

Which GDA94-GDA2020 Transformation Grid Should NSW Surveyors Use: Where, When and Why?

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ABSTRACT

The Geocentric Datum of Australia 2020 (GDA2020) is now the official national datum of Australia, but how should surveyors bring their existing datasets from GDA94 to GDA2020? GDA94-GDA2020 transformation grids, which can be easily obtained online and used with existing software, are expected to be commonly used for this task. The Intergovernmental Committee on Surveying and Mapping (ICSM) recommends the transformation grids as a simple and nationally consistent method for transforming between Australian datums. Two grids have been produced to cater for different realisations of GDA94. With a focus on NSW, this paper explains the composition and purpose of each grid, and identifies accuracy and data origin as the two key factors determining their appropriate use. Performance analysis results indicate that both grids are fit for purpose in NSW when used in the appropriate circumstances. Prior to transformation, users must know if their existing GDA94 dataset is affected by known GDA94 distortions (present in the Survey Control Information Management System, SCIMS), or if those distortions have been removed by other methods.

KEYWORDS: Datum modernisation, GDA2020, transformation grids, best practice.

1 INTRODUCTION

In October 2017, the Geocentric Datum of Australia 2020 (GDA2020) was gazetted as Australia's new, improved national datum (Gowans, 2017; Janssen, 2017; NMI, 2017; ICSM, 2018a), succeeding the Geocentric Datum of Australia 1994 (GDA94). When spatial information users wish to adopt the new datum, they may consider transforming their legacy datasets from the now superseded GDA94 to GDA2020.

In recent years, spatial data utilisation has soared, aided by open-source Geographic Information Systems (GIS) and government efforts to deliver open spatial data (e.g. ANZLIC, 2018). As a consequence, the role datum plays in meaningfully aligning data is highlighted. Failure to correctly manage datum across multiple datasets could compromise any analysis. Further, decimetre-accurate or better real-time positioning (e.g. RTK, DGNS or SBAS-based positioning) now means stamping datasets with appropriate metadata, such as datum and even date observed, has become critical. The user must know their data and know their datum.

In Australia's previous datum modernisation efforts (e.g. AGD66-AGD84 and AGD66-GDA94), transformation grids were utilised as a simple and efficient method for transforming datasets to the new national standard. This strategy has been continued to aid uptake of GDA2020 from GDA94 with the development of two transformation grids and a number of tools, plug-ins and services.

This paper examines the GDA94-GDA2020 transformation grids, provides an explanation of their composition and an evaluation of their performance in NSW, and answers a series of ‘Frequently Asked Questions’ for new users.

2 TRANSFORMING FROM GDA94 TO GDA2020

2.1 The Hard Way: 7-Parameter Conformal Transformation

A conformal (often called a similarity) transformation can be used to transform between reference frames. This transformation owes its name to its characteristic of preserving shape throughout the process. The 3-dimensional conformal transformation between GDA94 and GDA2020 is described in the GDA2020 technical manual (ICSM, 2018a) and accounts for the difference in scale, rotation and translation between reference frames. This transformation method is suitable for 3D data and requires coordinates to be expressed in an earth-centred Cartesian system. The transformation can be computed using just 7 parameters as in (ICSM, 2018a):

$$\begin{matrix} X'_{GDA2020} & t_x \\ Y'_{GDA2020} & t_y + (1 + s_c) \\ Z'_{GDA2020} & t_z \end{matrix} \begin{pmatrix} 1 & r_z & -r_y \\ -r_z & 1 & r_x \\ r_y & -r_x & 1 \end{pmatrix} \begin{pmatrix} X_{GDA94} \\ Y_{GDA94} \\ Z_{GDA94} \end{pmatrix} \quad (1)$$

Such a formula can appear daunting to users without a background in geodesy. Furthermore, conformal transformations cannot compensate for localised survey network distortion because this method only accounts for the mathematical differences and plate motion between the frames.

2.2 The Easy Way: Grid Transformation

A grid transformation is a simpler 2-dimensional method of transforming between reference frames and is the Intergovernmental Committee on Surveying and Mapping’s (ICSM’s) preferred method of transforming between datums (ICSM, 2018a). Here, transformation components (i.e. a series of latitude and longitude shifts across all of Australia) are initially computed across a grid at a set interval. Given a transformation grid, various interpolation methods can then be applied to compute shifts at an exact user-determined location (Figure 1). Often bi-linear interpolation is adopted, but other interpolation strategies are possible. For a detailed explanation on grid interpolation, the reader is referred to Collier (2002). Grid transformation is considered ‘reversible’, i.e. each transformation can be undone by applying the grid parameters in the opposite direction. It is also ‘traceable’ and ‘reproducible’ by all users.

Previous investigation by Collier et al. (1997) concluded the simplest and most effective way to facilitate uptake of a new datum by a wide variety of users was to provide the transformation components, including known datum-to-datum distortions, on a grid. Grid transformation is a well-established methodology and provides a method that is rigorous, simple and reversible. Transformation grids were produced to aid users in the transition from the Australian Geodetic Datum (e.g. AGD66, AGD84) to GDA94. As such, the new GDA94-GDA2020 transformation grids are backwards compatible with any existing software that can accept a user-input grid.

Two GDA94-GDA2020 transformation grids have been developed: ‘Conformal only’ and ‘conformal and distortion’. These are discussed in section 3.

