# The Practical Implications and Limitations of the Introduction of a Semi-Dynamic Datum – A New Zealand Case Study

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**Abstract.** In 1998 Land Information New Zealand introduced New Zealand Geodetic Datum 2000 (NZGD2000) as its new national datum. It is defined as a semi-dynamic datum and incorporates a national deformation model to ensure that the accuracy of the datum is maintained. The deformation model allows observations made at an epoch other than the datum reference epoch of 2000.0 to be modeled so that coordinates at the reference epoch can be generated. From a geodetic perspective its implementation is relatively straight forward. In New Zealand the geodetic system and datum also underpin the cadastre and spatial positioning. Cadastral surveys are made in terms of NZGD2000 and about 70% of parcels have NZGD2000 survey accurate coordinates. Many users of the geodetic system are non-technical users, for whom managing the dynamics of the datum presents a potential annoyance and complexity. LINZ manages the dynamics of the geodetic system which enables other spatial datasets connected to it to be updated. The implementation of a Continuously Operating Reference Station (CORS) network in New Zealand also presents a set of issues that need to be considered when CORS stations are incorporated as part of a semi-dynamic datum. This paper presents some of the implications and limitations for users of geodetic and related datasets when implementing a semi-dynamic datum and discusses solutions based on New Zealand experiences.

**Keywords.** Geodetic datum, semi-dynamic datum, deformation model, crustal deformation, 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.

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

In the 1990s Land Information New Zealand (LINZ) embarked on a project to consider options for a new national datum which was to be consistent with global reference frames. In 1998 LINZ implemented a new geocentric datum, New Zealand Geodetic Datum 2000 (NZGD2000) with a reference epoch of 1 January 2000 (2000.0).

## 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 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. In NZGD2000 this is achieved by incorporating a national horizontal deformation model (Fig. 1) to accommodate the effects of crustal deformation (Office of the Surveyor-General 2003).

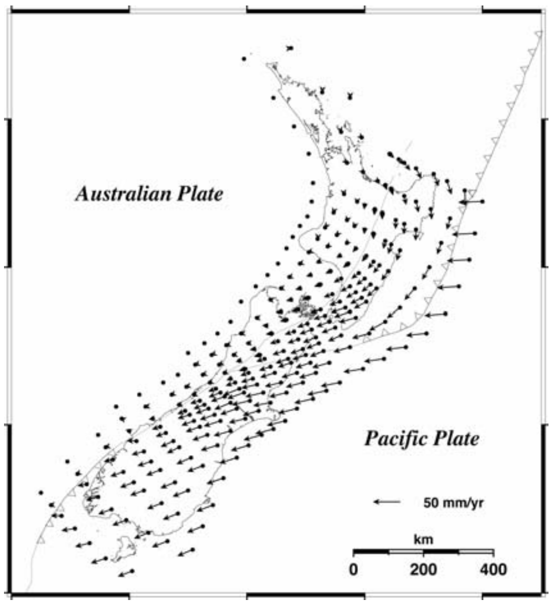


**Fig. 1** NZGD2000 deformation model, with horizontal velocities relative to the Australian plate.

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). In the case of localised deformation events such as earthquakes or landslides, it is proposed that these are modelled independent of the national deformation model, then added to the deformation model as a localised patch (Blick et al 2003; Jordan 2005).

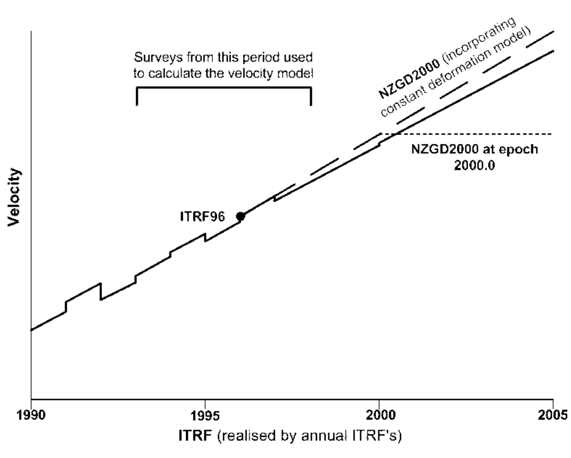


**Fig. 2** Relationship between ITRF and NZGD2000.

The current deformation model assumes a constant deformation velocity through time. The surveys used to determine the initial deformation model are now eight 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 future it may be necessary to re-coordinate marks as the deformation model becomes more and more complex and issue a new national datum at a different reference epoch to NZGD2000.

