How good is AUSPOS in NSW?

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AUSPOS is Geoscience Australia's free online Global Positioning System (GPS) processing service. It has successfully processed more than 1 million jobs worldwide over the last 10 years and was ranked highest in a global comparison of free online post-processing tools.

This article quantifies AUSPOS performance across NSW, demonstrating that it routinely delivers Positional Uncertainty (PU) at the 0.02-0.03 m level for horizontal position and 0.05-0.06 m for ellipsoidal height. We also show that AUSPOS provides a much better connection to the Australian Height Datum (AHD) across NSW than reported. These results reveal that AUSPOS is a very handy tool to have in your toolbox and another option to establish, propagate and strengthen the NSW Survey Control Network.

How do I use AUSPOS?

Static, dual-frequency, carrier phase and code data of at least 1 hour duration (recommended minimum 2 hours, maximum 7 consecutive days) is observed, and then submitted to the online web service, usually in 30-second RINEX data format. The user's antenna type (IGS naming format) is selected from a drop-down menu, and the height of instrument (measured vertically to the Antenna Reference Point, ARP) is manually entered.

AUSPOS then employs International GNSS Service (IGS) station data and products to compute precise 3D coordinates, using GPS data only. GDA2020, GDA94, ITRF2014 coordinates and an AHD height are contained in a report (pdf) emailed to the user, generally after a few minutes.

The report also includes the computed coordinate uncertainties, ambiguity resolution statistics, and an overview of the GPS processing strategy applied. For advanced users, Solution Independent Exchange (SINEX) files containing more detailed information are also available for download.

How does AUSPOS process my data?

The best available IGS products and services are used for processing (e.g. final, rapid or ultra-rapid orbits). Up to 15 surrounding IGS and Asia-Pacific Reference Frame (APREF) stations are selected as reference stations, generally the 7 closest IGS sites and the 8 closest APREF sites.

All CORSnet-NSW stations contribute to the AUSPOS service. Hence in NSW, this provides a relatively dense network for generating a reliable regional ionospheric delay model and tropospheric delay corrections to support ambiguity resolution. A precise solution is then computed using double-differencing techniques.

IGS station coordinates are constrained with uncertainties of 1 mm for horizontal position and 2 mm for ellipsoidal height. Lower-tier Continuously Operating Reference Station (CORS) coordinates are constrained with uncertainties of 3 mm for horizontal position and 6 mm for the vertical, due to the shorter CORS operation time span, lower data quality or lower-grade monumentation.

The GPS data is processed in ITRF2014 and then transformed to GDA2020 via the Australian Plate Motion Model. Derived AHD heights are computed by applying AUSGeoid2020 to the GDA2020 ellipsoidal heights. Legacy GDA94 coordinates are obtained from GDA2020 by transformation.

Positional Uncertainty (PU) is calculated according to SP1 version 2.1. The coordinate uncertainties of East, North and ellipsoidal height are scaled using an empirically derived model, which is a function of duration, data quality and geographical location, and expressed at the 95% confidence level.

How does AUSPOS support datum modernisation?

Spatial Services, a unit of the NSW Department of Customer Service, employs AUSPOS as one of several suitable methods to maintain and extend the State's Survey Control Network. To this end, AUSPOS data of at least 6 hours duration is used to propagate the datum in NSW, while AUSPOS data of less than 6 hours duration strengthens the datum. This distinction is made based on the higher quality of AUSPOS solutions exceeding 6 hours duration and their eligibility for inclusion in the National GNSS Campaign Archive (NGCA).

NSW Spatial Services is currently building an updated 'passive' Survey Control Network (in the Eastern and Central Divisions) with a minimum of one fundamental survey mark observed by 6+ hour AUSPOS every 10 km. Its vision is to ensure that any future user is no further than 5 km (and often much less) from such a fundamental mark providing direct connection to datum. Similarly, levelled AHD marks are observed by 6+ hour AUSPOS every 10 km, often at a far greater density.

This will allow users to achieve NSW Spatial Services' vision of a PU of 20 mm in the horizontal and 50 mm in the vertical (ellipsoidal height) component anywhere in the State and easily apply transformation tools to move between current, future and various historical datums and local working surfaces (e.g. railway datum or standard datum).

