Toitu te
Land whenua
Information
New Zealand

New Zealand Vertical Datum

2004/05 Milestone 6b Completion Report

Office of the Surveyor-General

28 June 2005

1 Introduction

The goal of the Vertical Datum Project is to produce a new nationally (and internationally) consistent height reference system for New Zealand. This work has been undertaken in conjunction with the Western Australian Centre for Geodesy at Curtin University of Technology in Perth, Australia.

The LINZ Priority Work Programme 2004/05 Milestone 6b is to:

> *"Publish an integrated vertical datum and geoid model for New Zealand and report to the Chief Executive by 30 June 2005 on the implications of implementation."*

This report, in conjunction with the material on the LINZ website (www.linz.govt.nz/nzvd05), completes this milestone. It is structured to give sufficient background to put the new datum in context and to describe its quality.

The existing New Zealand height systems are discussed before they are compared with an alternative height system. The New Zealand Vertical Datum and its component parts are then presented. A more detailed description of the gravimetric geoid, its computation and verification then follows. The positive and negative implications of the new vertical datum are discussed, followed by potential areas where future work could be concentrated.

The discussion and content of this report has been intentionally provided at a non-technical level. The detailed experimental work and analysis that has been undertaken to achieve an optimised vertical datum for New Zealand can be found in Amos and Featherstone (2003a, 2003b, 2003c, 2004), Amos et al. (2005a, 2005b) and Brett (2004). Additional technical reports describing recent results will be published at the conclusion of the Vertical Datum Project.

2 Current New Zealand Height Systems

2.1 *Background*

Prior to 1998 the official geodetic reference system for New Zealand was New Zealand Geodetic Datum 1949 (NZGD49). This was referred to as a two + one dimensional datum because the horizontal component was largely observed and defined independently of the height component. The horizontal (latitude and longitude) coordinates were determined by trigonometric observations that were referenced to astronomic positions. If a height was assigned to a NZGD49 mark (not all marks had heights) it was in relation to a local determination of mean sea level (MSL) in terms of a local datum. These heights were determined either by precise spirit levelling or vertical angle observations in a separate process to establishing the horizontal position.

In 1998 the New Zealand Geodetic Datum 2000 (NZGD2000) was implemented and replaced NZGD49 as the official geodetic datum. NZGD2000 is a three dimensional datum that has latitude, longitude and height determined simultaneously for each high-order point (normally using GPS in full observation techniques). The datum implementation resulted in an approximate 200 metre horizontal shift in the coordinates of marks that can be modelled using a specified transformation to sub-metre accuracy. NZGD2000 heights are expressed in relation to the internationally accepted Geodetic Reference System 1980 (GRS80) ellipsoid. This means that while the heights are internationally consistent they do not relate to the local systems used in NZGD49 or to local MSL.

For NZGD2000 to be practically implemented it is essential that a standard transformation between the authoritative ellipsoidal heights and the legacy local height systems is developed. This is needed to facilitate the use of the new datum and to enable the use of new technologies (e.g. GPS) with the local height systems.

2.2 *Local Levelling Datums*

New Zealand does not currently have a single national vertical datum. Instead the thirteen major levelling datums given in Table 1 and shown in Figure 1 are used. Each levelling datum is based on MSL observed at a local tide gauge at different times. Because of effects such as sea surface topography; sea level rise; vertical crustal motion; long-period tides; harbours and river outflow; the MSL determinations for each datum do not lie on the same equipotential (level) surface and can be offset from each other by up to 30 centimetres.

Once the MSL level was fixed the datums were extended from the tide gauges into surrounding regions, typically using precise spirit levelling techniques. Due to the nature of precise levelling operations this accurate transfer was limited to the major roads (Figure 1), with less accurate techniques used to extend it into limited areas between the levelling lines.

Datum	Origin Location	Region of Usage
One Tree Point 1964	Marsden Point	Northland Northern Kaipara Harbour
Auckland 1946	Auckland - Waitemata Harbour	Auckland Southern Kaipara Harbour Firth of Thames Coromandel Peninsula
Moturiki 1953	Tauranga	Central North Island Hamilton Bay of Plenty Wanganui
Gisborne 1926	Gisborne	East Cape
Napier 1962	Napier	Hawkes Bay Southern Hawkes Bay
Taranaki 1970	New Plymouth	Taranaki
Wellington 1953	Wellington	Wellington Wairarapa Horowhenua
Nelson 1955	Nelson	Nelson Marlborough Golden Bay Murchison
Lyttelton 1937	Lyttelton	Canterbury Westland
Dunedin 1958	Dunedin	Otago Central Otago Haast
Dunedin-Bluff 1960	No sea level origin	Southland Fiordland
Bluff 1955	Bluff	Invercargill
Stewart Island 1977	Halfmoon Bay	Stewart Island/Rakiura

Table 1 Levelling datums, origins, and extent of usage

Heights determined from precise spirit levelling are related to the local gravity field of the Earth (which is known to undulate). The critical feature of this is that the height relationships from spirit levelling will normally reflect the flow of water. For example if the height of point A is above that of point B then water will flow from A to B under normal circumstances. These heights are the most intuitive to understand as MSL will have a height approximately equal to zero.

While levelling is a precise means of transferring heights between points, it is very time consuming and costly, taking 40 years to complete the New Zealand first order levelling network. This means the network will most certainly be subject to uplift or subsidence due to a variety of processes within this time. This uplift/subsidence can be as much as 8.5 m over ~40 years in localised areas, and ~10 mm/yr over larger areas (Walcott 1984). This means that the networks are continually degrading with time. Because precise levelling is very expensive, slow and limited in spatial extent it is not desirable to re-observe the New Zealand height network by this method.

