Proposal for a Dynamic National Geodetic Datum for New Zealand

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ABSTRACT

New Zealand's current geodetic datum (New Zealand Geodetic Datum 1949) has been subjected to earth deformation of between 2 to 3 metres since the observations were performed but still the original coordinates of 1st order trig stations are held fixed. Trig stations, cadastral boundaries and the "fixed" assets of landowners are slowly moving relative to each other. Any future datum, if it also has fixed coordinates, will be measurably distorted within months and may need to be discarded within a decade.

A "dynamic" datum is one of the options being considered as a possible solution. Such a datum could maintain a defined relationship to the dynamic IERS Terrestrial Reference System. By including station velocity models along with periodic readjustments, the spatial accuracy of the datum could be maintained in the face of wide spread earth deformation; improvements in survey technology; and changing demands of geodetic density and accuracy. The implications for geodetic, cadastral and topographic databases and for the users of a dynamic datum are addressed.

1 INTRODUCTION

The age of New Zealand's current geodetic datum and its known limitations have resulted in moves for a new geodetic datum to be defined. This is not a step to be taken lightly. There are many agencies in New Zealand, including the Department of Survey & Land Information (DOSLI), that have a considerable investment in spatial data in terms of New Zealand Geodetic Datum 1949. The cost of converting this data to a new datum will be significant.

In New Zealand, as in many other countries contemplating a change of datum, there is a desire to "do it once and do it right". Hamilton and Doig (1993), in a study of datum options in the Maritime Provinces of Canada, note user requests to generate one definitive set of transformation parameters and to ensure that the resulting datum will last for several decades. They concluded that these two outcomes are conflicting. If the initial transformation is taken as definitive, its errors will eventually result in demands for a new datum. If the datum is to last for several decades, the transformations will need to be improved as better survey information becomes available.

The situation in New Zealand is more difficult than in the eastern provinces of Canada because of the pervasive effects of earth deformation. It is not just better survey information that will force New Zealand geodesists to modify transformations between old and new datums. The

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steady movement of control stations relative to each other and the rest of the world will also necessitate changes to the datum. A static geodetic datum in New Zealand can be accurate or it can be long lasting but it cannot be both accurate **and** long lasting.

2 NEW ZEALAND SURVEY SYSTEM

2.1 NEW ZEALAND GEODETIC DATUM 1949

New Zealand Geodetic Datum 1949 (NZGD49) is a classical datum designed to best fit the local geoid. The original adjustment incorporated 284 first order stations. A full description of the observation and adjustment of NZGD49 can be found in Lee (1978). NZGD49 is not geocentric. Transformations between NZGD49 and WGS84 include a horizontal component of about 200 metres.

NZGD49 is a 2 dimensional datum. Although deflections of the vertical were observed by astronomy at several stations, there was no attempt to model the geoid. Orthometric heights were used as if they were ellipsoidal heights.

The origin and orientation were defined by astronomic observations. Scale was defined by baseline measurement using invar bands. Propagation of the network was by classical triangulation. In the South Island (diagram 1 shows the main islands of New Zealand) the mountainous backbone and the west coast were not included in the original NZGD49 first order network. This resulted in a narrow network and a weak adjustment. The South Island west coast was brought into NZGD49 later through 2nd order adjustments but these did not influence the 1st order coordinates. The northern tip of the North Island is narrow and the network is weak there also.

Observation of baselines began in 1909. Geodetic triangulation began in 1921 and was completed in 1942. Astronomic observations were completed in 1949.

The observations were adjusted in a number of blocks by least squares using the condition equations method. As the adjustment was undertaken prior to the availability of electronic computers, it was not completely rigorous.

The coordinates of 1st order control stations derived in 1949 have been held fixed since. The only exceptions are two stations that were believed to have been disturbed. These were degraded to 2nd order status before their coordinates were changed.

Bevin & Hall (1994) compare the coordinates of a number of 1st order stations with GPS derived coordinates. The differences within New Zealand range up to 6 metres, as shown in diagram 1. These differences are due to earth deformation and to limitations of the network design, observations and adjustment.