The profession is encouraged to contribute to these datum modernisation efforts by submitting suitable AUSPOS data and

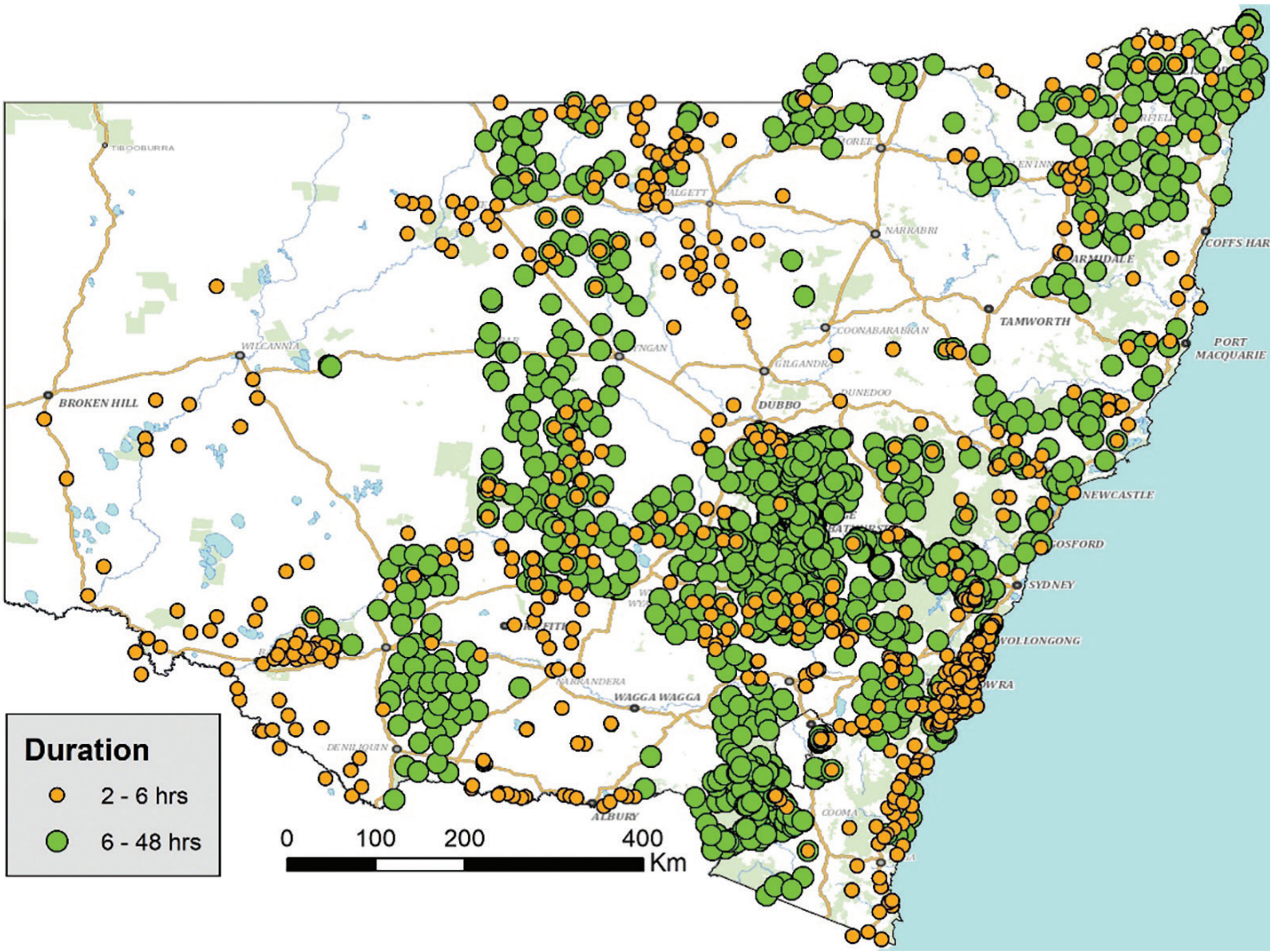

Figure 1: Location of the 2,464 successful AUSPOS solutions analysed across NSW, colour-coded to indicate observation length.

related metadata to us via *https://www.spatial.nsw.gov.au/surveying/surveying_services/forms_and_applications/auspos_submission* in order to facilitate the update of survey information 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, accuracy classifications and other metadata, provided in GDA2020, GDA94 and AHD.

