AUSGeoid09 radically improves height determination

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In March 2011, Geoscience Australia released AUSGeoid09, replacing its decade-old ancestor AUSGeoid98. AUSGeoid09 provides an improved geoid model for Australia to relate GNSS-derived ellipsoidal heights to the Australian Height Datum (AHD71, or AHD83 in Tasmania) and vice versa.

According to Geoscience Australia, it is expected to convert GNSS heights to AHD71 heights to better than 50 millimetres across most of Australia. In some areas the accuracy may exceed a decimetre due to localised errors in the ageing levelling network, GNSS observational errors, land subsidence, geoid anomalies, or simply a lack of data in some remote locations. In comparison, its predecessor AUSGeoid98 only provided an estimated accuracy of better than 0.4 metres in absolute terms. This article will show that the new AUSGeoid09 geoid model radically improves GNSS-based AHD71 height determination in New South Wales.

AUSGeoid09

AUSGeoid09 covers the same area as AUSGeoid98 and also refers to the GRS80 ellipsoid. But it is given on a 1' by 1' grid (about 1.8 by 1.8 kilometres), making it four times denser than its predecessor. In contrast to previous versions of AUSGeoid, the new AUSGeoid09 combines an improved version of the standard 'gravimetric geoid' model with a new additional 'geometric' component, colloquially referred to as the 'sliver' by its makers.

The first component of AUSGeoid09 is the latest gravimetric geoid model produced by the Western Australian Centre for Geodesy at Curtin University. It provides the height offset between the GRS80 ellipsoid and the geoid surface. This is a product far better than the one used in AUSGeoid98.

The second, and new, component of AUSGeoid09 is the offset between the gravimetric geoid and AHD71. This 'sliver' was calculated by empirical testing. It is mainly caused by AHD71 not taking into account sea surface topography, which includes the differential heating of the oceans. The warmer or less dense water off the coast of northern Australia is about one metre higher than the cooler or denser water off the coast of southern Australia. Therefore AHD71 is about 0.5 metres above the geoid in northern Australia and roughly 0.5 metres below the geoid in southern Australia. The introduction of the geometric 'sliver' component largely takes care of this one-metre trend across Australia (0.6-metre trend across NSW), thereby providing a better overall fit to AHD71. See Figure 1.

Considerations for traditional GNSS users

In the traditional base-rover field scenario, the published, local AHD71 height (H) of a temporary GNSS base receiver is converted to an ellipsoidal height (h) by adding the geoid undulation (N): $h=H+N$. The ellipsoidal height of the rover is then determined via Real Time Kinematic (RTK) or post-processing (PP) techniques and converted back to AHD71 using the same equation. The entire process is based on the calculated ellipsoidal height of the base receiver.

Most of the error in the absolute N values cancels due to the conversion being applied from AHD71 to ellipsoidal height and back again. The absolute N values involved may have large errors (e) but by applying the height conversion twice (forward and backward), the AHD71 height of the rover is only contaminated by the small difference in relative N value errors.

Considerations for CORS users

The use of Continuously Operating Reference Station (CORS) networks for GNSS real-time and post-processing applications has grown significantly over the last few years. This development has substantially increased the importance of accurate absolute (not relative) N values in regards to GNSS-based height determination.

When using CORS operated by third parties, the height conversion is only applied once (at the rover end) and is based on an observed (not calculated) ellipsoidal height at the CORS. The ellipsoidal height of most CORS in Australia (those following CORS Best Practice Guidelines) is determined via Regulation 13 certification. Geoscience Australia determines these site coordinates in a global (or, more precisely, regional) context based on a week of GNSS data and highly traceable, standardised, scientific processing. This provides a Recognised Value Standard for positioning infrastructure with respect to the national datum, GDA94.

Because the height conversion is only applied once (from ellipsoidal height to AHD71), any error (e) in the absolute N value will fully propagate into the AHD71 height of the rover. Consequently, the absolute accuracy of N values is now more critical than ever for AHD71 height determination using CORS techniques. See Figure 2.

