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Updating SCIMS with DEM-Sourced AHD Heights Across NSW

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ABSTRACT

The Survey Control Information Management System (SCIMS) is the state's database containing more than 250,000 survey marks on public record across NSW. It was recently updated with Australian Height Datum (AHD) heights (at Class U) sourced from a state-wide Digital Elevation Model (DEM) for 127,154 survey marks with existing Class U or null AHD height values. This allowed 18,854 survey marks to be assigned an AHD height for the first time, while 100 gross AHD height errors in SCIMS were identified and corrected. The updated AHD heights are displayed in SCIMS to the nearest metre and provide important benefits for industry, such as enabling the calculation and reporting through SCIMS of the Combined Scale Factor (CSF), the derivation of GDA2020 ellipsoidal height values at virtually all survey marks in NSW and supporting the readjustment of legacy terrestrial data in the growing GDA2020 state adjustment to further improve user access to survey information. DCS Spatial Services provides a DEM for all of NSW with a vertical uncertainty of ±0.9 m at the 95% confidence level and a horizontal grid density of 5 m. While it has been available through Geoscience Australia's Elevation Information System (ELVIS) as 2 km x 2 km data tiles for some time, the DEM can now be queried directly through a publicly accessible Application Programming Interface (API) to return an AHD height at a specified location. This paper outlines how this new interface has been used to query the coordinates of all marks in SCIMS to retrieve AHD heights from the elevation model, assess the accuracy of these AHD heights by comparison to SCIMS, and update SCIMS with DEM-sourced heights for survey marks with existing Class U or null AHD height values to yield a homogeneous dataset of known provenance and verifiable quality across NSW.

KEYWORDS: *Australian Height Datum (AHD), Digital Elevation Model (DEM), Survey Control Information Management System (SCIMS), datum modernisation.*

1 INTRODUCTION

As surveyors, we know that height and elevation data is crucial for a vast number of applications and that the survey control we provide underpins this data. At a national level, the Elevation and Depth 2030 strategy aims to achieve consistent nationwide digital elevation and depth models that people can interrogate with other information to make informed decisions for the betterment of our community, e.g. to better understand the dynamics of our environment, make sense of uncertainty, and provide a basis for community safety, economic growth and sustainable living (ICSM, 2018).

DCS Spatial Services, a business unit of the NSW Department of Customer Service (DCS), provides various imagery and elevation products as part of its ongoing custodial responsibilities regarding the NSW Foundation Spatial Data Framework (DCS Spatial Services, 2018). Accurate and reliable orthorectified aerial imagery and high-resolution elevation data is critical to effective planning, decision making, change monitoring and risk mitigation across NSW and is utilised by government, industry and the community. Reliable and quality-assured survey control is fundamental to ensuring the integrity of this data, which contributes significantly to economic, social and environmental sustainability in NSW. In this context, it is helpful to clarify the terminology used in this paper: A Digital Elevation Model (DEM) represents the bare-earth surface void of all natural and built features, while a Digital Surface Model (DSM) captures both the natural and built/artificial features of the environment (i.e. including the top of vegetation and buildings).

Survey accurate control and quality assurance underpins each of these imagery and elevation products. As such, the Imagery and Elevation program and project work conducted by the Survey Operations team at DCS Spatial Services supports the following (Powell, 2017):

- Digital Image Acquisition System (DIAS) program, which captures high-resolution 50 cm Ground Sample Distance (GSD) aerial imagery state-wide.
- Digital Town Imagery Capture (DTIC) program, which captures high-resolution 10 cm GSD aerial imagery over cities, towns and villages throughout NSW.
- Light Detection and Ranging (LiDAR) program, which captures highly accurate elevation data in high-risk areas across NSW.
- Surface Model Enhancement (SME) project (2014-19), which utilised a variety of technology including aerial imagery and LiDAR to create a high-resolution, state-wide DSM.

