Progress Towards a New Geodetic Datum for Australia

Joel Haasdyk
Survey Infrastructure and Geodesy, Land and Property Information
NSW Department of Finance & Services
Joel.Haasdyk@lpi.nsw.gov.au

Laurence Davies
Survey Infrastructure and Geodesy, Land and Property Information
NSW Department of Finance & Services
Laurence.Davies@lpi.nsw.gov.au

Tony Watson
Survey Infrastructure and Geodesy, Land and Property Information
NSW Department of Finance & Services
Tony.Watson@lpi.nsw.gov.au

ABSTRACT

Limitations in the current Geocentric Datum of Australia 1994 (GDA94) have been previously demonstrated, and the spatial community is currently discussing the best way forward to a next-generation datum, here hypothetically termed GDA201x. As previously described, each state and territory is collating all available geodetic measurements for submission to a simultaneous national adjustment. The product of this national adjustment will be a homogenous 3D coordinate datum across Australia which can be easily updated when new measurements become available. Initial workshops and discussion forums have been held in each state and territory to engage users during this development stage and to understand and address the needs, difficulties and potential applications associated with developing a new datum. This paper describes the technical progress towards a new simultaneous national geodetic adjustment with a focus on the work accomplished in New South Wales.

KEYWORDS: *GDA94, GDA201x, APREF, datum, dynamic.*

1 INTRODUCTION

The motivation and early progress towards developing a next-generation datum for Australia has been previously described (Haasdyk and Watson, 2013; Haasdyk et al., 2014). Any new datum, here hypothetically termed GDA201x, would replace the current Geocentric Datum of Australia (GDA94 – GA, 2014a) and align more closely to the best available global standard, the International Terrestrial Reference Frame (ITRF – Altamimi et al., 2011). A number of drivers for a datum change are discussed, which include but are not limited to:

- Technological improvement and more precise geodetic measurements gathered since 1994 can be used to compute improved coordinates and uncertainties.
- Systematic distortions of up to 300 mm (horizontal) have been detected by modern measurements such as from Global Navigation Satellite System (GNSS) Continuously Operating Reference Stations (CORS) and ‘site transformations’ are currently required to agree with local ground control.

- The Australian tectonic plate moves at approximately 7 cm per year, but GDA94 is defined by coordinates locked to epoch 1994.0. GDA94 is offset with respect to ITRF and other global coordinate systems by approximately 1.5 m as at 2015.
- This metre-level offset is large enough to affect the expected positioning accuracy of mass-market devices such as smartphones and tablets which will likely determine coordinates in the latest ITRF − without direct reference to GDA94 − by directly accessing International GNSS Service (IGS) products in real time.
- The Australian tectonic plate is also rotating slowly, introducing errors which are significant for surveying and geodesy applications (7 mm on a 30 km long baseline observed over a 20-year period).
- Ground deformation is readily apparent in the subsidence due to water, coal or gas extraction. Deformation due to seismic activity is observable within the Australian tectonic plate.
- A significant 9 cm vertical bias is present between ITRF92, upon which GDA94 is based, and the current ITRF models.

In addition, improvements in computing hardware and software capabilities now make it possible to quickly perform rigorous geodetic adjustments of a virtually unlimited number of stations and measurements, without a hierarchy of fixed control. As a result, distortions within state and territory adjustments, as well as discontinuities across borders, can be eliminated and new technologies and measurements can be incorporated as soon as they are available. The phased-adjustment software, DynaNet, was discussed in this context by Haasdyk and Watson (2013). DynaNet is used for least squares adjustments in this study and will be used for the full national adjustment for the determination of GDA201x.

The difficulties and benefits of datum update have been discussed at a first-round of forums across the nation (one per state or territory) with the dual aim of educating and involving the wider spatial community. As reported by Haasdyk et al. (2014), the final realisation of any new datum is being carefully considered. A next-generation datum would need to provide a platform for a wide range of user groups and applications, including high-accuracy surveying and scientific applications, an emerging mass-market positioning community of enormous size, as well as catering for existing GDA94 datasets which cannot be economically transformed.

This paper primarily describes the progress made to date by Land and Property Information (LPI) in New South Wales (NSW), as well as progress at a national level, to prepare the available geodetic data and develop adjustment methods required for a next-generation datum.

2 METHOD

The method for gathering and assessing the NSW dataset is generally the same as previously described by Haasdyk and Watson (2013), with the addition of a few new tools and data types, and is shown in Figure 1. The data described herein comprises the second official submission (in October 2013) by LPI to Geoscience Australia in support of the national adjustment.

In brief, all available GNSS measurements have been gathered from the LPI electronic archives by automated scripts and sorted into a collection of unique of 3D vector measurements in an Extensible Markup Language (XML) format. The weighting of each measurement is adopted from the minimally constrained adjustment of the campaign in which the data was gathered. Analysis of the data for potential outliers has been performed mainly using least squares adjustments, but more recently using the L_1 norm method described in section 3.2. Measurements which were flagged as potential outliers in the initial campaign adjustment have been 'ignored' (i.e. not been included in the adjustment), but have been set aside for further investigation and analysis.