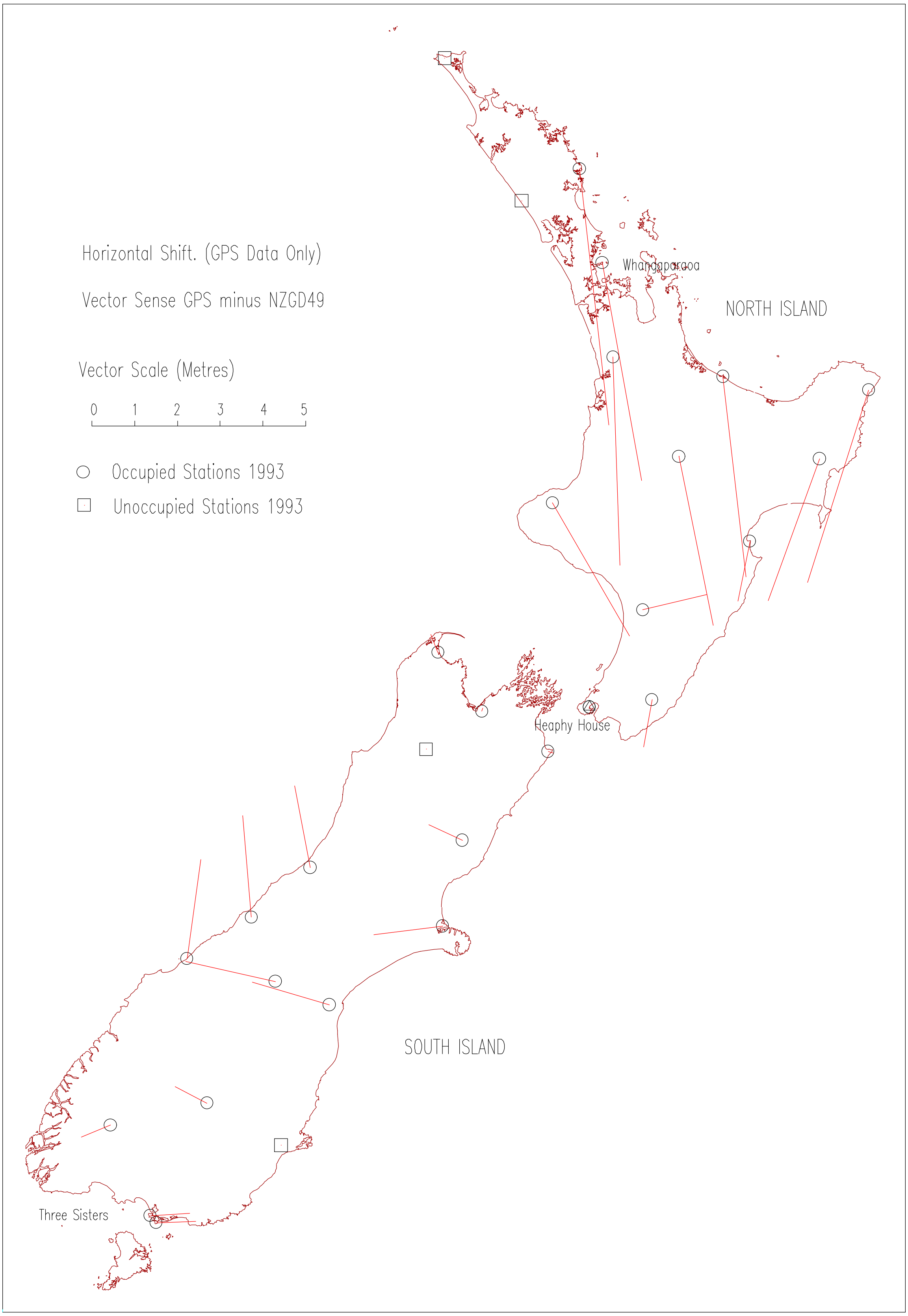

Diagram 1. Horizontal shift between NZGD49 coordinates and coordinates from a GPS network observed in 1993. In the GPS adjustment, the NZGD49 coordinates of Heaphy House, Wellington were held fixed. From Bevin & Hall, 1994.

2.2 GEODETIC IMPACT OF EARTH DEFORMATION

New Zealand lies across the obliquely convergent boundary of the Pacific and Australian plates. To the north east, the Pacific plate is subducted under the Australian Plate. To the south-west the Australian plate is subducted under the Pacific plate. In central New Zealand, the oblique collision of continental material has resulted in a combination of uplift and strike slip motion. Motion of about 40 to 55 mm per year occurs on the boundary through New Zealand. For a general description of the tectonics of New Zealand see, for example, Walcott, 1984.

Shear strain rates of up to 0.68 ppm/year have been derived from triangulation (eg, Bibby et al., 1986). Strain rates exceed 0.1 ppm/year over most of the country and values of 0.2 to 0.4 ppm/year are typical. There are a number of areas in New Zealand where the accumulated strain since observation of the datum exceeds 25 ppm. For example: Marlborough (57 years at 0.63 ppm/year); Kaikoura (57 years at 0.45 ppm/year); Wellington (66 years at 0.41 ppm/year); and East Cape (68 years at 0.38 ppm/year). These values are derived from Lee, 1978 and Bibby et al., 1986.

A number of major earthquakes occurred during or since observation of the geodetic datum resulting in ruptures of several metres. For example: Napier (1931) with 2 metres horizontal displacement and Inangahua (1968) with 1.8 metres horizontal displacement (Oborn, 1981).

Modern GPS observation and processing techniques allow accuracies better than 0.1 ppm which, in many parts of New Zealand, is equivalent to a few months' earth deformation. In 10 years, the magnitude of accumulated strain due to earth deformation will exceed the proposed accuracy standards for Class A, B and C geodetic surveys (Blick, 1994). In many areas, the accumulated strain will equal the proposed standards for Class D geodetic surveys (5 ppm). Only for the lowest proposed class of geodetic survey (Class E) could the earth deformation over 10 years be considered insignificant. Even then, it would only be insignificant in the absence of major earthquakes.

