Sandstone escarpments and valleys near Newnes in the Blue Mountains. Image credit: Hamilton Lund.

How good is AUSGeoid09 in the Blue Mountains?

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AUSGeoid09 is the current national model used to convert ellipsoidal heights determined via Global Navigation Satellite System (GNSS) technology to heights in the Australian Height Datum (AHD) and vice versa. It is known to provide AHD heights with an accuracy of about ±0.03 m to ±0.05 m (1 sigma) across most of Australia (e.g. see Position 53, June 2011). However, few studies have investigated how good AUSGeoid09 actually is in mountainous regions.

In this article, we evaluate AUSGeoid09 in the Blue Mountains of New South Wales (NSW) from a practical user's point of view. Along a 90km stretch of road incorporating flat to mountainous terrain, we have made comparisons between AUSGeoid09-derived heights and published AHD heights, using repeated Network Real-Time Kinematic (NRTK) GNSS observations based on CORSnet-NSW. The performance of AUSGeoid09 has also been evaluated relative to its predecessor (AUSGeoid98) and the latest gravimetric model (AGQG2009), which is rarely used by practicing surveyors.

AHD

Our first and only national height datum was defined by setting to zero the average mean sea level (MSL) values at 32 tide gauges around the country for a period of about two years that began in 1966 and adjusting 97,230km of two-way spirit levelling. Almost 45 years after its inception, we know that shortcomings in the AHD realisation (AHD71 for mainland Australia and AHD83 for Tasmania) resulted in MSL not being coincident with the geoid at the tide gauges involved.

These shortcomings included ignoring dynamic ocean effects (e.g. winds, currents, atmospheric pressure, temperature and salinity), a lack of long-term tide gauge data, and the omission of observed gravity. This means that the reference surface for AHD is not a truly level (geopotential) surface, although it was intended to be so when created and is generally used as if it were. For operational convenience and to avoid confusion, AHD continues to be used as a practical height datum that provides a sufficient approximation of the geoid (or working surface) for many applications.

The Intergovernmental Committee on Surveying and Mapping (ICSM) proposes to retain AHD until Stage 2. of its proposed Modernising Australia's Datum project, at which stage it will be reviewed and stakeholder feedback sought.

AUSGeoid09, AUSGeoid98 and AGQG2009

AUSGeoid09 was released in March 2011 by Geoscience Australia, replacing the previous model AUSGeoid98. Both models cover the same geographical area but AUSGeoid09 is provided as a 1' by 1' grid (approximately 1.8 km by 1.8 km), making it four times denser than its predecessor.

Previous versions of AUSGeoid were predominantly gravimetric-only quasi-geoids, and it was assumed that these were sufficiently close approximations of AHD – an assumption we now know to be incorrect.

In contrast to older versions, AUSGeoid09 combines a gravimetric quasi-geoid with an additional (and new) geometric model, which is sometimes colloquially referred to as the 'sliver'. The Australian Gravimetric Quasi-geoid 2009 (AGQG2009) is the latest gravimetric model produced by the Western Australian Centre for Geodesy at Curtin University. This is combined with an empirically derived geometric model, which accounts for the offset between the gravimetric quasi-geoid and AHD (up to about ±0.5m across Australia).

AUSGeoid09 has been shown to convert ellipsoidal heights to AHD heights with an accuracy of ±0.03m to ±0.05m (1 sigma) across most of Australia, with the exception of some pocket areas where the misfit can be larger than ±0.1m due to errors caused by factors such as the ageing levelling network, geoid height variability, data deficiency or blunders in the original observations.

Testing methodology

Owing to the increased use of GNSS Continuously Operating Reference Station (CORS) networks and Regulation 13 ellipsoidal heights, the absolute accuracy of N values (or geoid undulations if you prefer) is now more important than ever for AHD height determination using satellite positioning techniques. We have quantified the performance of the AUSGeoid09 model in mountainous terrain in the Blue Mountains, NSW, and investigated the effect of introducing the geometric 'sliver' component into AUSGeoid09.

A number of spirit-levelled benchmarks with known AHD heights of sufficiently high quality (Class LB Order L2 or better) on public record were used as test points. Replicating a practical scenario, these test points were occupied multiple times using the NRTK GNSS technique to obtain ellipsoidal heights.