## 3 The Implementation of NZGD2000 in New Zealand

Unlike many countries, in New Zealand LINZ is the sole agency that manages both the cadastral and geodetic systems which has facilitated the integration of both systems. Since NZGD2000 was implemented over 70,000 geodetic control marks (Fig. 3) have been accurately coordinated in terms of NZGD2000. Many of these marks are used to support cadastral surveys. Cadastral Survey Rules require that cadastral surveys are made in terms of NZGD2000 where practical.

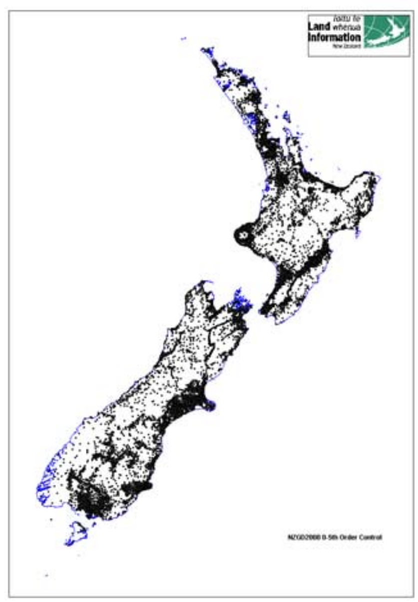

**Fig. 3** Location of geodetic marks in New Zealand

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 have also established CORS stations for crustal dynamic studies and to support local survey operations.

The LINZ CORS network consists of 30 sites fairly evenly spaced over the country (Fig. 4), plus 2 sites in Antarctica. Thirty second RINEX data is made freely available via the PositioNZ website[1].

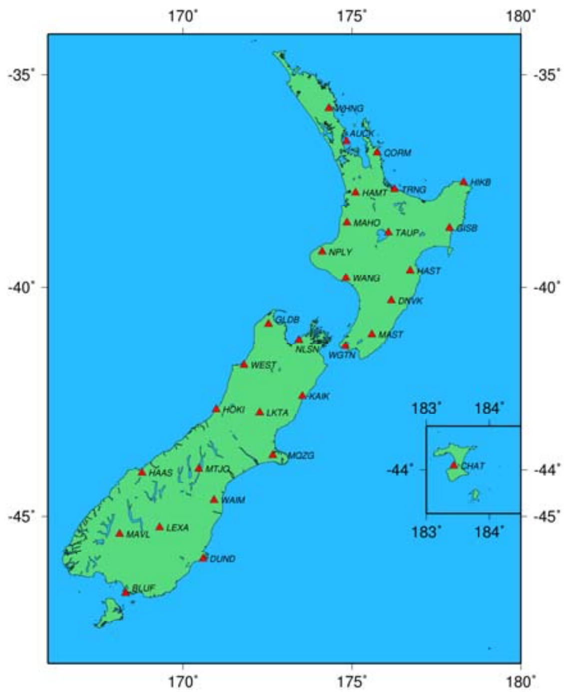


**Fig 4:** LINZ's CORS network (PositioNZ)

Two additional services are being developed from the LINZ CORS network. The first is an online post-processing service to provide users with the ability to obtain NZGD2000 coordinates from their GPS data in a rigorous yet simple manner. The second service is the provision of real-time one second GPS data from selected CORS sites to make the most use of existing infrastructure for real-time GPS data products. Such products to be developed and provided by other agencies might include single base station real-time kinematic (RTK) corrections, network RTK corrections, or differential GPS (DGPS) corrections.

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

## 4 Implications and Limitations of Using NZGD2000

From a geodetic perspective use of a semi-dynamic datum is relatively easy to implement and manage. For low accuracy users (meter), the datum appears static and the deformation model can be ignored, facilitating its ease of use. However, for high accuracy (centimetre) non-geodetic users, such as cadastral surveyors who use Global Navigation Satellite Systems (GNSS) technologies to measure precisely over long baselines, there is an increasing realisation that they need to manage the dynamics inherent in NZGD2000. 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.

### 4.1 CORS 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 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 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. A model of this sort is being run on California data by Scripps Institute of Oceanography[2].
3. Predict positions from a simpler model (eg the current deformation model) involving the NZGD2000 coordinates of the site and the NZGD2000 deformation model.

Example 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. Example 2 enables coordinates to be generated at any epoch; however, the model is complex and will need to be maintained. Example 3 also enables positions to be generated at any epoch, but uses the existing deformation model. However, 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.