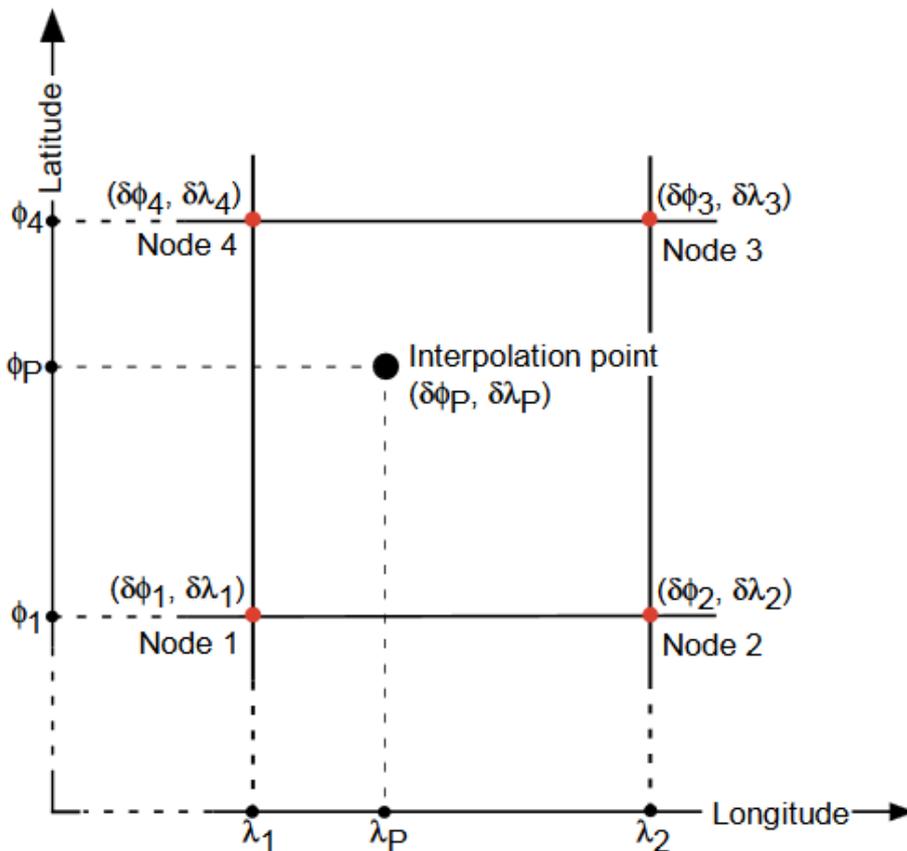


Figure 1: Grid interpolation principle from Collier (2002).

3 TRANSFORMATION GRID PRODUCTS

3.1 Transformation Grids

For some time, DFSI Spatial Services has been simultaneously providing two realisations of GDA94 for use in NSW (Janssen and McElroy, 2010). The first, based on the original GDA94 adjustment, termed GDA94(1997) in NSW, is available via the Survey Control Information Management System (SCIMS – see Kinlyside, 2013) and suffers from the adjustment deficiencies in the original GDA94 definition, and the subsequent accumulation of distortion in further adjustments. The second realisation, based on the most recent national realisation of GDA94, termed GDA94(2010) in NSW, is available via positioning technologies such as CORSnet-NSW (e.g. Janssen et al., 2016; DFSI Spatial Services, 2018a) and AUSPOS (GA, 2018), and is effectively distortion-free. For this reason, the NSW Surveyor General’s Directions recommend performing site localisations to align CORSnet-NSW-based surveys to SCIMS (Haasdyk and Janssen, 2012; DFSI Spatial Services, 2012, 2014).

Consequently, two transformation pathways from GDA94 to GDA2020 were required: one which assumes distortion-free input data, i.e. GDA94(2010), and one which compensates for the localised distortions embodied in SCIMS, i.e. GDA94(1997). Background information on coordinate reference systems, datums and transformations can be found in Janssen (2009),

The distortion component at each grid node has been computed based on the surrounding input data falling within a search radius of 45.5 km. If there are no input data points within this critical distance, the computation reverts to a conformal only solution and no distortion will be apparent.

3.1.3 Composition

Both national transformation grids are divided into five non-overlapping sub-grids (Figure 3, Table 1), each with a grid interval of 54 arc seconds (~1.5 km).

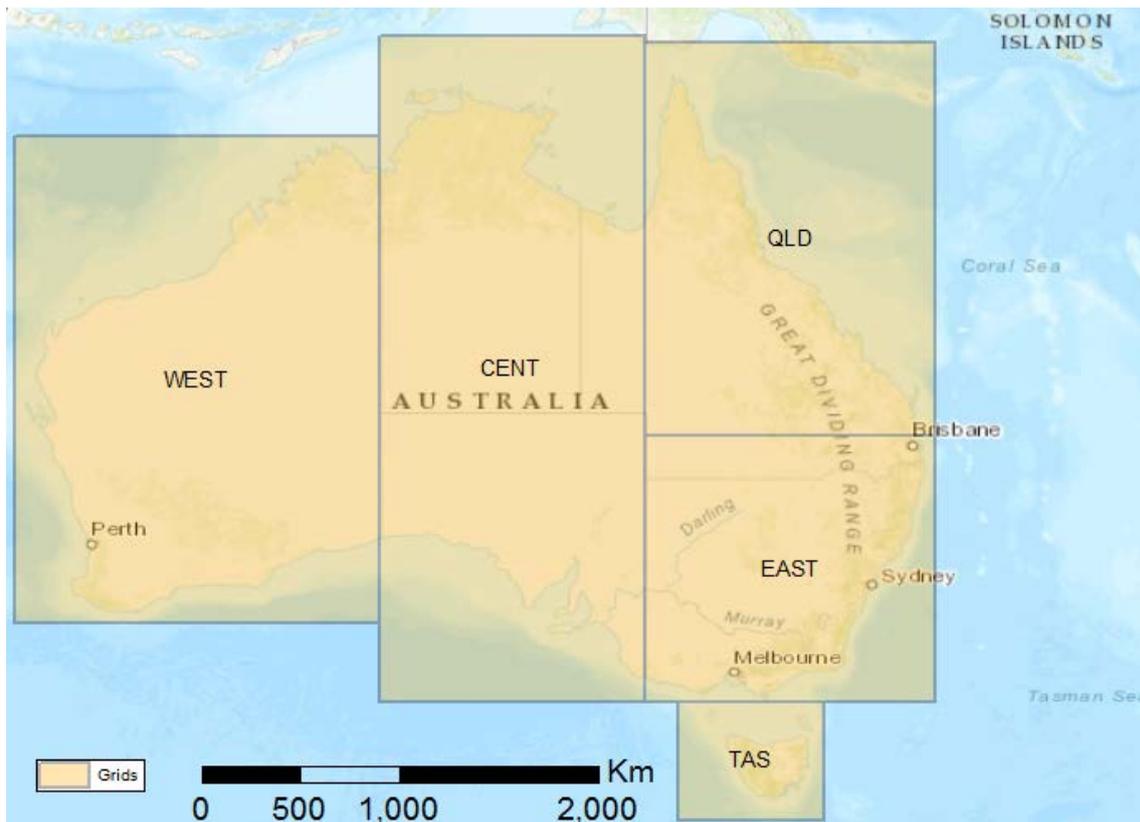


Figure 3: Transformation Grid composition and extents.