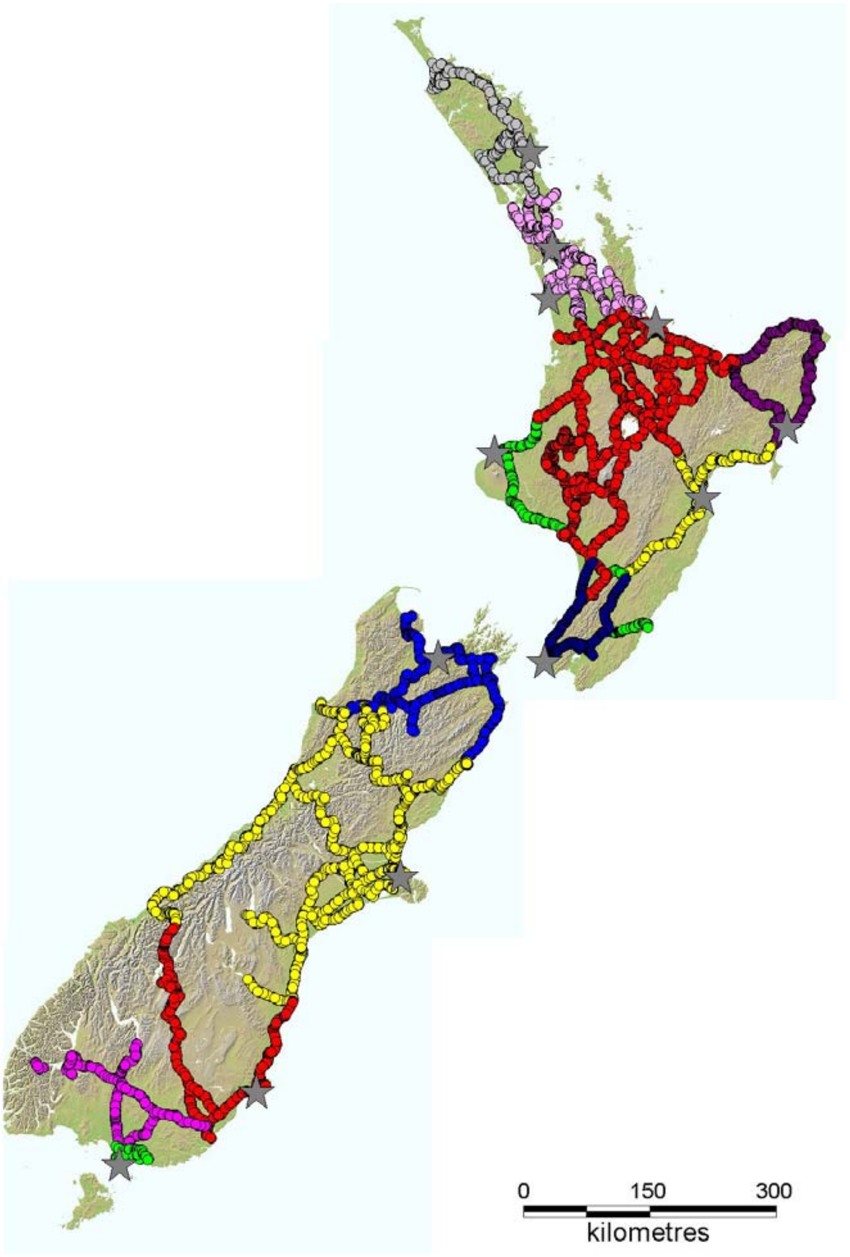

Figure 1 Tide gauges and levelling networks used to provide vertical control in New Zealand

2.3 *Ellipsoidal Heights*

The ellipsoid is a regular mathematical surface obtained by rotating an ellipse about its semi-minor axis. The dimension and orientation of the ellipse are chosen to give the best fit to mean sea level over a given area, in the case of GRS80 it is over the whole Earth. Because the ellipsoid is only a mathematical approximation of the shape of the earth, it will generally be either over or under the actual sea surface in any particular place.

The main advantage of an ellipsoid is that it is relatively easy to define numerically and so has benefits for mathematical operations and particularly for satellite systems such as the Global Positioning System (GPS). NZGD2000 heights are expressed in relation to the GRS80 ellipsoid, as are heights acquired from GPS observations. The disadvantage of the ellipsoid as a reference surface is that because the heights are defined independently of the local gravity field they are generally different to mean sea level and not suited to engineering applications (a major user of height information). In extreme cases the gradient of ellipsoidal heights can be in the opposite direction to levelling heights (c.f. Figure 2) in which case water would flow from a point of low ellipsoidal or GPS height to a point with a slightly higher ellipsoidal height.

2.4 *Height Relationships*

With the increasing use of satellite positioning systems, such as GPS, there is a need to provide a height reference system that supports this new technology as well as the conventional levelling based-systems. This can be achieved through the provision of a transformation between the ellipsoidal and levelling height systems.

The difference between ellipsoidal and levelling systems is not linear and ranges globally from -105 to +95 metres and 0 to 40 metres over the length of New Zealand. This difference can be modelled by an undulating equipotential surface called a geoid. If the geoid (N) is known then ellipsoidal heights (h) can be related to levelling heights (H) using the simple algebraic relation $H = h - N$. This is shown schematically in Figure 2 below.

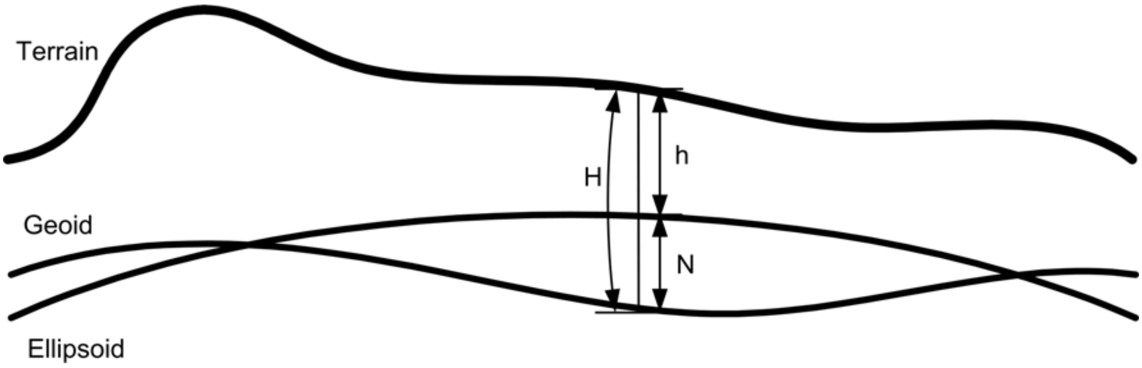

Figure 2 Relationship between levelling (H), ellipsoidal (h) and geoid (N) heights

Unlike many other countries, such as Australia (Featherstone et al., 2001), Canada (Véronneau, 2001), the United Kingdom (Ilffe et al., 2003) and the United States (Smith and Roman, 2001), New Zealand does not currently have a high-resolution regional geoid model.

Global geoids such as EGM96 (Lemoine et al., 1998) are available for use in New Zealand however the accuracy of these is approximately 1-2 metres with a 50 kilometre resolution and so is not sufficient to meet many user requirements (Amos et al., 2005a). Amos and Featherstone (2003a) give a discussion on the application of different global models to New Zealand and Australia.

3 New Zealand Geoid 2005

3.1 *Background*

A localised geoid model can be developed that enhances a global model over an area with additional data (e.g., gravity, topography). There are two main methods that can be employed to compute a geoid in New Zealand. The first approach (geometric) is to observe ellipsoidal heights on points that have known levelling-derived heights. The difference between these heights is the geoid-ellipsoid separation, if a good spatial spread of values is obtained a geoid can be computed to transform heights to the local levelling network. The geometric approach does not strictly determine a geoid rather it computes a transformation surface between the ellipsoidal and levelling height systems. The disadvantage of this is that the good spatial coverage of GPS-levelling points is difficult to obtain in large parts of New Zealand because the levelling-derived heights are limited to the major roads (c.f. Section 3.4).

The second method, called the gravimetric approach, uses gravity observations to model the Earth's gravity field and produce a subsequent geoid. Unlike the precise levelling coverage, spatially dense and accurate gravity and terrain data are available throughout New Zealand. This method has been used for the development of the New Zealand geoid.

The advantage of not using the GPS-levelling data in the geoid computation is that it can be used later to evaluate the precision of the computed geoid models. In theory the geoid values given by both approaches should be the same. In practice they are not and it is this difference that gives an indication of the quality of the computed geoid (acknowledging that there are errors in the GPS and levelling heights).

This section briefly summarises the process that was undertaken to compute the New Zealand geoid 2005 (NZGeoid05) and determine the individual datum offsets. It is not written as a detailed description of the testing and evaluation procedures that were carried out, this description can be found in Amos and Featherstone (2003a, 2003b, 2003c) and Amos et al. (2005b). Additional detail will also be provided in forthcoming technical papers.