2.3 CADASTRAL SYSTEM

At present in New Zealand, the geodetic system is funded by landowners for the support it provides to the cadastral system. It is generally accepted that the cadastral system needs reform if it is to allow the potential benefits of new technology to be passed on to landowners and to the nation in general. This reform will place increasing demands on the geodetic system and the datum.

The spatial definition of New Zealand's cadastral system has always been dynamic because it is defined by measurements to local control points which are subject to earth deformation. The ability of the cadastre to absorb earth deformation is an important feature. It ensures that boundaries and the major "fixed" assets of land owners generally move in concert with each other.

The current dynamics of the cadastre have resulted from the high legal status given to physical evidence of boundary location. Documentary evidence (boundary dimensions) and physical evidence (local boundary and witness marks) generally agree within survey limits. Boundary coordinates are currently generated but only provide a graphical definition of the cadastre. Where there is disagreement between physical and documentary evidence, good physical evidence, in the form of local reliable ground marks, usually has the greatest weight. Boundary dimensions and approximate coordinates may be changed if necessary.

The current cadastral system has high local accuracy. In urban areas, a missing boundary mark can usually be replaced with an accuracy of a few centimetres. In rural areas, the accuracy of boundary redefinition depends on the age of the original survey but the uncertainty is typically less than the size of a rural fence post.

However, the cadastral system does not have good "absolute" accuracy. The generation of cadastral coordinates with an accuracy better than 1 metre is not straight-forward. It generally demands a specific interpretation of the term "accuracy" to mean "accuracy relative to the nearest geodetic control station". With the advent of GPS and the possibility of high observational accuracy over distances of 10 to 20 kilometres, the nearest geodetic control station will not always be the one that is most relevant to the accuracy of cadastral coordinates.

For further discussion of the dynamics of the New Zealand cadastre see Grant (1995).

3 DATUM DYNAMICS

If we take a long term view of the datum and dependent databases, we can see that dynamics must eventually be included in the model. We need to be able to accurately relate observations to coordinates. We need to be able to match coordinate sets that are based on observations made at different times. We will no longer be able to assume that coordinate sets are based on the most local geodetic control marks. We need to be able to interpolate the dynamics in space and time.

3.1 SERIES OF FIXED DATUMS

The classical method of maintaining accurate coordinates in the presence of earth dynamics is to generate a series of fixed datums. Taking the short term view (which could cover a significant proportion of a surveyor's working life) the issue of dynamics can often be ignored. Datum changes can appear to be isolated events that merely disturb the status quo of fixed coordinates.

In fact, geodetic coordinate changes also occur between changes of datum. While the coordinates of 1st order stations may be fixed, as with NZGD49, the coordinates of 2nd, 3rd and 4th order stations are occasionally updated following network densification. These updates cause problems to users of the datum because they conflict with the general assumption that coordinates should normally be fixed.

If we take a longer term view, we see that the dynamics are being modelled by a step function. The flat parts of the steps are comfortable but the jumps from one step to another are traumatic to users. The dynamics of the datum are modelled in a jerky and unpredictable way.

The timing of a datum change is difficult. Users wanting high accuracy will find that an old datum does not meet their needs. New users that are about to start large investments in spatial data will want the datum to change before they invest rather than just afterwards.

On the other hand, users that have already made large investments, or users that have low absolute accuracy needs, will want the old datum preserved as long as possible. If the datum does change, they may refuse to switch over thus increasing confusion in the spatial data marketplace.

Datum changes are an inevitable consequence of the fact that coordinates are used to model spatial reality. The changes are not an aberration but a necessary mechanism.

3.2 DYNAMIC COORDINATES

An alternative to the series of fixed datums is a datum that includes the motion of control stations and coordinate axes in the datum definition. For example, the IERS Terrestrial Reference Frame 1991 in which velocities are assigned to station coordinates.

Therefore, a dynamic datum is one where the coordinates of geodetic control stations change in some consistent and organised way as:

1. the control stations move due to earth deformation;
2. spatial accuracy of the geodetic network is increased; and
3 (perhaps but not necessarily) as underlying global reference frames are refined.

Such a datum is four dimensional and the coordinates of a point are not defined correctly without a time tag. Mechanisms for management of the fourth dimension (time) are built into the dynamic datum and must also be built into systems that depend on the datum for high accuracy positioning. This adds to the set-up costs for these systems. However, long term maintenance costs will be reduced because the maintenance of spatial accuracy can be automated.

3.3 DYNAMIC TRANSFORMATIONS TO FIXED DATUM

Initially at least, many users of the datum will reject the costs involved in making their systems fully four dimensional. These users can be catered for through the application of dynamic transformations. Users can maintain a fixed coordinate system in their databases. This will most likely be a snapshot of the dynamic datum at some specified epoch.