Changes from the previous publication by Haasdyk and Watson (2013) include:

- The collection of *new* GNSS measurements by data-mining of the LPI archives performed in June 2013, as well as the inclusion of several new major control projects completed since that date and before October 2013.
- The inclusion of *all* ground marks, previously restricted to standard NSW Survey Control Information Management System (SCIMS – Kinlyside, 2013) marks such as TS, SS, PM, MM, but now including vectors between *any* mark types, permanent or temporary, to improve network connectivity. Appropriate care is taken with respect to station stability.
- The inclusion of new data analysis methods such as the L_1 norm adjustment
- The trial constraint of the network to an Asia-Pacific Reference Frame (APREF) weekly solution (refer to section 2.2.2).

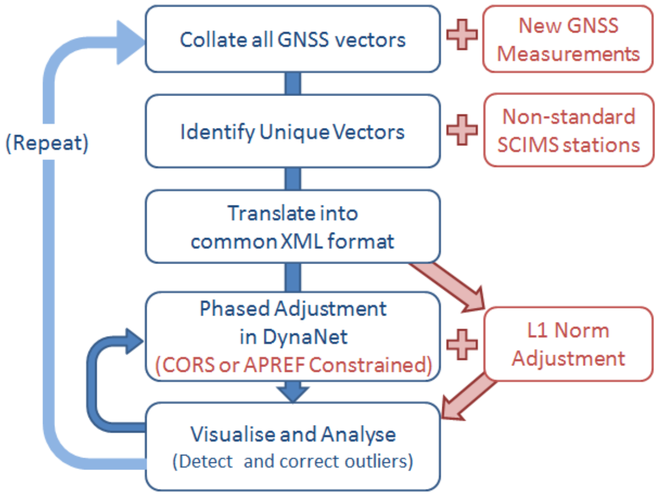

Figure 1: Flowchart of GNSS vector measurement acquisition and cleaning, with significant changes since last year (Haasdyk and Watson, 2013) highlighted in pink.

2.1 Data Sourcing (GNSS Vectors)

Table 1 indicates changes to the number of stations and measurements available from the LPI archives since last year, and since the GDA94 adjustment. Approximately 76,000 unique GNSS vectors are included in the latest dataset, which represent more than 62,000 unique baselines. The number of measurements is now 26 times the number of GPS measurements used in GDA94. Note that approximately 80% of these baselines have never been directly re-observed, and therefore gross error detection is limited to redundant network analysis. Figures 2 and 6 offer some additional description of this dataset.

Table 1: Number of stations and measurements in NSW adjustments.

(values rounded to nearest 100)	**GDA94 (NSW data)**	**APAS2013 dataset (NSW data for GDA201x)**	**APAS2014 dataset (NSW data for GDA201x)**
Stations	3,000	20,400+	24,500+
GNSS Baselines	2,900	62,000+	76,100+

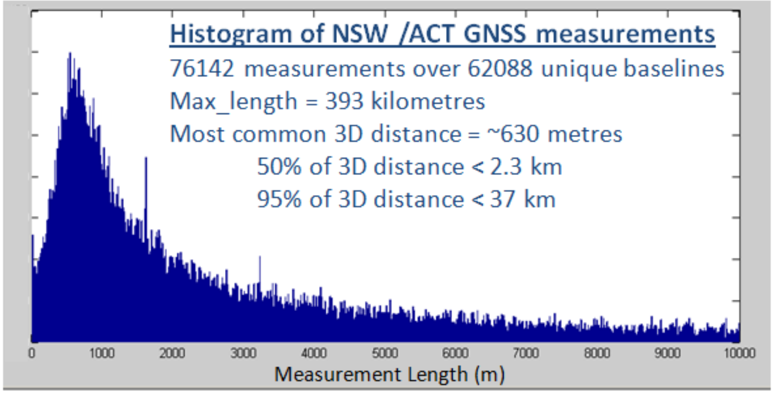

Figure 2: Histogram of LPI's current GNSS dataset for NSW (including GNSS vectors covering the ACT).

2.2 Adjustment Constraints

2.2.1 CORSnet-NSW Coordinates

Previously it was reported that a combination of Regulation 13 certified coordinates (GA, 2014b) and AUSPOS coordinates (GA, 2014c) were employed to act as network constraints. In the current analysis, the constraint is provided by the CORS network coordinates only, for the 131 CORS stations available in CORSnet-NSW (Janssen et al., 2011; LPI, 2014) at the time of analysis. These constraints were introduced with a standard deviation of 10 mm in each of the Cartesian (X,Y,Z) coordinates. The AUSPOS coordinate solutions were excluded due to some decimetre-level biases noted at multiple occupations of the same mark (data not shown), which have yet to be investigated (refer to section 2.2.3).

2.2.2 APREF SINEX

In the near future, the CORS constraints will be replaced by a weekly solution of CORS coordinates from the Asia-Pacific Reference Frame (APREF), which is a densely defined and accurate geodetic framework in the region, based on continuous GNSS data (GA, 2014d). The change to an APREF constraint is supported because the final national adjustment for GDA201x will employ APREF solution(s) as the sole constraint and will be free from external constraints. Additionally, the APREF solution is provided as a weekly solution in SINEX form (IERS, 2014). Thus, APREF provides not just coordinate values, but also the geometric relationship between the CORS and any changes that they experience over time due to the natural dynamic processes of the earth.

