Pushing the Boundaries of AUSPOS Cluster Processing

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ABSTRACT

AUSPOS is Geoscience Australia's free online Global Positioning System (GPS) processing service. Taking advantage of the International GNSS Service (IGS) core network station data and products together with Global Navigation Satellite System (GNSS) Continuously Operating Reference Stations (CORS) in and around Australia, it provides precise coordinates and their uncertainties based on static dual-frequency GPS carrier phase and code data submitted by the user in Receiver Independent Exchange (RINEX) format. AUSPOS data can be submitted and processed either individually (mark by mark) or collectively (in groups of concurrent observations). In the first case, the data collected at one mark is processed relative to the surrounding CORS network with no direct relationship to any other rover that was operating at the same time. In the second case, the data collected at several marks is processed together in a cluster, considering that the multiple data files were observed during the same time window and are thus correlated. Processing therefore includes baselines between the user sites, in theory providing a stronger relative connection. This paper investigates the quality of user-submitted positioning results from AUSPOS when the observation data is submitted individually as single-mark sessions versus when submitted as a cluster of several concurrently observed marks. Based on AUSPOS processing of about 3,000 observation files and 900 clusters of varying size across NSW, it is found that the AUSPOS positioning results do not significantly differ between single and cluster mode. Cluster processing also does not show any significant improvement in relative uncertainty between user-submitted stations, which is likely due to the decorrelating effect of constraining the AUSPOS reference stations.

KEYWORDS: *AUSPOS, cluster processing, uncertainty, GDA2020, datum modernisation.*

1 INTRODUCTION

Geoscience Australia's free online Global Positioning System (GPS) processing service, AUSPOS, was developed to provide an online positioning service based on Continuously Operating Reference Stations (CORS) primarily for Australian users, although it can process data collected anywhere on Earth (GA, 2024a). Initially released in 2000, it remains GPS-only and has been frequently upgraded to incorporate improvements. The current version 2.4 was released in August 2020, running in the Amazon Web Services (AWS) cloud environment with scalability and reliability (rather than on physical servers) to accommodate the increasing usage of AUSPOS. It delivers results in both the Geocentric Datum of Australia 2020 (GDA2020 – see Harrison et al., 2023) and its predecessor GDA94, as well as the International Terrestrial

Reference Frame 2014 (ITRF2014 – see Altamimi et al., 2016), along with derived heights in the Australian Height Datum (AHD – see Janssen and McElroy, 2021). Following the recent release of ITRF2020 (Altamimi et al., 2023), a new version of AUSPOS is planned to be released soon.

AUSPOS takes advantage of the International GNSS Service (IGS) core network station data and products (e.g. final, rapid or ultra-rapid orbits depending on availability – see IGS, 2024a) together with CORS in and around Australia to compute precise coordinates, using static dual-frequency GPS carrier phase and code data of at least 1 hour duration (recommended minimum of 2 hours, maximum of 7 consecutive days). When submitting 30-second Receiver Independent Exchange (RINEX – see IGS, 2024b; Janssen, 2024) data, users are required to specify the antenna type (using the IGS naming convention) and the vertically measured antenna height from the ground mark to the Antenna Reference Point (ARP). Following processing, an AUSPOS report (pdf) is emailed to the user (generally within a few minutes), which includes the computed coordinates and their uncertainties, ambiguity resolution statistics, and an overview of the GPS processing strategy applied. For advanced users, Solution Independent Exchange (SINEX) files (IERS, 2006) containing more detailed information are also available for download. A practical guide to AUSPOS can be found in Janssen and McElroy (2022).

DCS Spatial Services, a unit of the NSW Department of Customer Service (DCS), is responsible for the maintenance and improvement of the state's survey control network, which comprises more than 250,000 survey marks on public record made available via the Survey Control Information Management System (SCIMS). The backbone of the NSW survey control network is delivered by CORSnet-NSW, Australia's largest state-owned and operated Global Navigation Satellite System (GNSS) CORS network. CORSnet-NSW currently consists of 209 stations, providing fundamental positioning infrastructure that is authoritative, accurate, reliable and easy-to-use for a wide range of applications (e.g. Janssen et al., 2016; DCS Spatial Services, 2024a), thereby also representing a fundamental, high-density and long-term component of AUSPOS infrastructure. All CORSnet-NSW sites are part of the Asia-Pacific Reference Frame (APREF – see GA, 2024b), including 13 concrete-pillared NSW stations incorporated in the IGS network, and subject to the Regulation 13 certification process providing legal traceability with respect to the Recognised-Value Standard (RVS) of measurement of position in Australia (Hu and Dawson, 2020).

AUSPOS data can be submitted and processed either individually (mark by mark) or collectively (in groups of concurrent observations). In the first case, the data collected at one mark is processed relative to the surrounding CORS network with no direct relationship to any other rover that was operating at the same time. In the second case, the data collected at several marks is processed together in a cluster, considering that the multiple data files were observed during the same time window and are thus correlated. Processing therefore includes shorter baselines between the user sites, in theory providing a stronger relative connection. However, the effect of AUSPOS cluster processing has not yet been thoroughly tested and quantified.

This paper aims to fill this knowledge gap by leveraging the extensive GNSS observation datasets held by DCS Spatial Services. Based on about 3,000 observation files and 900 clusters of varying size across NSW, it evaluates any performance benefit offered by cluster processing through AUSPOS.

2 BACKGROUND

2.1 Using AUSPOS for Datum Modernisation in NSW

Datum modernisation and further improvement of survey infrastructure is required to accommodate the increasing accuracy and improved spatial and temporal resolution available from modern positioning technologies to an ever-broadening user base. With all CORSnet-NSW stations contributing to the AUSPOS service, it delivers high-quality positioning results even for shorter observation sessions of at least 2 hours across NSW, provided sky view conditions are reasonable (Janssen and McElroy, 2020). Consequently, in some situations, the use of AUSPOS campaigns has developed into a capable and reliable alternative to conducting traditional static GNSS baseline surveys, simplifying field work logistics and providing significant time savings in processing, adjustment and survey report writing. AUSPOS also forms a new and fundamental component of vertical datum modernisation across the state and enables propagation of the Australian Vertical Working Surface (AVWS – see ICSM, 2021; Janssen and McElroy, 2021) via its GDA2020 ellipsoidal heights.

Over recent years, DCS Spatial Services has observed new high-quality GNSS measurements to connect the existing survey network to CORS (Gowans and Grinter, 2013) and systematically rationalised, maintained, upgraded and collected AUSPOS datasets at key sites across the NSW survey control network, including trigonometrical (trig) stations and AHD spirit-levelled marks (Gowans et al., 2015; Janssen and McElroy, 2021). The desired end state is that a network of fundamental AUSPOS-observed survey marks is established at a 10 km density across the eastern and central divisions of the state, ensuring users are always within 5 km (as the crow flies), and often much less, of a fundamental AUSPOS point providing a direct link to datum.