One of the products provided by DCS Spatial Services is a state-wide DEM with a vertical uncertainty of ±0.9 m at the 95% confidence level (CL) and a horizontal grid density of 5 m. It was produced by a combination of category 1 LiDAR, category 3 LiDAR, 10 cm ground resolution imagery and 50 cm ground resolution imagery. While it has been available through Geoscience Australia's Elevation Information System (ELVIS – see GA, 2022a) as 2 km x 2 km data tiles for some time, the DEM can now be queried directly through a new publicly accessible Application Programming Interface (API) to return an Australian Height Datum (AHD – see Roelse et al., 1971; Janssen and McElroy, 2021) height at a specified location (DCS Spatial Services, 2022). An API is essentially a connection between computers or between computer programs, i.e. a software interface offering a service to other pieces of software, which is extremely useful when dealing with large amounts of data and/or machine-to-machine processes.

This paper outlines how this new API has been used to query the coordinates of all marks in the Survey Control Information Management System (SCIMS), the state's database containing more than 250,000 survey marks on public record, to retrieve AHD heights from the elevation model, assess the accuracy of these AHD heights by comparison to SCIMS, and update SCIMS with DEM-sourced heights for survey marks with existing Class U or null AHD height values to yield a homogeneous dataset of known provenance and verifiable quality across NSW.

2 AHD HEIGHT RETRIEVAL FROM THE DEM VIA API

In May 2021, AHD heights from the state-wide DEM were extracted via an in-house developed Python script using a publicly available API called 'public/NSW_5M_Elevation', hosted by DCS Spatial Services on the NSW Spatial Information Exchange (SIX) platform (DCS Spatial Services, 2022). In order to obtain a sufficiently large dataset for evaluation of the accuracy of the returned data, *every* survey mark in SCIMS (including witness marks, destroyed marks and interstate marks along the borders) was submitted to the API for a height retrieval. This included 301,200 survey marks at the time, using the marks' horizontal position in the Geocentric Datum of Australia 2020 (GDA2020 – see ICSM, 2022) for interrogation.

Due to the enormous number of queries required, and to prevent overload of the server, the submission data was separated into sets of 50 marks for asynchronous retrieval, with a wait timer introduced between sets. Retrieval was an iterative process, as failure rates for the server's identify function were as high as 50% of the submitted set at times (likely caused in part by inferior internet connections while working from home during the COVID-19 pandemic). Failed retrievals were re-added to the submission set for the next iteration and automatically resubmitted until completion. This process took approximately 8 days of continuous processor time.

It was found that 872 of the submitted positions returned no data, with 46 of these located on Lord Howe Island (which is not covered by this DEM nor *true* AHD). The remainder (apart from a few anomalies) were located along the Queensland, South Australian and Victorian borders. Closer inspection revealed that all these locations were outside the extent of the DEM (too far into the neighbouring states), noting that SCIMS includes several interstate survey marks close to the NSW border and that the Australian Capital Territory is entirely covered by the DEM.

3 QUALITY ASSESSMENT OF THE DEM ACROSS NSW

3.1 Comparison to SCIMS

For quality assurance, the lower-accuracy AHD heights retrieved from the DEM were compared to existing high-accuracy AHD heights of survey marks on public record in SCIMS that satisfied the following criteria:

- Established (Class D or better) horizontal GDA2020 coordinates.
- Accurate (Class B/LD or better) AHD height.
- Mark at or near ground level (no towers, fence posts, pillars, cairns, reference trees etc.).

The prerequisite for established horizontal coordinates at each survey mark is equally as important as an accurate AHD height, as local terrain undulations can quickly alter the height returned from the DEM. Similarly, selecting marks that are not on the natural surface (above or below ground) renders the comparison invalid. In this instance, 34% of the survey marks in SCIMS (102,437 of 300,328 that returned heights) met the required criteria to be included in the comparison.