New spatial data entering the database may need to be transformed back to the epoch of database coordinates. Database outputs may need to be transformed to the epoch of date. The transformations will change with time. The extent to which users will need to update their transformations will depend on their accuracy requirements.

For 0.5 metre accuracy (assuming no major earthquakes), the transformations may only need to change every decade. For databases of limited spatial extent in areas well away from the plate boundary, a particular transformation may suffice for 2 or 3 decades. On the other hand, for a national cadastral database requiring centimetre accuracy, transformations may need to be updated several times a year.

In order to generate the transformations with centimetre accuracy at the density of the cadastral fabric, a dynamic national geodetic control network will need to be maintained.

4 CONNECTING NEW ZEALAND TO THE ITRS

4.1 DYNAMICS OF THE ITRS

During 1987 the International Earth Rotation Service (IERS) was established by the International Astronomical Union (IAU) and the International Union of Geodesy and Geophysics (IUGG) and commenced operation on January 1, 1988. The IERS replaced the International Polar Motion Service (IPMS) and the Earth Rotation Section of the Bureau International de l'Heure (BIH) (Yokoyama, 1991).

One of the responsibilities of IERS is the definition and maintenance of a Conventional Terrestrial Reference System (CTRS) based on observing stations that use high-precision techniques in space geodesy (Feissel and Essaifi, 1994). The CTRS maintained by the IERS is known as the IERS Terrestrial Reference System (ITRS). Since 1988, IERS has realised the ITRS by producing a yearly set of global xyz coordinates. These coordinates are obtained by combining various SLR, LLR, VLBI and more recently GPS solutions to obtain an IERS Terrestrial Reference Frame (ITRF) which is qualified by a year (for example: ITRF88 and ITRF89).

For each space geodetic technique (SLR, LLR, VLBI and GPS) there are a number of analysis centres around the world that process the data using their own choice of software but comply with the standard reference system as defined by the IERS Standards (McCarthy 1989 and 1992). These individual realisations are adjusted by IERS Terrestrial Frame Section (ITFS), using the least-squares technique, to obtain station coordinates at an epoch, normally 1988.0, and an associated velocity field.

Prior to ITRF91, no velocity field had been derived so the AMO-2 model (Minister & Jordan, 1978) is used to account for the time evolution of ITRS. ITRF91 was the first realisation of ITRS to derive a global velocity field by combining site velocities estimated by SLR and VLBI analysis centres (Boucher and Altamimi, 1993). To ensure the condition of no-net-rotation of ITRS with respect to the earth's crust, NNR-NUVEL1 was selected as the reference motion model of ITRF92. NNR-NUVEL1 is a horizontal motion model only. For consistency of the three-dimensional nature of ITRS, the vertical velocity is set to zero with an assumed error of 1 cm/year (Boucher et al., 1993). For further details on specific ITRF solutions the reader should refer to the appropriate IERS technical note.

For the determination of a station’s position in an ITRF, the station is assigned to a specific tectonic plate. The point position of the station at time, *t*, on the surface of the solid earth is given by McCarthy (1992) as:

$$\vec{X}(t) = \vec{X}_o + \vec{V}_o(t - t_o) + \sum_i \Delta\vec{X}_i(t) \qquad (1)$$

where

$\Delta\vec{X}_i$ = corrections to the various time changing effects.

$\vec{X}_o$ = position at epoch t_o .

$\vec{V}_o$ = velocity at epoch t_o .

t_o = initial reference epoch (ie. 1988.0).

New Zealand's ITRF92 station Wellington (WELL) is assigned to the Australian plate (Boucher et al., 1993). The Wellington station, like most of New Zealand, is located within the deforming zone between the Australian and Pacific tectonic plates. Assigning Wellington to either plate is likely to be incorrect. Current ITRFs accommodate the horizontal velocity of sites on plate boundaries by assigning a larger a priori standard deviation (10 cm/year) to the site’s velocity than for sites located on the rigid part of a tectonic plate (3 mm/year) (Boucher et al., 1994). Therefore to improve the reliability of a New Zealand station’s connection to an ITRF solution, a specific plate motion or earth deformation model for New Zealand needs to be developed.

4.2 ITRF CONNECTION OPTIONS

We assume in this paper that any new geodetic datum for New Zealand will be based in some way on the ITRS as realised by one of the annual ITRFs. This is in line with IAG Resolution No. 1 adopted at the XX IUGG General Assembly in Vienna, 1991 (IAG, 1992). We also assume that the new datum will be geocentric, at least at some specified epoch. This is not a rigid requirement of the IAG Resolution but it is likely that such a decision will be made.

In other words, the development of a new datum will not merely aim to determine its relationship with respect to ITRS which is an option under IAG Resolution 1. At some epoch, the datum will be set close to an ITRF.