While traditional GNSS baseline surveys continue to be performed and adjusted by DCS Spatial Services, AUSPOS is also increasingly employed to improve the state's survey infrastructure. To this end, AUSPOS data of at least 6 hours duration is used to propagate the datum in NSW via the National GNSS Campaign Archive (NGCA) hosted by Geoscience Australia, while AUSPOS data of 2-6 hours duration strengthens the datum via the state's Jurisdictional Data Archive (JDA). To date, more than 15,000 AUSPOS solutions have been processed to help maintain and improve the NSW survey control network.

The surveying profession is encouraged to contribute to the maintenance of the NSW survey control network and the timely update of survey information in SCIMS by submitting suitable industry-observed AUSPOS datasets of at least 2 hours duration and related metadata via the DCS Spatial Services Customer Hub on our website (DCS Spatial Services, 2024b).

2.2 AUSPOS Cluster Processing

Simply put, AUSPOS data can be submitted and processed either individually (mark by mark) or collectively (in groups of concurrent observations). Individual, single-mark AUSPOS processing refers to the data collected at one mark being processed relative to the surrounding CORS network with no direct relationship to any other rover that was operating at the same time.

AUSPOS cluster processing considers that the multiple data files were collected during the same time window and are therefore correlated. Rather than individually connecting each user site to the surrounding CORS network, processing includes baselines between the user sites, which in theory provides a stronger relative connection, provided all user sites are observed in a similar time window and the baselines formed between user sites are less than 20 km in length (Figure 1). AUSPOS first detects which rover observed the longest, and this becomes the hub for the user data (regardless of the relative geometry of all user stations and CORS). In the ideal scenario, baselines are then formed between the hub and the surrounding CORS, while all other rovers are connected to the hub (provided there is sufficient data overlap).

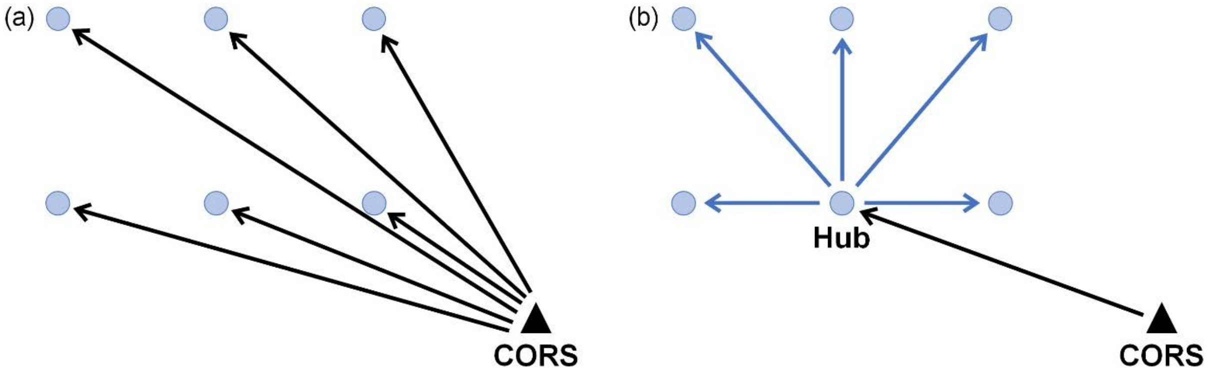

Figure 1: AUSPOS baselines in (a) single mode versus (b) the ideal scenario of cluster mode.

AUSPOS accepts submissions of up to 20 RINEX files in one job, which are then processed together as a cluster, using an observation window that contains the collected data at all sites (between earliest start time and latest end time). Individual observation sessions should overlap by at least 1 hour with respect to the hub, as this overlap is used to compute the baselines between user sites (and the direct L1/L2 ambiguity resolution strategy applied for short baselines is more reliable for data exceeding 1 hour). The baselines in the cluster are formed based on the maximum number of single-difference observations available. If the data overlap of a particular user site with respect to the hub is too short, AUSPOS attempts to compute a baseline to another user site instead (Figure 2a). If this is unsuccessful, a baseline to a CORS is formed, thereby losing the desired relative connection (Figure 2b).

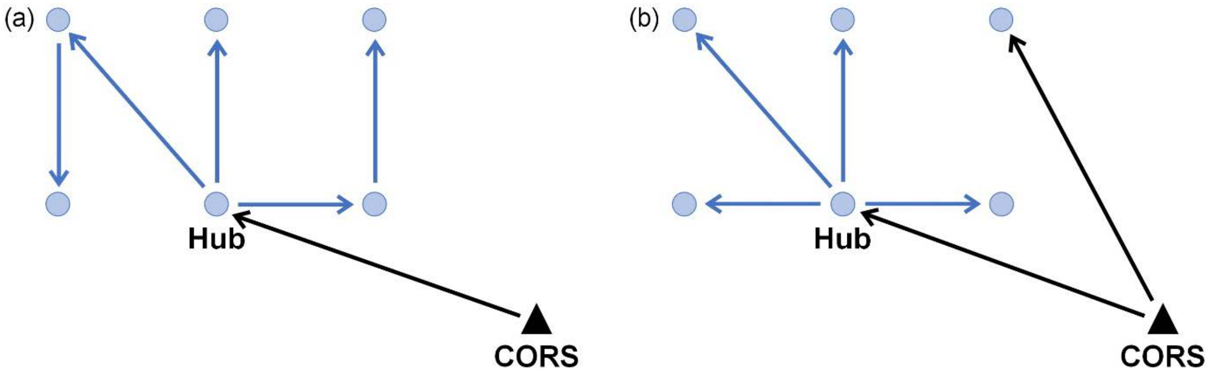

Figure 2: AUSPOS cluster processing with insufficient data overlap relative to the hub, resulting in (a) baselines between user sites not involving the hub and (b) a baseline to a CORS instead.

Figure 3 indicates the strategy used by AUSPOS to estimate the coordinates of the submitted user sites (C. Wang, pers. comm.). It is important to note that AUSPOS performs simultaneous multi-baseline processing, i.e. it combines GPS baseline processing of data collected at several sites in the same time window with a 3D least squares network adjustment before the results are delivered to the user. Commercial off-the-shelf software packages routinely used by industry, including DCS Spatial Services, only mimic this ideal, requiring a 2-step process of single-baseline processing followed by a network adjustment. Even if the user only submits one

RINEX file, AUSPOS still performs simultaneous multi-baseline processing because it uses data from up to 15 CORS. While the traditional 2-step process tends to focus on the delivery of coordinates, simultaneous multi-baseline processing delivers both coordinates and uncertainties, thereby providing better and more realistic uncertainty values.

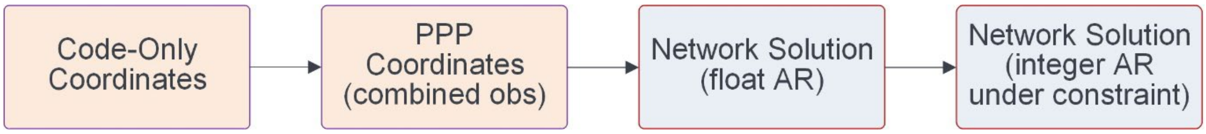

Figure 3: Strategy used by AUSPOS to estimate user coordinates.

