

CORSnet-NSW Network RTK: Same Look and Feel... Only Better



Land & Property
Management Authority

Volker Janssen, Joel Haasdyk and Simon McElroy
Survey Infrastructure & Geodesy
NSW Land and Property Management Authority
Email: Volker.Janssen@lpma.nsw.gov.au, Joel.Haasdyk@lpma.nsw.gov.au,
Simon.McElroy@lpma.nsw.gov.au

Abstract

CORSnet-NSW is a rapidly growing network of Global Navigation Satellite System (GNSS) Continuously Operating Reference Stations (CORS) providing fundamental positioning infrastructure for New South Wales that is accurate, reliable and easy to use. This positioning infrastructure supports a wide range of GNSS applications in areas such as surveying, agriculture, mining and construction. This paper presents the current status of CORSnet-NSW and briefly outlines the difference between the traditional, single-base Real Time Kinematic (RTK) and the Network RTK (NRTK) approaches. Initial results from some of the extensive testing of NRTK performance undertaken by LPI across eastern NSW are then presented. These tests have shown that while NRTK has the same ‘look and feel’ as single-base RTK, it produces superior coordinate results in regards to both precision (i.e. repeatability) and accuracy (i.e. agreement with the State’s survey ground control network). The benefit of averaging observations over a 1-minute window and re-occupying points 20-40 minutes later is illustrated. It is also shown that coordinate quality (CQ) indicators provided by the GNSS rover equipment are often overly optimistic, even under favourable satellite visibility and multipath conditions, and should therefore be used with caution.

Introduction

Global Navigation Satellite System (GNSS) Continuously Operating Reference Stations (CORS) networks are being introduced across Australia and internationally to provide improved access to positioning infrastructure for a wide range of GNSS applications in areas such as surveying, agriculture, mining and construction. Benefits include the rationalisation of infrastructure, establishment of multi-user systems, positioning services that are similar across the network, consistent and reliable connectivity to the national datum, and the ability to provide a degree of legal traceability for satellite-based positioning.

CORSnet-NSW is a rapidly growing network of GNSS CORS providing fundamental positioning infrastructure for New South Wales that is accurate, reliable and easy to use (Janssen et al., 2010). The network aims to support the spatial community and provide stimulus for innovative spatial applications and research using satellite positioning technology. It is built, owned and operated by Land and Property Information (LPI), a division of the NSW Land and Property Management Authority (LPMA). CORSnet-NSW aims to ensure that the best possible positioning infrastructure is available to NSW, while maintaining national and international standards and best practice (e.g. ICSM, 2002; 2007;

Lands, 2006) to accommodate established and developing positioning and navigation applications.

LPI's first CORS was installed in 1992 in Bathurst to support internal survey and aerial photography operations (Kinlyside and Yan, 2005). In 2004 a network of seven CORS was installed in the Sydney metropolitan area and made available to the public one year later under the name SydNET (Roberts et al., 2007). A renewed effort of expansion to extend the coverage of CORS throughout NSW commenced in 2009 and corresponded with the rebranding of the network as CORSnet-NSW (LPMA, 2011a). Currently consisting of about 60 permanent stations tracking multiple satellite constellations, CORSnet-NSW will expand to over 110 stations within the next two years. While SydNET has been operated in tandem with CORSnet-NSW over the last 18 months, all SydNET services will cease on 2 May 2011.

This paper presents the current status of CORSnet-NSW and briefly outlines the difference between the traditional, single-base Real Time Kinematic (RTK) and the Network RTK (NRTK) approaches. Initial results from some of the extensive testing of NRTK performance undertaken by LPI across eastern NSW are then presented.

Current Network Status and Rollout

The network currently (March 2011) consists of 59 CORS, mainly located in the highly populated coastal region and the eastern part of the State. Figure 1 illustrates the coverage of CORSnet-NSW, showing stations that are operational (indicated by small triangles) as well as planned stations (indicated by small circles). A 150 km radius around active stations is shown in order to illustrate sub-metre Differential GPS (DGPS) coverage, while a 50 km radius indicates the coverage area for single-base Real Time Kinematic (RTK) operation at the 2-cm level. Network RTK (NRTK) coverage at the 2-cm level (horizontally) is shown as a pink polygon. Initially only covering the Sydney metropolitan area, NRTK services have now been extend into the Illawarra, Central Coast and Lower Hunter regions.