Figure 1 illustrates the distribution of these survey marks across the state, while Figure 2 shows those in Greater Sydney. The threshold for a successful comparison was set at ±0.9 m, which is the quoted vertical uncertainty of the DEM (95% CL). It was found that the calculated height differences between the DEM and SCIMS were within this threshold for 95,866 survey marks, i.e. 93.6% of the comparison set (indicated in blue in Figures 1 & 2).

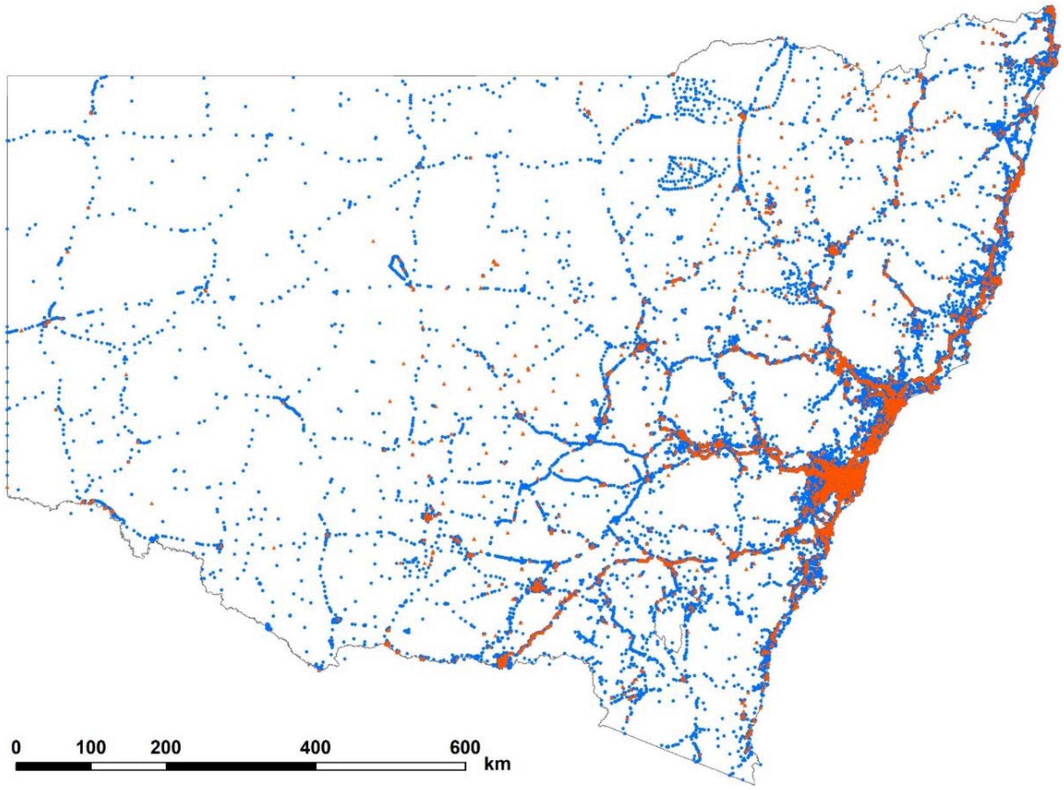

Figure 1: Location of 102,437 SCIMS marks used to assess the quality of the DEM across NSW, with those meeting the ±0.9 m threshold indicated in blue.