Table 1: Transformation grid composition and extents. Note that by NTV2 convention, longitude east of the prime meridian is negative.

Sub Grid Name	Southern Latitude (Decimal Degrees)	Northern Latitude (Decimal Degrees)	Eastern Longitude (Decimal Degrees)	Western Longitude (Decimal Degrees)
WEST	-35.55	-13.35	-128.90	-112.40
CENT	-39.15	-8.70	-140.90	-128.90
QLD	-27.00	-9.00	-154.10	-140.90
EAST	-39.15	-27.00	-154.10	-140.90
TAS	-44.55	-39.15	-149.00	-142.40

Currently, the transformation grids cover mainland Australia and Tasmania. Several offshore territories such as Lord Howe, Norfolk, Christmas and Cocos (Keeling) islands are not included in the provided transformation grids at this time.

3.1.4 NTV2 Format

The National Transformation version 2 (NTv2) format was developed by the Canadian Geodetic Survey of National Resources Canada for the North American Datum transition from NAD27 to NAD83. Since this time, NTV2 has been widely adopted for datum transformations by many international survey organisations and is supported in many GIS software packages. It provides a simple, efficient and comprehensive file structure for storing latitude and longitude shift parameters for each grid node (Figure 4). The file structure is kept relatively small because the coordinates of each grid node are not stored. Instead, the grid extents, grid interval and total number of grid nodes are given, linking the node shifts to their coordinates through a pattern specifying their order of occurrence. The NTV2 format is compatible with sub grids, which can be used to alter the overall coverage area or densify areas with high rates of change.

	SUB_NAME	EAST_DC5			
	PARENT	NONE			
	CREATED	17102017			
	UPDATED	21112017			
Sub grid header	S_LAT	-140940.0	Sub grid extents (arc-seconds)		
	N_LAT	-97200.0			
	E_LONG	-554760.0			
	W_LONG	-507240.0			
	LAT_INC	54.0	Grid interval (arc-seconds)		
	LONG_INC	54.0			
	GS_COUNT	714491	Total nodes in sub grid		
Sub grid Transformation components (left to right): Latitude shift, Longitude shift, Latitude reliability, Longitude reliability (arc-seconds)		0.047533	-0.022141	0.000471	0.000206
		0.047532	-0.022074	0.000473	0.000137
		0.047536	-0.022083	0.000045	0.000103
		0.047539	-0.022088	0.000046	0.000102
		0.047782	-0.022046	-1.000000	-1.000000
		0.047785	-0.022056	-1.000000	-1.000000
		0.047788	-0.022066	-1.000000	-1.000000
		...			

Figure 4: ASCII sample sub grid in NTV2 format. Note: reliability values of -1 denote that no reliability figure could be computed (conformal only solution).

In addition to latitude and longitude shifts, NTV2 provides space to report on the known or estimated accuracy of these shifts. In the GDA94-GDA2020 conformal and distortion transformation grid, this is a measure of the consistency (i.e. reliability) of the distortion surrounding the grid node rather than an absolute accuracy statement. Furthermore, reliability figures can only be computed where distortion is modelled, and hence grid nodes without any distortion influence exhibit a reliability figure of -1. It should be noted that the GDA94-GDA2020 transformation grids are supplied as binary grid shift (.gsb) files and are not human readable unless converted to text.

3.1.5 EAST Sub Grid (Conformal and Distortion) Behaviour

NSW users will be primarily concerned with the performance of the EAST sub grid, which covers the whole of NSW, ACT, Victoria, and some of Queensland and South Australia. The performance of the conformal only grid is uniform (see section 4.1) and does not require further review. The performance of the conformal and distortion transformation grid, however, varies with location. This variation is mapped in Figure 5 and provides a useful indication of the magnitude of distortion across NSW and Victoria.