NRTK observations were based on CORSnet-NSW (e.g. see Position 65, June 2013), the expanding state-wide network of currently 170 GNSS CORS providing fundamental positioning infrastructure for NSW. GNSS best practice was followed by applying the windowing (or averaging) technique to increase reliability of the resulting positions and re-observing each test point several times (using a tripod for stability) to ensure redundancy and allow for changes in satellite geometry between occupations (e.g. see Position57, Feb 2012).

Observed NRTK GNSS-derived ellipsoidal heights were then converted to AHD heights using three quasi-geoid models (i.e. AUSGeoid09, AUSGeoid98 and AGQG2009) and compared to the official, published AHD height at each test point. The test points were chosen to ensure that a sufficient number of these were located in flat terrain and mountainous terrain in order to allow evaluation of all models in both terrain conditions.

Study area

The study area incorporates 23 test points along Windsor Road and Bells Line of Road, a 90km stretch of road connecting the western outskirts of Sydney in the east with the townships of Richmond and Lithgow towards the west (see Figure 1.). It exhibits initially flat terrain (10m to 125m elevation – blue test points) changing into substantially undulating terrain (185m to 1,100m elevation – red test points), thus representing typical mountainous terrain conditions encountered in Australia (see Figure 2.).

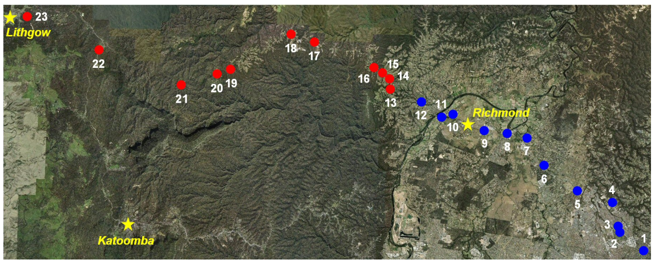

Figure 1. Location of the 23 test points.

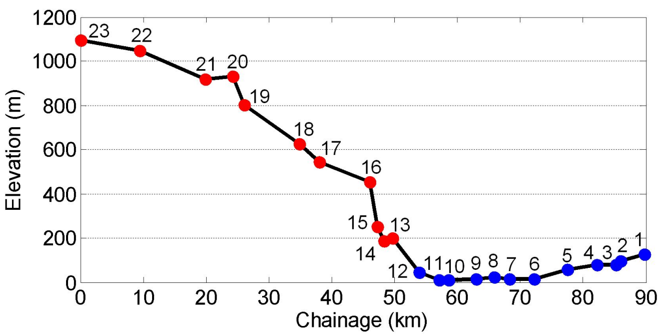

Figure 2. Cross section of the test points, indicating the range in elevation (AHD height).

Field work challenges

Whilst a lot of first-order levelled benchmarks (LAL1 – maximum misclose 4 mm) are available around Sydney, most of these have an 'unknown' classification for the horizontal class and order (UU). This means that the published horizontal coordinates are generally only accurate to between several tens of metres and hundreds of metres.

Furthermore, the locality sketches for most of these benchmarks were drawn in the early 1960s (when the benchmarks were placed) and did not have many useful references to locate the marks 50 years later. Most of the benchmarks were placed at regular mileages (give or take) on the side of the road and hence not near identifiable features such as road intersections, houses or other physical structures.

References mainly consisted of fencing, power poles and mile posts. Understandably, these features have been replaced, removed or have deteriorated over time. In addition, roads have been realigned or moved, and marks have been destroyed by road works.

As a result, many of these (LAL1) marks could not be recovered and some second-order levelled marks (LBL2 – maximum misclose 8 mm) had to be used instead. In mountainous terrain, along Bells Line of Road, only 8 LAL1 marks were found (25 benchmarks initially selected). Unfortunately, this resulted in a significantly reduced sample size, although the dataset was expanded with three LBL2 marks. All 12 marks used in flat terrain along Windsor Road are classified LBL2.

Another challenge that arose with four test points along Bells Line of Road was the inability to observe directly over a benchmark due to limited sky view or multi-path issues. This problem was overcome by placing an arbitrary (eccentric) mark a short distance away at a location with more favourable observing conditions. The AHD height of the benchmark was then transferred to the arbitrary mark using reciprocal EDM heighting. A spirit level was not used because this could not be achieved by one person in the field.

Results: flat terrain

Each test point was occupied between three and six times with NRTK GNSS using CORSnet-NSW and 3-minute observation windows. The AHD heights obtained by applying the three quasi-geoid models for each test point were then compared to the official, published values.