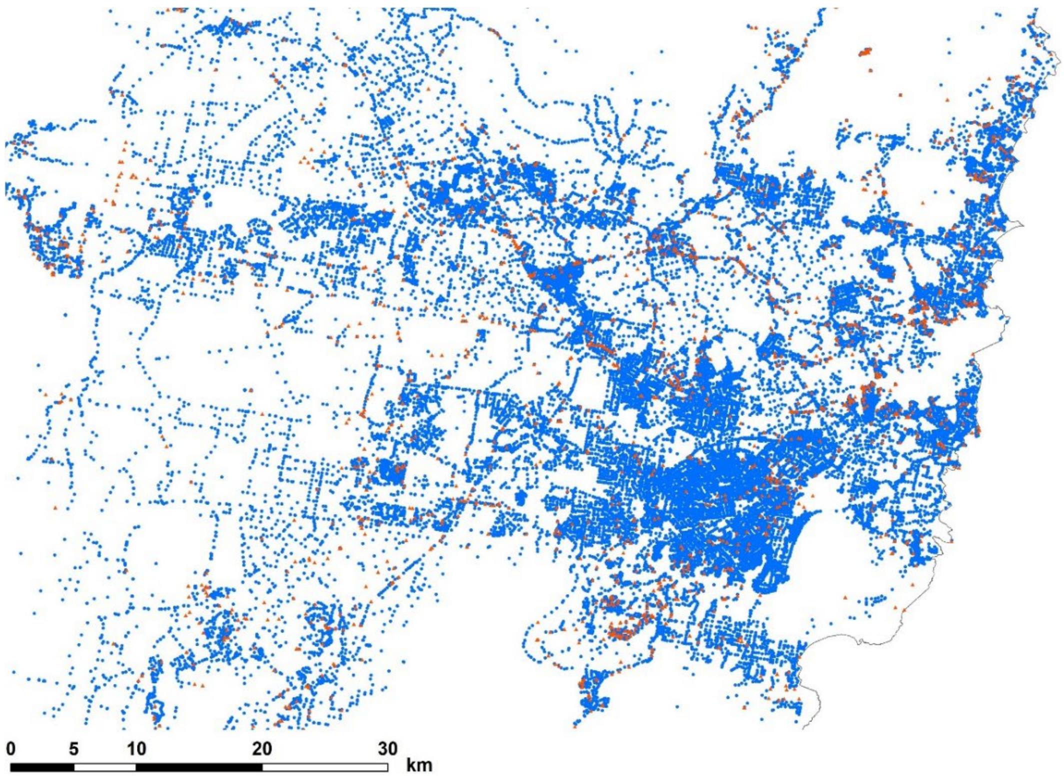

Figure 2: Location of SCIMS marks used to assess the quality of the DEM across Greater Sydney, with those meeting the ±0.9 m threshold indicated in blue.

The obtained pass rate of 93.6% is slightly lower than the quoted vertical uncertainty of the model (95%), which can be attributed to two main reasons:

- The comparison did not consider the vertical position of the survey mark above or below ground level at all survey marks, which typically amounts to up to 0.2 m in either direction for an appropriately placed mark. Accounting for this issue was deemed unnecessary as the result was fit-for-purpose and mark-to-ground-level information was only available for 3.7% of the marks included in the comparison set.
- The horizontal density of the DEM is 5 m, so AHD heights at survey marks located on undulating terrain may show some discrepancy, depending on the position of the mark relative to the sample points of the model (which are used to interpolate the height at the desired position).

For at least the last five years, DCS Spatial Services has recorded the mark-to-ground-level offset at each survey mark occupied or inspected as part of normal field operations. To examine the effect of including such metadata, the analysis was repeated for those 3,849 survey marks in the comparison set with available mark-to-ground-level information. This smaller sample exhibited a pass rate of 97.1% when the mark-to-ground-level correction was applied and a 96.2% pass rate when it was ignored. In combination with the earlier analysis, this result was deemed fit-for-purpose, confirming the stated DEM uncertainty.

It is also worth noting that 960 (14.6%) of the 6,571 marks that failed to meet the ±0.9 m threshold (indicated in orange in Figures 1 & 2) are located within 20 m of the centreline of a major highway or motorway. This can be explained by rapid changes in topography often occurring across the cross-section of the road corridor, including embankments and cuttings. Furthermore, some of these roads are extremely steep, such as the Great Western Highway between Penrith and Glenbrook. Finally, 1,082 (16.5%) of all the marks failing to meet the threshold are specified as ‘destroyed’ in SCIMS, indicating that their AHD height may relate to a time prior to road or other construction earthworks altering the topography.

