Proceedings of the 22nd Association of Public Authority Surveyors Conference (APAS2017)
Shoal Bay, New South Wales, Australia, 20-22 March 2017

GDA2020 in NSW

Nicholas Gowans
Spatial Services
NSW Department of Finance, Services & Innovation
Nicholas.Gowans@finance.nsw.gov.au

ABSTRACT

The first public release of the Geocentric Datum of Australia 2020 (GDA2020) has been computed along with its associated products: AUSGeoid2020, transformation parameters, and distortion grid. For several years, NSW has been building and expanding CORSnet-NSW into Australia's largest operator-owned Global Navigation Satellite System (GNSS) Continuously Operating Reference Station (CORS) network, conducting targeted state-wide new GNSS observing campaigns, and collating decades of existing geodetic measurements to contribute to this new national survey adjustment. This paper provides a brief overview of GDA2020 while detailing NSW's efforts and contribution to date. The performance of GDA2020 across NSW is evaluated in terms of positional uncertainty, and using a series of GDA94-GDA2020 case studies.

KEYWORDS: *GDA94, GDA2020, APREF, datum modernisation.*

1 INTRODUCTION

The first public release of the Geocentric Datum of Australia 2020 (GDA2020) has been produced by Geoscience Australia, with contributions from all Australian states and territories as part of Stage 1 of the datum modernisation effort (ICSM, 2017a). GDA2020 is a new, plate-fixed datum, aligned to the International Terrestrial Reference Frame 2014 (ITRF2014 – see Altamimi et al., 2016) and modelled forward to a reference epoch of 2020.0.

GDA2020 provides significant improvements in datum realisation in NSW and will succeed GDA94 in Australia as the recognised value standard for position by 1 January 2020. GDA2020 is a contiguous survey adjustment constrained to state-of-the-art Global Navigation Satellite System (GNSS) Continuously Operating Reference Stations (CORS) from the Asia-Pacific Reference Frame (APREF – see GA, 2017a), and densified with a combination of geodetic-grade GNSS and terrestrial measurements. Of particular significance to NSW is that GDA2020 is a truly 3D adjustment and will allow the establishment of true ellipsoidal height across the State's survey control network. GDA2020 is the world's first continental-scale survey adjustment to rigorously propagate uncertainty.

For background information on the specifics of the national GDA2020 adjustment and its products, the reader is referred to Janssen (2017). This paper will focus on the NSW effort towards GDA2020 and provide a preliminary evaluation of its performance in NSW via a series of case studies.

2 GDA2020 IN NSW

On behalf of the Surveyor General, Spatial Services, a unit of the NSW Department of Finance, Services and Innovation (DFSI), has a legislative and regulative responsibility to establish and maintain the geodetic control network across New South Wales. As such, DFSI Spatial Services has been preparing for the GDA2020 survey adjustment for several years with efforts to source, harvest, clean and utilise legacy geodetic measurements (Haasdyk and Watson, 2013), build state-of-the-art GNSS CORS network infrastructure (CORSnet-NSW – see Janssen et al., 2016; DFSI Spatial Services, 2017), observe new high-quality GNSS measurements to connect the existing survey network to CORS (Gowans and Grinter, 2013), and systematically rationalise, maintain and upgrade key sites across the state's trigonometrical (trig) station and Australian Height Datum (AHD) levelling networks (Gowans et al., 2015).

2.1 GDA2020 Adjustment: NSW Contribution

The NSW contribution to GDA2020 currently (February 2017) consists of approximately 335,000 measurements across 31,000 stations. The type and quantity of measurements involved are listed in Table 1.

Table 1: Measurement types and quantities contributing to GDA2020 from NSW.

Measurement Type	Quantity	Present in NSW GDA94 Contribution
Geodetic azimuth	324	Yes
Directions	26,249	Yes
Ellipsoid arc	4,639	Yes
GNSS baseline component	287,511	8,742
Orthometric height	2,052	Yes
Level difference	416	Yes
GNSS baseline cluster component	15,129	nil
GNSS point cluster component	528	nil

These measurement totals are composed of a number of new and legacy survey campaigns, dating as far back as the Australian Geodetic Datum 1966 (AGD66) adjustment. Such campaigns include:

- NSW GDA94 Terrestrial Spine Network (originally in AGD66).
- NSW GDA94 GPS Spine Network.
- NSW Survey Operations GNSS adjustments.
- NSW CORSnet-NSW GNSS local tie surveys.
- Trig upgrade and maintenance campaigns.
- Saving AHD campaigns.
- Positioning Rural NSW campaigns.

Each GNSS measurement is time-stamped, allowing for, firstly, alignment to a common reference epoch to account for the tectonic movement of the Australian continental plate, and secondly, time-dependent deformation analysis to be carried out.