3.1.1 *Gravity Anomalies*

The Earth's gravity field is not constant at all places and at all times. Spatial variations in it are caused by differences in the density and distribution of the material that makes up the Earth. Temporal variations are due to tides and geodynamics. The gravity field can be approximated using a standard gravity value and latitude function over a smooth ideal Earth. This is referred to as normal gravity. Gravity anomalies are a measure of how actual gravity deviates from this standard. Gravity anomalies are used in the computation of the gravimetric geoid.

3.1.2 *Geoid Undulations*

The geoid is a theoretical surface that most closely approximates sea level in the absence of topography, winds, ocean currents, and other disturbing forces. Geoid undulations are a measure of the deviation of the geoid surface from a reference ellipsoid (shown as N in Figure 2). Like gravity anomalies these deviations are caused by variations in the mass distribution within the Earth. The shape of the geoid is irregular, similar to that of a potato. Geoid undulations are the result of computing a geoid and thus determining how the "potato" shaped geoid differs from a smooth mathematical surface.

3.2 *Data Sets Used*

3.2.1 *Global Geoid*

A combination of the GGM02S (Tapley et al., 2005) and EGM96 (Lemoine et al., 1998) global geoid models (to degree and order 360) was used as the reference model. The combination was achieved by substituting the first 100 degree coefficients in the EGM96 model with those from GGM02S. This model has an effective resolution of approximately 50 kilometres. This means that any gravity anomaly or geoid undulation feature that is smaller than 50 kilometres cannot be represented by this model. The need to represent features smaller than this is a significant driver for computing a New Zealand geoid (the final geoid has an effective resolution of two arc-minutes or approximately 3.7 kilometres, section 3.3). Note that most surveys requiring accurate heights (e.g. flood plain mapping) are of lesser extent than 50 km.

3.2.2 *Terrestrial Gravity*

The terrestrial gravity data covers the main New Zealand islands, including the Chatham Islands and small sections of sea-bottom observations in Golden and Tasman Bays (Figure 3). A license to use the data was obtained from the Institute of Geological and Nuclear Sciences (GNS). The general data preparation procedure is given in Amos and Featherstone (2003b) however several notable points are additionally described below.

Figure 3 shows that the coverage of the 10737 land data points is not regular. The average density of observations is approximately one per 7.5 square-kilometres, but this is higher in areas of scientific or commercial interest and lower in areas where it is impractical or difficult to collect ground gravity data (notably in Fiordland). The gravity data is also biased by the fact that the observation locations are not random. In areas where the topography is rugged observations are typically made along the valleys with sporadic hill top measurements. This means that the "observed" gravity field underestimates the "real" gravity field. This can be partially corrected by using a digital terrain model using the reconstruction technique of Featherstone and Kirby (2000) as described in Goos et al. (2003). A description of the application of this procedure is given in Amos and Featherstone (2004).

The gravity data was initially converted into a consistent gravity datum (IGSN71) and then free-air and atmospheric corrections were applied. Before the gravity data can be used to compute the geoid it is necessary to condense the topographic masses onto the geoid using a terrain correction – this accounts for the effect on the local gravity field of (for example) the mass contained within mountains. A comparison of three techniques to compute this correction is given in Amos and Featherstone (2004). The technique chosen used a 56 metre digital elevation model to determine the terrain correction over New Zealand by way of prism integration. This was a computationally demanding procedure that took just under three months of continuous processing on an eight-processor server to complete.

3.2.3 *Marine Gravity*

Extensive ship-based marine gravity observations have also been used. These have been compiled from the records of GNS, the Ministry of Economic Development Crown Minerals, as well as the Continental Shelf Project records. The compiled data is shown on Figure 3. A problem of the supplied data was that it was supplied in inconsistent formats and often in terms of poorly or undefined datums. The ship-tracks were generally not in terms of each other so they could not be used effectively together. Intrepid Geophysics was contracted to initially convert the data into a uniform datum and format, and then to adjust it into an internally consistent data set by performing a crossover adjustment. The data reformatting and adjustment is described in Brett (2004).

It can be seen in Figure 3 that the coverage of the marine data is not uniform and that a number of gaps exist, particularly in areas that are a long way from land. Gravity observations derived from satellite altimetry are an additional data source that is particularly useful in offshore areas. A problem with altimetry is that it is known to degrade significantly when it gets close to land, conversely ship-track data tends to drift as it gets further from shore. It therefore follows that a combination of the ship-track data in near-shore areas and the altimetry data offshore will give the best marine gravity dataset. Such a combination was achieved using least-squares collocation, following the procedure described in Amos et al. (2005b).

The collocated marine anomalies and the terrestrial anomalies were each averaged onto respective two arc-minute (~3.7 kilometre) grids which were then combined to give the final two arc-minute grid shown in Figure 4.

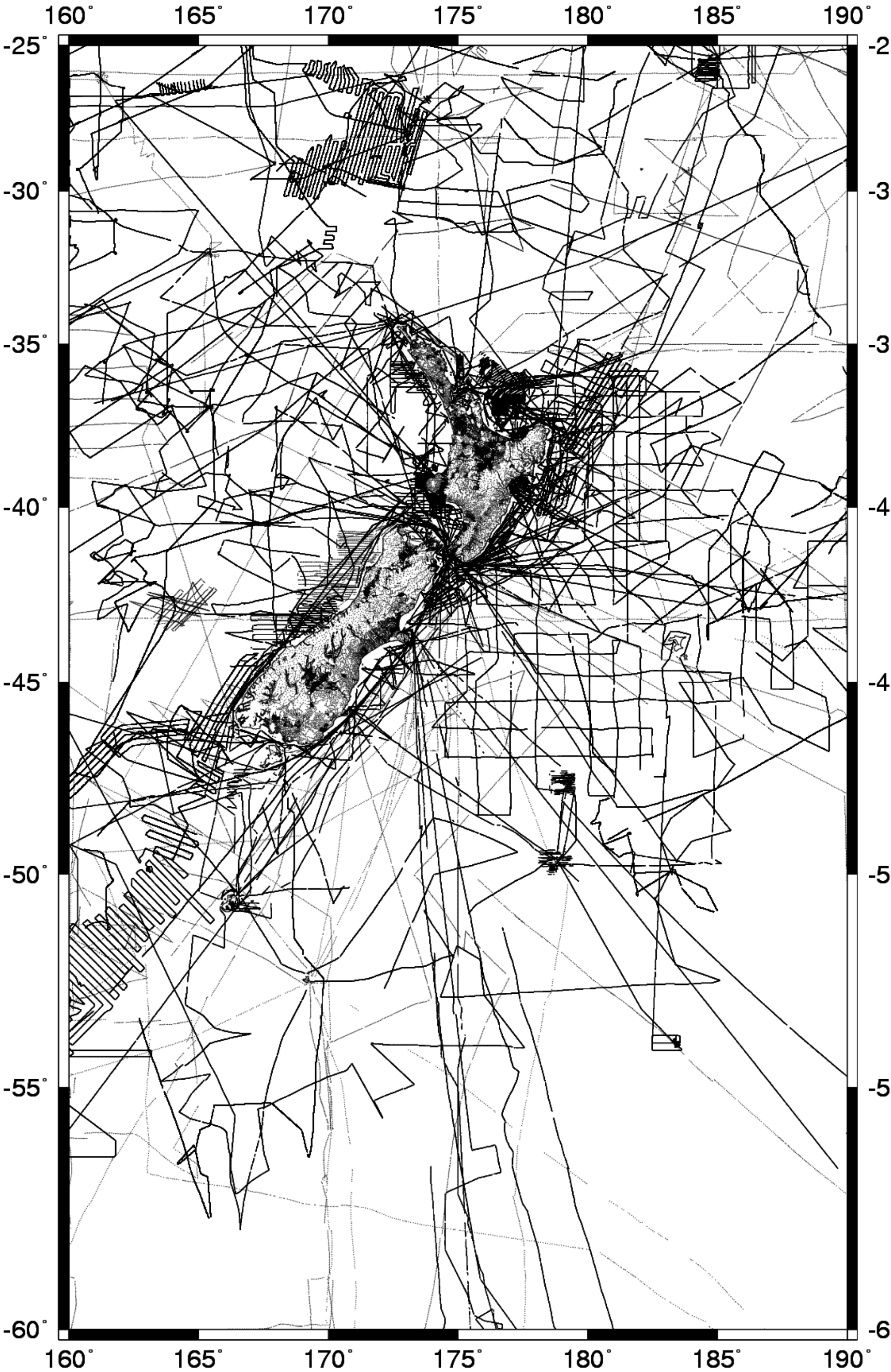

Figure 3 New Zealand gravity observations (40737 terrestrial, ~ 1.8 million marine)