Positional Uncertainty (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 datum. It can be separated into Horizontal PU (HPU) for horizontal position and Vertical PU (VPU) for ellipsoidal height. HPU is expressed as the radius of a 95% circle of uncertainty, generally calculated from the standard error ellipse produced by a least squares network adjustment. VPU is a linear quantity and obtained by scaling the standard deviation by 1.96 to convert it to 95% confidence.

AUSPOS calculates PU based on the East, North and ellipsoidal height coordinate uncertainties according to the Guideline for Adjustment and Evaluation of Survey Control, which is part of ICSM's Standard for the Australian Survey Control Network (SP1), version 2.2 (ICSM, 2020). The coordinate uncertainties of the East, North and ellipsoidal height components are scaled using an empirically derived model, which is a function of duration, data quality and geographical location (latitude and CORS density), and expressed at the 95% confidence level (Jia et al., 2016).

3 DATA AND METHODS

3.1 NSW GNSS Data Holdings

As the government agency responsible for the maintenance of the NSW survey control network under the Surveying and Spatial Information Act 2002, DCS Spatial Services maintains a repository of GNSS observation data, known as the NSW GNSS Observation Archive (NGOA). This study leverages such data where the observation duration is at least 2 hours, and the observation has successfully processed through AUSPOS version 2.4 (submitted as RINEX version 2.11).

3.2 Cluster Formation Strategy

Using in-house generated Python code, the NGOA has been interrogated to automatically form clusters based on the following criteria:

- Each observation must have been processed through AUSPOS version 2.4 submitted in single user station mode.
- Each observation may only be used in a single cluster and must not be re-used across separate clusters.
- Each observation within a cluster must have a minimum overlap of at least 2 hours with the longest observation (hub) in the cluster. No minimum overlap between all sessions in the cluster is set.

- Each station within a cluster must be located no further than 10 km (a distance nominated by the authors) from the nearest user-submitted station.
- Clusters must not contain more than 20 user-submitted observations.

This strategy resulted in the formation of 909 clusters of two or more observations using 3,124 of the 5,959 GNSS observation files that met the selection criteria (Table 1).

Table 1: Summary of clusters formed from the NSW GNSS Observation Archive.

Cluster Size	Count	Percentage	Cumulative Percentage
2	465	51.2	51.2
3	173	19.0	70.2
4	102	11.2	81.4
5	42	4.6	86.0
6	40	4.4	90.4
7	19	2.1	92.5
8	21	2.3	94.8
9	14	1.5	96.4
10	7	0.8	97.1
11	10	1.1	98.2
12	8	0.9	99.1
13	4	0.4	99.6
14	1	0.1	99.7
15	1	0.1	99.8
16	1	0.1	99.9
17	1	0.1	100.0
18-20	0	0.0	100.0

3.3 AUSPOS Processing Strategy

Each cluster was processed through AUSPOS, with the resulting AUSPOS report (pdf) and SINEX results being stored for analysis. Of the 909 clusters identified, 5 (0.6%) failed to process through AUSPOS and 199 observations (6.4%) across 131 clusters processed through AUSPOS with warnings of large PU. The failed clusters were discarded without further review, and the observations with large uncertainties were removed from the analysis. This resulted in 2,879 observation files that produced results through single and cluster processing that could be validly compared. Observations receiving large-uncertainty warnings were tallied according to the processing strategy applied and visualised in Venn diagram format, illustrating when a station observation received a warning for large PU: in single mode processing, cluster processing, both, or one and not the other (Figure 4).

This simple analysis shows that clustered solutions are more prone to resulting in large-uncertainty warnings, particularly at user stations with less-than-ideal observing conditions (e.g. poor sky view due to tree cover or other obstructions). This may be due in part to a different ambiguity resolution strategy adopted by AUSPOS with multiple submitted user stations as the baseline lengths within the cluster are shorter than those to the surrounding CORS. The short-distance, direct L1/L2 strategy applied for 0-20 km baselines may not perform as well in tough observing environments as the long-distance Quasi-Ionosphere-Free (QIF) strategy applied for 20-2,000 km baselines.

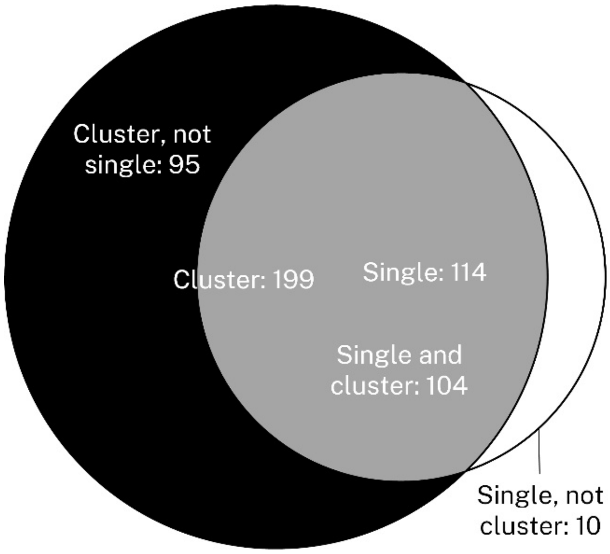

Figure 4: Venn diagram illustrating the number of observations producing warnings for each processing strategy.

Acknowledging the number of observations containing warnings in the AUSPOS report, it is worth noting that even though these observations do not produce centimetre-level positions, they may still be useful for sub-metre applications, e.g. to upgrade survey marks from Class U to Class E coordinates (DCS Spatial Services, 2021; Janssen and McElroy, 2022). Alternatively, the large-uncertainty warning may only be attached to the vertical component of the solution (generally due to a relatively short observation session affected by tree cover), while the horizontal component can still be considered fit-for-purpose. Results of this nature are routinely assessed by DCS Spatial Services on a case-by-case basis. There is further utility in storing such observation data, considering that a result that fails (or produces warnings) today may become acceptable in the future as processing strategies are refined over time.

3.4 Analysis Strategy

Following AUSPOS processing, the quality of results from single-processing and cluster-processing solutions was examined in terms of coordinate changes, derived baselines between user-submitted stations, Positional Uncertainty (PU) and Relative Uncertainty (RU). RU is calculated for a pair of survey marks (based on their PU) and can be separated into Horizontal RU (HRU) for horizontal position and Vertical RU (VRU) for ellipsoidal height.

All coordinates and quality values analysed were adopted from the GDA2020 SINEX files. PU and RU were computed from the variance-covariance matrix and expressed at the 95% confidence level. Horizontal uncertainties were computed as horizontal circular confidence regions according to the Guideline for Adjustment and Evaluation of Survey Control (ICSM, 2020), and vertical uncertainties were multiplied from their one-sigma level by expansion factor 1.96. These computations were performed using the GeodePy Python library (GA, 2024c).