GDA2020 is designed to be a 'living' adjustment such that it can be readily recomputed and improved as new measurements are made available, or as blunders are detected and removed. There is a change in philosophy from storing the solution, or coordinates, to storing the measurements. It is the intent of DFSI Spatial Services to continue contributing new and additional legacy survey measurements (such as street-corner traversing networks) as they become available to GDA2020 in an effort to continue to produce the best possible survey network adjustment for NSW.

2.2 GDA2020 Adjustment: NSW Uncertainty Results

NSW's survey network quality is currently evaluated according to hierarchical systems of Class and Order based on the superseded SP1 v1.7 (ICSM, 2007; Dickson, 2012). The GDA2020 least squares network adjustment is computed with DynaNet using a phased-adjustment least squares methodology and provides rigorous uncertainty across the entire network (Fraser et al., 2014). This result affords DFSI Spatial Services with the capability to adopt SP1 v2.1 (ICSM, 2014), which requires survey network evaluation in terms of positional (composed of both horizontal and vertical components), relative, or survey uncertainties.

An initial analysis shows that of the approximately 31,000 NSW stations included in the adjustment, more than 80% achieve a horizontal uncertainty of better than 0.02 m (Table 2). This is represented visually in Figure 1.

Table 2:GDA2020 uncertainties in NSW's survey control network.

Positional Uncertainty (95% CI)	Horizontal %	Vertical %
< 0.02 m	81.7	65.2
< 0.05 m	94.6	89.7
> 1 m	1.2	6.2

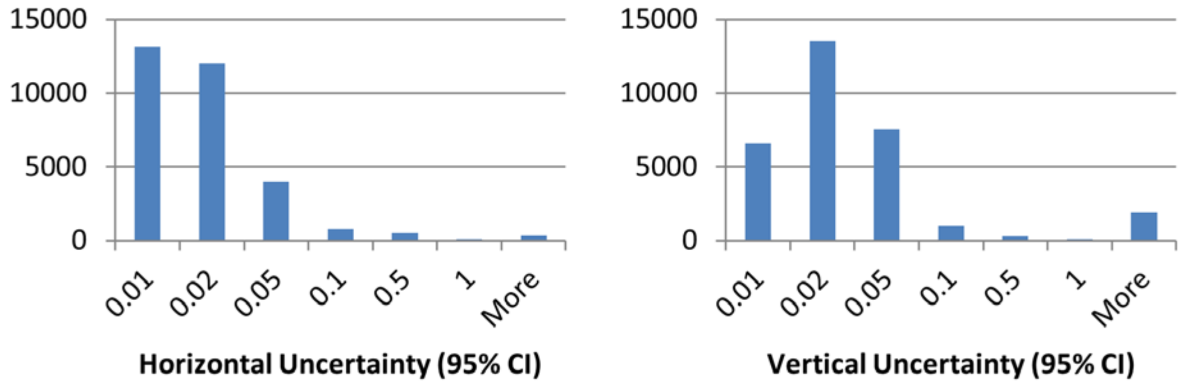

Figure 1: Horizontal and vertical uncertainty breakdowns.

The significance of this result for NSW cannot be overstated. For the first time, a state-wide survey network has been simultaneously adjusted to provide a homogeneous datum with uncertainty of better than 0.02 m at most stations. Users of the survey control network in traditional high-distortion areas of NSW will particularly benefit from the GDA2020 adjustment.

Those stations in the category greater than 1 m in horizontal uncertainty are usually part of GNSS 'island' networks, which have no connection to datum and are therefore assumed uncertainties in the order of 20 m. It is anticipated that these 'islands' will be gradually connected to datum by future targeted survey campaigns and as terrestrial adjustment data begins to be sourced, refined and contributed to the GDA2020 adjustment.

2.3 AUSGeoid2020

AUSGeoid2020 is the new national quasi-geoid for use with GDA2020. It delivers an improvement over AUSGeoid09, not only in terms of input data to the model, but in a world-first it provides uncertainty as a function of location (CRC-SI, 2017).

Like its predecessor AUSGeoid09 (Brown et al., 2011), AUSGeoid2020 is composed of both geometric and gravimetric components. The gravimetric component is based on a number of technologies and datasets such as modern earth gravity models, recent satellite-borne gravity missions, local airborne gravity datasets, and discrete absolute gravity measurements, and is therefore outside the scope of DFSI Spatial Services to contribute towards.

The geometric component of AUSGeoid2020 (the so-called 'sliver') basically fits the gravimetric quasi-geoid model to the Australian Height Datum (AHD – see Roelse et al., 1975), and it is to this component that DFSI Spatial Services has contributed over 2,500 points with co-located GNSS-AHD heights to the AUSGeoid2020 model, a remarkable improvement over the 100 co-located GNSS-AHD heights that informed AUSGeoid09 across NSW (Figure 2).