At present, the GDA2020 state adjustment incorporates approximately 30,000 survey control marks across NSW, i.e. 12% of all marks in SCIMS. Consequently, 88% of the marks in SCIMS are currently transformed from GDA94 to GDA2020. Uncertainties of these transformed GDA2020 coordinates are given null values until these are calculated via inclusion in the state adjustment.

As shown in this article, AUSPOS is a suitable method to accelerate the process of including additional survey marks into the state adjustment in order to improve user access to GDA2020 coordinates and uncertainties across the State.

Evaluating AUSPOS performance in NSW

We used 2,618 GNSS datasets observed by NSW Spatial Services over the last 5 years (November 2014 to August 2019). Data was collected under typical conditions generally encountered in the field, with observation session lengths ranging from 2 to 48 hours. Each dataset was processed individually with AUSPOS version 2.3, using final IGS products.

Some AUSPOS solutions were rejected for this analysis due to warnings in the AUSPOS report, referring to poor ambiguity resolution and/or large uncertainties. Overall, 154 sessions (5.9%) were rejected, including 121 (10.1%) of the 2-6 hour sessions and 33 (2.3%) of the 6-48 hour sessions.

Upon investigation of site photos and other metadata, this was generally attributed to ambitious attempts to observe survey marks in locations with substantial tree cover, resulting in poor sky view conditions. As expected, shorter observation sessions were more prone to be negatively affected by these unfavourable conditions.

For all 2,464 successful AUSPOS solutions, descriptive statistics were used to evaluate the uncertainties of the resulting GDA2020 coordinates. Figure 1 shows the location of these solutions, colour-coded to indicate observation length.

PU is defined as the uncertainty of the horizontal and/or vertical coordinates of a point, at the 95% confidence level, with respect to the defined datum. A description of the practical implementation of PU in NSW (particularly SCIMS) can be found in Azimuth 58(8), September 2019.

We performed three tests:

1. Analysing Horizontal PU (HPU) and Vertical PU (VPU) of the AUSPOS solutions for GDA2020 horizontal coordinates and GDA2020 ellipsoidal heights, respectively.
2. Analysing the repeatability of AUSPOS solutions for reoccupations on the same mark.
3. Analysing AHD results by comparing the AUSPOS-derived AHD height to levelled AHD heights on public record and investigating the AHD-PU reported by AUSPOS.

The results of two further tests can be immediately summarised:

- Whilst AUSPOS PU values are known to be affected (scaled) by latitude, the variation is negligible for user results within NSW.
- Whilst IGS products have continuously improved and CORS density has increased, AUSPOS version 2.3 performance has remained stable, predictable, repeatable and of high quality within NSW.

PU of AUSPOS solutions

First, we investigated the AUSPOS-derived HPU and VPU values. Table 1 summarises descriptive statistics for the entire dataset of 2,464 successful AUSPOS solutions (2-48 hour duration). It also provides this information for the 2-6 hour and 6-24 hour subsets to allow examination of the effect the observation session length has on the resulting uncertainties.

As expected, a longer observation span generally improves PU. This is demonstrated by mean values of 0.023 m ± 0.006 m (1 sigma) for HPU and 0.069 m ± 0.022 m (1 sigma) for VPU when using 2-6 hour data, compared to values of 0.015 m ± 0.003 m (1 sigma) for HPU and 0.033 m ± 0.016 m (1 sigma) for VPU when using 6-24 hour data. The median values indicate that no significant offsets caused by possible outliers are present.