Baselines between user stations were derived through coordinate differences from the SINEX files. Single-solution results were taken from their respective, discrete SINEX files and assumed uncorrelated (i.e. all covariances between stations are zero), while cluster-solution results adopted the relevant inter-station covariances as reported in the SINEX file.

4 RESULTS AND DISCUSSION

The four primary areas of interest (coordinates, derived baselines, PU and RU) show no significant change or improvement when AUSPOS cluster processing is employed. While there are some changes in the extremities of the distributions, these are not considered for further review because this study is looking for a clear trend.

Indeed, the mean and median changes for all coordinate components are less than one millimetre and well within the standard deviation of the distributions (Figure 5). This alone is sufficient to demonstrate that no significant difference is detectable between the two processing strategies based on the data available.

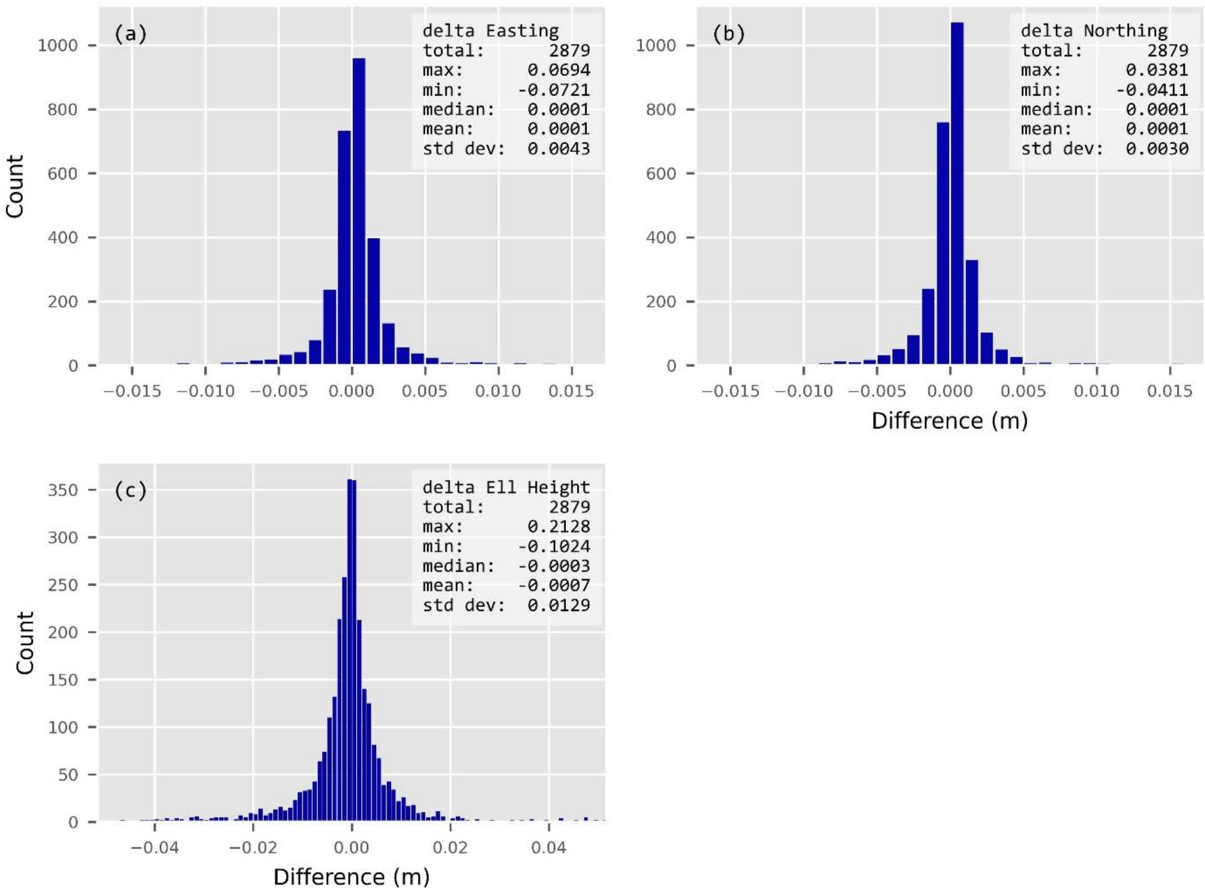

Figure 5: Histograms of GDA2020 coordinate changes in (a) Easting, (b) Northing and (c) ellipsoidal height for each observation. Differences are computed as cluster-solution coordinate minus single-solution coordinate.

Similarly, when baselines are derived between AUSPOS user-submitted stations, the average changes in baseline components are sub-millimetric (Figure 6), showing that even if a clustered solution might have a theoretically superior RU, no appreciable difference is evident in the actual relative positions.