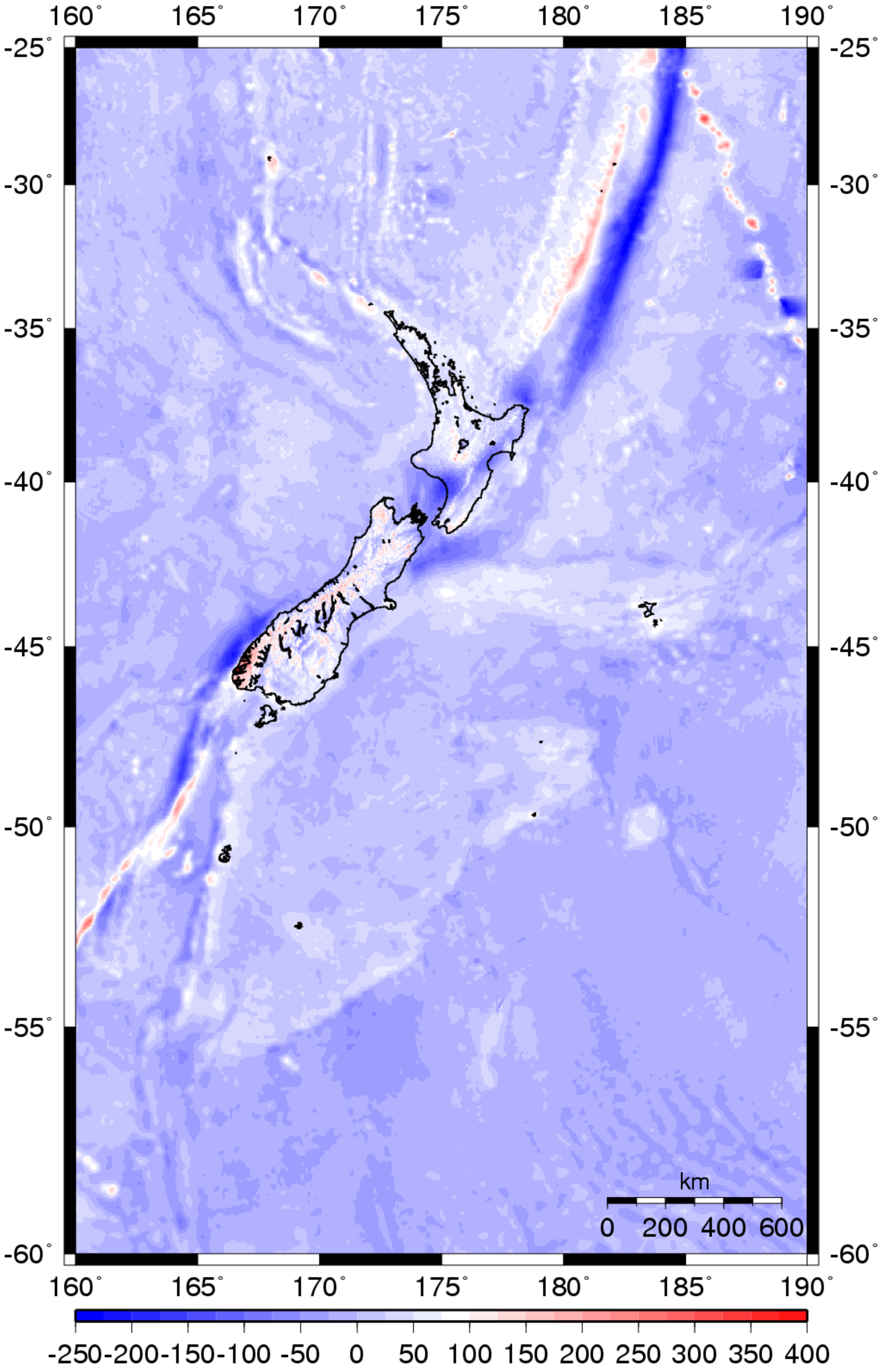

Figure 4 New Zealand Faye gravity anomalies (mgal)

3.3 *Geoid Computation*

Descriptions of the gravimetric approach used to compute the NZGeoid05 are provided in Featherstone et al. (2001), Amos and Featherstone (2003b, 2003c). A brief overview of the general computation process is provided below:

- The GGM02S-EGM GGM anomalies (degree and order 360) described in section 3.2.1 were subtracted from the grid of Faye anomalies to give residual anomalies;

- A one-dimensional Fourier transform was used to implement the Featherstone et al. (1998) modification of Stokes's integral to convert the residual gravity anomalies to residual geoid. The integral was computed with an optimised cap of 1.5° and 20 degree removal;

- The GGM02S-EGM GGM geoid was restored to the residual geoid to give a co-geoid;

- A primary indirect effect correction was applied to the co-geoid to give the final geoid shown in Figure 5 and Figure 6.

The NZGeoid05 has been calculated within the area from 160°E to 170°W and 25°S to 60°S. It is expressed on a two arc-minute grid that approximately equates to 3.7 kilometres. This grid resolution was chosen as it was considered appropriate given the resolution of the gravity data (~7.5 kilometres) and it required a reasonable computation time (doubling the resolution increases the processing time exponentially). The zero-tide Earth-tide model has been adopted for the geoid in accordance with the International Association of Geodesy Resolution 16, 1984.

The heights of the gravity observations are in terms of each of the local vertical datums. It is known that these datums are offset from each other therefore the gravity observation heights are not in terms of a consistent datum. This results in a bias when the heights are used in the gravity reductions. A technique proposed by Laskowski (1983) was used for the first time in New Zealand to correct for this bias.

The geoid was initially computed from the gravity anomalies computed on each local vertical datum and compared against the GPS-levelling data as described in section 3.4 below. This provided an initial estimate of the offset for each vertical datum. The effect of each offset was then applied by adding a correction to the original gravity anomalies according to the datum that they were located in. The geoid was then recomputed and compared with the GPS-levelling values. New offsets were then determined and the effect of them applied to the original gravity anomalies. The process was then repeated three times until the computed offsets (and standard deviations) did not change between iterations. The final iterated solution is shown in Figure 5 and Figure 6 and the analysis in section 3.4 below.