3.2 Comparison to Independent DEM

Following initial height retrieval, it was noted that the DEM returned an AHD height that was significantly different (> 20 m, e.g. a typical contour) from the value in SCIMS for 787 survey marks with an existing Class U AHD height on public record. This was investigated by querying Geoscience Australia’s 1-second Shuttle Radar Topography Mission (SRTM) DEM for the entire dataset via another API (GA, 2022b). The two DEMs were compared to each other and to SCIMS. Wherever the NSW DEM value differed from SCIMS by more than 10 m (i.e. in 4,690 cases), the 3-way comparison was recorded.

Any AHD height difference exceeding 20 m between the two DEMs was then manually investigated, resulting in 45 of 108 marks (41.7%) to be identified for exclusion from the SCIMS update (see section 4). All these excluded marks were located where an open pit mine had subsequently been created. Any other large differences between the two DEMs were a result of the coarser resolution of the SRTM DEM (1 arcsecond equates to approximately 30 m), e.g. for Trigonometric Station (TS) pillars located on the side of a cliff, the SRTM DEM sometimes returned the height partway down the cliff. Most remaining large differences between the NSW DEM and SCIMS appeared to be the result of transcription errors in the SCIMS height (e.g. 1,000 m instead of 100 m) or rounding to the nearest contour when the heights were initially entered into SCIMS.

4 IMPLEMENTATION OF DEM-SOURCED AHD HEIGHTS IN SCIMS

Reliable and quality-assured survey control is fundamental to ensure the integrity of the imagery and elevation products delivered by DCS Spatial Services (Powell, 2017). However, this connection can work both ways as these products can then be used to improve survey control information on public record in SCIMS. In this case, suitable DEM-sourced AHD heights were used to update SCIMS with these values (at Class U) to yield a homogeneous dataset of known provenance and verifiable quality across NSW. This essentially improved approximate AHD height values in SCIMS that were initially obtained from the nearest contour on 1:25,000, 1:50,000 and 1:100,000 topographic maps to DEM-sourced values with sub-metre uncertainty. Displaying these AHD values to the nearest metre in SCIMS (Class U resolution) fits well with their 0.9 m uncertainty.

4.1 SCIMS Update

Noting the uncertainty of the state-wide DEM product, survey marks were only selected for AHD height update if they met one of the following two criteria:

- The existing AHD height in SCIMS was null.
- The existing AHD height in SCIMS was Class U.

Furthermore, it is important to consider that SCIMS holds records for a wide range of different monument types. A location descriptor also indicates whether the mark was placed in the ground or on a structure. As such, further filtering was applied to limit the height update to only those marks that are likely to be at (or near) ground level. Consequently, several monument types (Table 1) and mark location descriptions (Table 2) were excluded from the update. As an additional precaution, any TS whose name includes the word 'TOWER' was also excluded from the update.

Table 1: Monument types excluded from the SCIMS update.

AERIAL	FIRE TOWER	OBELISK	RESERVOIR
BEACON LIGHT	LIGHTHOUSE	RADAR TOWER	SPIRE
CHIMNEY	LIGHTNING ROD	RADIO MAST	TOWER
FLAGSTAFF	MAST	RADIO TOWER	WIND VANE

Table 2: Mark locations excluded from the SCIMS update.

BUILDING OR STRUCTURE
SILO
OTHER STRUCTURE

It should be noted that RESERVOIR OR TANK should also have been included on the list of mark locations to be excluded in Table 2 but was unfortunately missed. This resulted in 30 trigonometric stations located on reservoirs incorrectly receiving a height at ground level. These will be revisited and corrected during the next 6-monthly GDA2020 SCIMS refresh in June 2022.

Once the update set had been filtered in this way and before the SCIMS update was executed in May 2021, a final test was performed to check for trends. In general, it was found that the data was normally distributed and 99.3% of the AHD heights included in the update were within 20 m of their existing SCIMS values (Figure 3). A 20 m error in height corresponds to approximately a 3 parts per million (ppm) error in the reduction of ground distances to the ellipsoid between two marks, which was deemed acceptable and fit-for-purpose.