There may be some resistance to a shift to a geocentric datum by users because of the disruption that a 200 metre horizontal shift could cause. Most low accuracy users could be partly insulated from the datum shift by a change to the definition of New Zealand Map Grid. Given a new geodetic datum (say, New Zealand Geodetic Datum 2000) we could devise a new survey and mapping projection (say, New Zealand Map Grid 2000) which would be consistent with the existing New Zealand Map Grid to within a few metres. Consistency better than a few metres cannot easily be provided because of the need to eliminate the existing distortions in NZGD49 which amount to several metres.

Given the above assumptions, there are a number of options for defining the axes of a new datum with respect to the ITRS.

1. We could choose the new datum axes to be as close as possible to the axes of a chosen ITRF. The ITRF coordinates and velocities of a number of tectonically stable stations in the region of New Zealand could be used to derive coordinates and velocities for stations in New Zealand that would then be consistent with the chosen ITRF.

2. As for option 1 except that the velocities of sites in New Zealand would be determined by assigning them to either the Australian or Pacific plates and using the ITRF model velocities for those sites. This option would be suitable for a datum located entirely within a tectonic plate where it would have the advantage of complete consistency with

the ITRF model. It would also work if it were reasonable to assume that the plate boundary has zero width.

However, it would be unsatisfactory for New Zealand where the deformation zone covers most of the country. The velocities of sites in New Zealand relative to the ITRF will differ from the velocities of both the Pacific and the Australian plates. This option cannot be recommended.

3. The datum could be attached to the Australian plate. This attachment could be achieved by setting the velocities of tectonically stable sites on the Australian plate to zero and using these sites to derive velocities for all other sites.

   Alternatively, the ITRF model velocities of the Australian plate could be subtracted from all observed velocities. For stable sites on the Australian plate the residual velocities would be small. The velocity of such a datum with respect to the ITRF would be equal to the ITRF model velocity for the Australian plate.

4. As for model 3 except that the datum could be attached to the Pacific plate. Given the increasing surveying and mapping links between New Zealand and Australia, this option has no advantages over option 3. It has the disadvantage of generating velocities between the New Zealand and Australian datums which serve no purpose.

5. As for models 3 and 4 except that the motion of the datum axes relative to the ITRF axes would be determined by application of a constraint to minimise velocities within New Zealand relative to the datum. The actual constraint applied could be: no-net-rotation; least absolute velocity; or least squares velocity across the land area of New Zealand.

Options 3, 4 and 5, by departing from the ITRF would become significantly non-geocentric within a decade or two. At that stage a new datum definition might become necessary for consistency with global data sets and global survey technology. Option 5 would maximise the length of time that some users could ignore the dynamics of the datum.

However, given that all options require dynamic modelling for accurate applications, there seems little justification for going to the expense of developing a dynamic datum if, within a decade or two, it is going to become non-standard and need revision. Of these options, option 1 is therefore preferred.

4.3 DYNAMIC TRACKING OF ITRS

We can go beyond the above options for connecting a new datum to an ITRF. Given that dynamic modelling of the datum is considered sensible due to internal deformation in New Zealand, there is no reason why we could not extend these dynamics to include the dynamics of the annual realisations of the ITRS.

Rather than make an arbitrary choice of ITRF on which to base the datum, we could base the datum on the ITRS using the annual ITRFs as the best current definition of the ITRS. As improvements in observations and modelling result in improvements and changes in the realisations of the ITRS, so the datum could track these changes by steering the datum axes towards the most recently defined ITRF axes. This is also discussed below in section 5.2.4.

For datum users in New Zealand, the subtle shifts in datum axes would be masked by greater coordinate changes resulting from earth deformation and improvements in geodetic control within New Zealand. In other words, the alignment of the datum to the ITRS rather than to a particular ITRF, would involve no significant additional cost or difficulty and would have the advantage of ensuring no long term drift of the datum away from the ITRS.

5 DYNAMIC MODELS

5.1 SPATIAL MODELS

Deformation will be directly estimable at a number of geodetic control points that have been remeasured. The users of the datum will require the dynamics of the coordinate system to be defined at a higher density of points - for example, at the density of land parcel boundaries. It will therefore be necessary to interpolate dynamics through some spatial function.

5.1.1 Heterogeneous Strain

Reilly (1986) describes the use of a second order strain model to model earth deformation in a part of New Zealand. Such a model may be appropriate in limited areas for scientific studies (the purpose for which it was devised) but, to adequately model the entire country would require a much higher order of model and a reasonably uniform density of geodetic observations.

The main problem with any attempt to apply a single model to the whole country is the variability across the country of:

1. deformation;
2. geodetic observations;
3. topography; and
4. accuracy requirements.

There will be some areas of the country where deformation is highly heterogeneous, where spatial accuracy requirements are high and, consequently, where geodetic control is dense and frequently remeasured. A heterogeneous strain model suitable for such an area will be too complex and have too many parameters for other areas where difficult topography and low accuracy requirements have resulted in sparse geodetic control which is infrequently measured.

This problem can be overcome by dividing the country into regions, each with an appropriate heterogeneous strain model. This creates discontinuities on the boundaries between regions as discussed below in section 5.1.2.