Performance of AUSGeoid09 in NSW

In order to quantify the expected improvement of replacing AUSGeoid98 with AUSGeoid09 in NSW, we carried out four tests. All tests utilised beta version 0.7 of AUSGeoid09, which is identical to the final product in NSW. Firstly, we used more than 500 AUSPOS solutions to investigate how well the two geoid models fit known AHD71 heights across the state. Secondly, we performed a similar analysis based on 38 sites of the state's GNSS CORS network, CORSnet-NSW. Thirdly, we studied the overall fit of several GNSS-based adjustments, incorporating different adjustment area sizes and various ranges in elevation. Lastly, we analysed the residuals of the height observations stemming from these adjustments.

Test 1: AUSPOS solutions

The first test investigated 513 solutions of Geoscience Australia's online GNSS processing service, AUSPOS (*www.ga.gov.au/geodesy/sgc/wwwgps/*). These were collected by the NSW Land and Property Management Authority (LPMA) on established marks with accurate AHD71 heights (LCL3 or C3, or better). Almost half of these marks had been optically levelled. The AUSPOS solutions were based on between 3 and 94 hours of GNSS data. It should be noted that about 100 (or 20%) of these AUSPOS solutions were used in the determination of the geometric component of AUSGeoid09.

AUSGeoid09 and AUSGeoid98 N values were interpolated for each location to determine the agreement with published AHD71 heights. Applying AUSGeoid09 to AUSPOS-derived GDA94 ellipsoidal heights rather than AUSGeoid98 resulted in an improvement of 270%, independent of the GNSS observation length. The overall accuracy was better than 70 millimetres, only slightly worse than the expected value stated by Geoscience Australia. Testing further indicated that the magnitude of absolute N values in NSW will change by up to 0.5 metres when AUSGeoid09 is introduced, thereby providing a much better fit to AHD71 across NSW.

Test 2: CORSnet-NSW sites

We performed a similar test based on 38 CORSnet-NSW sites with Regulation 13 certified GDA94 coordinates and accurate AHD71 heights (mainly A1 obtained by LPMA through a GNSS-based local tie survey). Using AUSGeoid09 resulted in an improvement of 410% in the agreement to AHD71. The overall accuracy achieved was about 40 millimetres, i.e. within the expected value of 50 millimetres stated by Geoscience Australia. The test confirmed that the magnitude of absolute N values in NSW will change by up to 0.5 metres when AUSGeoid09 is introduced.

The higher accuracy achieved in comparison to Test 1 is due to improved GNSS processing methods (Regulation 13 vs. AUSPOS) and the much more consistent quality of the input data (7-day vs. 6-hour or so datasets). The Regulation 13 certification and LPMA's local tie survey process are highly traceable and standardised, while the AUSPOS dataset was collected over many years with differing processing parameters. Both tests show that AUSGeoid09 provides an improved fit to AHD71 across NSW when compared to AUSGeoid98. See Figure 3.

Test 3: Constrained 3D network adjustment fit

To investigate the performance of the new geoid model in practice with regards to traditional GNSS-based survey adjustments in NSW, we ran seven specially selected 3-dimensional network adjustments using AUSGeoid98 and AUSGeoid09. All height control points were tightly constrained in the adjustment to their accurate (LCL3 or B2, or better), predominantly optically levelled AHD71 heights. Therefore the adjustment was highly constrained in height. The resulting variance factor and flagged residuals were inspected to get an indication of the overall fit of each adjustment to AHD71.

Figure 1. AUSGeoid09: improved access to AHD71 due to the geometric 'sliver' component (adapted from Geoscience Australia).