DFSI Spatial Services has made a unique and substantial investment into preservation and upgrade of its AHD survey infrastructure with its 'Saving AHD' campaigns. These measured points involve 6+ hour GNSS observations on stations which have AHD heights of class and order LCL3 or better in the Survey Control Information Management System (SCIMS – see Kinlyside, 2013). After the ellipsoidal height (h) is determined from the GNSS measurement, the geoid undulation (N) can be computed using:

$$N_{AHD} = h_{GDA2020} - H_{AHD} \tag{1}$$

The majority of these measured points were observed during the 'Saving AHD' campaigns (2015-16) across NSW. This unique NSW effort has been undertaken to provide a significant improvement to GNSS users' ability to deliver true local AHD. 'Saving AHD' has allowed DFSI Spatial Services to analyse and assess the accuracy of AHD71 and AUSGeoid2020 across the State, which in turn will provide for better informed decision making. At the time of writing, DFSI Spatial Services is currently evaluating the performance of AUSGeoid2020 across NSW.

It is imperative to note that AUSGeoid2020 is incompatible with GDA94 due to a change in the determination of the centre of mass of the Earth between ITRF92 and ITRF2014. Therefore any combined use of GDA94 and AUSGeoid2020, or GDA2020 and AUSGeoid09 will result in absolute heighting errors in the order of 0.1 m.

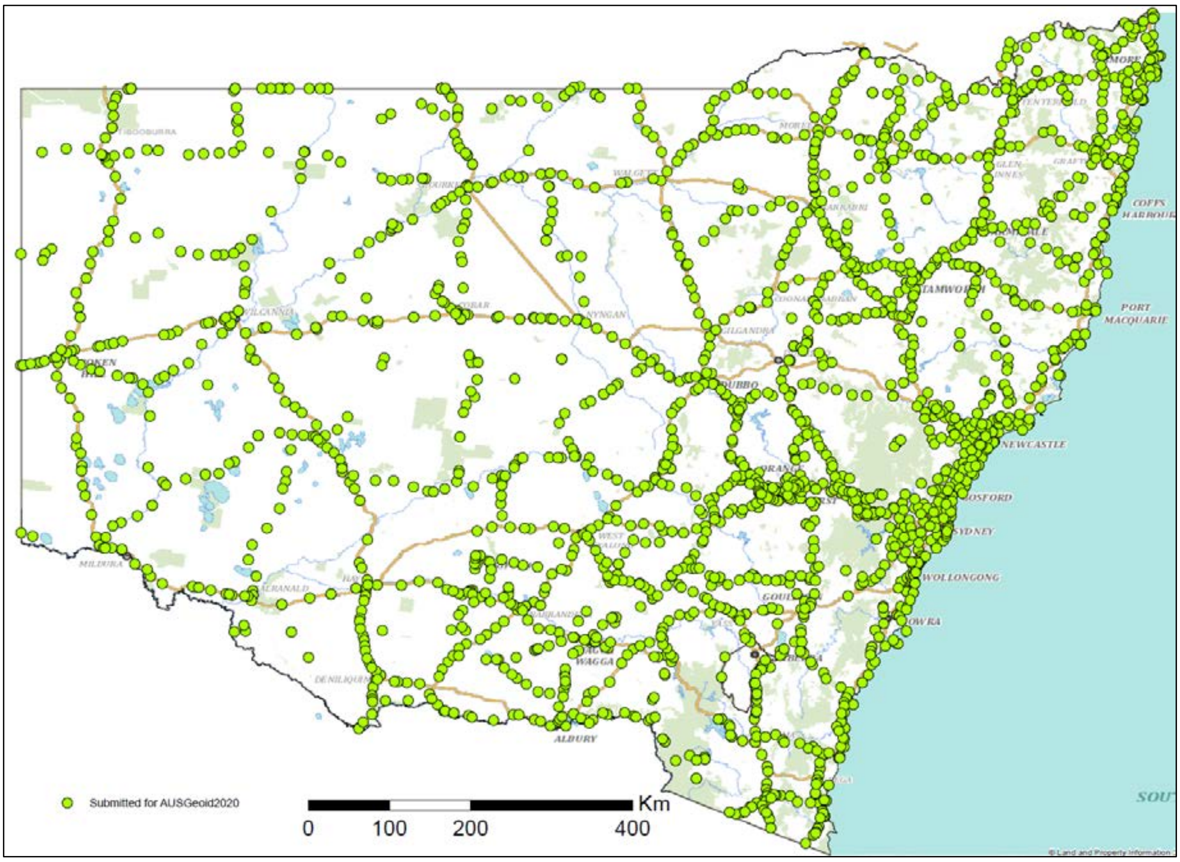

Figure 2: NSW measured points contributing to AUSGeoid2020 (as of February 2017).