5.1.2 Discrete Block Motion

Snay (1993) describes software used to predict horizontal displacements or velocities related to crustal motion in California. The state has been partitioned into 103 districts, each of which is allowed to translate, rotate and deform homogeneously at a constant rate. Motions due to major earthquakes are included in the model.

This model may be suitable for the dynamics of large scale geodetic networks (the purpose for which it is intended). However, it will not be suitable for modelling the dynamics of dense cadastral control or the cadastre itself. The high density of cadastral marks will mean that many will be on or near partition boundaries. Predicted coordinates may then be ambiguous depending on the partition to which a mark is assigned. This will result in gaps or overlaps in the cadastral fabric along partition boundaries.

We could apply the heterogeneous strain model of section 5.1.1 within the partitions. This may reduce discontinuities on the partition boundaries but would not eliminate them. Because of the extra parameters required for heterogeneous strain, the blocks or partitions would either need to be larger than for homogeneous strain or else a greater density of geodetic observations would be required.

5.1.3 Finite Elements

A finite element model could be applied, similar to that of the discrete block model with the difference that the dominant structures for modelling deformation would be the element boundaries rather than the elements themselves. The deformation within each partition would be constrained by the deformation determined on the boundaries. The size of the elements can depend on the density of geodetic observations, the variability of deformation and the accuracy of interpolation required.

This model would avoid the generation of overlaps or gaps between elements that was identified as a limitation of the discrete block model above. Depending on the complexity of the model, there might still be discontinuities in the horizontal gradients of strain. Such discontinuities might detract from the utility of the model for earth deformation research but would not greatly detract from its use in interpolating the dynamics of sites relative to the datum axes.

5.1.4 Least Squares Collocation

As well as the common application for gravity field modelling, least squares collocation has also been used for coordinate transformations (eg, Mortiz, 1972; Deakin et al., 1994). A key role in collocation is played by the covariance function. Covariance functions are usually dependent only on the distance between points. However, given an understanding of the geology and geophysics of the country, a more complex covariance function could be devised to provide a stochastic model of deformation. Covariances could be dependent, not just on distance, but also on whether stations are separated by an active fault and on the expected magnitude of deformation in the area.

Such a model would take time to develop but could be very powerful and flexible in time. Least squares collocation places heavy demands on computer resources but this is likely to become less of an issue by the time such a model could be implemented in practice (at least 10 years).

5.2 TEMPORAL MODELS

We also must be able to interpolate and extrapolate the dynamics at times other than the times of observation campaigns.

5.2.1 Constant Velocity

For stations well removed from tectonic plate boundaries, it is reasonable to assume that velocities are constant. This is the model used in the definition of IERS Terrestrial Reference Frames.

As with the model developed by Snay (1993), discrete events such as earthquakes would need to be incorporated in a constant velocity model. Such a model would probably be used as an initial approximation to the dynamics of the geodetic network. As information about the dynamics improved and as computing power increased, more complex models would become practicable. Note that one method of modelling more complex time dependencies is a series of constant velocity functions.

5.2.2 Other deterministic functions

In the context of vertical reference systems, Holdahl (1992) describes the use of a number of deterministic time dependent functions to model dynamics. The constant velocity model above is one example of a deterministic function. A series of constant velocity functions is the time partitioning model of Holdahl (1992).

One disadvantage of deterministic functions is that we seldom have enough data in the form of re-observations of geodetic networks, to be able to choose the best function with confidence. Another disadvantage is that it is difficult to distinguish between model errors and geodetic observation errors. Because the deterministic function is non-stochastic, any failure of this function to model actual behaviour will result in inflated residuals on the geodetic observations.

5.2.3 Kalman filter

An alternative to (or more correctly, an extension to) deterministic modelling is stochastic modelling of dynamics. A Kalman filter is one method of applying stochastic modelling.

A Kalman filter uses a deterministic dynamic model (such as the constant velocity model) and an estimate of the uncertainty of this model (the dynamic model errors which provide the stochastic component). The dynamic model errors allow deficiencies and variations in the deterministic model to be easily accounted for. For earth deformation, the dynamic model errors could be based on geophysical information. In areas where the deterministic model provides a good approximation, the dynamic model errors can be set small and the deterministic model dominates. In other areas where the dynamics are complex or unknown, the stochastic part of the model may dominate. The dynamic model can also incorporate discrete events such as earthquakes or more complex post seismic motion.

As an example, Stelzer & Papo (1994) propose an alternative model for Kalman filtering and smoothing to determine the coordinates of points in terms of a dynamic reference system.

5.2.4 Coordinate "steering"

In the time dimension, a local reference system (oscillator or clock) may be "steered" so as to remain within specified limits of a superior reference system (time standard). For example, GPS Time is maintained by the US Naval Observatory atomic time standard which is steered to maintain a close relationship to Universal Coordinated Time (UTC). The steering process avoids jumps in GPS Time. Similarly, some GPS receiver oscillators are steered to GPS Time so as to maintain accuracy without the need for timing jumps.