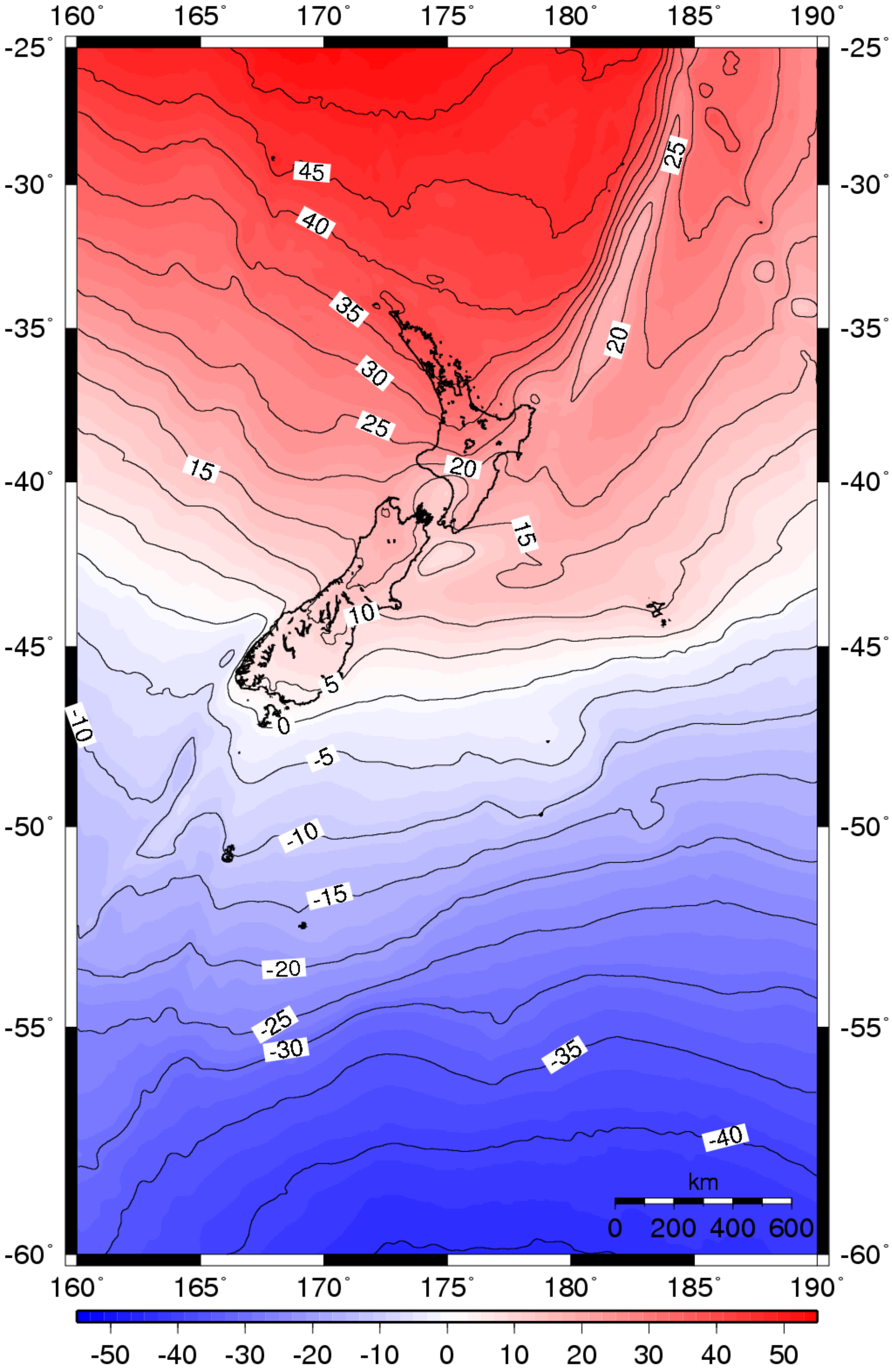

Figure 5 New Zealand Geoid 2005 (entire computation area) (metres)

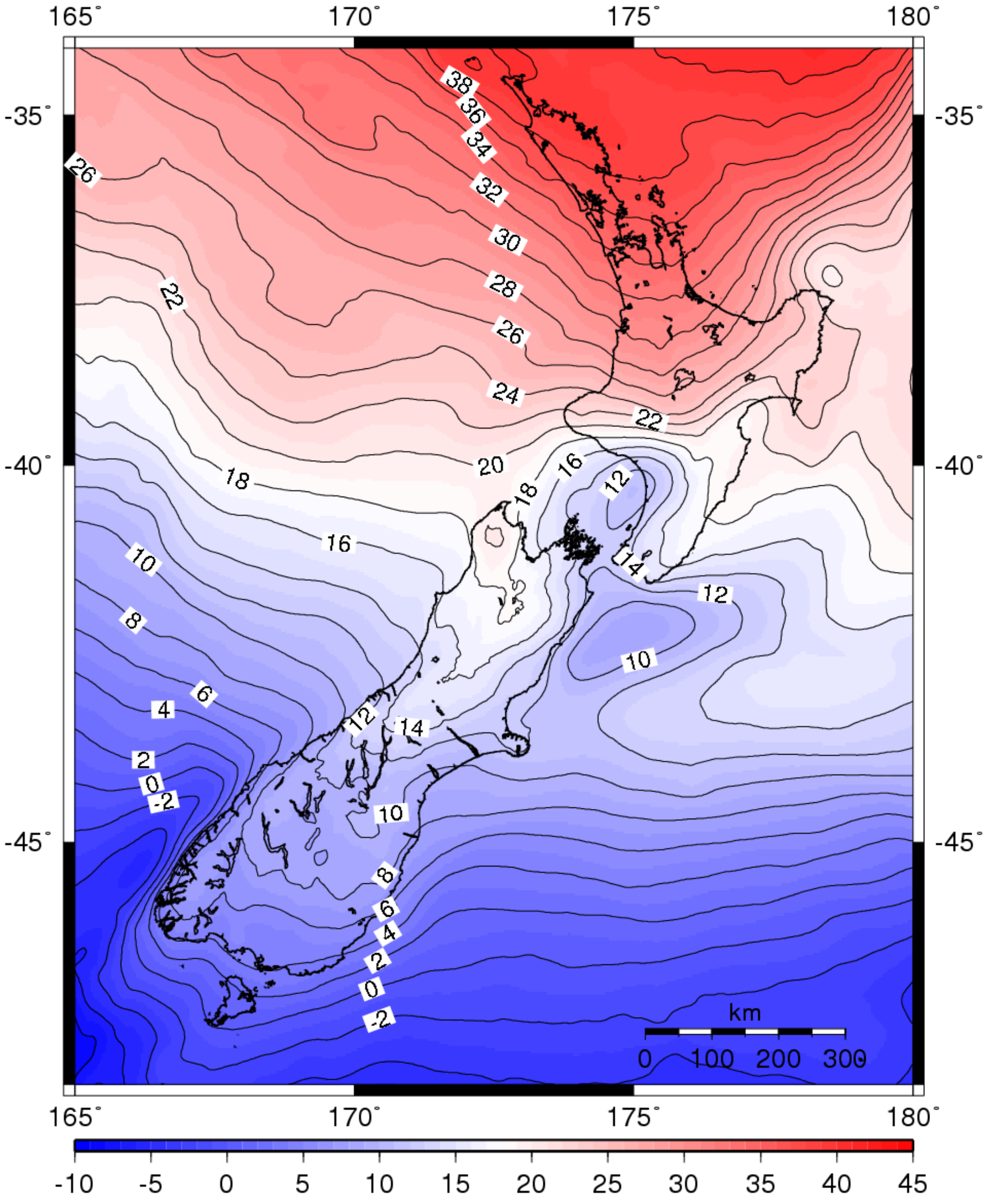

Figure 6 New Zealand Geoid 2005 (New Zealand section) (metres)

3.4 *Geoid Verification*

The “accuracy” of a geoid can be evaluated by comparing it with GPS-levelling observations at specified points. It is pertinent to note that GPS-levelling will not give a true estimate of geoid accuracy. Instead it gives an indication of the agreement of the geoid to the situation on the ground by ignoring any errors or distortions within the levelling and GPS height networks.