Dataset	Statistic	HPU	VPU
Entire dataset: 2,464 solutions	**Min.**	0.011	0.015
	Max.	0.074	0.161
	Range	0.063	0.146
	Median	0.017	0.042
	Mean	0.018	0.048
	STD	0.006	0.026
2-6 hour data: 1,076 solutions	**Min.**	0.014	0.029
	Max.	0.074	0.141
	Range	0.060	0.111
	Median	0.022	0.065
	Mean	0.023	0.069
	STD	0.006	0.022
6-24 hour data: 1,280 solutions	**Min.**	0.011	0.018
	Max.	0.042	0.161
	Range	0.031	0.143
	Median	0.014	0.027
	Mean	0.015	0.033
	STD	0.003	0.016

Table 1: Descriptive statistics for the HPU and VPU analysis (all values in metres).

Figure 2 presents a graphical visualisation of the results, showing PU as a function of observation session length for the 2-6 hour and 6-24 hour datasets. Most of the improvement is gained by increasing the observation length from 2 hours to about 4-5 hours, with minor but not insignificant improvement when it is increased to 24 hours and beyond.

Observation sessions exceeding 12 hours provide AUSPOS solutions of substantially higher quality in the vertical component. An investigation of site photos and other metadata attributed the larger VPU values evident for solutions greater than 15 hours duration to poor sky view conditions caused by substantial tree cover. As an example, Figure 3 illustrates the conditions encountered at the sites producing the three largest VPU values in Figure 2b. In spite of these poor conditions, AUSPOS solutions generally achieve acceptable HPU and heights with a VPU of better than 0.1 m.

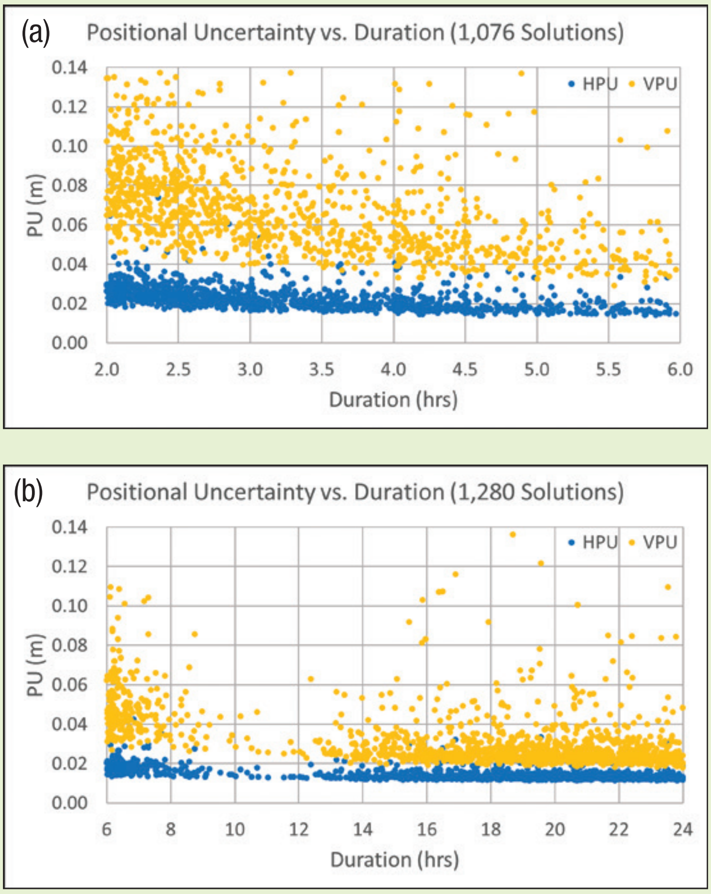

Figure 2: Positional Uncertainty (PU) vs. duration for (a) 2-6 hour data, and (b) 6-24 hour data.

Figure 3: Pushing the boundaries of reasonable sky view conditions in the field: (a) TS486, (b) SS4115, and (c) MM3634.

Cumulative distribution

The cumulative distribution allows us to quantify the percentage of AUSPOS solutions meeting a particular PU threshold. Figure 4 visualises the cumulative distribution in regards to HPU and VPU for the 2-6 hour and 6-24 hour datasets, indicating the relationship between uncertainty and reliability achievable with AUSPOS.

The reader can use these graphs as a simple 'look-up' tool to determine the likelihood of achieving any specified HPU or VPU threshold with 2-6 hour and 6+ hour observation sessions.

