AUSGeoid2020 improves AHD height determination in NSW

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The Geocentric Datum of Australia 2020 (GDA2020) was gazetted in October 2017 and is to replace GDA94 in practice by 2020. GDA2020 also requires a new quasigeoid model, AUSGeoid2020, to provide an improved connection between ellipsoidal heights derived from Global Navigation Satellite System (GNSS) observations and the Australian Height Datum (AHD). This article quantifies the improvement of using AUSGeoid2020 with GDA2020 ellipsoidal heights over using AUSGeoid09 with GDA94 ellipsoidal heights to access AHD.

Over the last three decades, NSW Spatial Services has evaluated and reported on the performance of each new AUSGeoid product within the bounds of mainland NSW. To enable the discerning reader to evaluate the significant improvements in AUSGeoid products (AUSGeoid98 to AUSGeoid09 – see *Position* 53, June 2011 – and now AUSGeoid2020), we have intentionally re-used the same test methodologies and re-visited the same datasets (with some improvements of course) to allow those improvements in AUSGeoid to be more visible.

Three tests were performed to investigate how well the two most recent quasigeoid models fit known AHD heights across NSW, based on (1) 138 CORSnet-NSW sites, (2) seven GNSS-based adjustments of varying extent and size, and (3) numerous height control points from these adjustments. The first test replicates what users of AUSPOS and CORSnet-NSW services can expect, while the other two tests replicate what can be expected when processing and adjusting baselines.

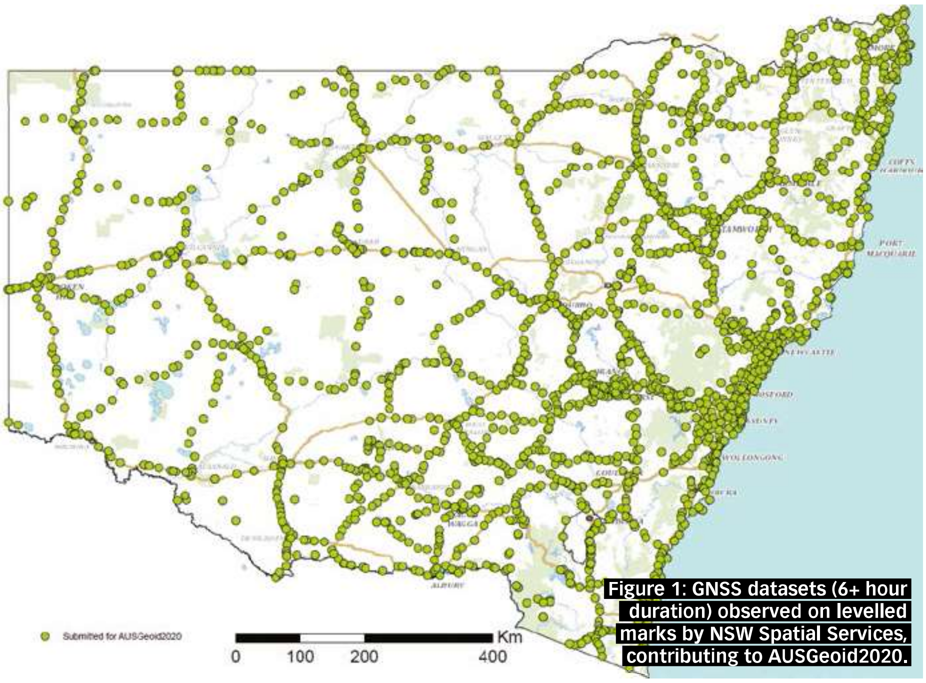

Figure 1: GNSS datasets (6+ hour duration) observed on levelled marks by NSW Spatial Services, contributing to AUSGeoid2020.

Background

In NSW, the move from GDA94 to GDA2020 causes the horizontal coordinates to shift by about 1.5m to the north-east, due to tectonic motion of the Australian plate from 1994 to 2020. The ellipsoidal height decreases by about 0.095m, due to improvements from the global ITRF92 to ITRF2014 reference frames to better define the shape and size of the Earth.