A sample APREF SINEX solution provided by Geoscience Australia, expressed in GDA94 coordinates, has been successfully tested as the sole constraint to the network (data not shown). However, the sample APREF solution contained only 93 of the CORSnet-NSW stations currently available, as shown in Figure 3. The entire CORSnet-NSW network is not included in this sample APREF solution as there is understandably some delay between construction of a CORS and its inclusion in the APREF solution, partly to ensure station quality and stability. It is anticipated that the remaining CORSnet-NSW network (totalling approximately 145 CORS) will be added to the APREF solution well before the national adjustment for GDA201x. At that time the APREF constraint will replace the CORS Regulation 13 coordinates as the sole constraint.

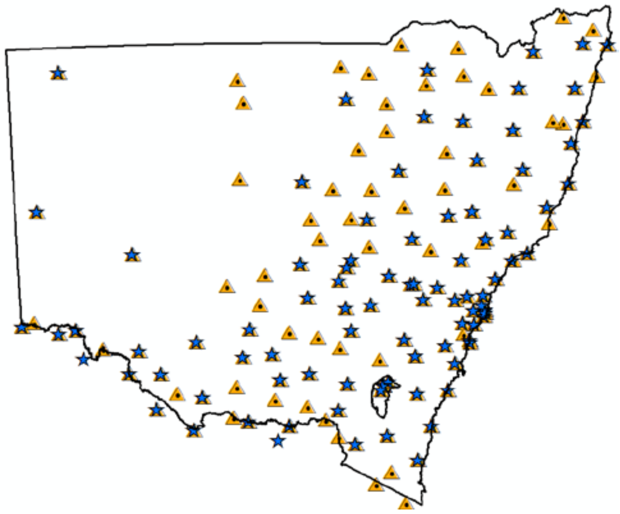

Figure 3: CORS stations from CORSnet-NSW (triangles) and from APREF SINEX sample (stars) in/near NSW.

2.2.3 AUSPOS SINEX and CORSnet-NSW Tie Surveys

AUSPOS observations of 4 hours or more (see Figure 4) have historically been submitted by each jurisdiction to a national GNSS archive and processed by the version of AUSPOS available at the time. When these measurements are included in the state-wide or national adjustment, they can serve to improve the Positional Uncertainty estimates of the observed stations (and adjacent stations connected by measurements) and/or highlight station movement.

At this time, however, some biases have been noted between multiple occupations of a small number of stations over the last decade (data not shown). The cause of these biases have not been definitively determined, but could be related to changes over the last decade in IGS satellite orbit modelling, updates to AUSPOS methodology, updates to ITRF or even station instability. For this reason AUSPOS coordinates are currently not used as constraints in this analysis. However, in preparation for datum modernisation, Geoscience Australia plans to re-process all such GNSS observations in a consistent version of AUSPOS to eliminate most sources of bias. All available CORS stations from APREF will be included in the solution, and results will be provided in SINEX format. In this way, AUSPOS measurements will provide not simply coordinate solutions as in the past, but rather a network of connections to the nearest CORS, strengthening GDA201x with connections from existing spine and sub-spine stations to the growing APREF framework.

Figure 4 indicates the location of the 1,200 AUSPOS solutions across NSW in the LPI archives, and also highlights the large number of new long-duration measurements gathered recently (250 during 2013 alone). This has resulted partly from an ongoing effort to carry out a maintenance program of NSW trigonometrical stations. Additional connections between CORS and the existing local control network are provided by the CORS tie surveys as described by Gowans and Grinter (2013). The current complement of tie surveys is shown in Figure 4b. At the time of publication, there are approximately 35 remaining tie surveys out of the eventual 145 CORS network. These will also be completed this year in preparation for the GDA201x adjustment.

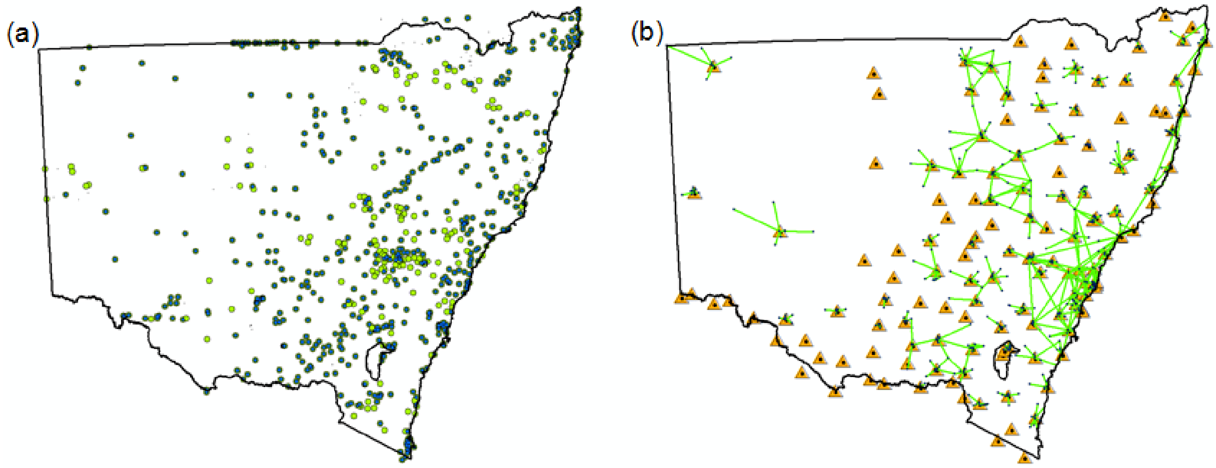

Figure 4: Connections between CORS constraints and local control: (a) location of AUSPOS (4-hour or more) solutions up to end of 2012 (blue circles) and end of 2013 (green circles), and (b) CORS tie survey GNSS connections (green lines) to local survey control points from CORS stations (triangles).