In an ideal world the difference between a GPS derived ellipsoidal height and a precisely levelled height (including corrections for gravity and plumb line curvature) will be equal to the value of the geoid height. In reality they are not equal due to errors in all three heights. An analysis of the differences between the GPS-levelling and geoid heights does however give an indication of the "fit" of the geoid to the "real world".

The differences were evaluated for each GPS-levelling point (Figure 7) and then they were grouped by levelling datum. The descriptive statistics of these results (by datum) are shown in Table 2 below. The "average" column is the estimate of the offset of the datum from the geoid "zero". The "Std Dev" column is an estimate of the reliability of the offset and the overall fit of the GPS-levelling observations to the computed geoid. There is insufficient data available on the Chatham Islands to estimate an offset, so it is assumed to be zero.

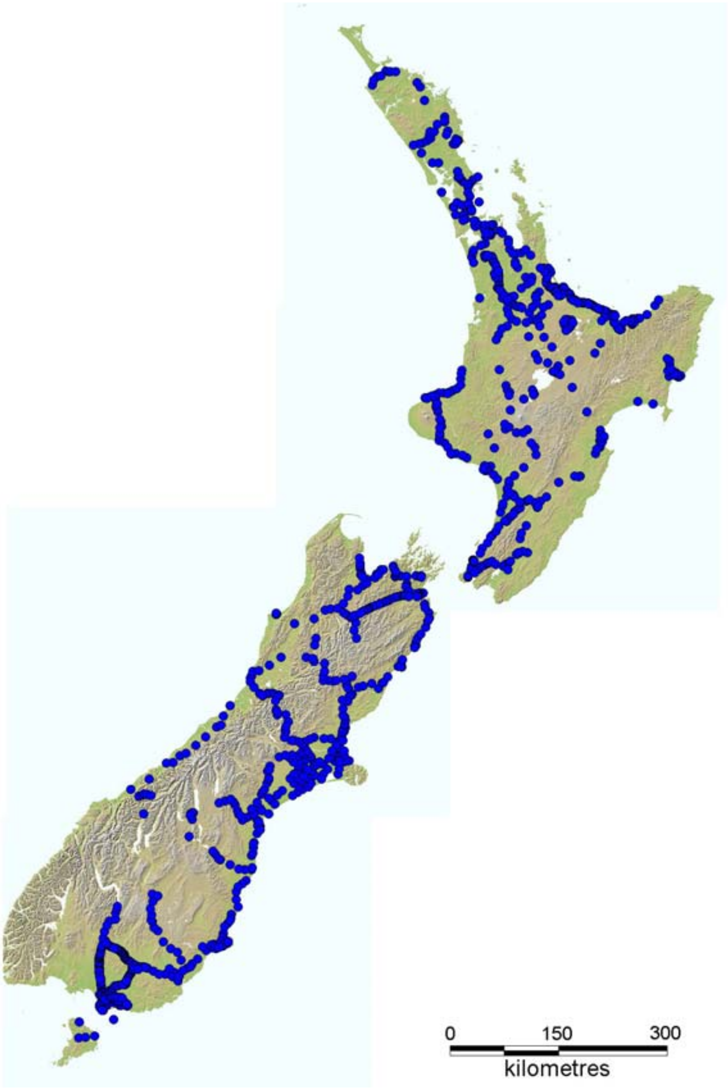

Figure 7 GPS-Levelling points (1356 points)

Datum	Points	Max	Min	Average	Std Dev
One Tree Point 1964	39	-0.158	-0.420	-0.255	0.060
Auckland 1946	137	-0.313	-0.655	-0.496	0.069
Moturiki 1953	227	-0.195	-0.646	-0.322	0.069
Gisborne 1926	61	-0.431	-0.697	-0.585	0.087
Napier 1962	31	-0.112	-0.394	-0.320	0.051
Taranaki 1970	70	-0.322	-0.595	-0.454	0.067
Wellington 1953	78	-0.416	-0.611	-0.506	0.040
Nelson 1955	111	-0.028	-0.431	-0.259	0.080
Lyttelton 1937	251	0.016	-0.609	-0.347	0.096
Dunedin 1958	73	-0.143	-0.722	-0.483	0.164
Dunedin-Bluff 1960	181	-0.016	-0.572	-0.255	0.076
Bluff 1955	92	-0.194	-0.462	-0.373	0.052
Stewart Island 1977	5	-0.236	-0.588	-0.395	0.115

Table 2 GPS-levelling comparison with NZGeoid05 on levelling datums (metres)

It can be seen from Table 2 that, with the exception of the Dunedin and Stewart Island datums, the agreement of the GPS-levelling observations to NZGeoid05 is better than the 0.10 metre target of the project (one-sigma confidence level). The high standard deviation on the Stewart Island datum can be explained by the small number of test points and their lesser quality levelling heights.

The Dunedin, Dunedin-Bluff and Lyttelton residuals are shown in Figure 8. It can be seen that as the Dunedin GPS-levelling points move inland the residual magnitude reduces, thus causing the high standard deviation seen in Table 2. This can also be seen to a lesser extent in the Dunedin-Bluff data. It may be possible to correct for the feature by using a tilted plane rather than a constant offset however this does not explain its cause. The effect could be attributed to biases in the precise levelling observations, errors in the GPS heights or incomplete correction for the topography when performing the gravity reduction. Overall, the Lyttelton data appears less affected by this problem.

It is recommended that additional work is carried out in these areas in an attempt to identify the cause of this problem. This work could include the acquisition of additional GPS heights on levelling benchmarks along the affected levelling runs to provide more check points for the geoid.

All of the adjacent datum offsets are significantly different from each other (at the 95% confidence level) with the exception of Moturiki-Napier and Bluff-Stewart Island. This confirms that there are differences between the zero points for most of the datums. Because only five points were used to fix the Stewart Island/Rakiura offset, it is not expected to be of a high standard. Additional GPS-levelling points need to be acquired to improve the offset computation.