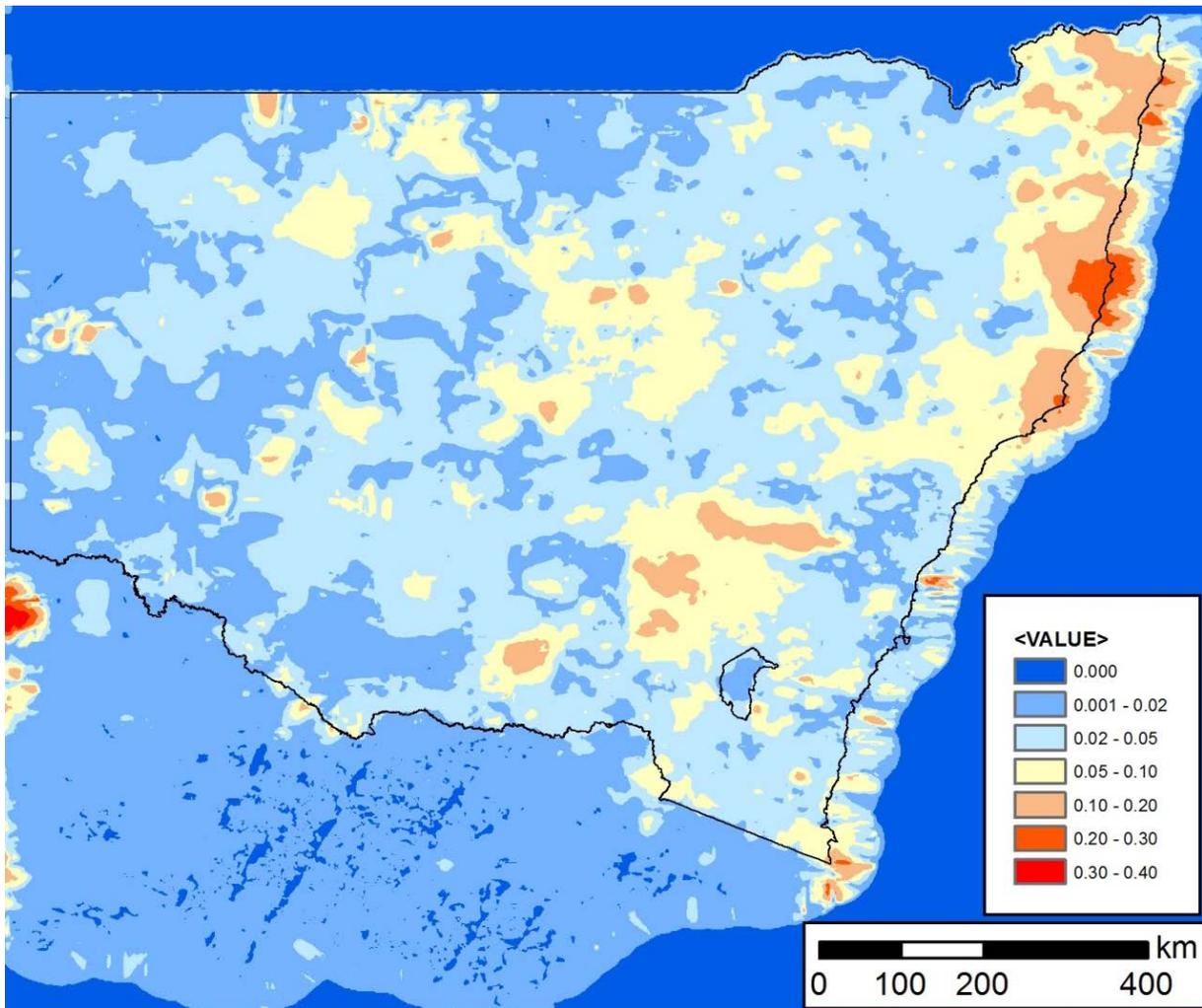


Figure 5: Distortion component across the EAST sub grid. Units are in metres.

Additionally, reliability figures have also been mapped (Figure 6), which indicate the consistency of distortion within each grid node computation.

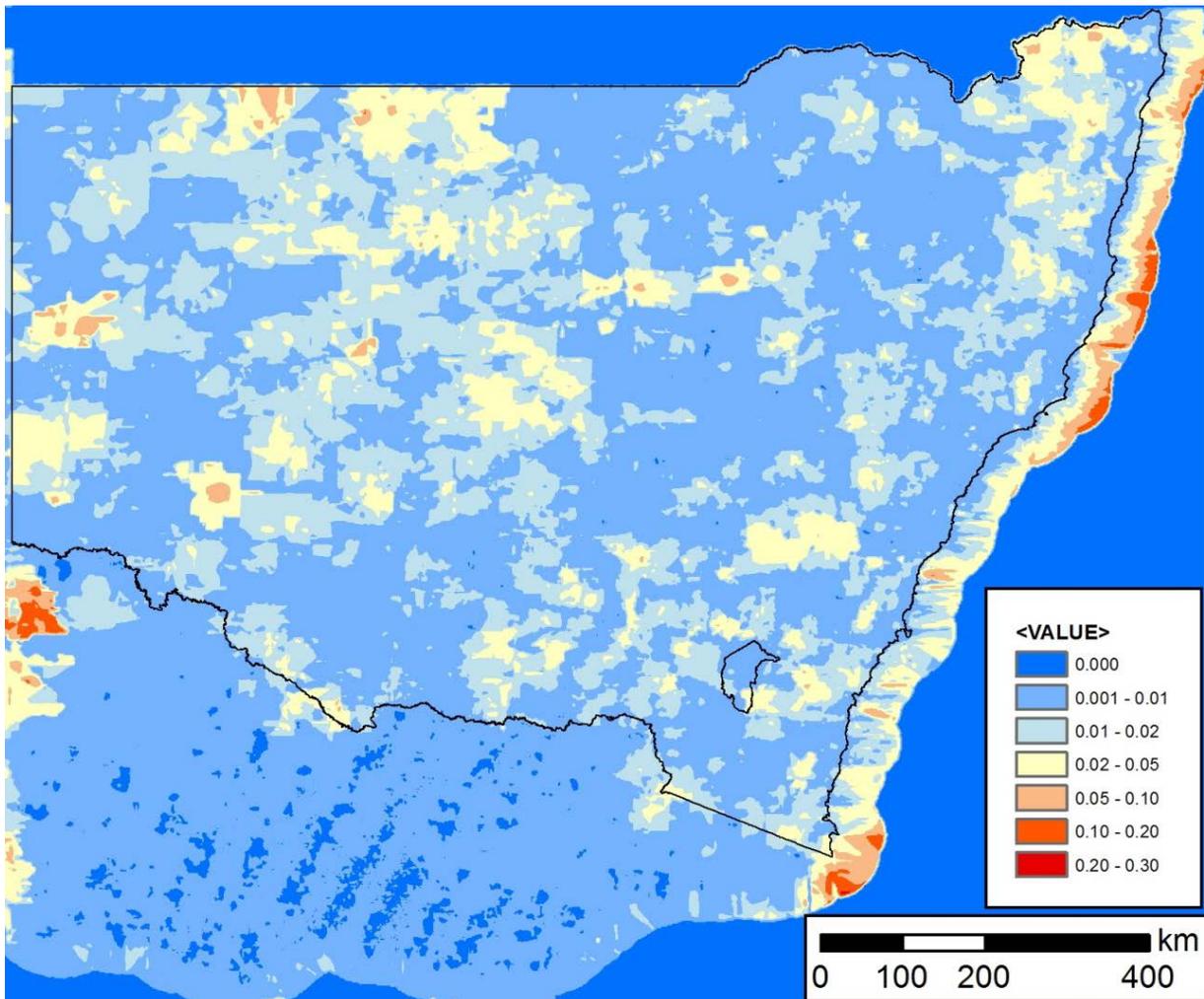


Figure 6: Reliability component across the EAST sub grid. Units are in metres.