3 ADJUSTMENT AND ANALYSIS

As previously reported by Haasdyk and Watson (2013), the adjustment and analysis of the measurements in these archives is an ongoing task and employs a variety of visual and numerical analysis methods including analysis of miscloses, 'observed minus expected' differences, measurement residuals (raw and normalised) from least squares, coordinate corrections, and vertical and horizontal Positional Uncertainty to name a few.

3.1 Least Squares Adjustment

The majority of the analysis to date has focussed on the least squares solution obtained for the entire network of GNSS vectors, via DynaNet. Figures 5 and 6 show the results of the least squares adjustment as reported last year ('APAS2013 dataset') and on the current dataset ('APAS2014 dataset') respectively. Normalised residuals (NR) are computed as the adjusted measurement residual (or 'correction') divided by the adjusted measurement standard deviation. Assuming a normal distribution, 99.7% of NR values are expected to fall within ±3. Outliers are flagged as orange, magenta or red, for NR greater than 3, 5 or 10 respectively. A common rule of thumb is that NR values greater than 3 indicate *possible* gross errors requiring investigation, but do not prove that any measurement is in fact in error. This '3σ rule' is too strict for automated error detection, and can result in a loss of good measurements if strictly applied (Lehmann, 2013). In any case, the least squares adjustment method is known to spread errors into surrounding measurements, and therefore clusters of outliers are often seen in adjacent measurements, often due to the effect of a single gross error.

The improvement of the NSW dataset compared to that reported last year is demonstrated in Figures 5 and 6, and summarised in Table 2. In the APAS2013 dataset, even after significant cleaning of the dataset, almost 5% of the measurements were flagged with NR > 3, and more than 100 measurements suggested very large errors, with N stat > 10. Notwithstanding the addition of 14,000 new baselines since APAS2013, there are significantly fewer outstanding issues in the APAS2014 data: only 2.4% of the measurements have NR > 3 and none have NR > 10. Close observation of these figures will reveal some outliers from the APAS2013 dataset which have since been ignored (proven to be erroneous) or have been corrected and/or accepted (no longer flagged as an outlier).

Table 2: Numbers of measurements flagged as potential outliers.

	APAS2013 dataset	**APAS2014 dataset**
GNSS Baselines	62,100+	76,100+
Measurements NR > 3	3,131 (5.1 %)	1,102 (1.1 %)
Measurements NR > 5	720 (1.1 %)	252 (0.3 %)
Measurements NR > 10	102 (0.2 %)	NIL (0.0 %)

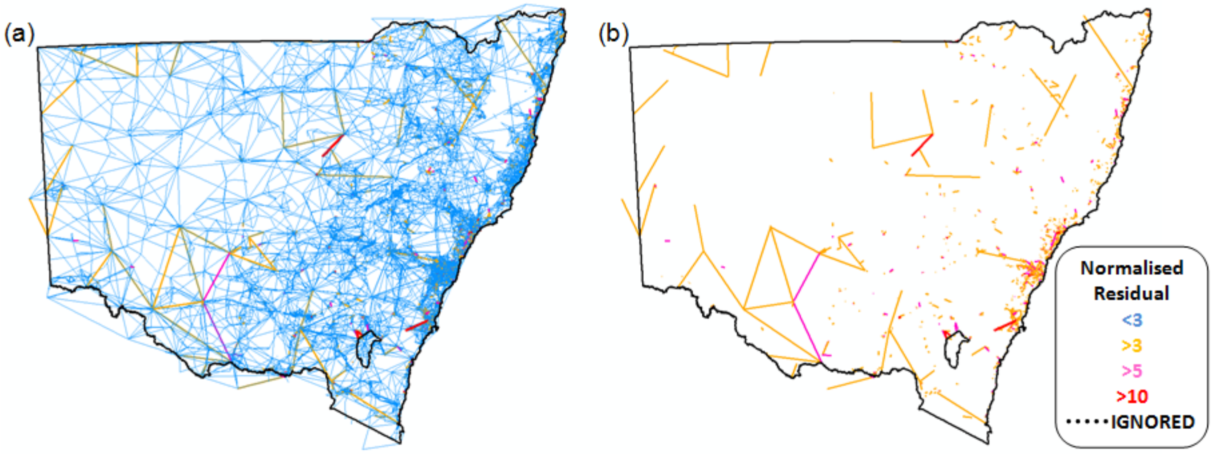

Figure 5: APAS 2013 dataset: (a) normalised residuals of least squares adjustment, and (b) as above but displaying only measurements with NR >3.

