its spatial accuracy meets user requirements. A number of developments are underway and potential future developments are being considered.

6.1 Updating the Deformation Model

Research has indicated that in parts of New Zealand, the existing deformation model is already unable to predict the current positions of geodetic marks at their required accuracy level (Amos 2006). Work is currently underway to develop a new deformation model and this will be incorporated into the datum to ensure that its spatial accuracy can be maintained. If the datum is still to be considered NZGD2000, the new deformation model will need to be consistent with the original datum definition.

6.2 Vertical Deformation Model

The current velocity model assumes a zero vertical velocity model. Clearly vertical deformation does occur in New Zealand although at a generally lesser rate than horizontal

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deformation (except in the volcanic zones of New Zealand). The recent Fiordland earthquake for example showed vertical deformations up to 250mm (Fig. 8) (Winefield et al. 2010).

There is a need to consider and include a vertical component in the deformation model so that the vertical accuracy of the datum can be maintained. This is particularly important as New Zealand has moved to a national vertical datum that is based on ellipsoidal heights and a national geoid model (Amos and Featherstone 2009).
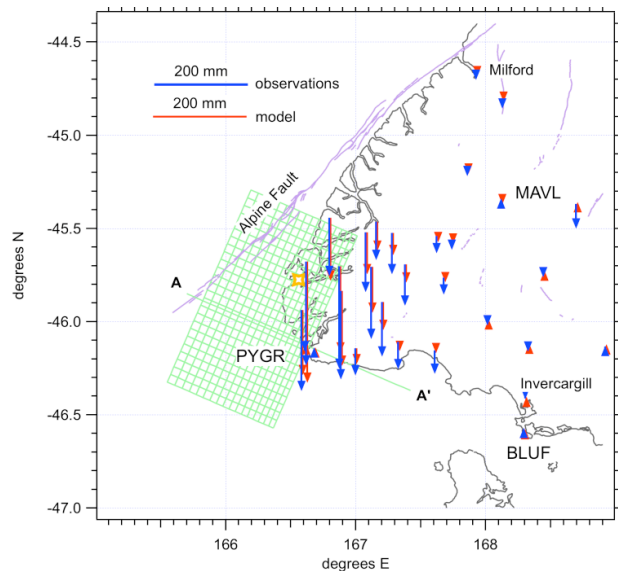

Fig 8. Observed vertical displacements from the 2009 Fiordland earthquake (Winefield et al. 2010).

6.3 CORS Real Time – Tools for Managing Coordinates

An automated post processing system (PositioNZ PP) is being developed for the LINZ CORS network (Palmer and Moore 2010).   One of the advantages of such a system will be that it will generate official NZGD2000 coordinates for marks using the deformational model and tools to ensure that corrections are applied efficiently and correctly. It has been proposed that with appropriate metadata coordinates generated from such a system could be loaded directly into the geodetic database thus generating geodetic control form third parties.

6.4 Tie to the ITRF - Going Fully Dynamic

NZGD2000 is realised in terms of ITRF96. Significant improvements have been made to the ITRF and for ease of computations and better data management, it is logical that NZGD2000 be moved to a later realisation of the ITRF. While the inclusion of a deformation model in NZGD2000 has meant that the accuracy of the datum has been able to be maintained for a much longer period than if it were a static datum, it is apparent that an updated

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deformation model will be required shortly. In the relatively near future a new or updated datum will be required – NZGD20XX.

Given the acceptance of a semi dynamic datum in New Zealand, the tools developed to manage its dynamics, and the experience gained in managing coordinates in a dynamic environment, it is logical that consideration should be given to a fully dynamic datum that maintains a constant relationship with the ITRF at some time in the future.

7. SUMMARY

NZGD2000 has now operated in New Zealand for over 10 years. The use of a semi dynamic datum has been well accepted and its implementation and use have been relatively straight forward from a technical and geodetic perspective. The use of the deformation model has meant that the accuracy of the datum has been maintained over a much longer time period than were it a static datum.

A number of issues have been identified from a user perspective, particularly that of maintaining the accuracy of the deformation model and also allowing users of the system to incorporate long distance observations in their surveys or to use real time CORS networks.