This technique could be applied to a spatial reference system also. The main difference will be that steering corrections applied to coordinates will be much less frequent than those usually applied to clocks. This is because the interval between geodetic observation campaigns is generally much greater than the interval between clock error observations.

Coordinate steering could allow a dynamic datum to incorporate the annual changes from one ITRF to the next. For example, consider a New Zealand dynamic datum - say, New Zealand Geodetic Datum 2000 (NZGD2000) - based on IERS Terrestrial Reference Frame 2000. At the start of 2002, the IERS would publish the latest realisation of the IERS Terrestrial Reference System (IERS), namely ITRF2001. In order to ensure that NZGD2000 remained in terms with the best definition of the ITRS, we could modify the dynamic definition of NZGD2000 so that its axes would, as close as possible, be coincident with the ITRF2001 axes by the end of 2002. At the start of 2003 another steering correction would be applied to bring the axes in terms of ITRF2002 by the end of 2003.

These annual changes to the NZGD2000 axes would ensure that the datum remained closely in terms with the ITRS. With the datum incorporating models for internal dynamics of New Zealand, the additional dynamics imposed by this process would not greatly impinge on the short term utility of the datum, but would avoid the long term need for datum "jumps" to bring the New Zealand datum back in terms with global systems such as those used by GPS.

6 USER IMPLICATIONS

6.1 EFFECT ON GEODETIC DATABASES

Even with New Zealand's current "static" datum, NZGD49, the coordinates of 2nd, 3rd and 4th order trigs are occasionally changed through network densification and re-adjustment. This causes difficulties to users of the datum. These difficulties result from the fact that the national geodetic database, maintained by the Department of Survey & Land Information (DOSLI), is not available on-line to all users. Plans to provide on-line access to DOSLI's databases, including the geodetic database, will overcome this problem.

It should also be noted that the coordinate changes that do occur in the national geodetic database, are fairly unpredictable to users outside DOSLI's geodetic section. The time taken between network re-observation and the implementation of new coordinates in the database is variable as it depends on work priorities. The coordinate changes may amount to several decimetres and, when implemented, cause an immediate coordinate jump.

With a dynamic datum, coordinate changes would generally be smooth and predictable. Except for earthquake rupture, deformation across the country occurs at the rate of approximately 1 mm per week. Coordinates would generally change no faster than this.

6.2 EFFECT ON CADASTRAL DATABASES

In Grant (1995), the case for a dynamic coordinated cadastre is made. In such a model, boundary coordinates would be accepted as definitive by cadastral surveyors in the absence of any contradictory physical evidence such as boundary marks. This would avoid the current need for expensive analysis of historical survey plans. Such analysis would take place in a cadastral survey database which would hold all evidence relevant to the definition of the cadastre.

Coordinates in the dynamic cadastral database would be changed, not only by the physical dynamics of the cadastre resulting from earth deformation, but also due to improvements in the totality of evidence of the cadastral fabric. For example, if reliable ground marks were found to be at variance with the database coordinates or if previously accepted survey observations were found to be in error, the cadastral fabric would be re-defined and coordinates would be changed.

The dynamics of the cadastral coordinates, far from being disruptive to cadastral surveyors, would enable them to use definitive coordinates to define land parcels and check new survey observations. This would eliminate much of the current expense of cadastral surveys. Surveyors would be required to obtain up-to-date coordinates from official databases. By the time such a system is implemented, on-line access from the field to these databases should be routine.

In other words, the role of coordinates would be to summarise evidence on the geometry of the cadastre. The fact that coordinates slowly change would not be a disadvantage to the cadastral surveyor. It would simply be a necessary reflection of an improvement in cadastral evidence.

6.3 EFFECT ON GEOGRAPHIC INFORMATION SYSTEMS

The greatest difficulty in dealing with a dynamic datum and a dynamic cadastre will lie in the application of geographic information systems. There is a wide variety of spatial databases in external agencies which have a need to be able to relate diverse data sets acquired at different times and in different ways.

Currently available GIS software packages tend not to distinguish between absolute and relative spatial relationships. For example, if utilities have been positioned relative to cadastral boundaries, the resulting derived coordinates are generally treated as absolute. Any change to the coordinates of the cadastral boundaries will often result in them becoming out of terms with the unchanging coordinates of the utilities.

Future improvements in GIS software may see increased opportunities for spatial relationships between entities to be maintained. In the interim, the solution will be to provide dynamic transformations that will allow diverse data sets to be transformed to a common epoch (section

3.3 above). As the datum changes, so will the transformations change. The nature of these transformations is not certain. It can be seen however that the variation of deformation across New Zealand is such that a national similarity (7 parameter) transformation will not suffice for high accuracy applications.

6.4 EFFECT ON TOPOGRAPHICAL DATABASES

For topographic mapping, the effect of the dynamics of the datum will be insignificant. Within a normal mapping revision cycle (say 20 years) the deformation across New Zealand will be 1 metre. For mapping scales smaller than 1:5,000 this is less that 0.2 mm at plot scale.