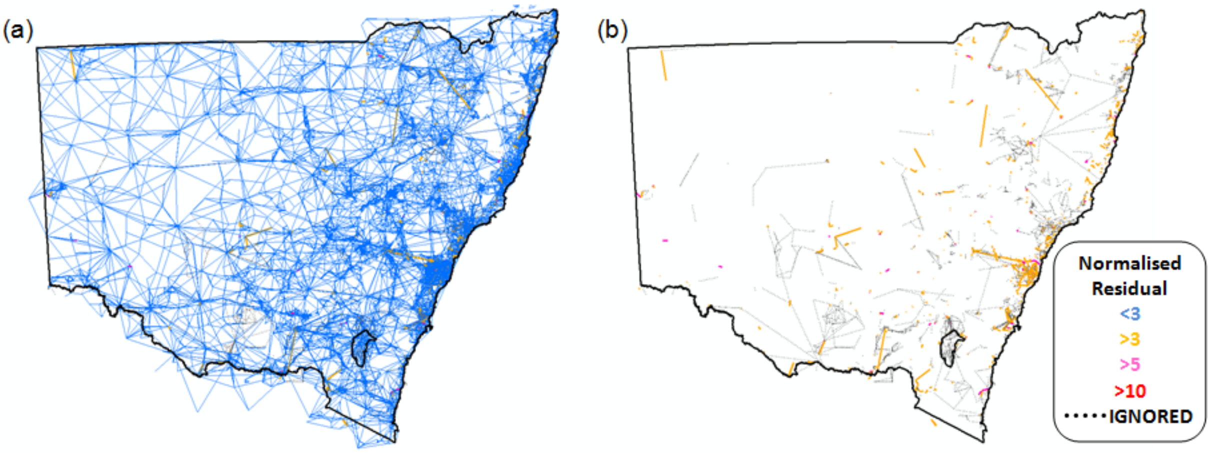

Figure 6: APAS 2014 dataset: (a) normalised residuals of least squares adjustment, and (b) as above, but displaying only measurements with NR >3.

3.2 L_1 Norm Method

Since the least squares adjustment method is known to hide measurement errors by spreading them into adjacent measurements, the detection and especially the *identification* of specific erroneous measurements can be quite difficult in such large datasets. An alternative method for analysis of the measurement data is via the L_1 norm method (hereafter simply L_1), which tends to highlight erroneous measurements (Branham, 1990; Harvey, 1993).

Unlike least squares (also known as the L_2 norm method), which minimises the sum of the *squares* of the measurement residuals, the L_1 norm minimises the sum of the *absolute values* of the residuals. In the L_1 method there is no significant penalty for assigning a large residual error (e.g. due to a large gross error) to a single measurement, whereas the *square* of the same residual represents an enormous penalty to the least squares method. As a result, least squares skews the adjustment (and all its measurements) to better fit any outlier, in a way that L_1 does not.

As a consequence of this simple difference between least squares and L_1, the objective of the adjustment changes from finding the 'best average fit' of all measurements (as in least squares), to finding the 'best candidate set' of measurements to compute the coordinates for all stations. Essentially L_1 does not *adjust* any measurements, but only selects enough measurements to solve the problem; this chosen set of measurements will have residuals equal to zero, and the remaining measurements have the smallest sum of the absolute value of their residuals. In this way, the L_1 solution disregards the remaining measurements for the purpose of computing the station coordinates. The residuals of the remaining measurements are, however, of use for examining the quality of the network and especially for the detection of gross outliers.

To visualise the difference between least squares and L_1, consider fitting a line of best fit to a set of points as in Figure 7. The least squares solution yields a line that passes through the 'centre of mass' of all points, while the L_1 solution chooses two points that represent the 'best' available solution and passes directly through them.

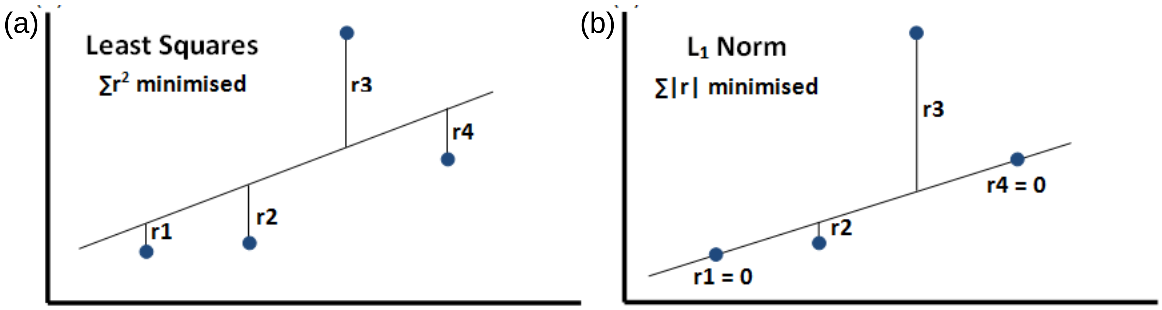

Figure 7: (a) Least squares vs. (b) L_1 norm method for fitting data points.

Figure 8 compares the least squares and L_1 solution at two locations within NSW. The least squares solution highlights a number of potential outliers in each region, while L_1 highlights a few specific observations as the most likely source of error. Indeed, analysis in these locations revealed small but significant gross errors in the L_1 outliers. The correction or removal of these offending measurements results in an acceptable least squares solution in the area.