Future enhancements to NZGD2000 will continue to ensure user requirements are met. The next step will be upgrading the deformation model, inclusion of a vertical component in the model, and perhaps moving to a later realisation of the ITRS. In the longer term, consideration will be given to moving to a fully dynamic datum but such a move is expected to be some years away.

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BIOGRAPHICAL NOTES

Graeme Blick, BSurv (Otago) MNZIS. Graduating from Otago University in 1980, Graeme worked as a scientist for the Institute of Geological and Nuclear Sciences using geodetic techniques to study plate tectonics and crustal deformation. In 1995 he joined Land Information New Zealand, initially with the Office of the Surveyor-General. He now works for the Customer Services Group as National Geodesist and Manager Geodesy where he continues to work on the development and implementation of the geodetic system in New Zealand.

Don Grant, Don was appointed Deputy Surveyor-General of New Zealand in 1996 and worked on the Landonline programme for automation of the survey and title systems. Since 2004, Don has been Surveyor-General. As such, he is responsible for the geodetic and cadastral survey systems, and also has responsibilities for electoral boundaries and geographic names. Don was made a Fellow of the NZ Institute of Surveyors in 2007.

Don Grant holds a BSc Honours in Physics from Canterbury University, a Diploma in Surveying from Otago University and a PhD in Surveying from the University of New South Wales. He registered as a surveyor in 1979 and is a licensed cadastral surveyor.

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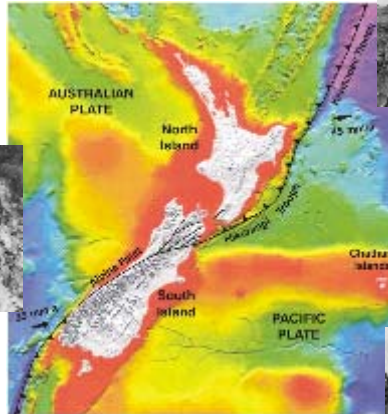Graeme Blick
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Land Information New Zealand

12 April 2010

Overview

- Crustal dynamics in NZ
- NZGD2000 – A Semi-Dynamic Datum
- The Implementation of NZGD2000
- What Has Gone Well
- Issues With The Implementation of NZGD2000
- Future Developments of NZGD2000

Crustal Dynamics in New Zealand

NZ lies across Plate Boundary

50mm/yr movement

NZGD2000 – A Semi-Dynamic Datum

NZGD49 – static datum
- Epoch 1949
- Local datum – best fit to New Zealand
- Regional distortions up to 5m

NZGD2000 – semi-dynamic datum
- NZGD2000 (ref epoch 1 Jan 2000)
- Geocentric origin
- ITRF96 with epoch 2000.0 coordinates
- Semi-dynamic datum
- Incorporates deformation model

The Implementation of NZGD2000

- **Since implemented over 70,000 geodetic control marks coordinated**
- **Primarily to support cadastral surveys**
- **Implemented PositioNZ CORS network**
  - 33 stations in NZ
  - datum monitoring
  - upgrading to provision of real time data
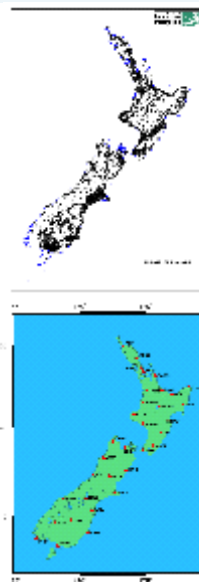
What Has Gone Well With The Implementation of NZ2000

- **User Acceptance**
  - Concept readily accepted
  - For low accuracy users datum appears static

- **Implementation of the Deformation Model**
  - Tools and processes developed
  - For technical/geodetic users process straightforward

- **Maintaining the Accuracy of Datum**
  - Relative accuracy aim is 5cm – without deformation model outdated in 1 year
  - Incorporating deformation model has enabled NZGD2000 to remain current for 10 years

Issues With The Implementation of NZGD2000 – (1)