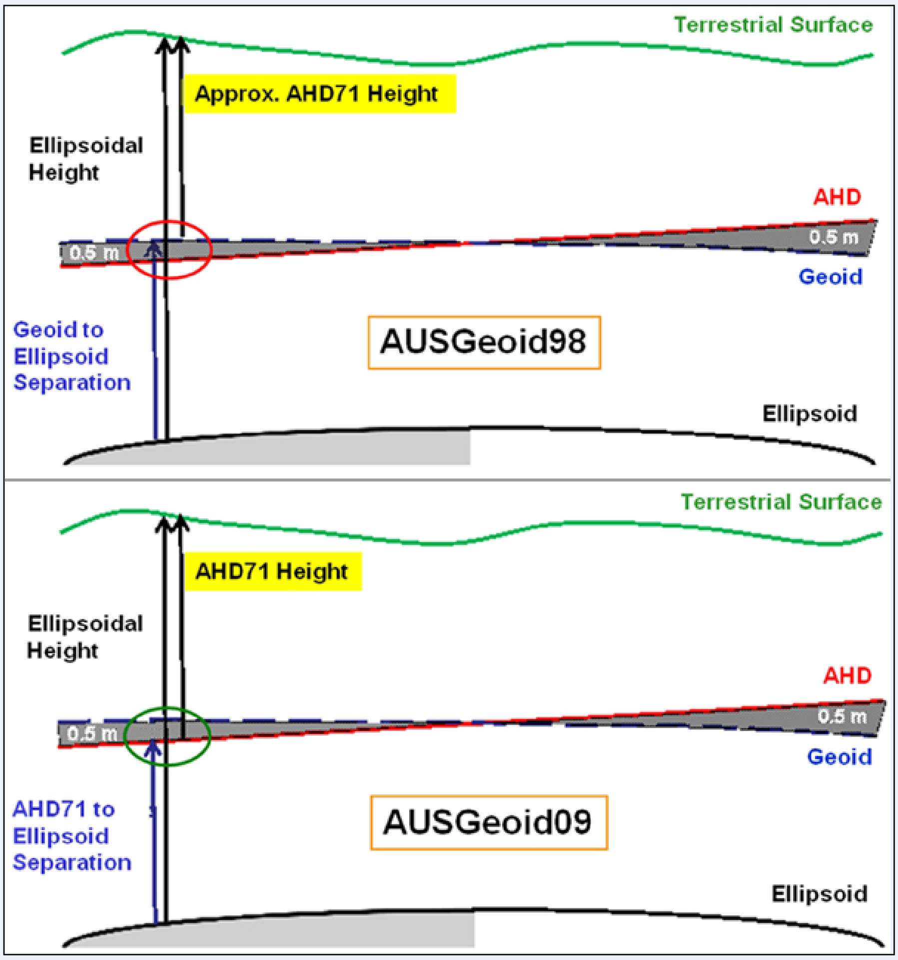


Figure 2. GNSS height transfer methodology using RTK or post processing (PP) in the past (a) and using CORS (b).

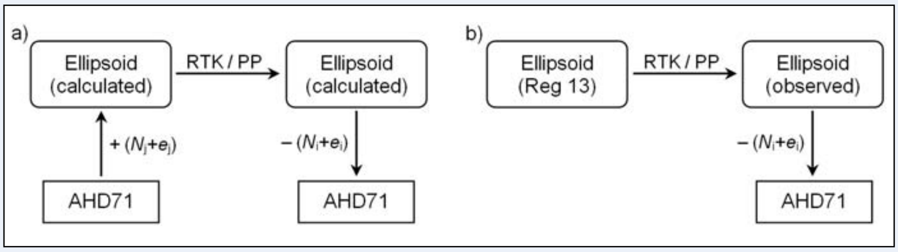
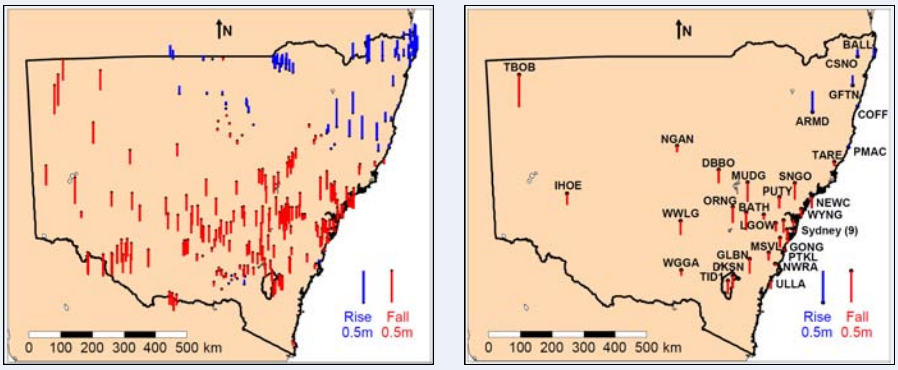


Figure 3. Test 1 & 2: N values across NSW will change by up to 0.5 metres when AUSGeoid09 is introduced, illustrated by AUSPOS solutions (left) and selected CORSnet-NSW sites (right).