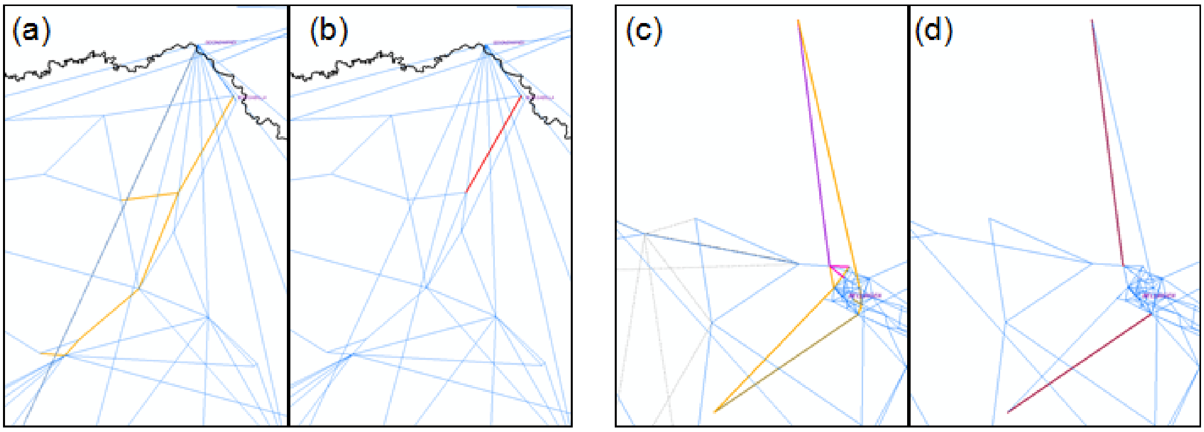

Figure 8: (a) Least squares adjustment and flagged outliers near Boggabilla and (b) L_1 of the same area.
(c) Least squares adjustment and flagged outliers near Bellingen and (d) L_1 of the same area.
Colour scheme as per Figure 5. Scale not shown.

L_1 is therefore usually considered to be a tool that is useful in addition to, but not as a replacement for, least squares. L_1 provides a very convenient tool for assessing the quality of measurements in the context of a large adjustment. In addition to detecting gross errors and station movement in the current dataset, L_1 will be useful for assessing the measurements that are currently being ignored in the least squares adjustment (i.e. those which were flagged during the initial campaign adjustments). In the future, L_1 could also be a useful assessment tool for the automatic initial vetting of new measurements from LPI or from third parties.

3.3 Positional Uncertainty

The recent adoption of the revised SP1 v2.0 standard by the Intergovernmental Committee on Surveying and Mapping (ICSM, 2014) means that it is now important to compute the Positional Uncertainty (PU) of each mark in the network. Even in the face of a small number of existing outliers, the simultaneous adjustment of the APAS2014 dataset can give a good estimation of the Positional Uncertainty of each station.

Figure 9 demonstrates that of the 24,000+ stations in the current NSW adjustment (which still represents only ~10% of the 250,000 stations in SCIMS) most have a computed horizontal PU (at 95% confidence) of better than 20 mm. The vertical results are similar, but with slightly higher uncertainties (approximately half the stations have a PU better than 20 mm, data not shown). As expected, stations in the western portion of NSW have higher PU (up to 200 mm) due to the relative scarcity of measurements. It should be noted that with the introduction of more CORS and more AUSPOS measurements, computed PU values will improve across the network. As an example, in Haasdyk and Watson (2013) the inclusion of available AUSPOS constraints reduced the horizontal PU in western NSW to approximately 100 mm.

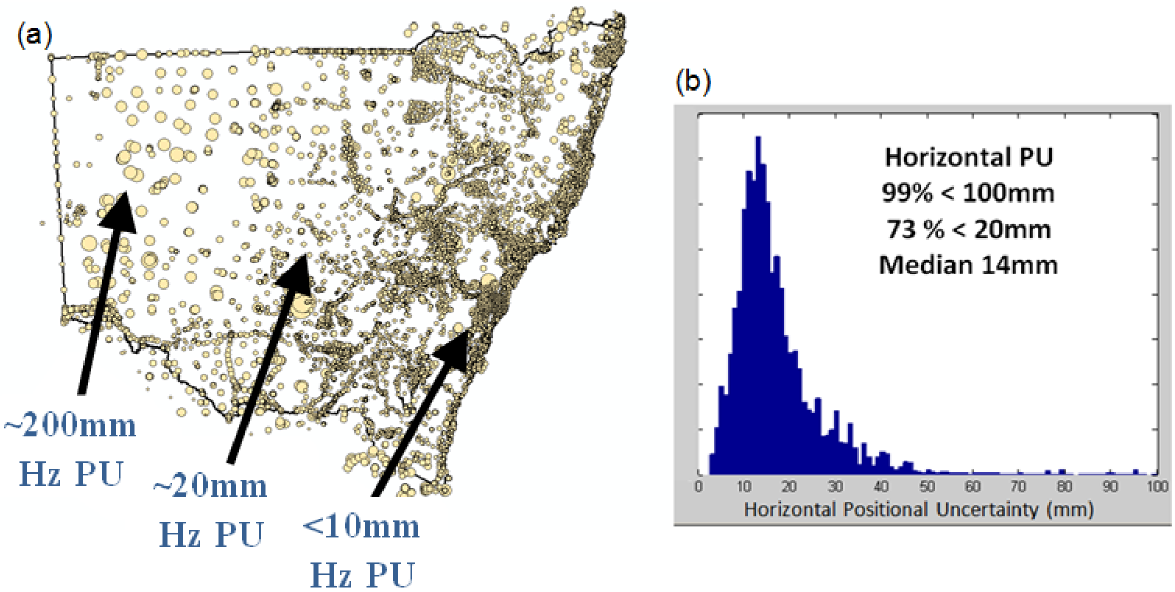

Figure 9: Horizontal PU after state-wide adjustment: ~200 mm in the Western Division, ~20 mm in central NSW and better than 10 mm along most of the NSW coast.