Vertical coordinates continue to be referenced to AHD. In order to connect to AHD via GDA2020 ellipsoidal heights, a new quasigeoid model (AUSGeoid2020) has been produced (see *Position* 98, December 2018).

Due to the difference in ellipsoidal heights between GDA94 and GDA2020, it is crucial for users to apply ***only*** AUSGeoid2020 to GDA2020 ellipsoidal heights, while its predecessor AUSGeoid09 ***must*** be used to convert GDA94 ellipsoidal heights. These quasigeoid models and datums ***cannot*** be mixed and matched.

AUSGeoid2020

Just like its predecessor AUSGeoid09, AUSGeoid2020 is a combined gravimetric-geometric quasigeoid.

The gravimetric component is a 1' by 1' grid (about 1.8 by 1.8km) of improved ellipsoid-quasigeoid separation values created using data from satellite gravity missions, re-tracked satellite altimetry, localised airborne gravity, land gravity data from the Australian national gravity database, and a Digital Elevation Model to apply terrain corrections. It is known as the Australian Gravimetric Quasigeoid 2017 (AGQG2017).

The geometric component is basically a 1' by 1' grid (about 1.8 by 1.8 km) of improved quasigeoid-AHD separation values, derived from a much larger dataset of collocated GNSS ellipsoidal heights and AHD heights across Australia. Its purpose is to account for the offset between the quasigeoid and AHD. Note that only a single grid, which combines these two components into ellipsoid-AHD separation values, is made available to users.

While AUSGeoid2020 has the same extent and density as its predecessor, it is based on a much larger and much more homogeneous dataset. For example, NSW Spatial Services has collected over 2,500 extended GNSS datasets (at least 6 hours but generally 12-24 hours duration) on levelled benchmarks across NSW (Figure 1).

These datasets inform the geometric component of AUSGeoid2020, thereby helping to provide a much improved connection to AHD across the state. For AUSGeoid09, only 100 such control points were available.

AUSGeoid2020 provides a rigorous uncertainty value at each grid node, associated with the separation between the ellipsoid and AHD. In contrast, AUSGeoid09 only provides a constant uncertainty estimate (±0.05 m at 1 sigma) for the entire area. Consequently, AUSGeoid2020 users are expected to benefit from more realistic uncertainty information, particularly in the coastal zone where offshore data is included in the model computation and in mountainous regions or other areas that exhibit sparser input datasets.

AUSGeoid2020 performance

A comparison between AUSGeoid09 and AUSGeoid2020 necessitates the availability of both GDA94 and GDA2020 coordinates for the test points utilised.

We can quantify the expected improvement in the derivation of AHD via comparison to known AHD heights of sufficient quality on public record in the Survey Control Information Management System (SCIMS). SCIMS is the State's database containing about 250,000 survey marks across NSW, including coordinates, heights and metadata.

Since it is necessary to consider coordinate differences of opposite signs, the Root Mean Square (RMS) is used to quantify the average agreement to AHD.

Test 1: CORSnet-NSW sites

CORSnet-NSW is Australia's largest state-owned and operated network of GNSS Continuously Operating Reference Stations (CORS). It is built, owned and operated by Spatial Services, a unit of the NSW Department of Customer Service.

NSW is the nation's largest contributor of CORS to the Australian government's National Positioning Infrastructure (NPI), which aims to deliver instant, reliable and accurate access to positioning and timing information anytime and anywhere across Australia.

As of June 2019, CORSnet-NSW consists of 202 reference stations, providing fundamental positioning infrastructure that is authoritative, accurate, reliable and easy-to-use for a wide range of applications (Figure 2). Further expansion of CORSnet-NSW is being considered to include up to 220 CORS.

138 of these CORSnet-NSW sites were selected for comparable test calculations. At the time, these sites had both Regulation 13 certified GDA94 coordinates and a locally 'established' SCIMS AHD height (obtained by NSW Spatial Services through an A1 class/order GNSS-based local tie survey). The GDA2020 coordinates of these sites were obtained directly from the national GDA2020 adjustment and can be assumed equivalent to the GDA2020 certified Regulation 13 coordinates issued later.