2.4 GDA2020 Distortion Grid in NSW

An upcoming publication by Geoscience Australia staff will quantify the relationships between GDA94, GDA2020, and ITRF, which is required to align and meaningfully analyse spatial datasets that refer to separate reference frames. GDA94 and GDA2020 are both plate-fixed reference frames (ICSM, 2017b; Janssen, 2017) and therefore can be transformed between using a 7-parameter conformal transformation. ITRF, being a time-dependent, earth-fixed reference frame, requires known rates of change, and therefore necessitates a 14-parameter conformal transformation to relate to GDA94 or GDA2020.

It is important to note that these conformal transformations do not take into account any distortion present in the realisation of GDA94. In NSW, 2A0 Spine control has been intentionally fixed at its original realisation value (as at 1997), and this may result in errors of up to 0.3 m (e.g. Janssen and McElroy, 2010; Janssen et al., 2016).

Such stations, which may have been originally coordinated with lower-precision terrestrial measurements, were generally not updated as newer, higher-precision GNSS measurements became available. The widespread adoption of absolute GNSS positioning technologies, such as AUSPOS (GA, 2017b) or CORSnet-NSW (Janssen et al., 2016; DFSI Spatial Services, 2017), has meant that distortions are very easy to detect in areas of coarser network precision and decimetre-level differences can be found. These network distortions can complicate surveys crossing state borders, where other jurisdictions have updated coordinates as new measurements became available, as well as surveys for large infrastructure projects. For more information on dealing with GDA94 distortions in NSW, the reader is referred to Janssen and

McElroy (2010), who term the SCIMS realisation of GDA94 in NSW as GDA94(1997) and the absolute realisation offered by AUSPOS and CORSnet-NSW as GDA94(2010).

The national distortion grid will provide a transformation that accounts for such distortions. Approximately 26,000 common points between SCIMS and the GDA2020 adjustment were provided to inform the distortion grid across NSW. These points from SCIMS were selected on the basis that they are within NSW, are common between SCIMS and GDA2020, have an order of 4 or better; and produce a comparable distortion vector within the trend of the area. The distortion vectors are represented graphically in Figure 3.

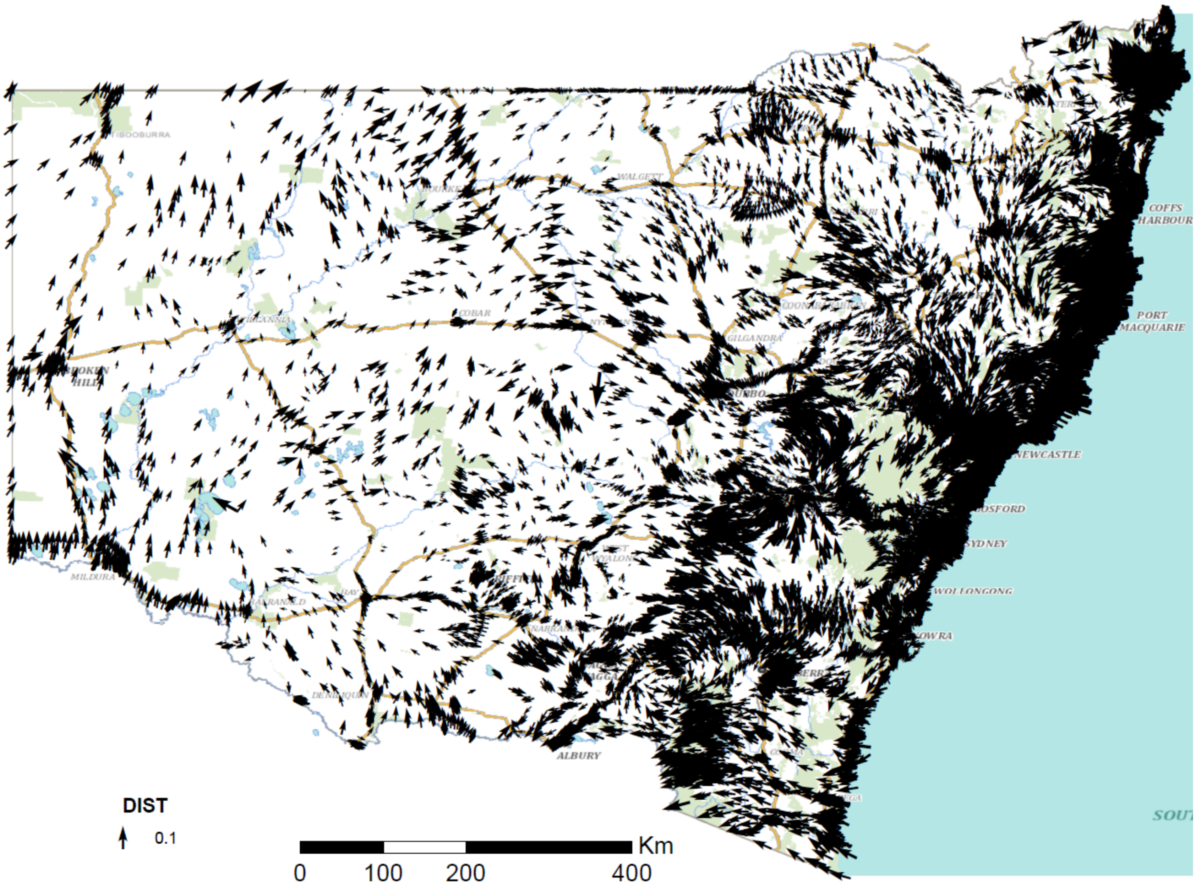

Figure 3: GDA94(1997) to GDA94(2010) distortion vectors across NSW.