## 4.2 Managing 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.

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. 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 may be up to 50m in magnitude. This "geodetic cadastre" is managed in a system called Landonline.

**Managing Alignment:** As land is developed, new parcels are continually created and these are integrated into the cadastre using least squares. Existing coordinates are not re-adjusted unless the adjustment statistics indicate that they are inaccurate.

Where the new data is consistent with the old data, integration is a straight-forward process and the new coordinates generated are consistent with the surrounding cadastre. Where inconsistencies between the new and underlying work are identified, some of the underlying observations are brought into the least squares adjustment to enable all the relevant data to be adjusted together.

In some cases, the magnitude of the inconsistency means that it is necessary to re-adjust the entire local area in an adjustment. The time-consuming nature of this process means that it is only used where the inconsistencies are particularly serious.

Currently, when geodetic marks have their coordinates updated, there is no efficient process to update the nearby cadastral coordinates. 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.

**User Impact of Misalignment:** The creation of the digital cadastre has meant 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. Once the survey is submitted, LINZ may find it difficult to validate, as automated tests will identify any discrepancies between existing and new coordinates, even where the observations are correct (Donnelly and Palmer 2006).

The complexity of the data integration and alignment process means that it is unlikely that this task will be carried out by cadastral surveyors in the foreseeable future. In particular, the re-alignment of the cadastre over a wide area needs to be managed in a centralised way to ensure consistency of results.

[2] http://sopac.ucsd.edu/processing/refinedModelDoc.html

**Third Parties**: Third party users include local government and other GIS users. These users have found the survey-accurate parcel layers to be extremely useful. However the ready availability of this highly accurate data has highlighted the fact that 30% of the land parcels are not survey accurate. Many GIS systems cover regions containing a mixture of survey accurate and non survey accurate areas. This varying accuracy makes it difficult for GIS users to integrate the cadastral layers with their other spatial layers. These users have indicated a desire to work with LINZ to upgrade certain areas of the cadastre to survey accurate status. LINZ has produced some guidelines to help users with the required data capture, a process which needs to be overseen by a Licensed Cadastral Surveyor. Once the captured data is submitted to LINZ, LINZ will ensure that it is integrated into the network.

### 4.3 Cadastral surveyors and other high accuracy users

The New Zealand cadastral system is based on a fundamental premise that 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.

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 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. Until the deformation model is incorporated into third party software, the most practical solution is for the surveyor to apply the deformation model to the coordinates to generate current epoch coordinates.

Currently where a cadastral surveyor is required to submit a survey for lodgement, it is important that the observations are submitted uncorrected for deformation. In processing the survey, LINZ will apply the deformation model and generate epoch 2000.0 coordinates.

## 5 Discussion

LINZ has developed a deformation model as part of its national datum, NZGD2000, which enables NZGD2000 coordinates to be generated for the datum reference epoch of 2000.0. This model needs to be maintained to accurately reflect the complex nature of the deformation it models. As time passes the model may become more complex as it accommodates more localised deformation.

The deformation model supports the accuracy requirements of the geodetic system. In fulfilling this requirement, it also provides 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. Accordingly, tools need to be provided that are simple to use and allow coordinates to be generated at an epoch other than 2000.0. Some of these tools may need to be implemented by survey hardware and software developers.

LINZ databases currently provide coordinates for survey marks at epoch 2000.0 only. To assist users, a simple solution would be to provide a facility to obtain coordinates at any epoch other than 2000.0. For example, LINZ would apply the deformation model to the selected coordinates. To enable the ready use of CORS data in surveys, LINZ will need to provide coordinates of those stations at epochs other than 2000.0. By using these datasets computed at the epoch of the survey, the user would ignore the effects of deformation. Once the survey is completed, the surveyor would submit his or her observations to LINZ, who will then generate epoch 2000.0 coordinates.

The responsibility for maintaining the accuracy of the geodetic system, and the alignment of the cadastral system with it, as well as integration of cadastral surveys lies with LINZ. To do this, the deformation model must be constantly monitored and upgraded to ensure that the spatial accuracy of these databases is maintained.

When considering the implementation of a semi-dynamic datum, consideration needs to be given to simplifying the complexities of data for users. This can be achieved through the provision of tools to allow coordinates other than at the reference epoch of the datum to be generated and provided. If implemented correctly, a semi-dynamic datum provides a practical solution to maintaining datum currency, without the continually changing coordinates associated with a fully dynamic datum or the inevitable outdating of a static datum.

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