We found thatAUSGeoid09 allows AHD height determination with an accuracy of about ±0.03m (1 sigma) in flat terrain. This accuracy agrees very well with previous studies across NSW and Australia. As expected, using AUSGeoid09 rather than its predecessor AUSGeoid98, resulted in substantially better agreement with published AHD heights (at the 700% level).

Comparing the results obtained with AUSGeoid09 against those using AGQG2009 illustrated, as expected, the benefit that the introduction of the geometric component of AUSGeoid09 has had on the determination of AHD heights with satellite positioning technology (250% improvement). For all test points, AUSGeoid09 provided heights that are about 30-50mm closer to the published AHD values than those obtained using AGQG2009.

This improvement is consistent with the geometric 'sliver' component of AUSGeoid09 generally amounting to about -0.05m or less in this area. The evolution from AUSGeoid98 to AGQG2009 and AUSGeoid09 has significantly improved the fit between GNSS-derived and published AHD heights in this part of the study area. So far, so good.

Results: mountainous terrain

The same procedure was applied to the remainder of test points, located in mountainous terrain along Bells Line of Road. In this part of the study area, AUSGeoid09 allows AHD height determination with an accuracy of about ±0.06m (1 sigma), i.e. half the accuracy of flat terrain. Again, as expected, AUSGeoid09 provided substantially better agreement with published AHD heights than its predecessor AUSGeoid98 (250% improvement).

Interestingly, two test points showed much larger discrepancies (at the 120mm level) to the published AHD heights than all other test points in the study area. At point 18, this disagreement may be attributed to mark subsidence, but the limited data available precludes a definitive answer in both cases. If these two test points were removed from the analysis, the accuracy of AUSGeoid09-derived AHD heights improves to ±0.05m (1 sigma).

Now things get really interesting. Comparison of the results obtained with AUSGeoid09 and AGQG2009 showed that, contrary to the findings in flat terrain, the introduction of AUSGeoid09's geometric component overall has not had a positive effect in this part of the study area. Closer inspection revealed that for elevations below 500m, the geometric component improved the fit to published AHD heights by about 10-20mm.

However, for elevations above 500m, the geometric 'sliver' component appears to degrade the fit by about 10-30mm. For elevations above 1,000m, this negative effect is even larger. While we recognise that the sample size is small, this does indicate possible problems with the geometric component at high elevations – not surprisingly, as it is well known that suitable datasets for the generation of the geometric component are notoriously sparse in mountainous regions.

It also needs to be remembered that the gravimetric geoid is weaker in mountainous regions because (1) gravity data are limited, (2) existing gravity data are biased along the ridges (roads) and creeks for ease of access, and (3) the terrain effect is less well modelled in regions of large elevation changes in topography.

Investigating the effect of the geometric 'sliver' component in more detail, it is interesting to note that the improvement of fit to published AHD steadily decreases from east to west in the study area, from about 55mm in the western outskirts of Sydney to zero near Kurrajong. Heading further west through the Blue Mountains, the geometric component increasingly degrades (almost linearly with distance) the GNSS-based determination of AHD heights in the study area, culminating in up to 80mm at the highest elevation near Lithgow (see Figure 3.).

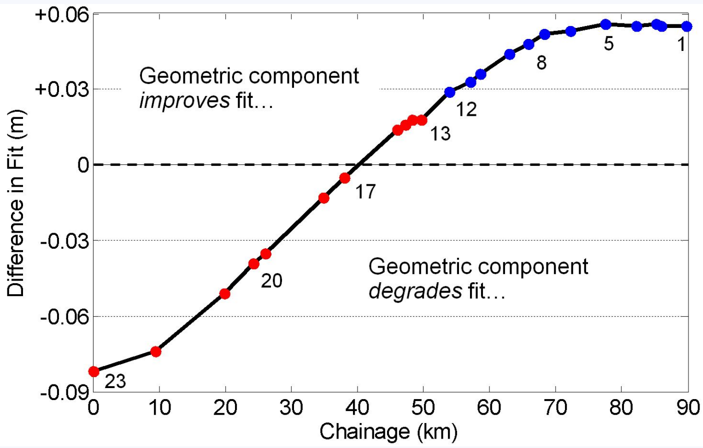

Figure 3. Difference in fit to published AHD heights between AUSGeoid09 and AGQG2009 derived AHD heights in the study area.

