Maintaining Accurate Coordinates for Geospatial Datasets after a Geodetic Datum Update

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SUMMARY

With ever-increasing demands for accuracy, geodetic datum updates are becoming more frequent. In its widest sense, a geodetic datum update can include anything from updating the coordinates of a single mark, to establishing a new datum affecting hundreds of thousands of geodetic marks.

The geodetic datum provides the underlying spatial framework for numerous other geospatial datasets, including cadastral, engineering and topographic. Often significant effort is expended to ensure that these datasets are in terms of an accurate geodetic datum. However, maintaining the spatial accuracy of these datasets is a problem which is often given little attention. For any dataset using geodetic mark coordinates as control, consideration needs to be given to updating the dataset's coordinates whenever a geodetic update or readjustment occurs. This is particularly crucial where coordinates in the dataset have associated accuracy values and coordinates are stated to comply with a given accuracy standard.

This paper outlines potential techniques for updating coordinates. Several scenarios are identified which may trigger a geodetic datum update. These include nationwide datum readjustment, updates in response to a deformation event (such as an earthquake) and updates to incorporate additional observations into the geodetic network. Knowing the nature and extent of the geodetic update is important, as this will affect the technique chosen to maintain the accuracy of geospatial datasets. An approach is suggested, which considers the problem in two parts: how to update coordinates and how to update the accuracy values on those coordinates. For some scenarios, both coordinates and accuracy values will need to be updated, in others only the coordinates. It is the characteristics of the geodetic update which will determine what needs to be updated. Techniques for updating coordinates and accuracy values are identified, linking them to the geodetic update scenarios for which they should be considered. The New Zealand cadastre is used as an example.

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1. INTRODUCTION

The official datum for New Zealand is New Zealand Geodetic Datum 2000 (NZGD2000). This datum was brought in to support the requirement for greater spatial accuracy in geospatial datasets, particularly the cadastre. It is a semi-dynamic datum, which incorporates a National Deformation Model (NDM). This model is used to generate coordinates in terms of NZGD2000 at Epoch 2000.0. The NDM can also incorporate deformation events such as earthquakes, a reasonably frequent occurrence in New Zealand.

Land Information New Zealand is the government department charged with managing New Zealand's geodetic system. There is an ongoing programme of work to improve the quality and accessibility of the geodetic datum, which means that aspects of the datum, such as mark coordinates, are subject to change. Even in the absence of such changes, New Zealand sits across two tectonic plate boundaries and is therefore subject to significant tectonic movement. At a future date, this may require a mass update of geodetic coordinates (for example, if coordinates are computed at a new epoch).

Many geospatial datasets rely on a geodetic datum for their absolute accuracy. The more accurate the dataset, the more important it is that managers of that dataset are aware of the potential for geodetic datum changes. In most cases these geodetic datum changes will not impact on the geospatial dataset. But in some instances they will, particularly for high-accuracy geospatial datasets, such as the cadastre.

This paper describes the reasons why geodetic datum updates occur, outlining three broad scenarios. These scenarios are then used to describe whether geospatial dataset accuracies, as well as coordinates, need to be updated. Methods of updating coordinates and accuracies are discussed, again in relation to the various scenarios. Finally, the example of the New Zealand cadastre is used to illustrate some of the principles.

2. GEODETIC DATUM UPDATES

There are three scenarios in which geodetic coordinates get updated, which potentially require coordinate updates to be made to other geospatial datasets. Further detail about these scenarios can be found in Donnelly and Palmer (2006).

2.1 Scenario 1: Nationwide Datum Readjustment

As well as including the introduction of a new reference frame or datum, this scenario covers the situation where most (or all) of the geodetic marks in a given datum have new, more accurate, coordinates assigned. For example, in 2007 the National Geodetic Survey (NGS) completed a new realisation of the United States' geodetic datum, North American Datum 1983 (NAD83). One of the main reasons this was done was to resolve inconsistencies between state networks and the national Continuously Operating Reference Station (CORS) network (Pearson, 2005). This is an issue faced by many countries with datums which pre-date their CORS networks.