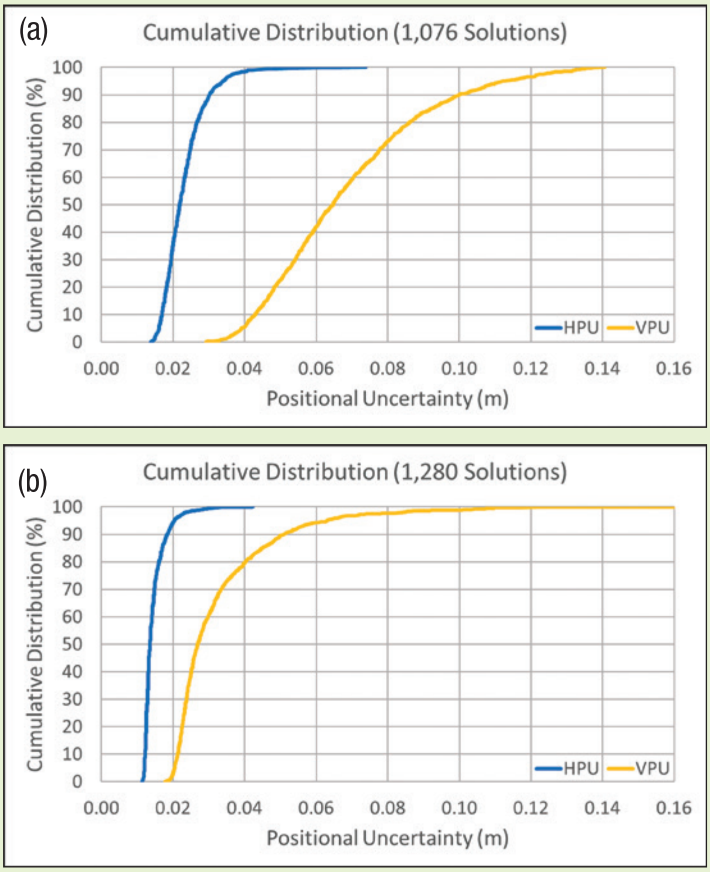

Figure 4: Cumulative distribution of PU for (a) 2-6 hour data, and (b) 6-24 hour data.

Across the entire dataset (2-48 hrs), 70.6% of AUSPOS solutions have HPU values of 0.02 m or better, i.e. these solutions have an absolute reported horizontal accuracy slightly larger than the size of a 50c piece (radius of 16 mm) with respect to the national datum.

This includes 38.6% of the 2-6 hour AUSPOS solutions and 95.2% of the 6-24 hour solutions with HPU values at this level. Similarly, 95.7% of all solutions have HPU values of 0.03 m or better, including 90.8% of the 2-6 hour solutions and 99.5% of the 6-24 hour solutions.

Regarding ellipsoidal height, 61.0% of the AUSPOS solutions have VPU values of 0.05 m or better across the entire dataset. This includes 23.3% of the 2-6 hour AUSPOS solutions and 89.7% of the 6-24 hour solutions with VPU values at this level. Similarly, 71.8% of all solutions have VPU values of 0.06 m or better, including 42.7% of the 2-6 hour solutions and 94.3% of the 6-24 hour solutions.

These results are impressive, remembering that the uncertainties are stated at the 95% confidence level. As expected, a longer observation span improves PU, particularly in the vertical component.

Repeatability

We investigated repeatability by comparing independent reoccupations on the same mark. Where possible, independent pairs of sessions on the same mark were selected for three scenarios: two short sessions (2-6 hrs), one short (2-6 hrs) and one long session (6+ hrs), and two long sessions (6+ hrs).

In each scenario, each session was only paired once. Since it is necessary to consider coordinate differences of opposite signs, the Root Mean Square (RMS) is appropriate to quantify the average agreement in the vertical component.

Table 2 summarises descriptive statistics referring to the horizontal distance between the two AUSPOS solutions, as well as the difference in ellipsoidal height (shorter minus longer session). Figure 5 visualises these results graphically.

Again, it is evident that AUSPOS produces high-quality positioning results with good repeatability. While longer observation sessions improve the precision (repeatability) and reduce the risk of outliers (range), shorter sessions provide suitable results. The median values indicate that no significant offsets caused by possible outliers are present.