3.2 How Can I Access/Apply the Grids?

A suite of transformation products and tools has been published online (ICSM, 2018b). Users are guided towards the grid (.gsb) files, an online transformation service which can be operated with simple ‘drag-and-drop’ functionality, as well as software and plug-ins.

3.3 Which Grid Should I Use?

The accuracy and the origin (i.e. provenance) of the dataset both need to be considered when applying a transformation grid from GDA94 to GDA2020. The difference between GDA94 and GDA2020 horizontal positions in NSW is about 1.5 m. Therefore, any dataset referenced to GDA94 with an accuracy of worse than a few metres is already GDA2020 compatible and does not require transformation.

In NSW, the largest known horizontal distortions are in the order of about 0.3 m (Haasdyk and Watson, 2013; Gowans, 2017). The conformal only transformation grid is sufficient for any GDA94 data with an accuracy of 0.5 metres (but either grid could be applied at these accuracy-levels). For data more accurate than 0.5 metres, the origin of the data must be considered. If the data is derived from local (SCIMS) survey control, then the conformal and distortion transformation grid is appropriate. If the data is derived directly in GDA94(2010), e.g. from CORSnet-NSW (without a site localisation) or from AUSPOS in GDA94(2010),

then distortions in local survey control are already eliminated and the conformal only transformation grid is appropriate. A decision-making flow chart is provided in Figure 7 to guide NSW users.

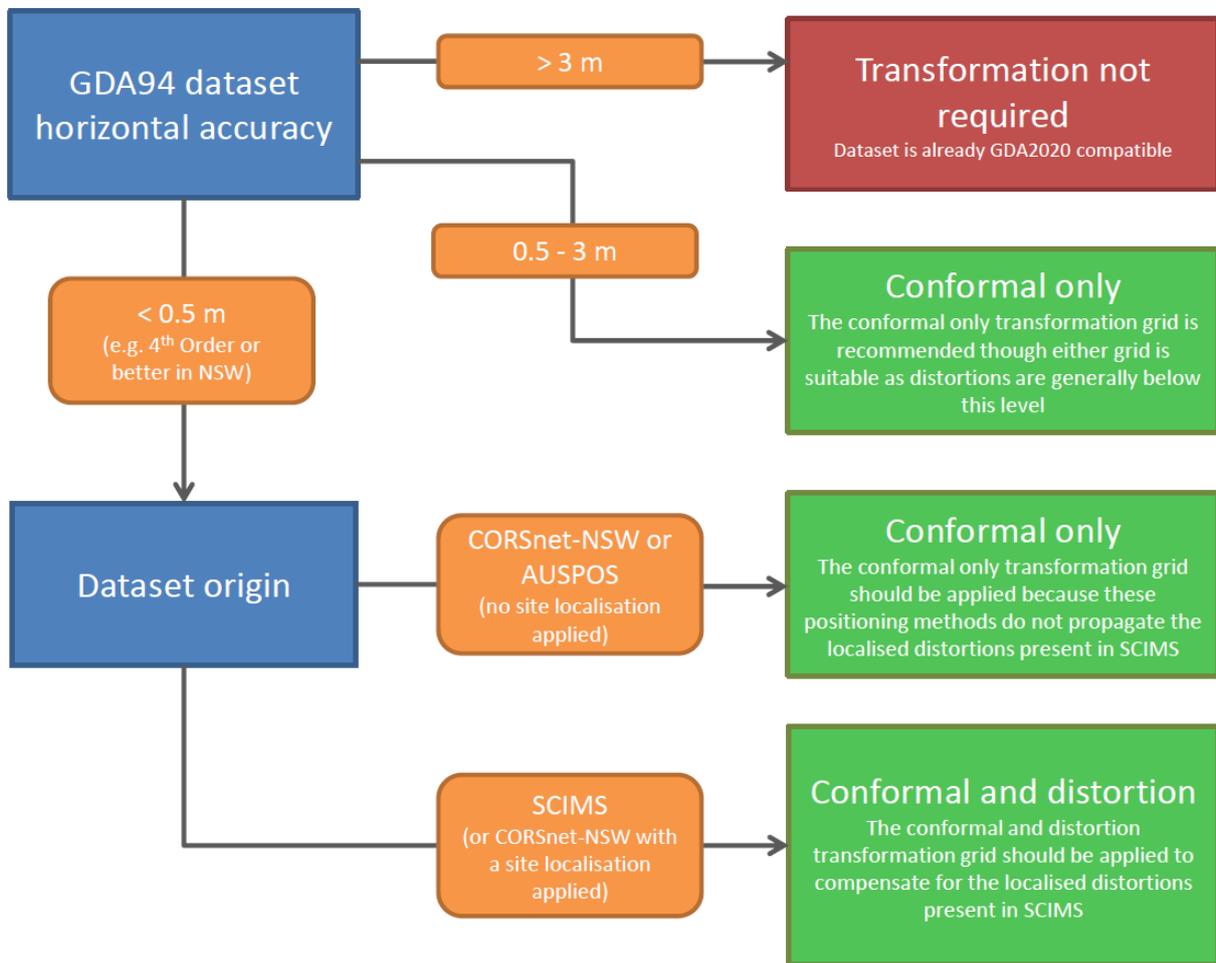


Figure 7: Decision-making flow chart for selecting a GDA94-GDA2020 transformation grid in NSW.

If the origin of a GDA94 dataset is unknown, then it is not possible to transform to GDA2020 and retain a nominal accuracy better than the known local distortions. For this reason, metadata is critical and has been affectionately described as a “love note to the future”.

Where the original survey measurements (with connections to GDA2020 stations) are available, a new least squares network adjustment based on GDA2020 control will provide the most accurate and rigorous solution. However, this can be far more time consuming and is not applicable to point-based datasets.

4 EVALUATION OF THE TRANSFORMATION GRIDS

4.1 Evaluation of the Conformal Only Transformation Grid

The conformal only transformation grid was evaluated by transforming the 250,000 marks across Australia comprising the GDA2020 national adjustment from GDA2020 to GDA94 using the 7-parameter conformal transformation (Equation 1) and then back to GDA2020 with

the conformal only transformation grid. The resulting coordinates were compared against the original GDA2020 coordinates.