3 CASE STUDIES

The case studies presented here provide an introduction into how the new Australian datum performs in NSW. For simplicity of comparison, the coordinate differences shown between original GDA94 and new GDA2020 adjustments have been corrected for the effects of tectonic motion between reference epochs, as if both datum epochs were aligned to a common reference epoch of 1 January 1994. This allows a valid comparison with current GDA94 Regulation 13 certification (GA, 2017c) to be made where appropriate.

3.1 Case Study 1: Gilgandra 2D Traverse Network

Gilgandra is a rural town in NSW's central west. The Gilgandra traverse network consists of 296 directions and 291 distances to 99 stations. In 2013, the terrestrial network was readjusted based on 13 control stations established in a new GNSS subspine network. The adjustment is displayed in Figure 4.

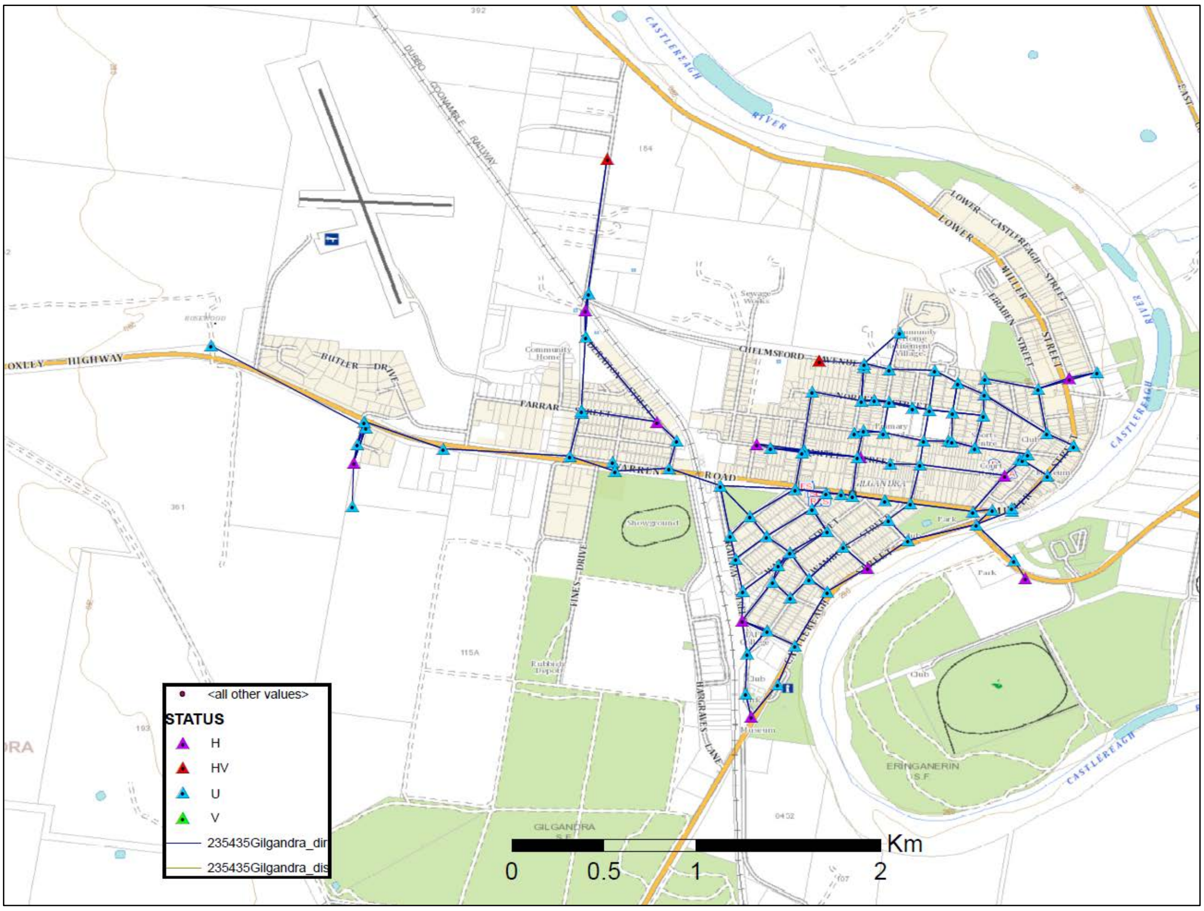

Figure 4: Gilgandra GDA94 traverse adjustment.