Dataset	Statistic	Diff in Hz	Diff in EHGT
Short sessions: 145 pairs	**Min.**	0.001	-0.079
	Max.	0.083	0.119
	Range	0.082	0.199
	Median	0.010	0.000
	Mean	0.013	0.000
	STD	0.009	0.026
	RMS	0.016	0.026
Short-long sessions: 75 pairs	**Min.**	0.003	-0.044
	Max.	0.043	0.050
	Range	0.041	0.094
	Median	0.010	0.003
	Mean	0.011	0.000
	STD	0.008	0.021
	RMS	0.015	0.021
Long sessions: 95 pairs	**Min.**	0.001	-0.064
	Max.	0.029	0.072
	Range	0.028	0.137
	Median	0.006	-0.002
	Mean	0.008	-0.002
	STD	0.006	0.019
	RMS	0.010	0.019

Table 2: Descriptive statistics for reoccupied pairs (all values in metres).

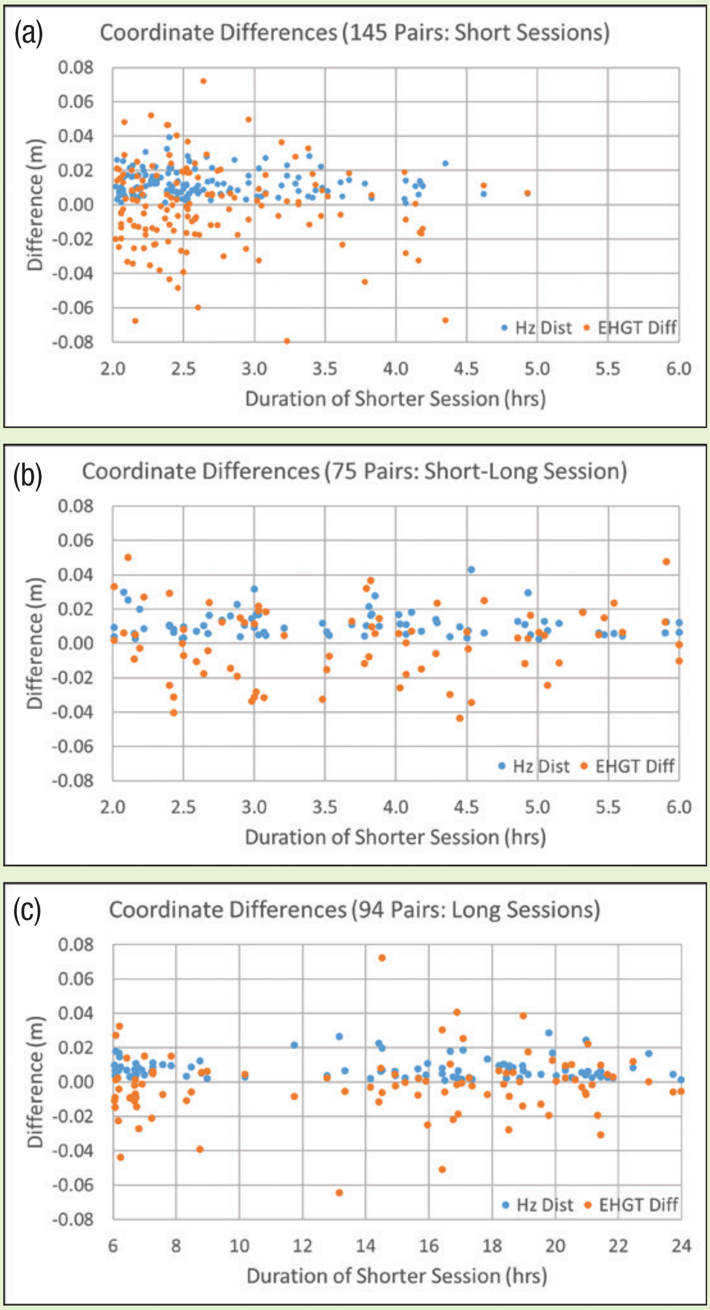

Figure 5: Difference in horizontal and vertical coordinates vs. duration for (a) short-session pairs, (b) short-long-session pairs, and (c) long-session pairs.