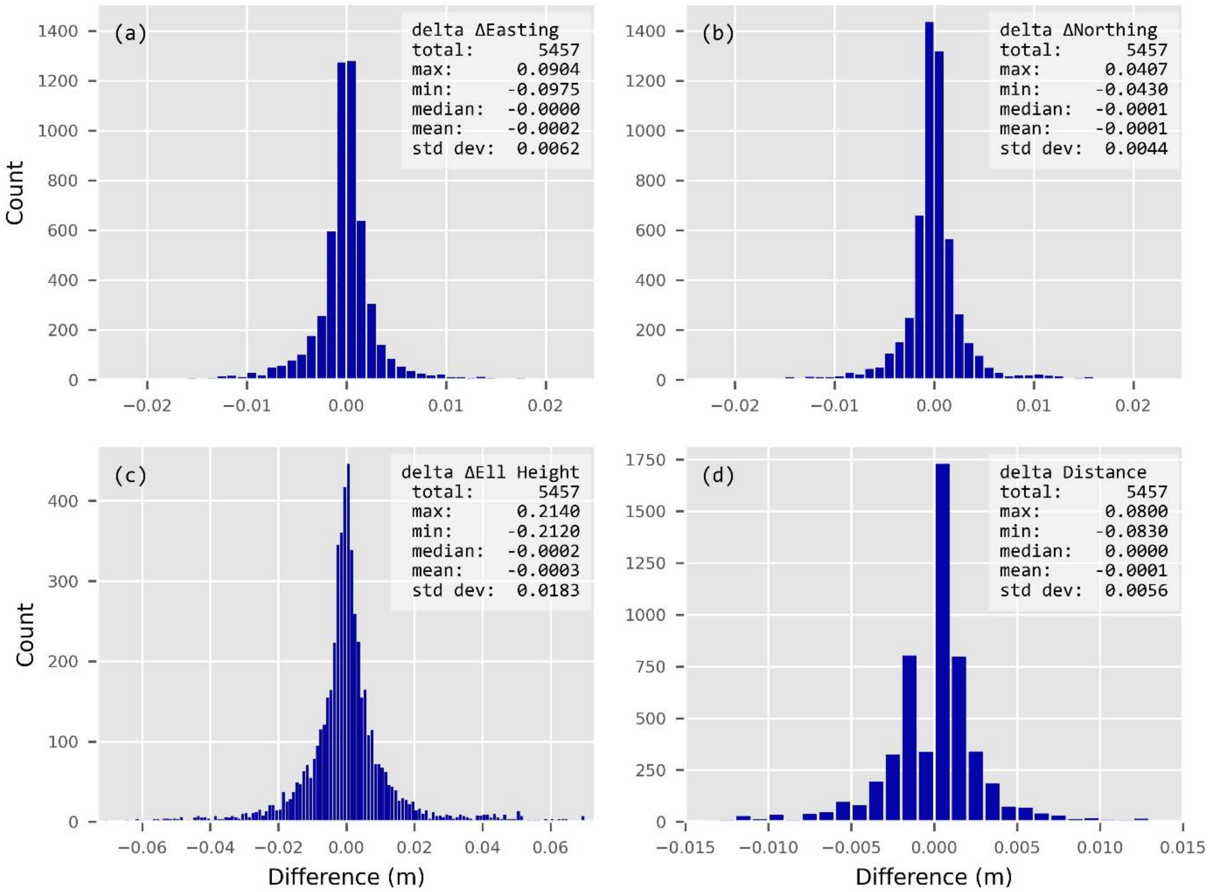

Figure 6: Histograms of derived GDA2020 baseline component changes in (a) Easting, (b) Northing, (c) ellipsoidal height and (d) geodesic distance. Differences are computed as cluster-solution baseline minus single-solution baseline.

For completeness and to quantify the distribution of uncertainty in the datasets investigated, histograms of the obtained GDA2020 PU and RU values for single and cluster solutions are presented in Figures 7 & 8. Inspection confirms the high quality of AUSPOS solutions, and that little change is present between the two processing modes.

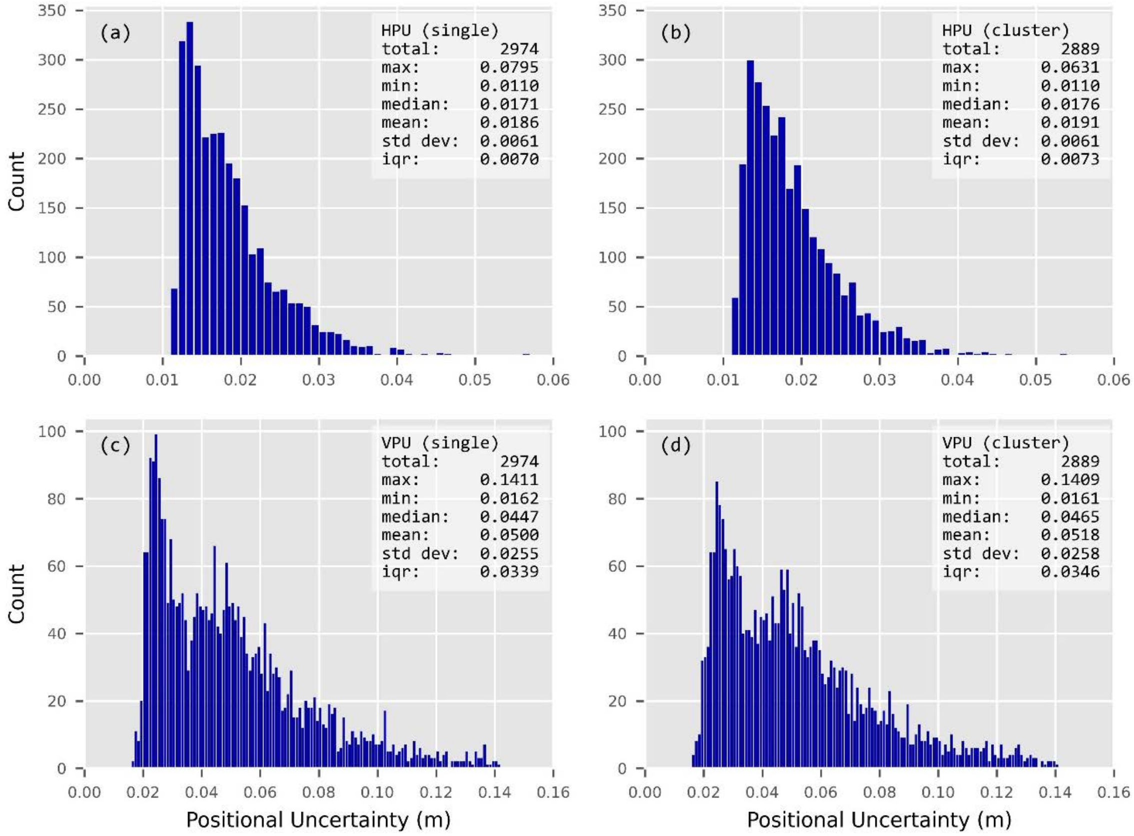

Figure 7: Histograms of GDA2020 (a) HPU in single mode, (b) HPU in cluster mode, (c) VPU in single mode and (d) VPU in cluster mode.