The current GDA94 adjustment fails the Chi-Square test on the variance factor, coming in low at 0.31, which indicates the observation standard deviations are generally more generous than their overall fit in the network. Additionally, no residuals are flagged, which indicates a clean survey network.

Re-running the adjustment in GDA2020 allows for two options. Firstly, the 'fixed' control coordinates can simply be updated from the result of the national adjustment, and secondly, the control can be constrained based on their station positional uncertainties as determined by the national adjustment.

Fixing the new GDA2020 control introduced two new additional control stations, for a total of 15 fixed. The adjustment still fails the Chi-Square test, with a variance factor of 0.47. No outliers are flagged, and residuals fall within their allowable tolerances. The average change to coordinates is seen to be [ΔE: +0.021 m; ΔN: -0.040 m], which is indicative of the level of distortion in GDA94(1997) in Gilgandra. Standard deviations are available on the output coordinates, but they have little relevance to their connection to datum.

Constraining the new GDA2020 control based on their uncertainties from the national adjustment results in a drop in the variance factor to 0.32. The increased number of observations, as station uncertainties, is the causative factor here. This average difference in coordinates to the GDA94 adjustment is nearly identical at [ΔE: +0.021 m; ΔN: -0.041 m]. However, the resultant station standard deviations are now influenced by the overall network's connection to datum, and thus their 2D uncertainties can be estimated in accordance with SP1 v2.1 (ICSM, 2014). In this instance, the average 2D uncertainty is 0.013 m at the 95% confidence interval.

Overall, this study demonstrates that GDA2020 still looks and feels like GDA94, but provides significant advantages in terms of datum homogeneity and provision of rigorous uncertainty with respect to datum.

3.2 Case Study 2: Nimbin GNSS CORS Tie Survey

Nimbin CORS is located within NSW's North Coast survey network, an area notorious for its significant distortion, caused by the coarser precision of older terrestrial measurements. The CORS tie survey network was designed to connect TS12213 Nimbin CORS into the NSW survey network for the GDA2020 adjustment (Figure 5). For the purpose of this analysis, a test GDA2020 network has been created with these measurements removed to preserve the rigour of the test.

The adjustment is composed of 15 stations and 27 GNSS baselines. A high level of tension is evident in the GDA94 fixed adjustment, whose variance factor (VF) fails the Chi-Square test at VF = 4.12, having 4 outliers flagged. Residuals of up to 0.18 m, or 10 ppm, are present. In this instance, the tension is entirely caused by the measurements having a finer precision than the control available. The minimally constrained adjustment shows no issue with the measurements at VF = 0.29. In part, the low variance factor is also due to low network redundancy. In this network, the low level of redundancy is not overly concerning as the measurements are validated with the constraint of control stations.

The GDA2020 3D fixed adjustment computes with a VF of 0.58 and no flagged outliers. Coordinates for TS12213 Nimbin CORS match the Regulation 13 certificate at the centimetre level at [ΔE: +0.010 m; ΔN: +0.008 m; ΔEHGT: -0.013 m]. This shows that GNSS CORS and the passive ground survey stations are now aligned to within GNSS measurement precisions. The average change to horizontal coordinates is seen to be [ΔE: -0.090 m; ΔN: +0.082 m] which is indicative of the level of distortion in GDA94(1997) around Nimbin.

The GDA2020 3D constrained adjustment fails the Chi-Square test with a VF of 0.52. No outliers are flagged. This average difference in coordinates to the GDA94 adjustment is nearly identical to the GDA2020 fixed adjustment at [ΔE: -0.091 m; ΔN: +0.082 m] and, as in the previous case study, positional uncertainty with respect to the datum can be rigorously propagated. In this survey, on average, 2D uncertainty is 0.009 m and 3D uncertainty is 0.019 m.

Traditionally, when dealing with a network of this nature, the user is forced to either float control or down-weight good measurements to fit poor control. This issue has been resolved on two fronts. Firstly, the national adjustment of all geodetic measurements provides a level of network precision never before seen in NSW, and secondly, even if this new level of precision is still insufficient for some applications, the station positional uncertainties provide a rigorous measure of absolute uncertainty with respect to datum.