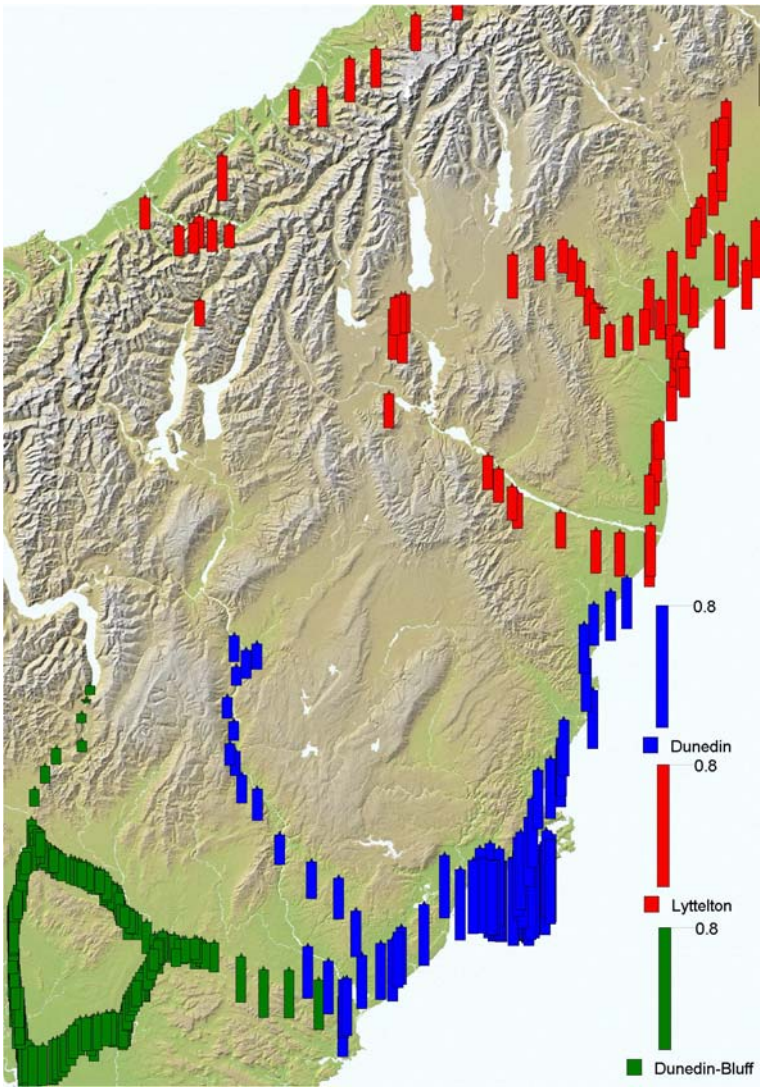

Figure 8 GPS-levelling residuals for selected South Island datums (metres)

If the calculated offsets for each datum are removed from the respective comparison points (to give an average offset of zero) all 1356 points can be combined together to give a nation-wide indication of the fit of NZGeoid05 to the GPS-levelling (Table 3). This indicates that the expected one-sigma reliability of the geoid is 0.083 metres.

Points	Max	Min	Average	Std Dev
1356	0.363	-0.324	0.000	0.083

Table 3 GPS-levelling comparison with NZGeoid05 over all datums (metres)

4 New Zealand Vertical Datum 2005

A new vertical datum called New Zealand Vertical Datum 2005 (NZVD05) has been developed in conjunction with the Western Australian Centre for Geodesy at Curtin University of Technology.

NZVD05 will use NZGD2000 ellipsoidal heights as the official authoritative heights. A gravimetric geoid (NZGeoid05) is also defined as part of NZVD05 so that the datum can be related to an equipotential or level surface. The geoid is offset from each of the thirteen levelling datums by different amounts. To allow proper integration, an offset for each datum from the geoid is specified in Table 4.

To ensure consistency with NZGD2000 (and other international systems) ellipsoidal heights will be in terms of the GRS80 ellipsoid (Moritz, 1992). The gravity reductions have been applied and NZGeoid05 computed in terms GRS80 standard. The zero-tide Earth-tide model has been adopted for the geoid in accordance with the International Association of Geodesy Resolution 16, 1984.

Datum	Average	Std Dev
One Tree Point 1964	0.255	0.060
Auckland 1946	0.496	0.069
Moturiki 1953	0.322	0.069
Gisborne 1926	0.585	0.087
Napier 1962	0.320	0.051
Taranaki 1970	0.454	0.067
Wellington 1953	0.506	0.040
Nelson 1955	0.259	0.080
Lyttelton 1937	0.347	0.096
Dunedin 1958	0.483	0.164
Dunedin-Bluff 1960	0.255	0.076
Bluff 1955	0.373	0.052
Stewart Island 1977	0.395	0.115

Table 4 NZVD05 Datum Offsets (metres)

This development process is similar to that which has been proposed for height modernisation in Canada (CGRSC 2004). One of the leading justifications used here for changing from a precise levelling defined vertical datum to an ellipsoid/geoid approach was cost. Precise levelling is extremely expensive and time consuming to carry out and maintain, especially in mountainous areas like large parts of the South Island. By comparison ellipsoid/geoid datums do not require dense road networks to observe along so additional marks can easily be located in remote areas with relatively high accuracy.

This datum approach will provide a consistent height reference system across New Zealand that has the additional benefit of allowing GPS observations to be transformed into heights in relation to each local vertical datum. This means that users can continue to utilise the local levelling datums for day-to-day operations and the geoid model only needs to be incorporated when transformations from ellipsoidal heights need to be made (e.g. GPS is used). The datum offset can also be used to convert levelling heights between levelling datums.

5 Implications of Implementing New Zealand Vertical Datum 2005

The most significant benefit that will accrue to surveyors as a result of NZVD05 will be the availability of a geoid that can be used to transform ellipsoidal heights to levelling heights on any of the thirteen major levelling datums (and vice versa). This could make the use of surveying techniques such as GPS more viable for survey work where heights related to sea level are required.

NZVD05 includes offsets between the thirteen different levelling datums. This will mean that the heights in adjacent (or unconnected) datums will able to be combined if required.

NZGeoid05 is provided on a two arc-minute (~3.7 kilometre) grid. A problem with a regular grid of points to define the geoid is that it needs to be interpolated at the points of interest. This means that any geoid change within the spacing of the grid points will be averaged into the grid. These differences are not expected to be significant for a majority of users. However where high accuracy results are desired or absolute elevations above sea level are critical it will still be essential that an on-site verification of the geoid is performed or a site-specific transformation from local GPS-levelling heights is computed.

When NZVD05 is implemented the authoritative heights will be expressed in relation to the ellipsoid rather than the local MSL. The Surveyor-General’s Rules for Cadastral Survey 2002/2 (by way of SG Ruling 2005/3) do not include NZGD2000 as a “preferred height datum”. This ruling actively discourages the use of non-MSL datums for cadastral surveys. The Surveyor-General specifies in Ruling 2004/1 that NZGD2000 is the preferred datum for cadastral surveys. Therefore NZVD05 and its associated ellipsoidal heights are implied as the preferred vertical datum because it is part of NZGD2000. This contradicts the Ruling 2005/3 which excludes ellipsoidal heights in its preferred height datums. The practical implication of this contradiction is considered minor and so should be rectified when the Surveyor-General’s Rules are reviewed.

NZGD2000 is referred to as a semi-dynamic datum. This is because it has a horizontal deformation model as part of its definition to correct for crustal movement within New Zealand. The result of this is that observations in terms of NZGD2000 have the deformation model applied to them to produce coordinates fixed at 1 January 2000. Because the deformation model is only horizontal the vertical ordinate of a position remains in terms of the time that it was surveyed. This means that the horizontal and vertical components of the NZGD2000 position will not strictly be in terms of each other. The differences are likely to be sub-decimetre at the moment, but will increase with time. To resolve this discrepancy the proposed revision of the deformation model should include vertical as well as horizontal motion. It is also noted that due to the age of the gravity observations, it is highly likely that the heights of these points (used for gravity reductions) will be incorrect, these could also benefit from the application of a vertical deformation model.