The results from this test show that the conformal grid will introduce a negligible amount of computational error when compared to the 7-parameter conformal transformation. The descriptive statistics (Table 2) show a maximum difference in Easting and Northing of ± 0.001 m, with standard deviations of 0.0003 m.

Table 3: Descriptive statistics of conformal-only transformation assessment.

	Δ Easting (m)	Δ Northing (m)	Horizontal Distance (m)
Mean	0.0000	0.0000	0.0002
RMS	0.0003	0.0003	0.0004
Std Dev	0.0003	0.0003	0.0004
Minimum	-0.0010	-0.0010	0.0000
Maximum	0.0010	0.0010	0.0014

The conformal only transformation grid is considered fit for purpose for use in NSW and is far simpler to use than the alternative 7-parameter conformal transformation (Equation 1) method.

4.2 Evaluation of the Conformal and Distortion Transformation Grid

4.2.1 Test 1: Common Stations Between SCIMS and GDA2020

The conformal and distortion transformation grid was evaluated by transforming the coordinates of approximately 26,000 SCIMS marks from GDA94 to GDA2020, and comparing against the adjusted GDA2020 coordinates. The chosen marks were part of the GDA2020 national adjustment and required SCIMS coordinates with horizontal order 4 or better and GDA2020 coordinates with horizontal Positional Uncertainty (PU) of 0.1 m or better (1 sigma).

The descriptive statistics (Table 3) and histogram plot (Figure 8) quantify what is a very good result: 86.3%, 96.4% and 99.6% of SCIMS to GDA2020 transformed coordinates are within 0.01 m, 0.02 m and 0.05 m, respectively, of the expected GDA2020 adjusted coordinates with no notable differences between Easting and Northing components.

Differences of up to 0.27 m have been seen at a very small number of the marks analysed (i.e. $< 0.1\%$). However, these rare outliers occur where SCIMS behaves inconsistently, e.g. where a remote trigonometrical station was re-surveyed and its position improved, but its eccentric marks were not updated in SCIMS, altering the relationship between trigonometrical station and eccentric marks.

Table 3: Descriptive statistics of conformal and distortion transformation assessment (SCIMS to GDA2020 transformed vs. GDA2020 adjusted).

	Δ Easting (m)	Δ Northing (m)	Horizontal Distance (m)
Mean	0.000	0.000	0.006
RMS	0.007	0.006	0.010
Std Dev	0.007	0.006	0.008
Minimum	-0.229	-0.267	0.000
Maximum	0.120	0.139	0.271

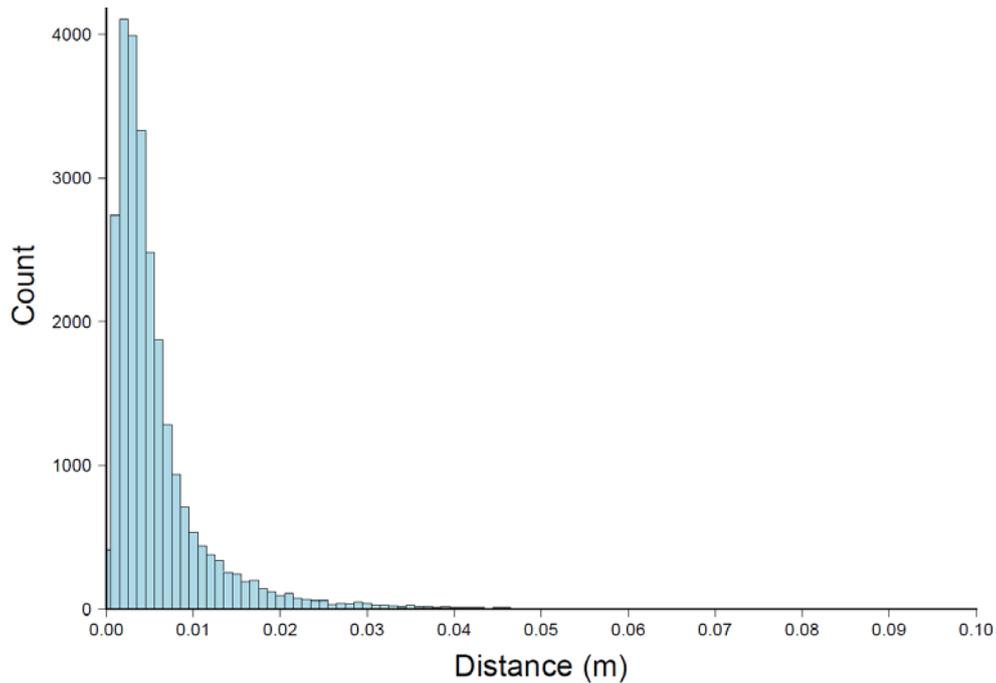


Figure 8: Differences in horizontal distance for SCIMS to GDA2020 transformed vs. GDA2020 adjusted.

4.2.2 Test 2: Independent Data

DFSI Spatial Services is currently preparing to enable GDA2020 in NSW. Some early proof-of-concept studies were carried out in an effort to assess the value in transforming versus readjusting our terrestrial ‘street corner’ traversing networks, which currently are not in the GDA2020 national adjustment. Survey networks in six NSW towns containing a total of 1,881 direction sets, 4,337 distances and 2,635 height differences at 2,759 stations were examined in this evaluation. Each network was readjusted based on constraints from the national GDA2020 adjustment. The results of the adjustments were compared with the results of transforming the SCIMS coordinates via the conformal and distortion transformation grid.

On average, the difference in horizontal position between the two methods was 0.006 m, with the largest being 0.04 m (Table 4). This analysis provides a high level of assurance that transforming SCIMS control will deliver a result close to the more rigorous (and far more time consuming) method of readjusting.

Table 4: Descriptive statistics of conformal and distortion transformation assessment (SCIMS to GDA2020 transformed vs. GDA2020 adjusted). Note that the values for Vincentia are higher compared to the other sites due to a previous transformation from AGD66 (i.e. SCIMS order U).