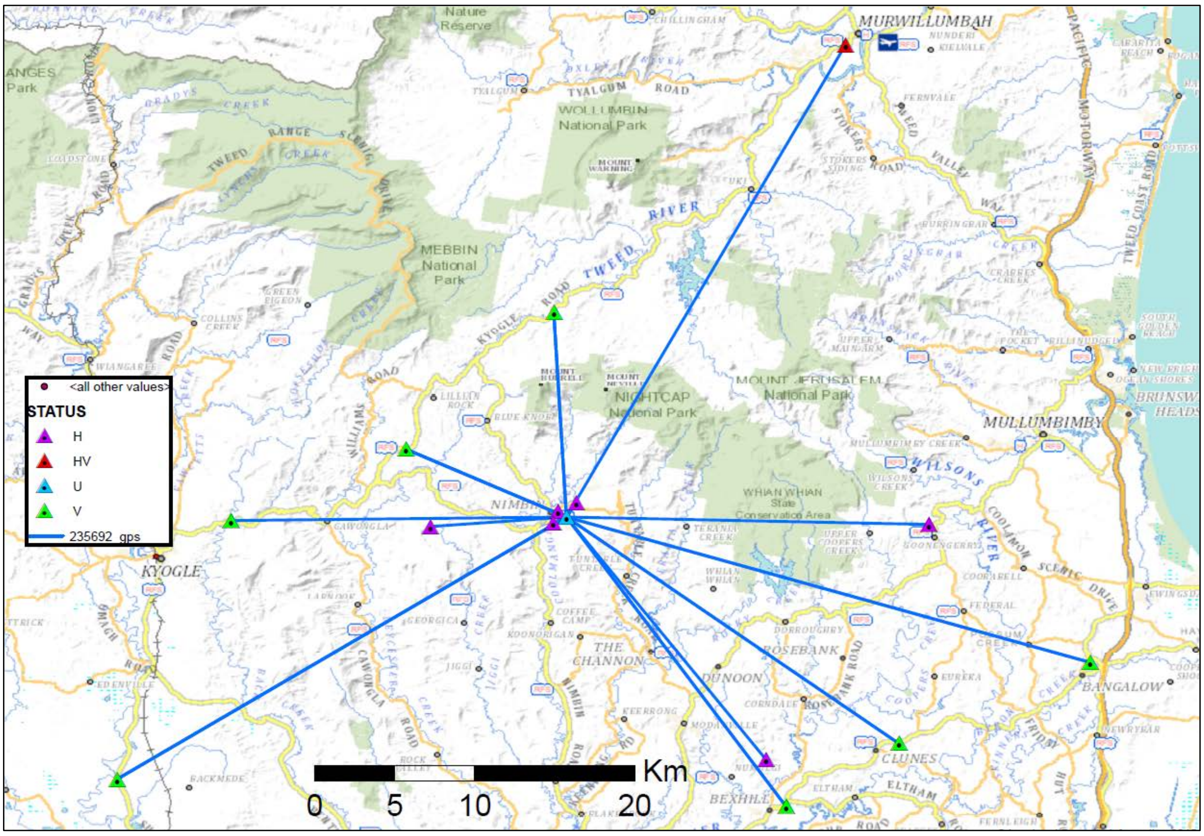

Figure 5: Nimbin CORS tie survey GNSS adjustment.

4 DISCUSSION

The GDA2020 adjustment provides a much needed rejuvenation to the NSW survey control network. The original GDA94 network was based on the coordinates of the Australian Fiducial Network (AFN) and Australian National Network (ANN) sites – 8 and 78 stations, respectively. Such a sparse control network compounded by a lack of GNSS measurements in key areas caused distortions in the order of 10 ppm or more. GDA2020 has been built upon approximately 450 CORS, several orders of magnitude better than was done for GDA94 originally.

GDA2020 is a modern CORS-based datum, densified by modern datum-focussed GNSS campaigns, GNSS CORS tie surveys, and 20 years' worth of GNSS Survey Operations networks. In effect, this rich, high-density control network provides an improved level of datum homogeneity right across NSW, as well as a seamless transition into bordering jurisdictions, which delivers an improvement of up to two orders of magnitude over GDA94.

Importantly, it is not only the numbers that have been improved. Key components of the datum modernisation campaigns have been the preservation and upgrade of survey infrastructure, including physical maintenance of permanent survey marks (including TS, PM and SS) and the update of metadata such as photographs and records (Gowans et al., 2015).

The 2020.0 epoch (i.e. 1 January 2020) aligns the National Geospatial Reference Frame to the International Terrestrial Reference Frame (ITRF) to within a few decimetres initially, and will improve until 2020, when Australia is expected to adopt an earth-fixed reference frame as part of Stage 2 of datum modernisation (ICSM, 2017a).

The provision of rigorous uncertainty across the entire GDA2020 adjustment will permit NSW to move towards the current SP1 v2.1 for evaluation of survey control networks, although this change will not likely be available through SCIMS until a successor to the current version is available (Kinlyside, 2013).

DFSI Spatial Services is currently evaluating the provisional AUSGeoid2020 and distortion grid products. Having supplied such rich datasets, there is every expectation that the new products will provide substantial improvements over their predecessors. The results of these evaluations will be published at a later date.