7 IMPLEMENTATION CONSIDERATIONS

A dynamic datum is unlikely to be implemented in less than a decade. Therefore, we can count on significant improvements in computer hardware and software. Early implementations will include compromises which can be eliminated as knowledge increases and technology improves. This ability for the dynamic datum to improve itself is one of its desirable features.

7.1 OBSERVATION OF DYNAMICS

Until the advent of GPS, the effort and cost involved in re-observation of a national datum was very high. That is one of the reasons why New Zealand has persisted with NZGD49 for so long.

A new geodetic network known as the Zero Order 2000 network, which will be continuously observed by GPS, is now being established in New Zealand. Initially this will consist of 3 sites on the main islands of New Zealand and one site on the Chatham Islands to the east that will provide a stable Pacific plate connection. The Australia Fiducial Network to the west will also contribute to New Zealand's zero order network. Within 10 years, we can expect the processing of data from the zero order network to be automatic.

A First Order 2000 breakdown of the Zero Order 2000 network has also been established. This network of 29 stations, similar to the network shown in diagram 1, was observed in a single observation campaign of 3 days in March 1995. Annual or biennial re-observation of this network to monitor earth deformation is well within the financial and logistical capabilities of DOSLI.

Observation of a new Second Order 2000 network was also undertaken this year. In 4 months, observations of this network and connections to the existing NZGD49 1st order network covered two thirds of New Zealand. The new stations are easily accessible and future re-observations will be faster and cheaper because there will be no need to re-connect to the NZGD49 stations which are mostly on hill or mountain tops. Future re-observations of the Second Order 2000 network will be scheduled according to need. In areas of high accuracy requirements or high deformation (as indicated by re-observations of the First Order 2000 network) re-observations will be more frequent than in remote or tectonically stable areas.

Next year, Third Order 2000 breakdowns are likely to commence in strategic areas. The first epoch of these observations will be the most expensive because of the need to connect to 2nd and 3rd order stations in the NZGD49 network. Observations of the 3rd Order 2000 network will use rapid static GPS observation techniques for maximum efficiency.

In addition to the work undertaken by DOSLI, a number of research projects on earth deformation in recent years have contributed to New Zealand's geodetic network. Cooperation between DOSLI and the organisations undertaking this research provides mutual benefits.

Cadastral surveyors, in meeting future requirements to connect their surveys to the geodetic network, will contribute to knowledge of the dynamics of the proposed Fourth Order 2000 network and cadastral control.

The scope of this geodetic activity indicates that New Zealand has a wealth of geodetic data which will continue to contribute to knowledge of the dynamics of New Zealand.

7.2 DYNAMIC ADJUSTMENT

The most difficult task will not be the collection of geodetic data but its processing. However, it is useful to reflect that the 1949 manual adjustment of the 1st order geodetic network took 3 years to complete the adjustment of 505 condition equations for 284 stations. Today, a more rigorous adjustment can be completed in less than a minute on a personal computer. Equally dramatic improvements in computing power can be expected over the next 10 to 15 years.

The first implementations of a dynamic datum will probably involve compromises. Initially, a static datum could be established for national surveying and mapping. In the background a dynamic datum could be developed and maintained. The first role for this datum would be to provide a consistent framework for geodetic computations. Dynamic transformations from this dynamic datum to the static datum would be used to transform the results of new adjustments into the less accurate static datum.

Some users requiring high accuracy and with moderate sized national data sets (for example civil aviation) might prefer to work directly in the dynamic datum. As time goes by, as user database software improves, and as the discrepancy between the dynamic and static datums increases, more users may come to depend on the dynamic datum.

When the cadastral survey system becomes fully digital, it would be supported by the dynamic datum and the static datum would probably be maintained purely as a service to those users who do not require high accuracy and who do not want to shift to the dynamic datum.

For a dynamic datum to work in practice, users of the survey system will require on-line access to survey system databases. Geodetic and cadastral survey observations will need to be digitised and available on-line to ensure that dynamic coordinate adjustments can be propagated throughout the survey system. These developments are already planned and will occur with or without a dynamic datum.

New Zealand is a relatively small country and has no land boundaries with other countries. Realisation of a national dynamic datum will be easier in New Zealand than most other countries.

8 CONCLUSIONS

The ideas presented in this paper are so far just ideas - not official policy. However, the Department of Survey & Land Information proposes development of a fully digital survey system for New Zealand. The dynamic datum concept is seen by the authors as a key component of a system that can be implemented by the year 2010 and which will have the flexibility to provide a stable spatial foundation for New Zealand for the foreseeable future.

Many users of the survey system seek stability in coordinates. This is an understandable desire given the limitations of spatial data processing today. However, in a deforming country such as New Zealand, it is an unachievable goal if the coordinate system is to remain accurate and useful. What the dynamic datum can provide is not stable coordinates but a stable datum architecture. With mechanisms for change and improvement built into the datum architecture, a dynamic datum can provide a complete and adaptable coordinate system with the stability that users seek.

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