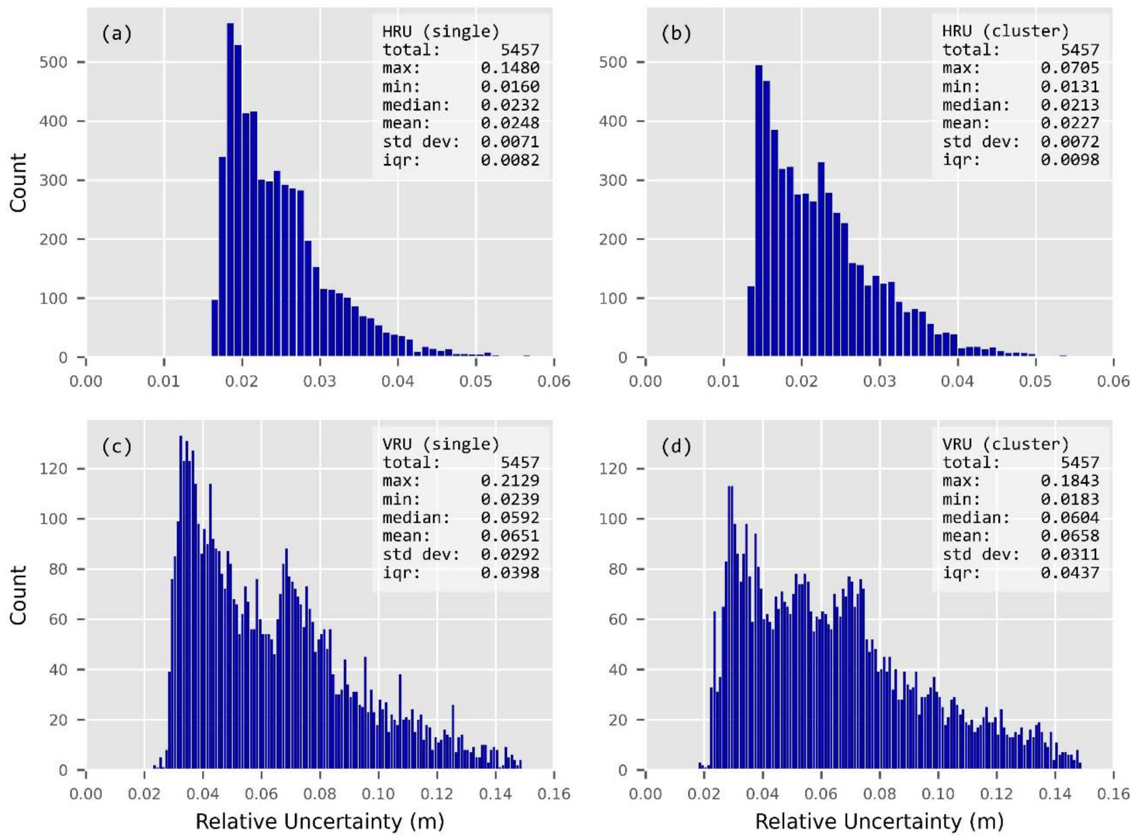

Figure 8: Histograms of GDA2020 (a) HRU in single mode, (b) HRU in cluster mode, (c) VRU in single mode and (d) VRU in cluster mode.

However, investigating the changes in uncertainty presented more mixed results (Figure 9). Cluster processing, on average, saw a very small degradation in horizontal and vertical PU while small improvements were observed in horizontal and vertical RU. Neither of these changes exceeded one-sigma of their distributions and therefore these changes are also considered statistically insignificant. The most notable uncertainty improvement using cluster processing was a median change of 0.0028 m in HRU, falling comfortably within the one-sigma level of 0.0038 m. However, it should be noted that the improvement to RU is computed from uncertainties expressed at the 95% confidence level. When converted back to the one-sigma level, the difference is closer to 1 mm, which is an improvement of questionable value to any surveyor, for any application.

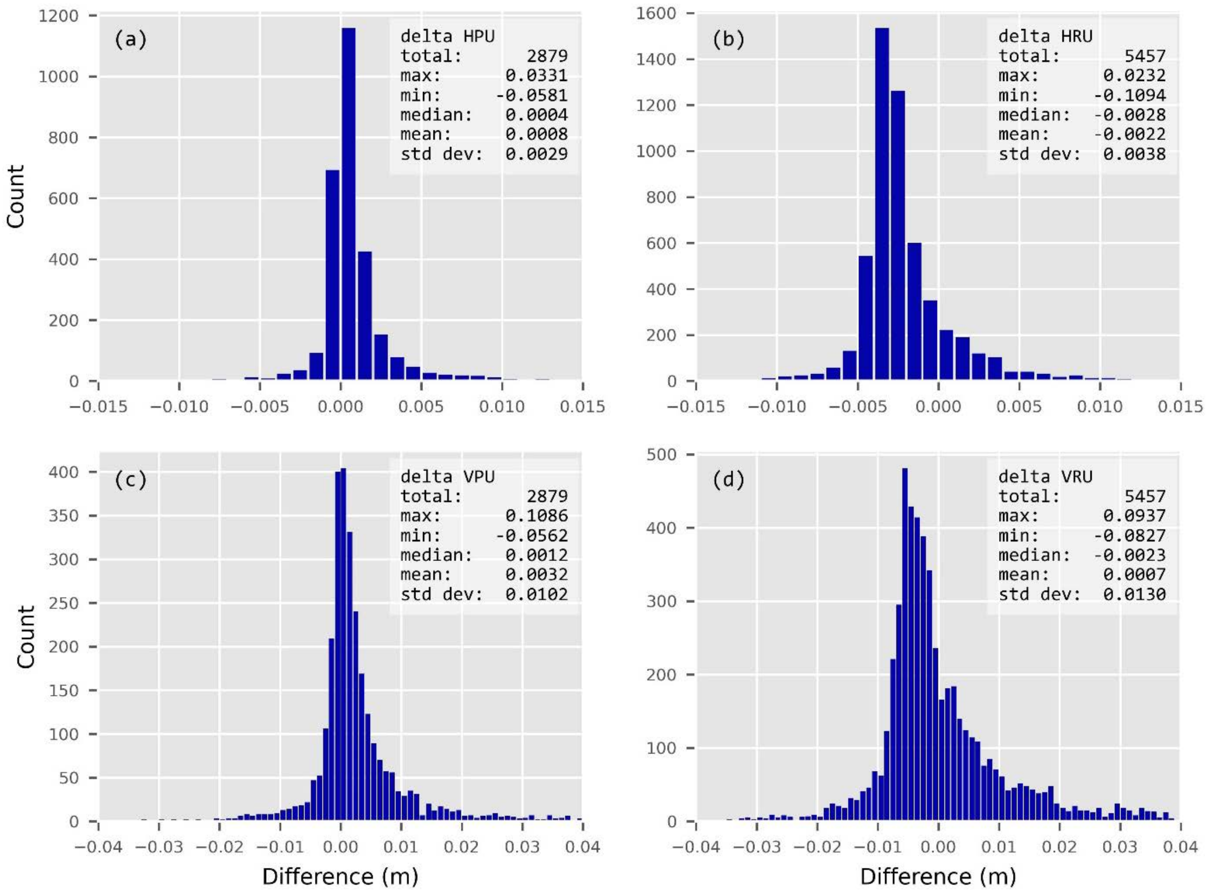

Figure 9: Histograms of changes in GDA2020 (a) HPU, (b) HRU, (c) VPU and (d) VRU. Differences are computed as cluster-solution uncertainty minus single-solution uncertainty.

Such small improvement in RU may come as a surprise. On first consideration, one would expect that stations observed concurrently and processed together should have a more precisely determined relative position, which would yield improved RU. However, the variance-covariance matrix provided by AUSPOS may not be well suited to RU computations due to the large number of constraints employed by AUSPOS, which are constrained at 1 mm horizontally and 2 mm vertically (IGS stations) or 3 mm horizontally and 6 mm vertically (other CORS). This likely decorrelates the uncertainty estimates at the user stations, resulting in RU values that are almost indistinguishable from those obtained when the observations are processed as discrete single solutions. This effect is readily seen in least squares network adjustments with very good connection to datum where the precision of the constraints 'overpowers' the measurements between stations. Even if this is the case, the minimal change in coordinates still supports the conclusion that AUSPOS cluster processing, in its current form, offers no real advantage over single processing.

On the other hand, the high quality of results in single mode across NSW may be in part due to the dense CORS network contributing to AUSPOS (Figure 10). The bar may be set so high that little benefit is gained with the supply of additional observations between user stations.