In New Zealand, such a readjustment has not taken place. However, at some stage the National Deformation Model will need updating (Beavan and Blick, 2007), at which time a national readjustment may be required.

2.2 Scenario 2: Local Geodetic Control Update

A local geodetic control update refers to the updating of geodetic coordinates in a localised area. This includes improvements to the coordinates of existing marks, as well as the addition of new geodetic control marks.

Improvements to existing geodetic coordinates primarily occur where these coordinates are based on terrestrial observations and subsequent GNSS surveys provide higher-quality data.

New geodetic control marks are installed primarily in areas of significant land development, where the existing control network is too sparse to support the increased activity.

2.3 Scenario 3: Deformation Event

Countries such as New Zealand, which sits astride two tectonic plates, are subjected to significant earthquakes with reasonable frequency. These have the potential to move land by several metres and have impacts over hundreds of kilometres.

Such an event has not occurred in a populated area since the introduction of NZGD2000. If such an event were to occur, the general strategy would be to update the geodetic datum by creating a Localised Deformation Model (LDM) (Denys et al, 2007).

3. GEOSPATIAL DATASETS CONNECTED TO GEODETIC DATUM

Most geospatial datasets covering any sizable area are connected to a geodetic datum, even though this connection may be indirect. In considering whether a geospatial dataset is affected by a geodetic datum update, the prime consideration is the magnitude of the update and how this compares to the required accuracy of the dataset.

For example, a geodetic update which may change coordinates by a few centimetres will not have any significant impact on a geospatial dataset which is accurate to half a metre. However, if the update is several metres (perhaps due to an earthquake), then consideration must be made as to how best to incorporate this movement.

With increasing frequency, geospatial data is being collected using techniques such as Real-Time Kinematic GPS (RTK), which easily enable data to be collected to the sub-decimetre level, relative to the datum axes. At this level, even relatively minor changes in geodetic coordinates potentially impact on the geospatial dataset.

In this paper, geospatial datasets are assumed to have the following characteristics:

- connection to a geodetic datum (usually through use of geodetic marks to control the geospatial dataset)
- a high degree of accuracy relative to geodetic control (at least a few decimetres)
- accuracy information associated is with the coordinates of features in the dataset

4. DETERMINISTIC AND STOCHASTIC MODELS

There are two problems to be resolved when considering how the accuracy of geospatial datasets should be maintained or improved, subsequent to a geodetic datum update.

Firstly, we wish to know the new coordinates of the geospatial features (coordinates which better reflect their real-world location). These coordinates are a deterministic quantity, meaning that they have a definite position (even though we do not know that position with perfect accuracy). Thus we need to have a deterministic model to provide the new coordinates.

Secondly, we wish to know how accurate the coordinates are. This accuracy is a stochastic (statistical) quantity. Where accuracy-related information is required, we will need to incorporate a stochastic model.

Whenever a significant[1] geodetic datum update occurs, a deterministic model for updating the geospatial dataset needs to be used (new coordinates need to be calculated). If the dataset has accuracy-related attributes, this information may or may not need to be updated using a stochastic model.

We assume here that geodetic control is treated as fixed in the geospatial dataset. This makes the stochastic model for the geospatial dataset independent of the stochastic model of the geodetic marks. If the geodetic and geospatial datasets are adjusted together, or if the fit of the dataset with the geodetic coordinates is used to re-weight the dataset, then the stochastic model of the dataset is affected, and a re-evaluation of accuracy would need to be carried out.

The question of whether the stochastic model needs to be applied is important, as much time can be saved if the existing accuracy information can be retained even where the coordinates have updated values.

[1] Significance is assessed by comparing the size of the geodetic coordinate changes with the accuracy of the geospatial dataset

The table below summarises some common situations which occur for each of the update scenarios, noting whether an update to geospatial dataset accuracy information is required.