5 CONCLUDING REMARKS

GDA2020 provides a much needed refresher and rejuvenation to NSW's survey control network. A single 'living' 3D network adjustment now incorporates all available geodetic-grade measurements. GDA2020 delivers significant, real, measureable improvements to NSW's survey control network and thus to its users:

- Rigorous uncertainty can now be provided across the entire survey network, and to better than 2 cm horizontal uncertainty at most stations.
- An improvement in datum homogeneity of up to two orders of magnitude is delivered while eliminating previous cross-border issues.
- GNSS CORS and passive ground marks are now aligned to with GNSS measurement precision.

ACKNOWLEDGEMENTS

DFSI Spatial Services staff, both past and present, are acknowledged and thanked for their efforts which have contributed to this state-wide survey network.

REFERENCES

Altamimi Z., Rebischung P., Métivier L. and Collilieux X. (2016) ITRF2014: A new release of the International Terrestrial Reference Frame modelling nonlinear station motions, *Journal of Geophysical Research: Solid Earth*, 121, 6109–6131.

Brown N.J., Featherstone W.E., Hu G. and Johnston G.M. (2011) AUSGeoid09: A more direct and more accurate model for converting ellipsoidal heights to AHD heights, *Journal of Spatial Science*, 56(1), 27-37.

CRC-SI (2017) 1.24 AUSGeoid2020, http://www.crcsi.com.au/research/1-positioning/1-24-ausgeoid2020/ (accessed Feb 2017)

DFSI Spatial Services (2017) CORSnet-NSW, http://www.corsnet.com.au/ (accessed Feb 2017).

Dickson G. (2012) Control surveys: Why things are the way they are and not the way you think they should be!, *Proceedings of Association of Public Authority Surveyors Conference (APAS2012)*, Wollongong, Australia, 19-21 March, 12-28.

Fraser R., Leahy F. and Collier P. (2014) DynaNet 3.1 user's guide.

GA (2017a) Asia-Pacific Reference Frame (APREF), http://www.ga.gov.au/scientific-topics/positioning-navigation/geodesy/asia-pacific-reference-frame (accessed Feb 2017).

GA (2017b) AUSPOS – Online GPS processing service, http://www.ga.gov.au/scientific-topics/positioning-navigation/geodesy/auspos (accessed Feb 2017).

GA (2017c) Regulation 13 certificates, http://www.ga.gov.au/scientific-topics/positioning-navigation/geodesy/regulation-13-certificates (accessed Feb 2017).

Gowans N. and Grinter T. (2013) Tying it all together: CORSnet-NSW local tie surveys, *Proceedings of Association of Public Authority Surveyors Conference (APAS2013)*, Canberra, Australia, 12-14 March, 104-119.

Gowans N., McElroy S. and Janssen V. (2015) Survey infrastructure preservation and upgrade: Trigonometrical stations in NSW, *Proceedings of Association of Public Authority Surveyors Conference (APAS2015)*, Coffs Harbour, Australia, 16-18 March, 67-84.

Haasdyk J. and Watson T. (2013) Data-mining in NSW: Towards a new and improved Australian datum, *Proceedings of Association of Public Authority Surveyors Conference (APAS2012)*, Canberra, Australia, 12-14 March, 85-102.

ICSM (2007) Standards and practices for control surveys (SP1), version 1.7, http://www.icsm.gov.au/publications/sp1/sp1v1-7.pdf (accessed Feb 2017).

ICSM (2014) Standard for the Australian survey control network (SP1), version 2.1, http://www.icsm.gov.au/publications/ (accessed Feb 2017).

ICSM (2017a) GDA modernisation, http://www.icsm.gov.au/gda2020/change.html (accessed Feb 2017).

ICSM (2017b) Frequently asked questions on Australia's datum modernisation, http://www.icsm.gov.au/gda2020/faqs-2.html (accessed Feb 2017).

Janssen V. (2017) GDA2020, AUSGeoid2020 and ATRF: An introduction, *Proceedings of Association of Public Authority Surveyors Conference (APAS2017)*, Shoal Bay, Australia, 20-22 March, 3-20.

Janssen V., Haasdyk J. and McElroy S. (2016) CORSnet-NSW: A success story, *Proceedings of Association of Public Authority Surveyors Conference (APAS2016)*, Leura, Australia, 4-6 April, 10-28.

Janssen V. and McElroy (2010) Coordinates and CORSnet-NSW: Dealing with distortions in GDA94, *Position*, 50, 24-27.

Kinlyside D. (2013) SCIMS3: The next generation Survey Control Information Management System, *Proceedings of Association of Public Authority Surveyors Conference (APAS2013)*, Canberra, Australia, 12-14 March, 174-186.

Roelse A., Granger H.W. and Graham J.W. (1975) The adjustment of the Australian levelling survey 1970-1971, *Technical Report 12* (2nd edition), Division of National Mapping, Canberra, Australia, 109pp.