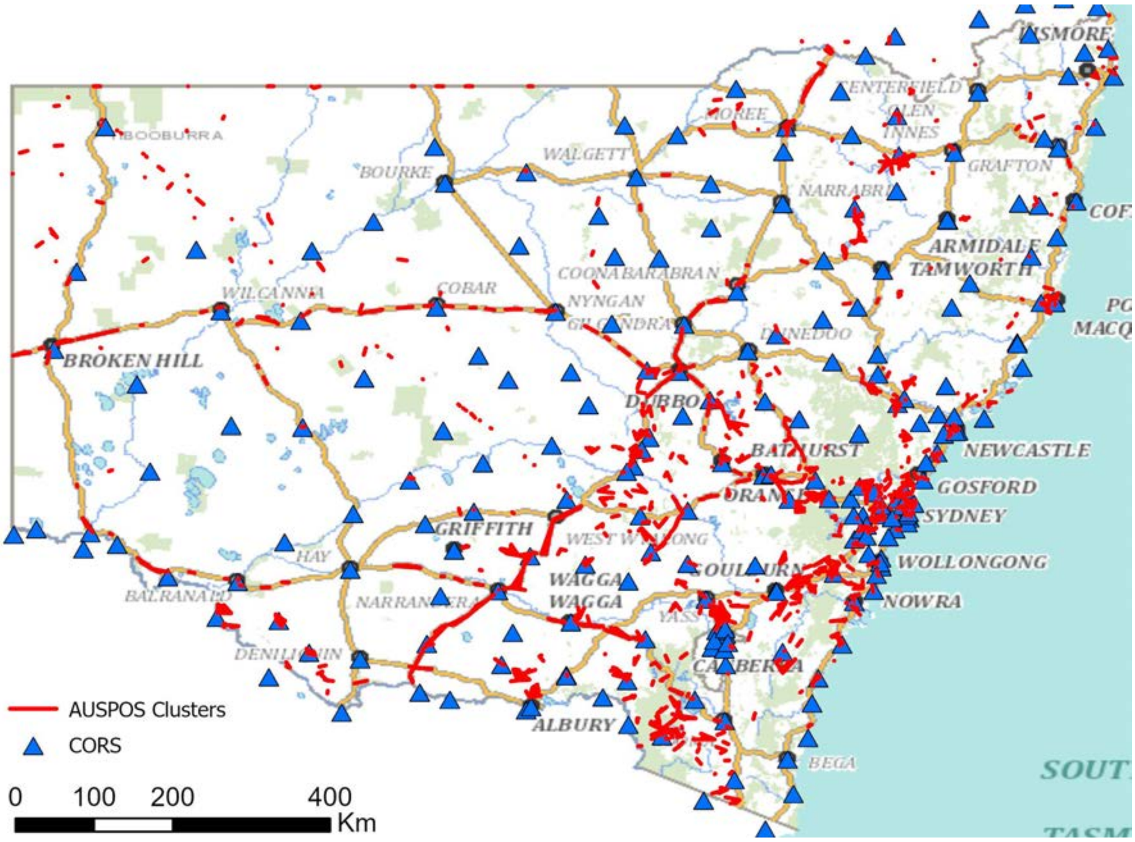

Figure 10: Baselines between user-submitted cluster stations with respect to the CORSnet-NSW network.

With no clear trend in RU between single-solution and cluster-solution, the change in RU was examined with respect to the distance between stations (Figure 11a). Additionally, it is noted that the full duration of each observation may not be utilised by AUSPOS depending on the observation overlap between stations which form a baseline. Such baselines are used by AUSPOS for ambiguity resolution, and therefore any section of observation which falls outside the overlapping window cannot be used by AUSPOS for this purpose. As such, the RU for each pair of stations was examined with respect to the overlapping observation time reported in the SINEX file (Figure 11b). In both cases, no discernible correlation was evident. This supports our earlier assertion that the large number of CORS constraints can cause a decorrelation of the uncertainty estimates at the user stations.

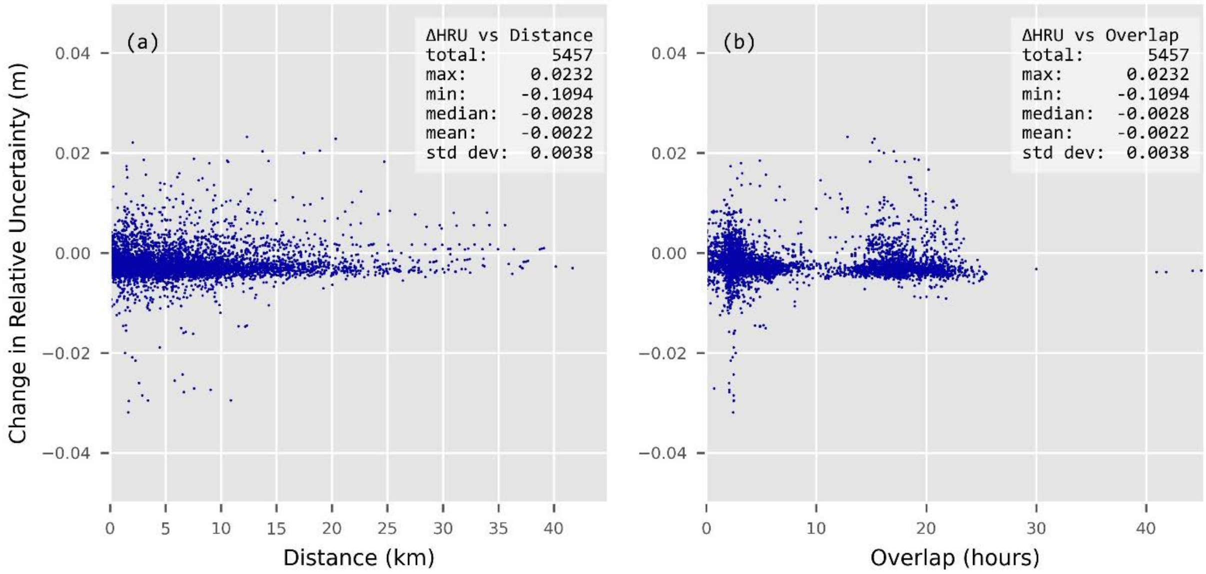

Figure 11: Scatter plot of changes in RU and their (a) station separation distance and (b) observation session overlap. Differences are computed by cluster-solution uncertainty minus single-solution uncertainty.

Similarly, no significant correlation was found between the change in RU and the cluster size (Figure 12). The decrease in standard deviation at the upper end should be weighed against the smaller sample sizes of available clusters. It should also be noted that the number of clusters stated here differs from those in Table 1 due to the large-uncertainty warnings encountered (see Figure 4). Affected stations were removed and the clusters then 're-sized' accordingly.