Site	RMS ΔE (m)	RMS ΔN (m)	RMS Distance (m)	Mean Distance (m)	Max Distance (m)
Blayney	0.005	0.005	0.007	0.004	0.040
Curlewis	0.004	0.002	0.005	0.004	0.027
East Hills	0.004	0.004	0.006	0.005	0.014
South West Rocks	0.003	0.003	0.004	0.003	0.019
Vincentia	0.012	0.008	0.014	0.011	0.037
Yamba	0.004	0.002	0.008	0.070	0.036

The conformal and distortion transformation grid is considered fit for purpose for use in NSW, and again is far simpler to use than the alternative 7-parameter conformal

transformation (Equation 1) method, which has the additional disadvantage that it cannot compensate for local distortions.

5 FREQUENTLY ASKED QUESTIONS

Why are there two grids?

Separate grids are required for the different realisations of GDA94 used in NSW: GDA94(1997), which is based on SCIMS and includes localised distortions of up to 0.3 m horizontally, and GDA94(2010), which is sympathetic with AUSPOS and CORSnet-NSW and is essentially distortion-free.

How do they differ?

The conformal only transformation grid is the 2D equivalent of the 7-parameter transformation. It accounts for mathematical differences between reference frames and does not compensate for any localised distortions in the state or territory realisations of GDA94. The conformal and distortion transformation grid is composed of the conformal component and a distortion component that will compensate for any known localised distortions in the state and territory realisations of GDA94.

What does conformal mean?

Shape is preserved throughout the transformation, i.e. the 7-parameter transformation accounts for the difference in scale, rotation and translation between each reference frame. The term 'similarity transformation' is often used to describe a conformal transformation.

Do any other jurisdictions besides NSW have distortions?

Yes, to varying extents. Both transformation grids cover all states and territories across mainland Australia and Tasmania.

What happens at the NSW-ACT/QLD/SA/VIC border?

Since the GDA94 adjustment, different jurisdictions have adopted different business rules for maintaining and propagating their survey networks. For example, NSW chose to preserve and hold fixed the original GDA94 adjustment (and its distortions) while Victoria and Queensland have readjusted their networks over time to remove distortions. The grid computation strategy is such that each node is influenced by contributing marks within 45.5 km, weighted according to proximity. This ensures the behaviour of the grid accurately represents the survey networks of each jurisdiction. There is one exception to this rule: Queensland, having periodically readjusted their survey network to remove distortion, opted for zero distortion to be present in *both* transformation grids across Queensland. In effect, this means distortions from NSW, SA and NT were only able to influence the 1st grid node into Queensland. After this point, the grid nodes revert to a conformal only solution.

Is there a difference between using the 7-parameter conformal transformation and the conformal only transformation grid?

There is no significant *horizontal* difference between the conformal only transformation grid and the 7-parameter transformation. However, it is important to note that the 7-parameter transformation provides a 3-dimensional transformation whereas the grid transformation is only 2-dimensional.

How should I transform 3D data?

3-dimensional data can be transformed using the transformation grids provided, but only the latitude and longitude components will be affected, i.e. height will be preserved (remains unchanged). If the height component is referenced to the Australian Height Datum (AHD), no height transformation should be undertaken between GDA94 and GDA2020 anyway.

The 7-parameter transformation can provide a true 3D transformation for data with ellipsoidal heights, but will not compensate for localised distortions. The GDA2020 technical manual (ICSM, 2018a) recommends users with ellipsoidal heights first convert their data to earth-centred Cartesian (XYZ) coordinates, apply the 7-parameter conformal transformation, and then convert back to geodetic or grid coordinates as required. ICSM (2018a) provides the formulae and a number of spreadsheets to perform these computations.

The ellipsoidal height difference from GDA94 to GDA2020 varies across NSW by approximately 0.01 m (i.e. just one centimetre!), from -0.10 m in the north-east to -0.09 m in the south-west (Figure 9). Consequently, it is possible to apply a simple ‘block shift’ of -0.095 m to transform ellipsoidal heights from GDA94 to GDA2020, but each user will need to assess if this approximation is suitable for their datasets and applications.

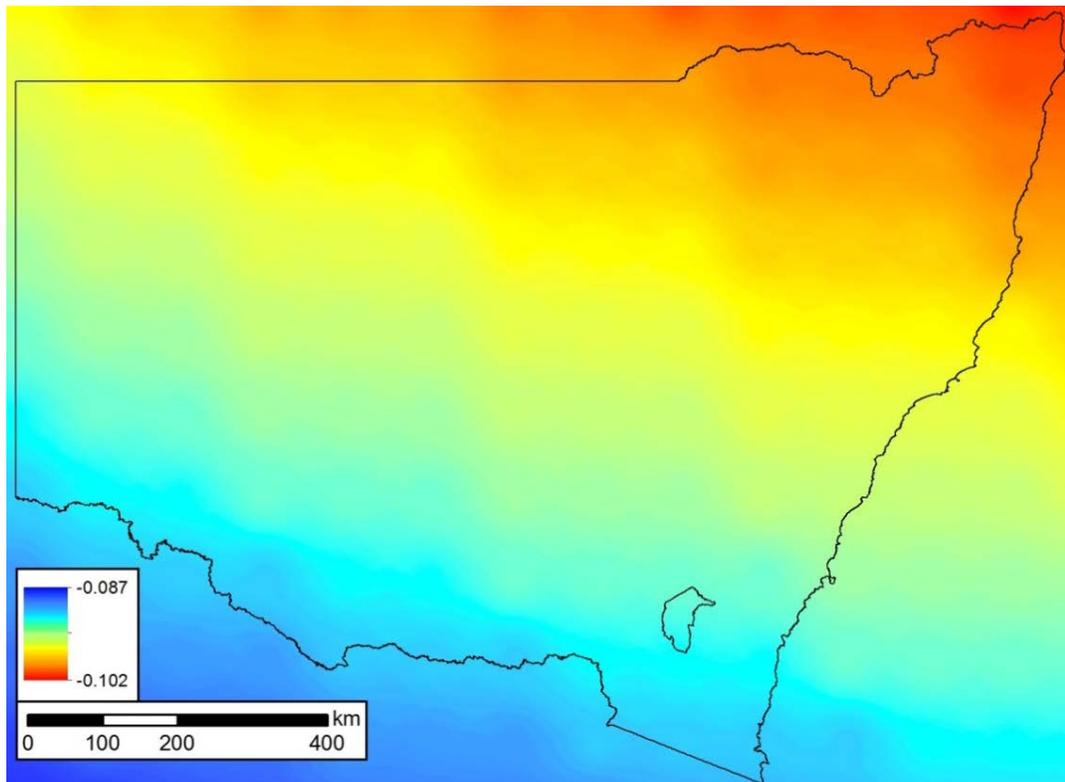


Figure 9: GDA94 to GDA2020 ellipsoidal height differences across NSW. Units are in metres.