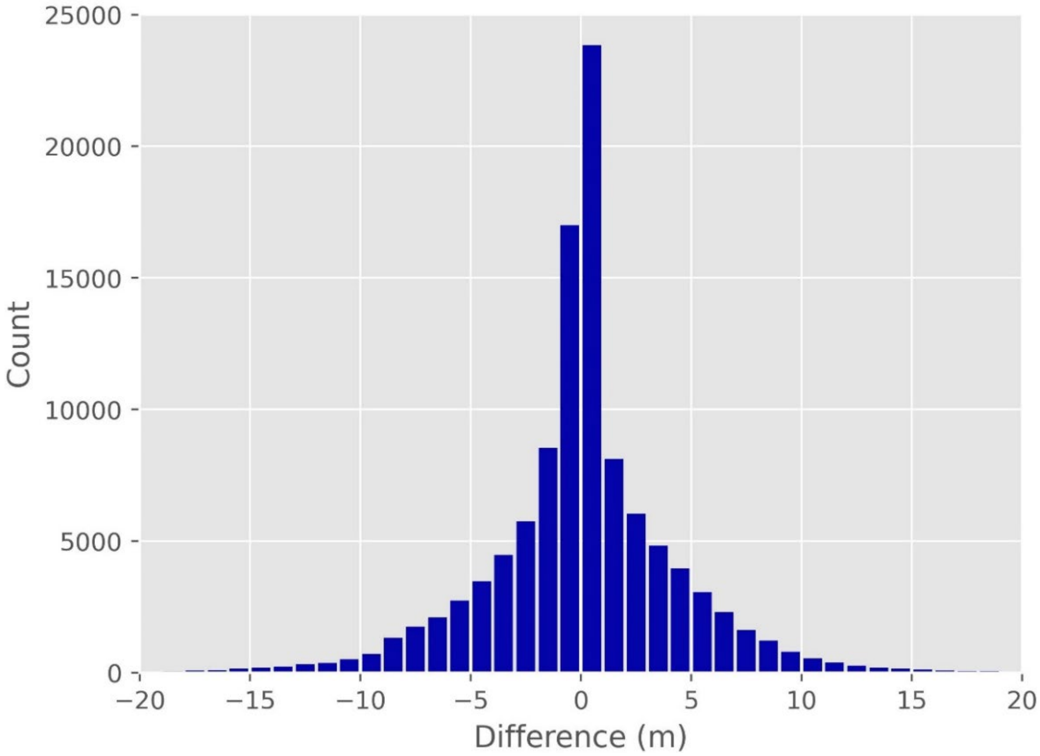

Figure 3: Histogram of the difference between DEM-sourced AHD height and existing AHD height in SCIMS (723 outliers exceeding ±20 m not shown).

Height differences larger than 20 m were generally attributed to either of the following two reasons (see section 3.2):

- Transcription or rounding errors in the existing SCIMS value (corrected by the update).
- Marks located where an open pit mine had subsequently been created (excluded from the update with mark status updated in SCIMS as 'destroyed').

4.2 Results and Benefits

The May 2021 SCIMS update resulted in the provision of DEM-sourced AHD heights at Class U for 127,154 survey marks, of which 18,854 marks (14.8%) were assigned an AHD height for the first time (Figure 4). Putting this large number into perspective, this means that 42.3% of the survey marks that returned a DEM-sourced AHD height during the initial retrieval were updated during this process – a huge improvement in the access to reliable, approximate AHD heights of known quality in SCIMS, ensuring that nearly every survey mark in NSW has an AHD value of 0.9 m uncertainty or better.

When inspecting Figure 4, it is worth noting the near-perfect straight line of AHD height updates to survey marks running from north-west to south-east through the centre of the state. Despite appearing to be an artefact, this is actually a series of marks located along a gas pipeline easement, which connects to the main distribution network on the east coast.