Scenario	**Situation**	**Geospatial dataset accuracy information needs updating?**
1. Nationwide Datum Readjustment	New reference frame	No
	New National Deformation Model	No
	New or removed marks	No[2]
	New observations to existing marks (which have not physically moved)	No
2. Local Geodetic Control Update	New or removed marks	No[2]
	New observations to existing marks (which have not physically moved)	No
3. Deformation Event	New LDM	Yes
	New observations to existing marks (which have physically moved due to deformation)	Yes

Table 1: Scenarios for geodetic datum updates

This table is further explained in the remainder of this section.

4.1 Scenario 1: Nationwide Datum Readjustment

4.1.1 <u>New Reference Frame</u>

Changing the reference frame of a datum (which is effectively changing the datum), does not impact on the accuracy of a geospatial dataset. For example, if the centre of the Earth has been more accurately determined, the translation simply needs to be applied to the geospatial coordinates. The errors on the observations used to originally generate those coordinates have not changed, so existing accuracy information can be retained.

[2] Although an update may be desirable, see Section 4.1.3

4.1.2 New National Deformation Model

If the datum is being updated because there is an improved National Deformation Model, then geospatial dataset accuracy remains the same. This is because changes to a national model will have little impact on the predicted relative deformation at a local level. Thus adjacent geodetic marks are likely to have consistent coordinate changes, which can then be applied to the geospatial dataset.

However, if the change to the national model is significant (for example, if a deformation model is being used for the first time where previously there was none), then consideration should be given to updating accuracy values. The relative changes to geodetic coordinates may be such that when these are used to constrain the geospatial dataset, the accuracy information differs significantly from what was determined when no account was made for deformation.

4.1.3 New or Removed Marks

Any new marks in the geodetic network become fixed points controlling the coordinates of geospatial datasets to which they are connected. This increases the absolute accuracy of geospatial features in the vicinity of the fixed mark. However, the inclusion of the new geodetic mark as control would normally occur as part of the maintenance of the geospatial dataset, and it is at this stage that there would be a re-evaluation of the accuracy. Thus there is no need to immediately update the accuracy of the geospatial dataset, although this may be desirable to increase its usefulness.

If a geodetic mark is removed, perhaps because additional information reveals it is unreliable, it can no longer be used as fixed control for the geospatial dataset. When the dataset is next maintained, the absolute accuracy of geospatial features in the vicinity of those marks will probably decrease. In this situation it is more important to re-evaluate the geospatial dataset quickly, as its accuracy may be overstated.

For example, if we consider an aerial photograph which has been rectified using geodetic control, a new geodetic control mark would increase the accuracy of the rectification in the vicinity of that mark. Removal of a geodetic mark would decrease the accuracy of that area, if the photo were re-rectified.

4.1.4 New Observations to Existing Marks

New geodetic observations to existing marks will not affect the accuracies of geospatial features, because geodetic coordinates are treated as fixed in the geospatial dataset. Any relative geodetic coordinate changes resulting from these new observations are assumed to be negligible at the accuracy level of the geospatial dataset.

4.2 Scenario 2: Local Control Update

4.2.1 New or Removed Marks

The impact of new or removed marks is the same as for Scenario 1.

4.2.2 New Observations

The impact of new observations is the same as for Scenario 1.

4.3 Scenario 3: Deformation Event

4.3.1 New Localised Deformation Model (LDM)

Where a LDM is produced, the size of the deformation is often such that the error associated with the deformation model cannot be ignored. Thus where an LDM is used to update the coordinates of a geospatial dataset, the error in the LDM should be combined with the existing error in the dataset to arrive at new accuracy values.

4.3.2 New Observations to Existing Marks

In this case, we assume that the new observations have been made to update the coordinates of marks directly, rather than to create an LDM. In this case, using the new coordinates to control the geospatial dataset is likely to identify that the geospatial dataset (pre-deformation event) conflicts with the geodetic control (post-deformation event). Such a conflict means that accuracy values need to be updated.