Applying AUSGeoid2020 to GDA2020 national-adjustment derived ellipsoidal heights as opposed to applying AUSGeoid09 to Regulation 13 GDA94 ellipsoidal heights revealed an improvement by a factor of 2.7 in the agreement to AHD with the RMS dropping from 0.054m to 0.020m. The range of residuals improved by a factor of 2.2, decreasing from 0.25m (-0.107m to +0.142m) to 0.12m (-0.053m to +0.063m). As we will see below, this is within the published range of AUSGeoid2020 uncertainty values.

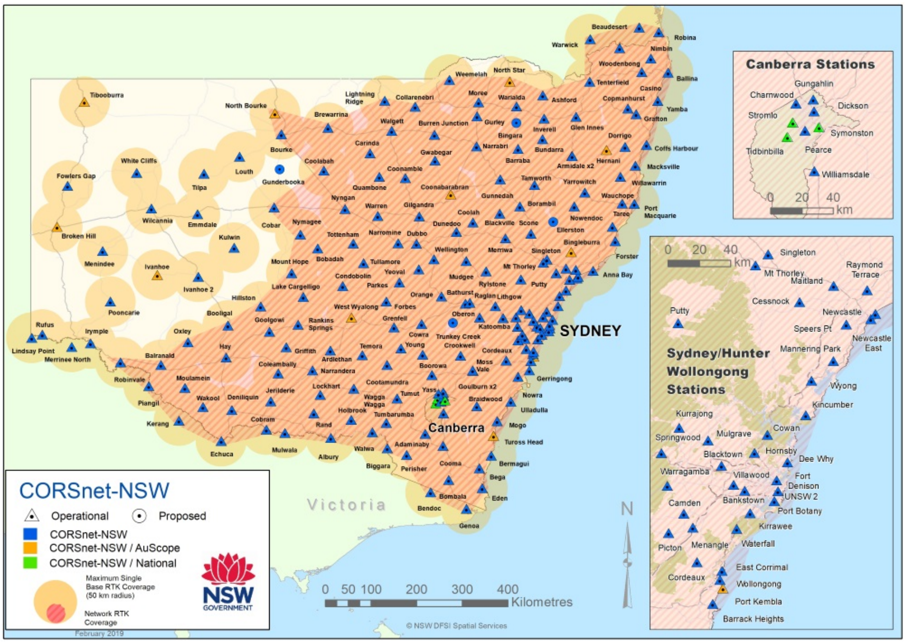

Figure 2: CORSnet-NSW network map as of June 2019.

Test 2: Overall fit

In order to investigate the performance of the new quasigeoid model in practice, seven 3-dimensional GNSS-based least squares network adjustments were run with GeoLab using GDA94+AUSGeoid09 and GDA2020+AUSGeoid2020.

Height control points used for these adjustments had accurate (i.e. LCL3 or B2, or better), predominantly levelled AHD heights that were converted to ellipsoidal values before the adjustment using the selected quasigeoid. All accurate height values were tightly constrained and the resulting variance factor and flagged residuals were inspected to evaluate the overall fit of the adjustment to AHD across NSW.

Seven GNSS-based adjustment datasets were examined, increasing in size, extent and height variation from small to a state-wide network. Table 1 summarises relevant information about these adjustments, while Figure 3 illustrates their location and extent in NSW. Each baseline component is represented as a separate observation.

Adjustment	Extent (km)	Height Range (m)	Number of Sites	Number of Obs	Number of Hgt Constraints	Baseline Length (km)	Average Bsl Length (km)
1: South Coast	21 x 18	7 – 296	18	159	12 (67%)	0.4 – 12	5
2: Oxley Hwy	53 x 35	116 – 1,208	13	108	6 (46%)	0.03 – 53	16
3: Singleton	33 x 42	30 – 442	87	631	55 (63%)	0.6 – 30	5
4: Bellingen	40 x 27	2 – 1,041	107	565	63 (59%)	0.3 – 23	2
5: Bland	212 x 162	167 – 544	155	1,075	70 (45%)	0.1 – 67	12
6: SW NSW	633 x 553	20 – 645	34	752	26 (76%)	8 – 270	128
7: NSW	1,000 x 800	2 – 2,229	89	1,721	11 (12%)	3 – 393	130

Table 1: GNSS-based adjustment datasets used in this study.