TS3663 PANORAMA

In July/August 2019, trigonometrical station TS3663 PANORAMA (located in Bathurst, close to NSW Spatial Services) was occupied 38(!) times, providing an opportunity to investigate the repeatability of AUSPOS solutions on this high-quality, concrete-pillared mark with excellent sky view.

The longest observation session (48 hours) was assumed ground truth, with the AUSPOS results of the shorter sessions being compared against it (Figure 6). The average agreement is 0.006 m ± 0.003 m (1 sigma) in the horizontal component, and the RMS in ellipsoidal height is 0.010 m (1 sigma).

This shows that observation sessions of less than 6 hours in length have high reliability and repeatability under good sky view conditions. A bullseye plot of the difference in horizontal position from the 48-hour solution is shown in Figure 7, providing a spatial perspective and illustrating the high precision of these results.

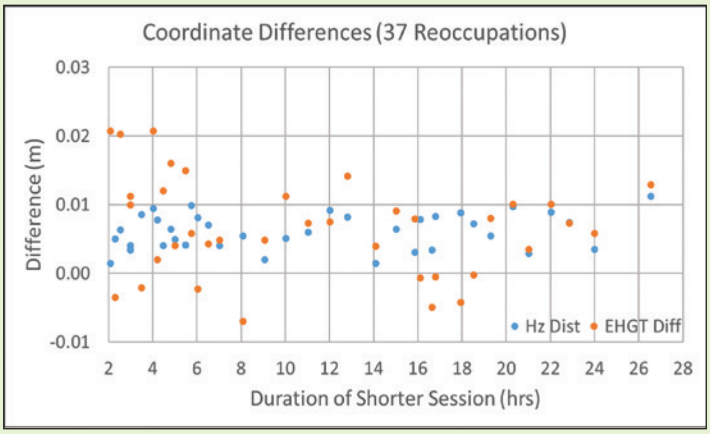

Figure 6: Difference in horizontal and vertical coordinates vs. duration for TS3663 PANORAMA.

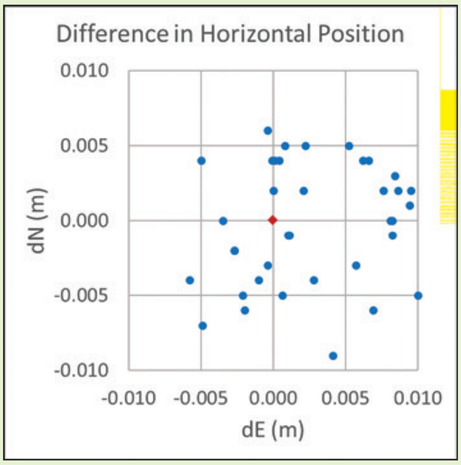

Figure 7: Difference in horizontal position from 48-hour solution for TS3663 PANORAMA (37 reoccupations).

AHD Results

For a subset of marks, we compared the derived AHD height determined by AUSPOS (using AUSGeoid2020) to levelled AHD heights of sufficient quality (class LC or better) on public record in SCIMS, ensuring full independence from the data used to produce AUSGeoid2020.

Table 3 summarises descriptive statistics referring to the difference between the AUSPOS-derived AHD height and the levelled AHD height in SCIMS, as well as the derived AHD-PU provided by AUSPOS. Figure 8 visualises the results for the 2-6 hour and 6-24 hour data.

The AUSPOS solutions are consistent across all marks and observation durations, delivering AHD heights with an RMS of about 0.040 m (1 sigma) or 0.078 m (95% confidence level) and a range of about 0.35 m (-0.20 m to +0.15 m).

The derived AHD-PU reported by AUSPOS appears to be overly conservative for the data investigated, providing a mean AHD-PU of 0.182 m, which is more than double the RMS for the difference to the levelled AHD height at the 95% confidence level (i.e. about 0.078 m).

This can be explained by the conservative AUSGeoid2020 uncertainty grid values applied. The best-case official AUSGeoid2020 uncertainty in NSW is about 0.14 m at the 95% confidence level. It is pleasing to see that AUSPOS provides a much better connection to AHD across NSW than reported.