4.4 Other Updates to Geospatial Datasets

It is worth noting that the majority of updates which are made to geospatial datasets occur because extra information about the dataset is received. For example, when a new cadastral survey occurs, the digital cadastre needs to be updated.

In these situations the stochastic model of the dataset itself is affected, so new accuracy information needs to be determined. This would normally take place as part of the scheduled maintenance of a dataset.

5. TECHNIQUES FOR MAINTAINING THE ACCURACY OF GEOSPATIAL DATASETS

5.1 Classical Least Squares

Classical least squares incorporates both deterministic and stochastic models and is a rigorous method of determining coordinates and accuracies. It is used extensively in high precision applications such as geodetic and engineering surveying. A downside of least squares is that the time taken to run an adjustment increases non-linearly as the number of coordinates to be calculated increases. A large geospatial dataset may contain millions of coordinates, making a full least squares adjustment impractical. It is possible to reduce the time taken to run an adjustment if the requirement to output full statistical information can be dispensed with.

5.2 Block Least Squares

Block least squares (Helmert Blocking) is a variation on classical least squares, which accounts for the difficulties of running large adjustments. The adjustment is broken into a number of smaller parts, based on the theory that it is more efficient to do a number of small adjustments in a stepwise fashion, than one large adjustment. The coordinates calculated in the series of blocks are identical to those that would have been calculated if the data had been adjusted as a single block. This technique incorporates deterministic and stochastic models.

Block least squares has traditionally been used for large geodetic adjustments, such as the readjustment of NAD83 (Pearson, 2005).

5.3 Simple Linear Interpolation

Simple linear interpolation involves moving coordinates in proportion to the movements at adjacent control points. It is the simplest possible method of adjusting coordinates, making implementation straight-forward and efficient. This makes it a particularly viable option for large geospatial datasets. Another advantage is that this technique is implemented in a number of commonly-available GIS software packages. A downside is that the coordinates generated will not be as good as those generated using least squares.

Interpolation is solely deterministic, so there is no direct way of estimating the accuracy of the new coordinates. If required, accuracy would need to be assessed as part of a separate process.

5.4 Accuracy Function

Where coordinates are generated using a technique which does not incorporate a stochastic model, an accuracy function may be used to update the accuracy of a geospatial dataset.

The accuracy function may be as simple as making an assessment, based on experience, as to how accurate the dataset is likely to be. For more complex, accurate, or inhomogeneous datasets, the function may need to be based on data characteristics such as:

- proximity to geodetic control
- age of data
- number of repeated measurements
- equipment used to collect the data
- physical characteristics of object being coordinated (for example, a small diameter stainless steel pin can be coordinated more precisely than a large diameter fence post)
- stability of the object

5.5 Appropriate Techniques for Scenarios

Having identified the various scenarios and techniques, these can be matched together. The suggestions in the table below are based on choosing the most efficient method, while still providing accuracy information where this is required (based on discussion in Section 4). These recommendations are generalisations and the final technique (or combination of techniques) chosen will depend on the individual characteristics of the geospatial dataset to be updated.

Scenario / Situation	**Classical least squares**	**Block least squares**	**Inter-polation***
1. Nationwide Datum Readjustment			
New reference frame	x	x	√
New National Deformation Model	x	x	√
New or removed marks	x	√	X
New observations to existing marks (which have not physically moved)	x	x	√
2. Local Geodetic Control Update			
New or removed marks	•	√	X
New observations to existing marks (which have not physically moved)	•	√	√
3. Deformation Event			
New LDM	•	√	√
New observations to existing marks (which have physically moved due to deformation)	•	√	√
Key √ = potential method • = potential method in some situations (eg small adjustments) x = not a feasible method			
*Assuming accuracy information, where required, is obtained from an Accuracy Function			

Table 2: Potential methods for geospatial dataset updates

6. CASE STUDY: THE NEW ZEALAND DIGITAL CADASTRE

About 70% of New Zealand's digital cadastre is "survey-accurate", meaning that boundary points are accurate to a few centimetres, relative to the local geodetic control. This level of accuracy was achieved through capture of bearings and distances from paper survey plans (Rowe, 2003). The accuracy of the cadastre is specified at reasonably fine gradations using the concept of mark "orders". The order of a mark, to some extent, determines the purposes for which it can be used (for example, some marks are suitable for use as an origin in a cadastral survey, others are not). It is therefore important that the accuracies are correct.