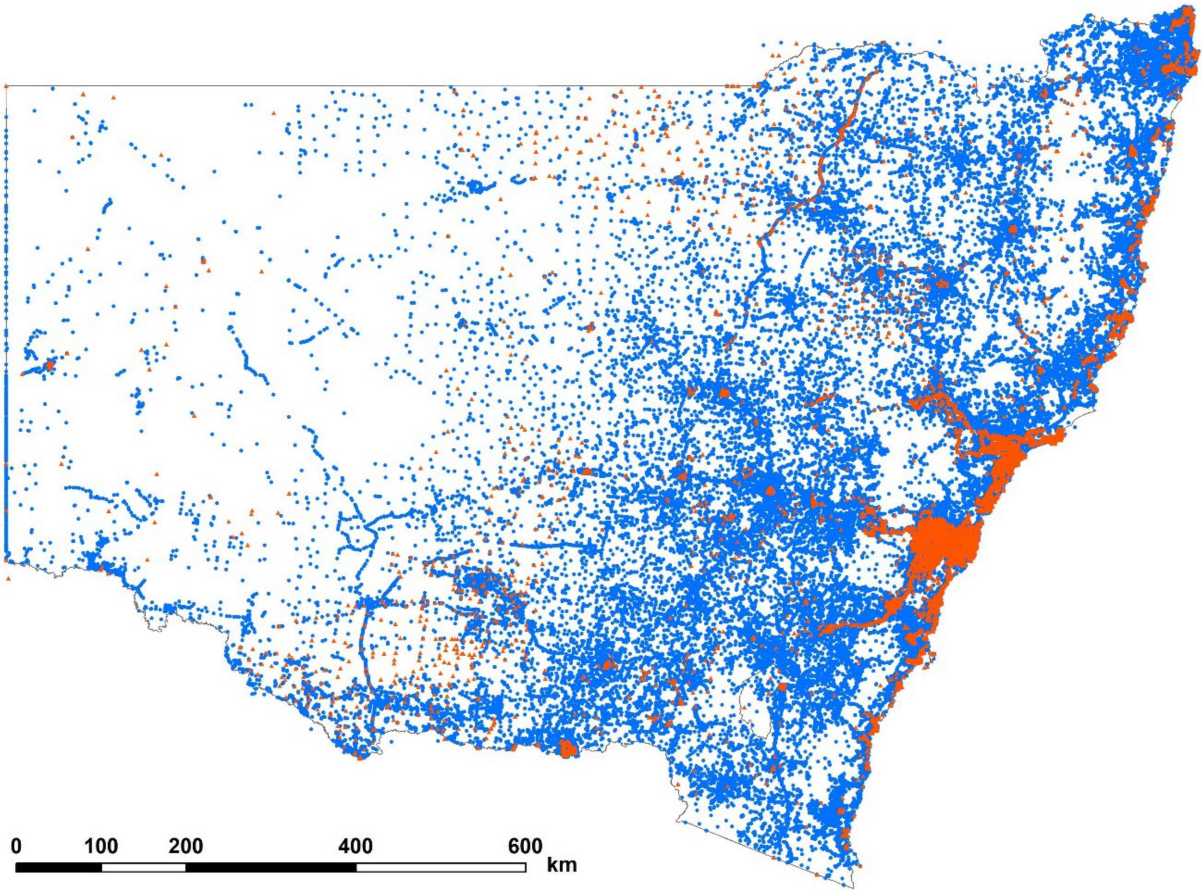

Figure 4: Location of survey marks included in the May 2021 SCIMS update, indicating which marks received an AHD height for the first time in orange.

Table 4 summarises descriptive statistics related to the update dataset, showing the minimum, maximum, mean and median differences between the new and existing AHD height in SCIMS along with the resulting standard deviation. The existence of large outliers, as previously discussed, is confirmed by the difference between the mean and median values.