Managing the Deformation Model

- Surveys used to determine deformation model now 15 years old

- Errors in velocities are leading to increased errors in calculated coordinates

- In some areas model is unable to predict positions at required accuracy (5cm)

- Incorporating the effects of several large earthquakes (eg Fiordland Earthquake)

- Accommodating effects of post-seismic movements, slow earthquakes

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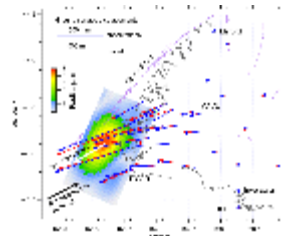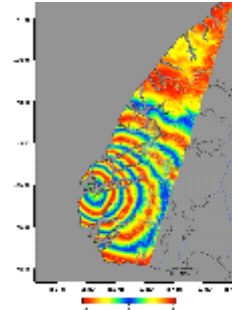
Issues With The Implementation of NZGD2000 – (2)

Managing Changing Coordinates - CORS Real Time Network

- To provide post-processing or real time CORS surveys, coordinates at CORS need to be generated at epochs other than 2000.0

- Not a trivial - various options

  — Publish weekly values based on GNSS observations

  — Predict values based on CORS time series

  — Use deformation model

Daily solutions for AUCK

East

North

Up
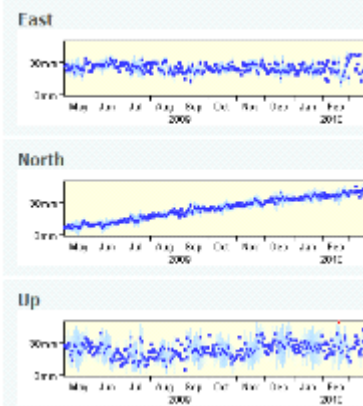
Issues With The Implementation of NZGD2000 – (3)

Managing Changing Coordinates – Surveys With Long Base Lines

- GNSS surveys make use of longer lines in surveys – the effects of crustal deformation must be included

- Observations need to be transformed to a common epoch (2000.0 or epoch of the survey)

- Users must incorporate the dynamics in their adjustments - this can be complex

Velocity Model

Chatham Islands

5 cm/yr

Note: Map not to scale

Issues With The Implementation of NZGD2000 – (4)

Managing the Spatial Alignment of the Cadastral System

- 70% of cadastre is survey accurate

- Applying deformation model to a few thousand geodetic marks is a trivial task

- Applying to many million cadastral marks is more complex

- Need to find an efficient method to do this

Issues With The Implementation of NZGD2000 – (5)

Misalignment of Readjusted Historic Geodetic Control with new Control

- Managing and updating NZGD2000 involves:
    - readjusting old marks using the deformation model; and
    - survey of new marks
- There can be a discrepancy between adjusted marks and surveyed mark positions

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Future Developments of NZGD2000

Updating the Deformation Model
- Enable spatial accuracy to be maintained
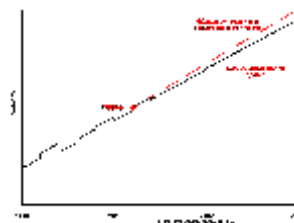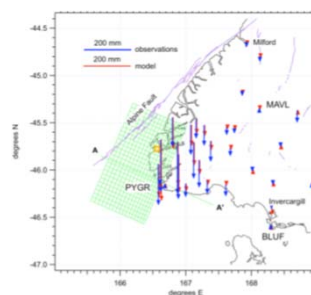
Vertical Deformation Model
- Assumes zero vertical deformation

CORS Real Time
- Tools for managing changing coordinates

Tie to ITRF - Going Fully Dynamic
- Significant improvements to ITRF since ITRF96
- Consider maintaining a constant relationship with ITRF – i.e. going fully dynamic

Summary

- NZGD2000 has operated for over 10 years and accuracy of the datum has been maintained
- Use of a semi-dynamic datum has been well accepted
- Its implementation from a technical point of view has been straight forward
- A number of issues have been identified and are being addressed
- Future enhancements are continuing to ensure user requirements are met
- In the long term consider a fully dynamic datum using ITRF

Questions