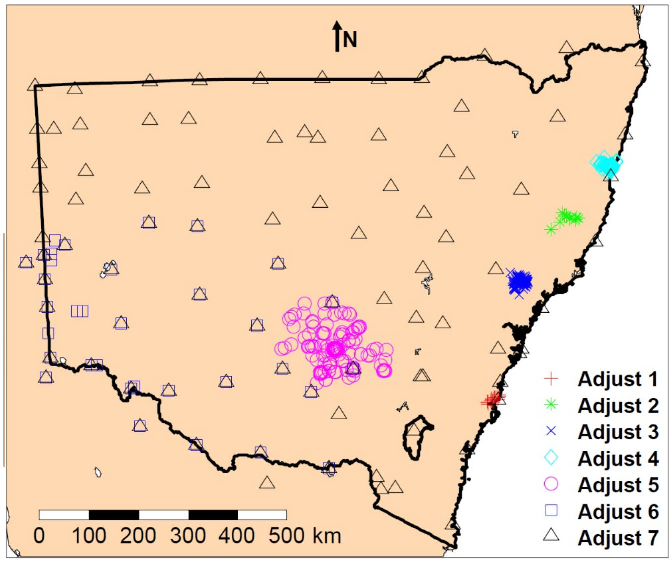

Figure 3: Location and extent of the GNSS-based adjustment datasets investigated.

In general, AUSGeoid2020 improved the variance factor and resulted in a comparable number of flagged residuals, indicating a better adjustment result in comparison to using AUSGeoid09.

The largest improvement was gained in adjustment 5, with the variance factor improving by a factor of 2.3, while the number of flagged residuals was reduced from 1 to 0. This adjustment covers a moderately sized area and exhibits a moderate variation in height, illustrating the positive effect AUSGeoid2020 can have on GNSS-based height determination in NSW.

Adjustments 3 and 4 cover equally small areas and contain rather short baseline lengths. However, the improvement gained by using AUSGeoid2020 is much more pronounced for adjustment 3, which exhibits a moderate variation in height (variance factor improving by a factor of 1.8).

For adjustment 4, which incorporates a large variation in height, the variance factor improves by a factor of 1.2, suggesting that most improvement is gained in areas exhibiting moderate height variations. Intuitively, this makes sense as input data density for AUSGeoid modelling is routinely lower at higher elevations.

The overall fit of the large adjustments (6 and 7) also improved but only slightly (factor of 1.1). These adjustments cover very large areas with average baseline lengths of 130km, reaching up to 270km and 390km respectively. It can therefore be expected that distance-dependent error sources mask the improvement achieved by using AUSGeoid2020 somewhat.

In one case, adjustment 2 (a small adjustment exhibiting a large variation in height), the variance factor increased slightly, bringing it a little closer to unity, while the number of flagged residuals increased from 0 to 2. However, this does not necessarily mean that AUSGeoid2020 performs worse than AUSGeoid09 in this case. A possible explanation is that previously hidden outliers are now detectable.

It is evident that AUSGeoid2020 considerably improves the residuals in most cases with improvement factors generally around 1.4.

From the limited amount of data analysed here, no correlation is evident between the number of constrained AHD heights included in the adjustment and the improvement gained by utilising AUSGeoid2020.

Test 3: Height observation residuals

Based on the seven adjustments mentioned above, a third test was performed. Here, only one observed AHD height was held fixed (a stable mark located in the centre of the adjustment area), while the others were introduced as observations and allowed to float.

Therefore, the adjustment was minimally constrained in height. For the marks that had accurately known AHD heights, the adjusted heights (obtained by applying AUSGeoid09 to GDA94 ellipsoidal heights or AUSGeoid2020 to GDA2020 ellipsoidal heights) were compared against their known AHD values by analysing the residuals of the height observations after the adjustment.