During the development of NZVD05 there has been a high level of interest in its progress from a variety of external groups, for example surveyors, local authorities, GIS users and equipment manufacturers. A result of this interest is that when NZVD is publicly released it is expected that the uptake will be strong. This will mean that Customer Services is likely to receive additional queries regarding the datum and its usage. Customer Services will be assisted in answering these queries through the provision of education material that is likely to be in the form of fact sheets, internet based information and answers to frequently asked questions.

Landonline has been developed with the ability to include a geoid model to enable transformations from NZGD2000 to levelling systems. When NZVD05 has been included in the applicable standard it will be necessary for Customer Services to include NZGeoid05 within Landonline as part of its maintenance process.

Although NZVD is being published on the LINZ website now, it will not be actively promoted until essential utilities are developed to enable it to be more easily used. Such utilities will include the ability to enter a coordinate and obtain a geoid value, as well as transforming heights between height systems. This work is estimated to be complete by the end of 2005.

6 Future Work

The new vertical datum has been established using the optimum techniques and data that are available for the New Zealand region at the present time. The tasks that are required to be completed in the next six months to ensure the successful implementation of NZVD05 and its associated standard are listed in section 6.1. These tasks will be managed from within the current Vertical Datum Project.

It may be possible to enhance the quality of the vertical datum, geoid and offsets between levelling datums by carrying out additional work in the areas described in sections 6.2 to 6.5. For a number of the areas identified, the additional work is limited to monitoring new developments. These tasks can be carried out as part of “business as usual” by the responsible business area. Other areas will require a more “hands-on” role, if this requires significant additional work a business case should be prepared on a case-by-case basis.

6.1 *The Next Six Months*

A number of tasks need to be completed in the next six months to enable the successful implementation of NZVD05.

- Publication of technical documentation describing the computation, testing and analysis of NZVD05 and NZGeoid05. This will comprise the publication of technical papers and the submission of a PhD thesis.

- Development of online utilities to enable practical usage of NZVD05 and NZGeoid05. This is likely to include enhancements to the *coordinate conversion* utility on the LINZ website, potential changes to the *geodetic database*, and standalone applications. These changes will be made in conjunction with Customer Services.

- Initiate process to include NZGeoid05 in Landonline. Once initiated this will need to be managed by Customer Services

- Development of educational material to be supplied to key users and Customer Services to enable the answering of queries.

6.2 *Global Geopotential Models*

New and improved global geoids are regularly being developed by various international and academic organisations. It is not practical for New Zealand to compute its own global geoid however it is prudent to take advantage of new GGM solutions as they will be able to provide an improved regional model for New Zealand with relatively little effort now that the main work has been done.

The major GGMs that are scheduled for release in the near-future fall into two groups. Models that are derived solely from satellite observations will continue to be improved with the new data being acquired from the various new satellite gravity missions that are currently being flown. The next major “combined” model (models that combine satellite and terrestrial data) is a replacement for the de facto global geoid, EGM96. It is programmed for release at the end of 2005 and has been provisionally named EGM05. The developers of EGM05 expect significant improvements on EGM96.

New GGMs should be evaluated to determine whether they are capable of providing an improved geoid solution for the New Zealand region on a regular basis. Whether the new GGM provides a sufficiently significant improvement to warrant the release of a new regional geoid (and the resulting implementation issues) needs to be considered before a decision to publicly release it is made.

6.3 *GPS-Levelling Observations*

To determine the agreement of the computed regional geoid model with the existing levelling datums it is necessary to establish ellipsoidal (GPS-derived) heights on marks that have levelling heights assigned to them. It can be seen in Figure 7 that the spatial distribution of the existing GPS-levelling points is poor. This has the effect of possibly introducing a bias into the computed datum offsets and the estimate of the reliability of the geoid. This problem can best be rectified by establishing accurate ellipsoidal heights on additional levelling marks in areas where they are currently deficient. Potential areas are Stewart Island/Rakiura, Chatham Island, Central Otago and the central North Island. This work could either be implemented as part of the Customer Services annual geodetic programme or through specific additional funding based on a business case.

6.4 *Gravity Observations*

The regional geoid has been computed from gravity observations that have an average density of approximately one per 7.5 square-kilometres. The final geoid is expressed on a two arc-minute grid (~3.7 kilometre resolution). To increase the reliable resolution of the geoid in areas of sparse gravity coverage the acquisition of additional gravity observations could be considered. The existing observations tend to be sparse along the coast, so if other work is being carried out by LINZ in this area (e.g. aerial photography, LIDAR) consideration should be given to observing gravity at the same time – e.g. airborne gravity which may only require the addition of a gravimeter to an already planned flight mission at little extra cost.

6.5 *Computation Procedures*

Geoid computation and vertical datum definition/unification are reasonably active areas of research internationally. This means that new techniques and approaches are regularly being developed. It is highly likely that some of these developments will enable the computation of new improved geoids and better vertical datums. It is not possible to predict when these advancements will be made therefore it is necessary to keep abreast of developments so that when promising approaches are proposed these can be tested in the New Zealand situation to determine their applicability. Key areas that should be monitored or investigated are:

- The ability and availability of higher resolution topography and density models to improve the results of the gravity reconstruction, terrain correction calculation and downward continuation;

- Many areas of New Zealand exhibit very steep topography which makes the calculation of terrain corrections more difficult. As new techniques for this are developed (or existing techniques revised) they should be assessed for potential improvements to the regional geoid;

- NZGeoid05 has been computed using the Featherstone et al. (1998) modified version of Stokes' integration kernel. A modified integration kernel is used in an attempt to compensate for the fact that global gravity observations are not used (the observations are limited to a specified distance of the integration point). There are many different modifications that can be used; several of these have been tested in this investigation. As other modifications are developed, the more promising variations should be tested as they become available to determine their suitability to New Zealand;

- As new developments in methods to achieve vertical datum definition and unification become available, they should be evaluated from a New Zealand perspective. Serious consideration should be given in regard to participating in international projects, for example establishing world height systems, to ensure that they are compatible with New Zealand – thus ensuring that New Zealand's Vertical Datum can be made consistent with a future Global Vertical Datum – just as NZGD2000 is consistent with the International Terrestrial Reference System.

7 Summary

The NZVD05 uses NZGD2000 ellipsoidal heights as the authoritative height reference. To enable this datum to be used with the existing levelling datums a gravimetric geoid with offsets to each of the datums has been defined. This will enable users to continue using their existing systems and to connect to the NZGD2000 system when this is necessary (e.g. when using GPS for heights).

NZGeoid05 has been computed from gravity observations that have been compiled from land, marine and altimetry sources. The marine and satellite data was combined into a consistent data set and the land data corrected for its biased sampling and the effect of topography. The gravity anomalies were converted to a geoid using a modified version of Stokes's integral. An iterative process was used to correct the gravity anomalies for the effect of the offset datums. The result was a gravimetric geoid of New Zealand and offsets from it to each of the thirteen levelling datums.

A number of implications of implementing NZVD05 have been identified. These highlighted a conflict in the current Surveyor-General's Rules, a problem with the application of the deformation model in NZGD2000, a potential increase in queries received by Customer Services, and necessary future modifications to Landonline. It has also been stated that NZVD05 will not be actively promoted until the necessary utilities for usage have been developed towards the end of 2005.

Tasks for the next six months and potential areas where additional work could be completed were also described. It was highlighted that some of this work only requires a monitoring function whereas other items will require a formal business case to acquire funding to complete them.

A description of NZVD05 and the files containing the geoid and datum offsets are available on the LINZ website: www.linz.govt.nz/nzvd05.

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