A number of GNSS islands still exist, which are not connected to the CORS constraints in any way. The 320 stations in these islands have very high PU values (metre-level, data not shown) by virtue of their lack of connection to the constraining stations. This state-wide analysis has enabled these islands to be identified and they are currently being connected into the existing contiguous control network, in preparation for the national adjustment.

3.4 Coordinate Differences

As a result of removing the distortions within and between jurisdictions, a transformation will be required to compare coordinates between GDA94 and GDA201x. Figure 10 shows the expected coordinate differences (after removing the systematic 1.5 m shift resulting from 20 years of tectonic motion) as computed by the simultaneous adjustment of the APAS2014 dataset, using CORS Regulation 13 constraints. It can be seen that the expected coordinate changes are systematic but not constant across NSW and would require a complex transformation such as the National Transformation (NTv2) grid method previously employed between AGD66/84 and GDA94 (ICSM, 2006).

Figure 10 shows that the majority of established marks in this adjustment (~20,300 of Class C or better) are expected to change by less than 40 mm. Any marks exhibiting significantly larger station movement (e.g. metre-level) will be investigated for gross errors in associated measurements. Again, it is salient that the stations in this adjustment represent less than 10% of the approximately 250,000 ground control marks in SCIMS (or 14.5% of the 140,000 established marks) and that additional measurements are needed to 'complete' the network.

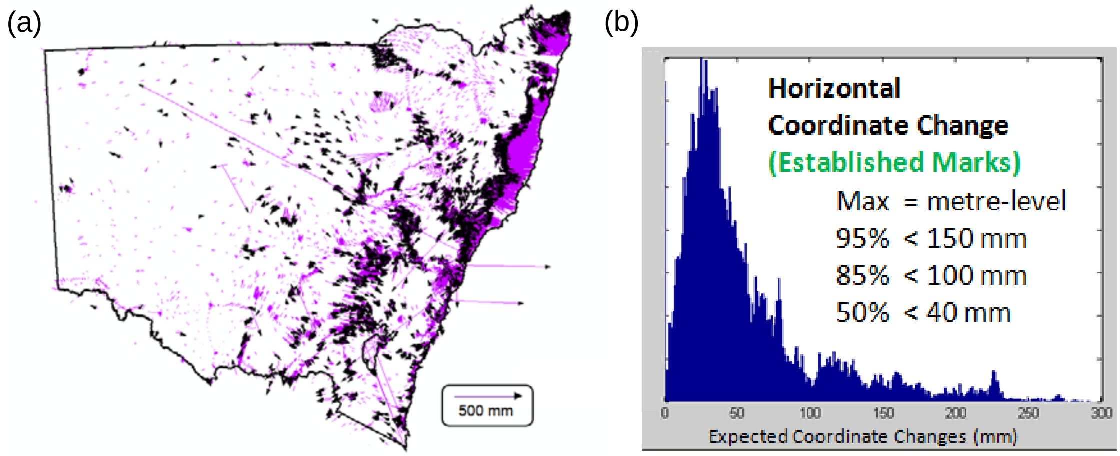

Figure 10: Horizontal PU after state-wide adjustment (~200 mm in the Western Division, 20 mm in central NSW and better than 10 mm along most of the NSW coast)

4 NATIONAL PROGRESS

4.1 Other Jurisdictional Data

In Australia, each state or territorial jurisdiction is the custodian for its own geodetic measurements and authoritative source for ground control coordinates. Consequently, since GDA94 was defined, each jurisdiction has gathered and adjusted its survey control measurements using different methods, with some jurisdictions holding fixed the geodetic control coordinates originally adopted, and others re-coordinating all control stations as new measurements become available.

Figure 11 shows some examples of similar efforts to collate and clean geodetic datasets in other jurisdictions. Victoria, for instance, will provide both contemporary GNSS and historical terrestrial measurements to the national adjustment, with a total number of measurements greater than 140,000. As with NSW, these have been gathered from an archive of measurements spanning several decades. In contrast, Tasmania has largely re-observed its entire 70-station fiducial GNSS network to provide a new framework for GDA201x. These differences highlight the different resources, tools, processes and methods being used to gather, store, adjust and analyse the data in each jurisdiction.

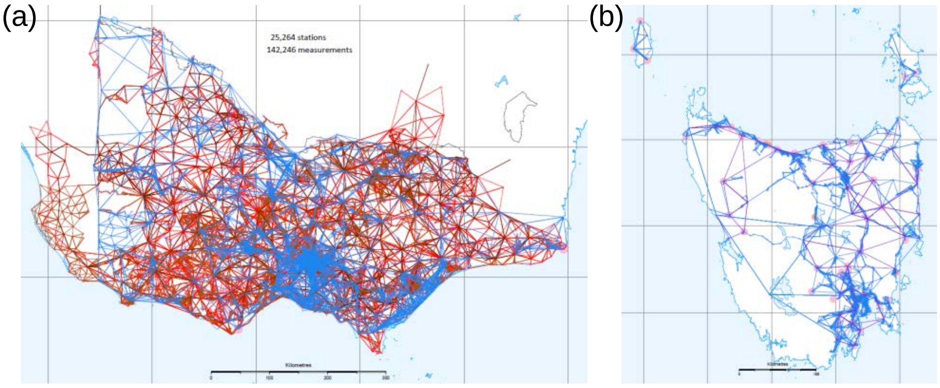

Figure 11: Datasets from (a) Victoria and (b) Tasmania. Scales vary. Colour schemes vary, e.g. Victoria data: blue = GNSS, red = terrestrial. Note that not all observations are displayed in the Tasmanian network, i.e. GNSS clusters are shown as points only.