Table 4: Descriptive statistics of the difference between DEM-sourced and existing AHD height in SCIMS for the update dataset (723 outliers exceeding ±20 m were excluded from the calculation of the standard deviation).

Minimum (m)	-964.725
Maximum (m)	1022.783
Mean (m)	0.185
Median (m)	0.013
Std Dev (m)	4.228

These updated AHD heights provide several important benefits across the state such as enabling the better calculation and reporting of the Combined Scale Factor (CSF) with confidence at virtually all survey marks (99.98%) in NSW through SCIMS. CSFs are now typically up to 1.5 ppm better because heights have been improved from 10-metre to sub-metre accuracy. The DEM-sourced AHD heights also support datum modernisation efforts through the ongoing readjustment of legacy terrestrial data hosted by DCS Spatial Services for inclusion in the growing GDA2020 state adjustment by facilitating the rigorous reduction of terrestrially measured distances to the ellipsoid. This translates into more survey marks in SCIMS being assigned a Positional Uncertainty (PU), directly benefitting our customers.

Furthermore, this process was able to identify and correct 101 extremely large (100-1,000 m) AHD height errors (Class U) in SCIMS. It follows that retrieved DEM-sourced heights can now also be used to identify gross errors on SCIMS marks with existing accurate (Class B/LD or better) AHD heights, further contributing to our 'Saving AHD' efforts, which aim to ensure that users have continued and easy access to reliable physical heights and their uncertainties across NSW (Janssen and McElroy, 2021).

Finally, with SCIMS now holding AHD heights of known quality at virtually all survey marks across the state, ellipsoidal height was derived by applying AUSGeoid2020 (e.g. Brown et al., 2018; Janssen and Watson, 2018; Featherstone et al., 2019) at all applicable survey marks with existing null ellipsoidal height values in SCIMS. During the 6-monthly GDA2020 SCIMS refresh in November 2021, this provided ellipsoidal heights for 267,581 survey marks for the first time, ensuring that virtually all marks in SCIMS now also have an ellipsoidal height. Publishing these values allows surveyors and other users to easily verify that they have set their height datum and/or applied AUSGeoid2020 correctly during both field operations and office processing and reductions.

5 CONCLUDING REMARKS

DCS Spatial Services provides a state-wide DEM to the public with a vertical uncertainty of ±0.9 m (95% CL) and a horizontal grid density of 5 m. This DEM can now be queried directly through a new publicly available API to return an AHD height at a specified location. This paper has described how this new API was used to retrieve AHD heights from the elevation model for about 300,000 survey marks (including witness marks, destroyed marks and interstate marks along the borders) in SCIMS and assess the accuracy of these DEM-sourced AHD heights across NSW by comparison to SCIMS. This revealed that for survey marks at or near ground level, with established GDA2020 coordinates and accurate AHD height, 93.6% of marks showed agreement within ±0.9 m between the DEM and the published SCIMS values (97.1% agreement for a smaller sample considering the mark-to-ground-level correction), thereby confirming the stated DEM uncertainty.

We have then outlined how SCIMS was updated with DEM-sourced heights (at Class U) for 127,154 survey marks with existing Class U or null AHD height values to deliver a homogeneous dataset of known provenance and verifiable quality across NSW. This process allowed 18,854 survey marks to be assigned an AHD height for the first time, ensuring that virtually all survey marks in SCIMS now include an AHD height value, while many gross AHD height errors in SCIMS were identified and corrected. The updated AHD heights provide important benefits for industry such as enabling the calculation and reporting of the combined scale factor with confidence (up to 1.5 ppm better) at practically all survey marks in NSW through SCIMS and supporting the readjustment of legacy terrestrial data in the growing GDA2020 state adjustment to further improve user access to survey information. Lastly, ellipsoidal height values were derived using AUSGeoid2020 and published in SCIMS, allowing 267,581 survey marks to receive an ellipsoidal height for the first time and ensuring that virtually all marks in SCIMS now also have an ellipsoidal height.

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