The values of these residuals indicate how well the quasigeoid model fits the AHD heights. For each of the seven adjustment datasets, the height observation residuals are summarised in Table 2.

Adjustment	Parameter	AUSGeoid09	AUSGeoid2020	Improvement Factor
1: South Coast (11 marks)	RMS (m)	0.024	0.022	1.1
	Range (m)	0.070	0.059	1.2
2: Oxley Hwy (5 marks)	RMS (m)	0.034	0.038	0.9
	Range (m)	0.050	0.076	0.7
3: Singleton (53 marks)	RMS (m)	0.029	0.021	1.4
	Range (m)	0.104	0.076	1.4
4: Bellingen (60 marks)	RMS (m)	0.053	0.044	1.2
	Range (m)	0.340	0.246	1.4
5: Bland (68 marks)	RMS (m)	0.049	0.027	1.8
	Range (m)	0.281	0.115	2.4
6: SW NSW (24 marks)	RMS (m)	0.087	0.061	1.4
	Range (m)	0.408	0.234	1.7
7: NSW (9 marks)	RMS (m)	0.144	0.071	2.0
	Range (m)	0.411	0.231	1.8

Table 2: Results of the height observation residual analysis.

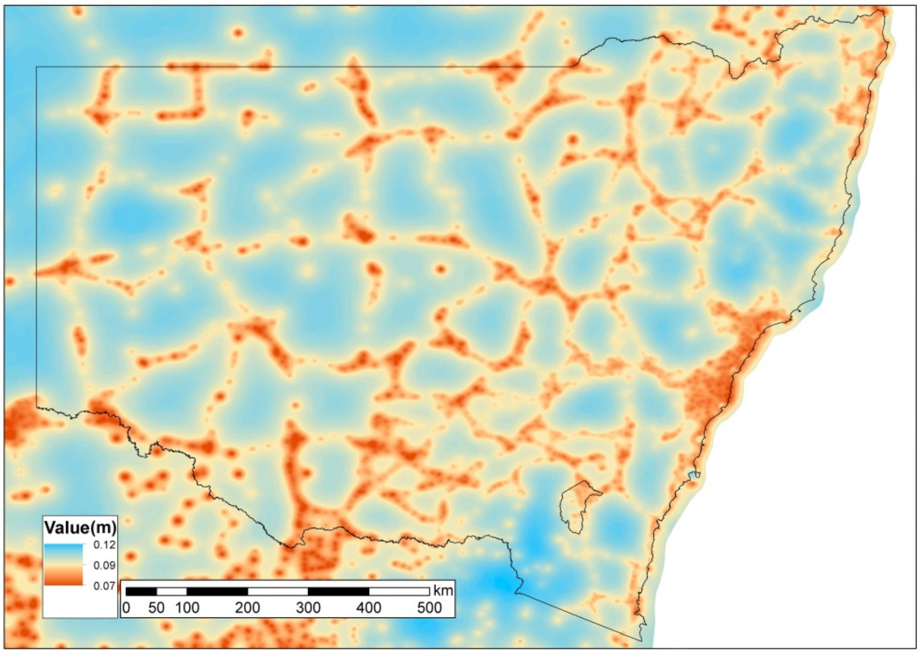

Figure 4: Distribution of absolute AUSGeoid2020 uncertainty across NSW.

It is evident that AUSGeoid2020 considerably improves the residuals in most cases with improvement factors generally around 1.4. By far the largest improvement is achieved for adjustment 5 with improvement factors of 1.8 for the RMS and 2.4 for the range of the residuals.

In all but one case, the RMS values of the AUSGeoid2020 results show significant improvement and fall well within ±0.05m, i.e. the accuracy estimate stated (and verified) for AUSGeoid09, although the range of residuals remains rather large in some cases.