The seven adjustments were chosen carefully to incorporate different adjustment area sizes, ranging from small (20 by 20 kilometres) to state-wide (1,000 by 800 kilometres). The average baseline lengths varied between 2 and 130 kilometres. The datasets included various ranges in elevation: small (290 metres), moderate (380 to 620 metres) and large (1,000 to 2,200 metres). The number of sites included in each adjustment varied from 18 to 155 sites, incorporating between 33 and 567 baselines.

In general, AUSGeoid09 improved the variance factor and reduced the number of flagged residuals, indicating a better adjustment result in comparison to AUSGeoid98. The smaller adjustments (1 and 2) showed a large improvement in the overall fit. Here the variance factor improved by 230% and 460%, while the number of flagged residuals was significantly reduced from 13 to 2 and from 7 to 0 respectively. The improvement is more prominent for adjustment 2 which displays a much larger variation in height across the area. Owing to the higher density of AUSGeoid09, this could be expected.

The overall fit of the larger adjustments also increased but only showed slight improvements in the variance factor and the number of flagged residuals. Adjustments 6 and 7 cover very large areas with baseline lengths reaching up to 390 kilometres. They showed minimal improvements in the variance factor, while the number of flagged residuals was reduced slightly to 0 and 1 respectively. It can be expected that distance-dependent error sources mask the improvement achieved by using AUSGeoid09 to some degree in these cases. In summary, the seven adjustments give further evidence that AUSGeoid09 considerably improves access to AHD71 across NSW compared to AUSGeoid98.

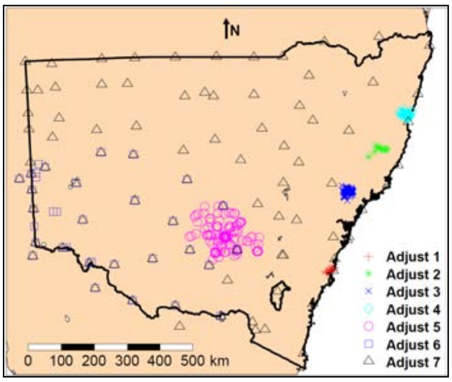


Figure 4. Test 3 & 4: Location and extent of the seven GNSS-based adjustment datasets investigated.

Test 4: Minimally constrained 3D network adjustment fit

The final test was based on the same seven GNSS-based adjustment datasets. In this case, we only held one observed AHD71 height fixed (located in the centre of each adjustment area). The others were introduced as observations and allowed to float. Therefore, the adjustment was minimally constrained in height. For those marks that had accurately known AHD71 heights, the adjusted heights (obtained by applying AUSGeoid98 or AUSGeoid09) were compared against their known AHD71 values by analysing the residuals of the height observations after the adjustment. The values of these residuals indicate how well the geoid model fits the AHD71 heights in practice.

The use of AUSGeoid09 considerably improved the residuals, generally by at least 150%, but reaching up to 460%. In most cases the accuracy of the AUSGeoid09 results falls within the expected ±0.05 metres stated by Geoscience Australia. Only adjustments 6 and 7 show larger values, reaching ±0.09 and ±0.14 metres respectively. This was expected because these two adjustments cover large areas and contain relatively long average baseline lengths of 130 kilometres (reaching up to 270 and 390 kilometres respectively). These baselines were processed with 1990's-era commercial GNSS software having limited modelling options, and distortions in AHD71 are more prominent over longer distances.

Conclusion

All four tests have shown that AUSGeoid09 radically improves the determination of AHD71 via GNSS techniques in NSW. The improvement is due to the larger and higher-quality input dataset, improved modelling and the increased density of AUSGeoid09, as well as the inclusion of the new geometric 'sliver' component. This allows a more direct determination of AHD71 heights from GNSS observations. For the purists, it is important to understand that AUSGeoid09 now provides a correction surface between the GRS80 ellipsoid and AHD71, not the geoid as its predecessor AUSGeoid98 did. AHD71 continues to be a practical but less than ideal height datum, which is being decimated by construction. A strategy to preserve and upgrade it needs to be discussed at the national level. In the meantime, LPMA has adopted AUSGeoid09 for all operations (including CORSnet-NSW) and urges all spatial professionals to do the same. It should be noted that several beta versions have preceded the official release of AUSGeoid09. Double-checking that the final version is used in practice is therefore highly recommended. ■

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