This can be explained by the decreasing density of datasets available for the empirical determination of the geometric component away from metropolitan areas. It is also interesting that across the entire study area, featuring both flat and mountainous terrain, AUSGeoid09-derived AHD heights are always lower than the published AHD heights. This indicates that there is room for improvement in regards to future versions of the AUSGeoid model, provided additional datasets are collected or included in this region.

Cross-sections

In order to provide another visual perspective of these results, cross sections were generated showing published AHD heights and NRTK GNSS-derived AHD heights based on the three quasi-geoid models investigated (see Figure 4.). The cross sections run from left to right in a west-to-east direction and have been scaled and exaggerated (separately for each part of the study area) to allow visual inspection.

Across both terrain types, it is clearly evident that AUSGeoid09 (green) provides a far better fit to published AHD (dark blue) values than its predecessor AUSGeoid98 (light blue). In flat terrain (eastern part of study area), AUSGeoid09-derived heights are consistently closer to published AHD than AGQG2009-derived heights (red), showing the benefit of the geometric component. The shape of all quasi-geoid-derived cross sections is very similar to the shape of AHD in this part of the study area.

In mountainous terrain (western part of study area), the shape of all quasi-geoid-derived cross sections is very similar but deviates from the shape of published AHD in several cases. This behaviour is most obvious at test point 18, a mark that has already been identified as possibly being affected by subsidence. The cross sections also visualise that the geometric component of AUSGeoid09 appears to increasingly degrade the fit to published AHD for the marks investigated west of test point 17.

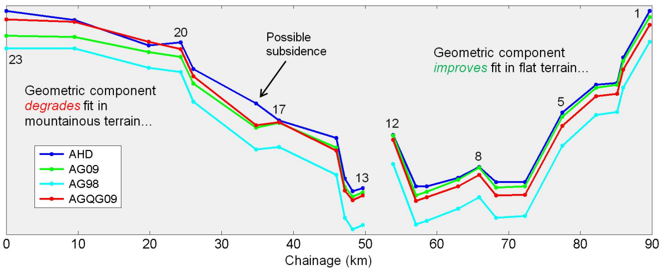

Figure 4: Cross sections showing published AHD heights and NRTK GNSS-derived AHD heights using different quasi-geoid models, separately scaled and exaggerated in each part of the study area.

Conclusion

We have evaluated AUSGeoid09 performance in the Blue Mountains, from a practical user's point of view, using repeated NRTK observations based on CORSnet-NSW. AUSGeoid09 performs well across the study area and (as expected) provides a significant improvement over AUSGeoid98. AUSGeoid09 generally allows AHD height determination at the ±0.03 m level (1 sigma) in flat terrain and at the ±0.06m level (1 sigma) in mountainous terrain.

This level of accuracy agrees well with findings reported in previous studies and is very encouraging, particularly in light of GNSS technology and CORS networks being increasingly used for vertical surveys. However, across the entire study area, AUSGeoid09-derived AHD heights were found to be consistently lower than the published AHD heights.

Comparison of the results obtained with AUSGeoid09 against those using AGQG2009 in flat terrain illustrates the benefit that the introduction of the geometric 'sliver' component of AUSGeoid09 has had on the determination of AHD heights with satellite technology. However, for elevations above 500 m it appears that the geometric component degrades the fit to AHD in the study area. This indicates that there is room for improvement in regards to future versions of the AUSGeoid model, provided additional datasets are collected or included in this region.

Levelled benchmarks are crucial for the maintenance and preservation of the national height datum. We therefore recommend that the availability of higher-quality horizontal coordinates for benchmarks is addressed, so these can be easily found and occupied with long-duration GNSS to improve the quality of the geometric component.

This is particularly important in light of the planned introduction of a next-generation datum for Australia and the increasing need to preserve existing survey mark infrastructure. A new AUSGeoid is expected to be publicly available in 2017, as part of ICSM's next-generation datum project.

This article is based on a paper that has recently received the Research@Locate15 best paper award. Joseph Allerton <joe.allerton@hotmail.com>is with McKinlay Morgan & Associates Pty Ltd. Dr Volker Janssen <Volker.Janssen@lpi.nsw.gov.au>works in the Survey Infrastructure and Geodesy branch of NSW Land and Property Information, which operates CORSnet-NSW. Dr Bill Kearsley <w.kearsley@unsw.edu.au>is with the University of New South Wales. ■