Which transformation grid should I use if my GDA94 data is based on ... ?

As a general rule, data that is based on absolute positioning technologies such as CORSnet-NSW or AUSPOS should use the conformal only transformation grid, except when a site localisation has been applied to align it to SCIMS. Data that is based on SCIMS should apply the conformal and distortion transformation grid. Table 5 provides a decision-making guide in this regard.

Table 5: Decision-making guide for selecting a transformation grid based on the positioning technology used.

Positioning Technology	Conformal Only	Conformal and Distortion
SCIMS	✘	✔
AUSPOS	✔	✘
CORSnet-NSW (V)RINEX/(N)RTK (without a site localisation)	✔	✘
CORSnet-NSW (V)RINEX/(N)RTK (with a site localisation)	✘	✔

What do I do if I have a problem? This is all too hard, who can I talk to?

There are several communication avenues available. Fact sheets, videos, FAQs and even an online forum have been produced by ICSM (2018a, 2018b, 2018c). Alternatively, your local state or territory geodetic agency may provide assistance. DFSI Spatial Services publishes its technical papers online to assist the profession (DFSI Spatial Services, 2018b).

6 CONCLUDING REMARKS

Since October 2017, GDA2020 is Australia’s new, improved national datum. DFSI Spatial Services is currently preparing to enable GDA2020 in NSW. This paper has shown that the GDA94-GDA2020 transformation grids provide a fast, accurate and simple method for spatial professionals to transform their existing datasets from GDA94 to GDA2020. Two transformation grids have been developed to cater for the different realisations of GDA94 currently available to users. Accuracy and data origin have been identified as the two key factors determining their appropriate use.

Prior to transformation, users in NSW must know if their existing GDA94 dataset is affected by known GDA94 distortions (present in SCIMS) or if those distortions have been removed by other methods. Spatial professionals transforming datasets based on SCIMS should use the conformal and distortion transformation grid, while the conformal only transformation grid should be used for datasets based on CORSnet-NSW or AUSPOS services where a site localisation has not been applied.

Each transformation grid has been evaluated across NSW and found to be fit for purpose, with the conformal only transformation grid accurately representing the 7-parameter conformal transformation and the conformal and distortion transformation grid providing centimetre-accuracy in almost all cases. Spatial professionals are encouraged to properly understand the accuracy and lineage of their GDA94 datasets before selecting a transformation grid to transform to GDA2020.

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REFERENCES

- ANZLIC (2018) Foundation Spatial Data Framework, <http://fsdf.org.au/> (accessed Mar 2018).
- Collier P. (2002) Development of Australia's national GDA94 transformation grids, Consultant's Report to the Intergovernmental Committee on Surveying and Mapping, <http://www.icsm.gov.au/gda/natgrids.pdf> (accessed Mar 2018).
- Collier P.A., Argeseanu V.S. and Leahy F.J. (1997) Development of a GDA94 transformation process, Consultant's Report to Land Victoria.
- DFSI Spatial Services (2012) Surveyor General's Direction No. 12: Control surveys and SCIMS, http://spatialservices.finance.nsw.gov.au/surveying/publications/surveyor_generals_directi_ons (accessed Mar 2018).
- DFSI Spatial Services (2014) Surveyor General's Direction No. 9: GNSS for cadastral surveys, http://spatialservices.finance.nsw.gov.au/surveying/publications/surveyor_generals_directi_ons (accessed Mar 2018).
- DFSI Spatial Services (2018a) CORSnet-NSW, <http://www.corsnet.com.au/> (accessed Mar 2018).
- DFSI Spatial Services (2018b) GNSS publications, http://spatialservices.finance.nsw.gov.au/corsnet-nsw/gnss_publications/ (accessed Mar 2018).
- GA (2018) AUSPOS – Online GPS processing service, <http://www.ga.gov.au/scientific-topics/positioning-navigation/geodesy/auspos> (accessed Mar 2018).
- Gowans N. (2017) GDA2020 in NSW, *Proceedings of Association of Public Authority Surveyors Conference (APAS2017)*, Shoal Bay, Australia, 20-22 March, 21-31.
- Haasdyk J. and Janssen V. (2012) Site transformations: A block shift in thinking, *Proceedings of Association of Public Authority Surveyors Conference (APAS2012)*, Wollongong, Australia, 19-21 March, 29-47.
- Haasdyk J. and Watson T. (2013) Data Mining in NSW: Working towards a new and improved Australian datum, *Proceedings of Association of Public Authority Surveyors Conference (APAS2013)*, Canberra, Australia, 12-14 March, 85-102.
- ICSM (2018a) Geocentric Datum of Australia 2020 technical manual, version 1.1.1, <http://www.icsm.gov.au/gda/GDA2020TechnicalManualV1.1.1.pdf> (accessed Mar 2018).
- ICSM (2018b) Transformation products and tools, <http://www.icsm.gov.au/gda/tools.html> (accessed Mar 2018).
- ICSM (2018c) GDA2020 forum, <http://www.icsm.gov.au/gda/forum.html> (accessed Mar 2018).
- Janssen V. (2009) Understanding coordinate reference systems, datums and transformations, *International Journal of Geoinformatics*, 5(4), 41-53.
- Janssen V. (2017) GDA2020, AUSGeoid2020 & 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 S. (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.
- NMI (2017) National Measurement (Recognised-Value Standard of Measurement of Position) Determination 2017, <https://www.legislation.gov.au/Details/F2017L01352> (accessed Mar 2018).
- Wessel P., Smith W.H.F., Scharroo R., Luis J.F. and Wobbe F. (2013) Generic mapping tools: Improved version released, *EOS*, 94(45), 409-410.