Although New Zealand does not have a coordinate cadastre, accurate coordinates improve the efficiency of cadastral surveys. It also improves the efficiency of checking the accuracy of new cadastral surveys, as accurate coordinates are used in automated checks to identify potential errors in new work. High quality coordinates also make the cadastre more useful for other GIS-related purposes.

LINZ manages the cadastre, and part of this involves ensuring that cadastral coordinates and accuracies are updated whenever there is a geodetic datum update.

As mentioned previously, NZGD2000 has to date made neither a nationwide update, nor an update to account for a significant deformation event. There have, however, been frequent updates which fall under Scenario 2, Local Geodetic Control Update.

Until 2007, no efforts were made to update the cadastre subsequent to these geodetic updates. This meant that significant portions of the cadastre were out of alignment with the geodetic system, sometimes by up to a decimetre. This was starting to cause noticeable problems for surveyors and LINZ staff who need to work with both geodetic and cadastral data.

Since 2007, ad hoc updates have been made in areas where the alignment of geodetic and cadastral data is particularly poor. However, it was determined that a more systematic approach is required and a pilot has been running since early 2009 to develop and refine a methodology for cadastral coordinate updates.

In this case we often have new geodetic control marks, so both the deterministic and stochastic models are changing. Based on Table 2, the methods to consider are Block Least Squares and Classical Least Squares. In making the decision, the following factors were considered:

- LINZ already has a system which can do Classical Least Squares
- The size of the areas to be adjusted is normally so large that the data cannot be run in a single adjustment
- Additional cadastral surveys have usually been submitted since the previous adjustment, so accuracy information needs to be updated
- It is important that coordinates and their stated accuracies are as reliable as possible, as this information is used by cadastral surveyors and GIS managers

The approach being piloted uses classical least squares, but splits the country into adjustment blocks of a manageable size. Where possible, adjustment blocks have had their boundaries set based on the blocks used in the creation of the survey-accurate digital cadastre (Rowe, 2003). This provides continuity between the original adjustment used to coordinate the marks and the subsequent readjustment(s). Where there is no existing adjustment block, boundaries are selected to coincide with topographic features such as roads and rivers.

Classical least squares is then used to readjust the cadastral data in terms of the new or updated geodetic control. Once these adjustments have been set up, it is a fairly quick and straight-forward process to run any subsequent readjustments. Any new data (observations or updated geodetic coordinates) are spatially selected into the adjustment, based on the adjustment block boundaries. The adjustment is then run and new coordinates and accuracies generated.

7. CONCLUSION

In considering whether a geospatial dataset needs to be updated after a geodetic datum update, the primary consideration is whether the magnitude of the geodetic coordinate change is significant in terms of the accuracy of the dataset.

A number of scenarios and situations have been identified, with a focus on whether there is a requirement to update the accuracy information relating to the geospatial dataset. Different techniques are appropriate for different situations, and sometimes a combination of techniques is required.

While it is convenient to calculate coordinates once and not update them, for high accuracy geospatial datasets this approach may lead to a gradual degradation in accuracy. Geospatial dataset managers should be aware of these issues and consider whether they impact on the datasets in their custody.

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BIOGRAPHICAL NOTES

Since graduating with surveying and science degrees from Otago University, Nic has worked in the geodetic team at Land Information New Zealand. He is involved in setting the geodetic survey and maintenance programmes and is working on issues around maintaining the alignment of the New Zealand's geodetic and cadastral datasets.

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