Dataset	Statistic	Diff to AHD	Derived AHD-PU
Entire subset: 810 solutions	**Min.**	-0.206	0.147
	Max.	0.148	0.251
	Range	0.354	0.104
	Median	-0.012	0.179
	Mean	-0.012	0.182
	STD	0.038	0.016
	RMS	0.040	0.183
2-6 hour data: 394 solutions	**Min.**	-0.201	0.160
	Max.	0.148	0.233
	Range	0.349	0.073
	Median	-0.011	0.180
	Mean	-0.013	0.183
	STD	0.036	0.012
	RMS	0.039	0.183
6-24 hour data: 383 solutions	**Min.**	-0.206	0.147
	Max.	0.104	0.251
	Range	0.310	0.104
	Median	-0.011	0.175
	Mean	-0.010	0.181
	STD	0.040	0.019
	RMS	0.041	0.182

Table 3: Descriptive statistics for AHD analysis, considering levelled marks only (all values in metres).

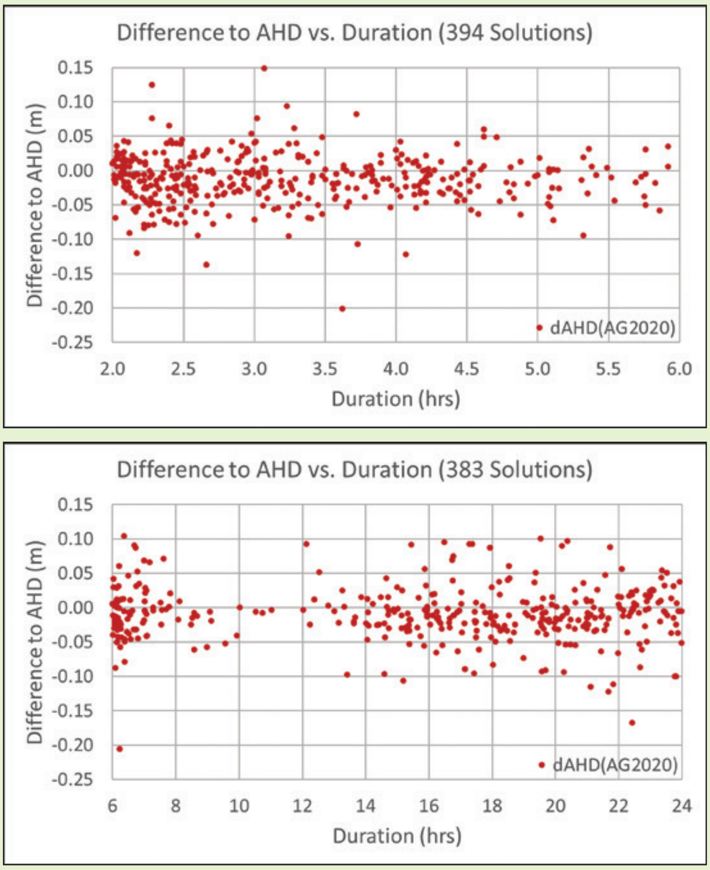

Figure 8: Agreement to levelled AHD vs. duration for (a) 2-6 hour data, and (b) 6-24 hour data.

Conclusion

In NSW, AUSPOS routinely delivers PU values of 0.02-0.03 m (horizontal) and 0.05-0.06 m (vertical). PU is substantially improved by increasing the observation length from 2 hours to 4-5 hours. Observation sessions exceeding 12 hours provide much higher quality in ellipsoidal height.

AUSPOS results have a high degree of predictability and repeatability throughout the State at sites with good sky view, over at least the last 5 years. At sites with tree cover, acceptable HPU and ellipsoidal heights with a VPU of better than 0.1 m can be achieved.

The derived AHD-PU values reported by AUSPOS appear to be overly conservative for the data investigated (0.18 m reported vs. 0.08 m presented here). This is due to the conservative AUSGeoid2020 uncertainty grid values applied by AUSPOS.

These results demonstrate that AUSPOS is a very handy tool to have in your toolbox and another alternative to establish, propagate and strengthen the NSW Survey Control Network. The profession is encouraged to contribute to these datum modernisation efforts by submitting suitable data to NSW Spatial Services via our online collection tool.

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