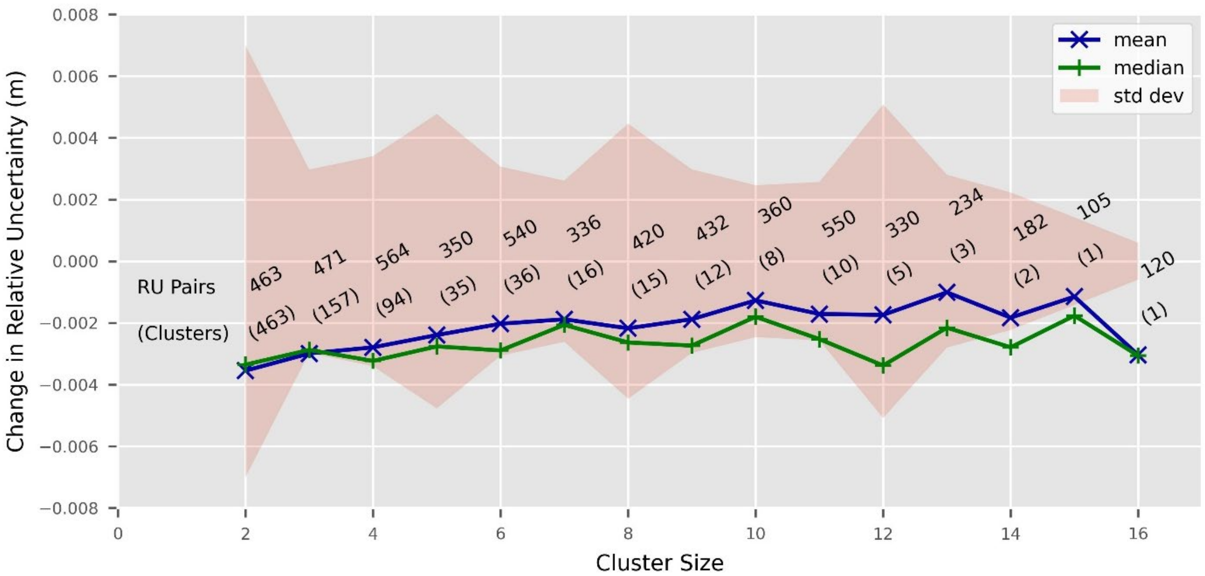

Figure 12: Changes in RU categorised by cluster size. Differences are computed by cluster-solution uncertainty minus single-solution uncertainty.

Finally, the experiment was rerun with the RU analysis restricted to only include pairs of stations where AUSPOS reported that a baseline had been formed during processing. With this constraint, 1,455 pairs of stations could have their RU analysed (Figure 13). These results were not significantly different to the full analysis (see Figures 9b & 9d).

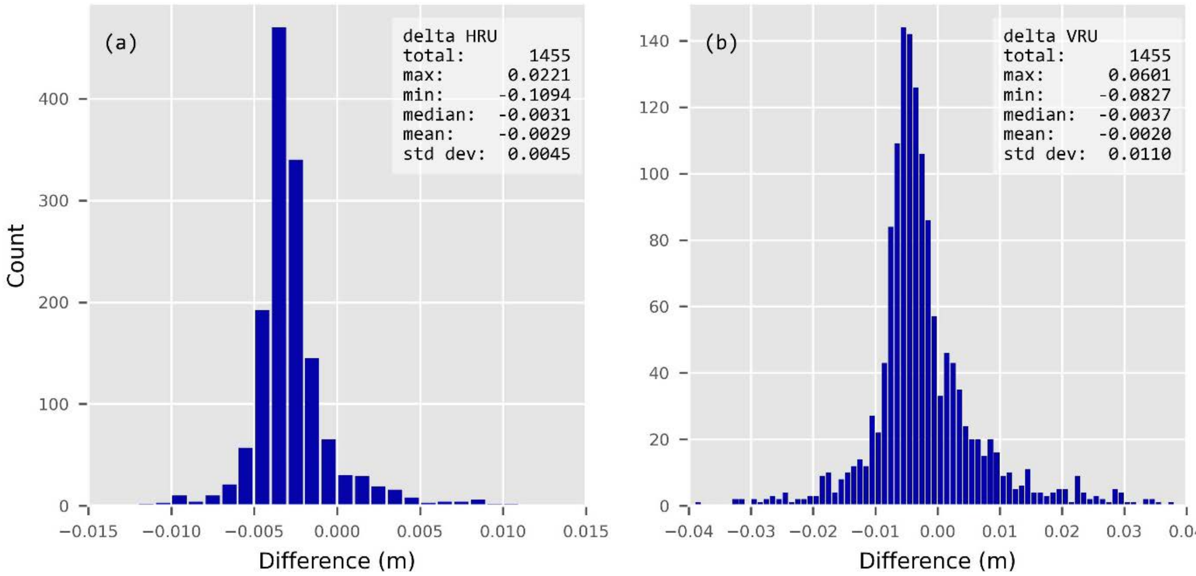

Figure 13: Histograms of changes in (a) HRU and (b) VRU between pairs of stations where AUSPOS has reported a baseline. Differences are computed by cluster-solution uncertainty minus single-solution uncertainty.

It should be noted that while the coordinates and uncertainties analysed here are based on the AUSPOS GDA2020 SINEX results, the AUSPOS ITRF2014 SINEX results were also reviewed and similarly showed little change between single and cluster processing. In the initial design of the study, we sought to additionally process observations from a purposely observed cluster campaign (i.e. a cluster as it would be planned and observed in surveying practice, see Figure 1b) through a traditional baseline processing engine in the event a 'deciding vote' was required. Given the results encountered here are statistically indistinguishable, this was abandoned.

Based on the results presented here, it can be concluded that AUSPOS positioning results do not significantly differ between single and cluster mode. Considering the additional effort required for field work planning and logistics, purpose-designed cluster networks offer little benefit, at least in regions covered by a dense CORS network such as NSW. Furthermore, in some instances, AUSPOS users may encounter more frequent large-uncertainty warnings where cluster-processing is employed (see Figure 4), especially at sites with challenging sky view conditions. If such problems are encountered, the user is advised to try single mode AUSPOS processing.

However, AUSPOS clustering may be more convenient for some users and applications because concurrently observed RINEX files can be submitted together in one job and the processing results are received in a single AUSPOS report. This is a decision of convenience rather than performance and will depend on the user's preferences and the task at hand. In any case, AUSPOS continues to deliver high-quality positioning results via a sophisticated but convenient online service.

5 CONCLUDING REMARKS

This study has leveraged the extensive NSW GNSS Observation Archive to automatically form concurrently observed clusters and investigate the quality of results produced by AUSPOS in single-processing and cluster-processing modes. It incorporated AUSPOS processing of about 3,000 observation files and 900 clusters of varying size across the state.

Based on an analysis of absolute and relative coordinate changes, Positional Uncertainty and Relative Uncertainty, no significant change is detected between the single and cluster processing strategies. A slight improvement in RU may exist, but this is not apparent in the SINEX variance-covariance matrix, likely due to the decorrelating effect of tightly constraining the reference stations. Even if a variance-covariance matrix based on a minimally constrained AUSPOS solution could provide a theoretical improvement to the estimate of RU, the average changes to absolute and relative positions are all below one millimetre and are virtually undetectable, thereby making no difference in real-world applications. For sites with challenging sky view conditions due to tree cover or other obstructions, using the single-processing mode may be more robust than processing observations as a cluster. In practice, utilising AUSPOS in single or cluster mode is a decision of convenience rather than performance, at least in NSW.

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