However, while adjustments 6 and 7 show improvement in RMS, the actual RMS values are greater than 0.05m. This was expected because these two adjustments cover large areas and contain relatively long average baseline lengths of 130km. On the positive side, the range of residuals is significantly reduced in these two cases (by factors of 1.7 and 1.8 respectively).

Only adjustment 2 shows no improvement over AUSGeoid09, with both the RMS and range of residuals increasing slightly. Considering the small sample size and the large height variation of this adjustment, this result needs to be taken with caution.

Rigorous AUSGeoid2020 uncertainty

AUSGeoid2020 provides a rigorous uncertainty value associated with the separation between the ellipsoid and AHD, varying as a function of location. This is a world first – no other nation has successfully computed rigorous geoid uncertainties.

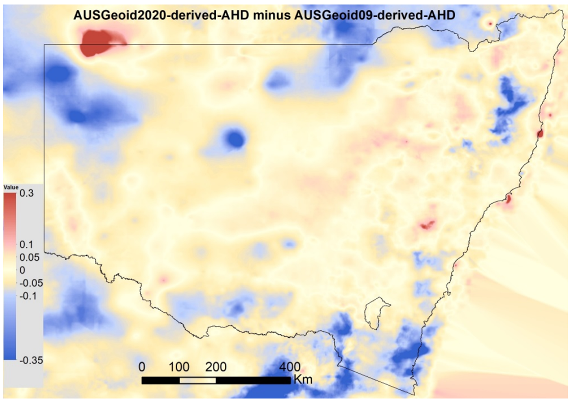

Figure 5: Difference in metres between AUSGeoid2020-derived AHD and AUSGeoid09-derived AHD across NSW.

These uncertainties are based on a linear combination of errors from the gravimetric quasigeoid, the published AHD heights and the GDA2020 ellipsoidal heights. This was deliberate to account for errors originating from all data sources contributing to AUSGeoid2020.

In order to briefly investigate the practical usefulness of the new uncertainty component of the AUSGeoid product, absolute uncertainty values were calculated for each survey mark used in this study (approximately 610 in total).

About 70 percent of these AHD heights are independent of the data used to compute AUSGeoid2020. The resulting absolute (1 sigma) uncertainty values were determined via bi-cubic interpolation and ranged from about 0.07m to 0.11m, with a mean of 0.086m.

Figure 4 illustrates the distribution of this AUSGeoid2020 uncertainty across NSW, as obtained from the official AUSGeoid product. The location of levelled benchmarks along major roads, observed by NSW Spatial Services in preparation for the AUSGeoid2020 product (see Figure 1), is clearly visible with a commensurate improvement in uncertainty at those locations.

The results presented in this article (with RMS on small to medium sized jobs well within ±0.05m) show that these uncertainty values appear overly conservative. Furthermore, the smallest rigorously propagated uncertainty value (0.07m) is larger than the (constant) ±0.05m accuracy estimate stated (and verified) for the previous product (AUSGeoid09), although the new product is based on much improved input datasets and modelling.

Consequently, the absolute AUSGeoid2020 uncertainty grid currently should be used as a guide only. Note that we have not investigated the *relative* uncertainties of the AUSGeoid2020 uncertainty grid (between marks). These will be much smaller – GNSS heighting using AUSGeoid2020 was recently demonstrated to be better than third-order levelling at distances of more than 3km (see *Position* 98, December 2018).

Our brief comparison can only provide a general assessment of the current rigorously calculated AUSGeoid2020 uncertainties. ICSM plans to refine AUSGeoid in the coming years, so more thorough investigations will be required in the future.

Conclusion

All three tests have shown that AUSGeoid2020 substantially improves access to AHD for GNSS-based positioning in NSW. Furthermore, our results agree with absolute testing performed on a national level.

Note that derived AHD values generally change by a few centimetres in NSW when moving from GDA94+AUSGeoid09 to GDA2020+AUSGeoid2020, but larger changes of up to ±0.3m occur in some areas (Figure 5).

Considering that AUSGeoid2020 is based on a much larger dataset and better modelling than its predecessor, this was expected. The effect of this offset will be much smaller for *relative* GNSS heighting between marks located nearby.

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