APREF, currently with 268 CORS across Australia, will provide the geodetic framework against which all states and territories will contribute their GNSS and/or terrestrial datasets. The result will be a homogenous contiguous network, which provides coordinates at a density and quality determined by the measurements provided in each region. A universal format for the automated communication of these jurisdictional datasets and adjustment results, known as eGeodesy, is also currently under development (Donnelly et al., 2013).

4.2 National Computational Infrastructure (NCI)

Currently, the NSW dataset of approximately 70,000 measurements can be computed using DynaNet on a desktop computer in less than one hour. However, the proposed national adjustment will be carried out on a new Australian supercomputer known as 'Raijin', currently the 27th fastest computer in the world (NCI, 2014). Primarily intended for climate modelling, Raijin is available for other computationally-intensive activities of national interest.

Testing of hypothetical large national adjustments has already been undertaken in preparation for GDA201x, with a 400,000-station network comprising over 1.2 million GNSS measurements computed within approximately 50 hours. Further improvements to the efficiency of the software are planned, which have the potential to substantially reduce the duration and memory requirements of the adjustment.

4.3 User Forums

A first round of education and discussion forums has been convened by state, territory or national geodetic authorities across the country in the last two years. These forums aimed to introduce the issues and benefits of a next-generation datum to a diverse group of spatial data users, and to understand the perceived and real costs, benefits and opportunities associated with datum modernisation from the users who will be most affected by these changes.

The first forum, internally run at LPI in late 2012, highlighted the diverse groups (councils, engineering, mining, construction, research, etc.) currently utilising legacy datasets in

GDA94. The first open forum was held at the APAS2013 conference in March 2013 with predominantly surveyors (around 250) interested in centimetre-level positioning. The second, in April 2013 at the SSSC2013 conference in Canberra, was targeted at geospatial professionals and the audience included a diverse range of users. Since then, additional forums have been held in NSW, VIC, ACT, NT, TAS and webinars describing datum modernisation issues have been made available (Haasdyk and Donnelly, 2013).

The reader is directed to Haasdyk et al. (2014) for further discussion on the potential realisation(s) of a next-generation Australian datum. It is, however, reiterated here that the decision of spatial data holders to modernise their existing datasets should be dependent on readiness of their systems. For the future application of data it is important to improve metadata management, in particular information about when data was captured and the methodology and estimated precision of the data capture.

4.4 Geodetic Measurements By Third Parties

As we seek to re-observe and densify the geodetic data available for a national adjustment (and subsequent verification of station stability), the importance of third-party contributions is increasing. Outsourcing and even judicious crowd-sourcing of geodetic data collection are becoming increasingly frequent. For example, given a proper treatment of metadata (e.g. records and checks regarding equipment, antenna heights and time-stamp metadata), many GNSS measurements can contribute to the national GNSS archive for AUSPOS processing. In the future, Geoscience Australia intends to make such contributions easier by allowing contributions directly via the AUSPOS submission page, but until that time, your local survey control authority will have instructions on requirements for contributions (e.g. LPI, 2012).

5 NEXT STEPS

The previous status report by Haasdyk and Watson (2013) highlighted a number of 'next steps' required to complete the NSW dataset for GDA201x. Most of these, listed again in Table 3, have seen progress but are not yet complete. Some, such as in the inclusion of terrestrial measurements have been tested, but will likely require the development of additional methodology and tools. As LPI completes the installation of its CORS network in January 2014, preparation for GDA201x will become a major focus and additional resources will be devoted to completing the tasks outlined in Table 3.

Table 3: Additional labour at LPI in preparation for GDA201x.

Tasks for NSW Dataset	Progress
Include additional stations	✓
Mine new data as available	✓ Methods are in place
Identify remaining gross outliers	✓ Ongoing
Identify station movement	✓ Ongoing
Connection of GNSS islands	✓ Ongoing
Inclusion of APREF SINEX	✓ Method tested
Inclusion of AUSPOS SINEX	✗ Waiting for GA solution
Mine metadata for time stamp	✗
Inclusion of terrestrial measurements	✗ Initial testing only
Review measurement weighting	✗ Adopted as in archive

6 CONCLUDING REMARKS

The preparation of geodetic data in support of a next-generation Australian datum is an on-going task for all states and territories in Australia. This paper has described the progress made and the remaining tasks related to collating and cleaning the available geodetic data for a new simultaneous national adjustment. While particular focus is given to the improvements in the state-wide adjustment of a NSW-wide GNSS dataset, other state, territory and national efforts have also been discussed.

LPI has made significant improvements to the quality and analysis of the state-wide adjustment of available GNSS measurements for NSW in the past year. Significant numbers of new measurements and new stations have been included. New tools utilising the L_1 norm method have been developed and will assist with the detection of remaining outliers. LPI remains on track to submit a final cleaned and verified GNSS dataset for the initial GDA201x adjustments later in 2014.

An important product of this work is the development of a database of geodetic measurements, which will continue to assist future datum development and planning of geodetic observations. Eventually, the methods and analyses developed during the production of this GDA201x dataset will make it easier to automate (or semi-automate) the verification and inclusion of data from new campaigns and/or third parties.

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