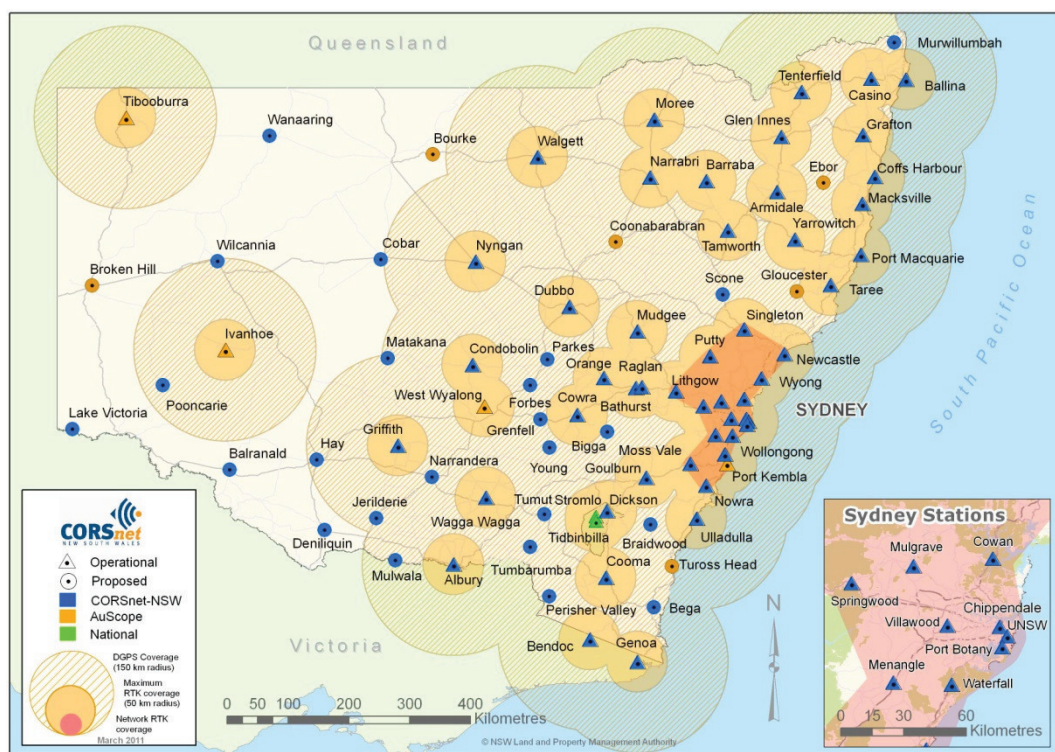


Figure 1: Current coverage of CORSnet-NSW (March 2011).

Currently more than three quarters (78%) of the area of NSW is covered by the DGPS service, while single-base RTK is available to one third (31%) of NSW. It should be noted that the latter percentage is not expected to reach 100% state-wide coverage since vast areas of western NSW are very sparsely populated and dense CORS coverage is therefore not justified. In the vicinity of CORSnet-NSW stations, the network is well-suited to support efforts to improve cadastral infrastructure in rural areas with RTK GNSS techniques (Janssen et al., 2011).

All CORSnet-NSW reference stations currently in operation are equipped with the most recent dual or triple constellation GNSS hardware (e.g. GPS, GLONASS and Galileo), purposely mixing GNSS equipment from different manufacturers. In order to provide a legally traceable survey monument that allows the GNSS antenna to be oriented to True North without the need to introduce an antenna height, a new CORS antenna mount, the CORSnet-NSW Adjustable Antenna Mount (CAAM), was developed in-house and a patent submission has been accepted. LPI has invested nearly one million Australian dollars in software over the last 18 months, being the second institution in the world to install Trimble Navigation's VRS³Net CORS network management software.

CORSnet-NSW is operated and managed by an expert team consisting of seven staff in the technical group and three staff in the customer support group. The network is fully funded by LPI. A number of CORS-net NSW stations have been built to geodetic specifications with support from federal sources, allowing their participation in the scientific, national AusCORS network managed by Geoscience Australia (Janssen, 2009b). Additionally, a large number of CORSnet-NSW stations are hosted by local councils, and in the near future several sites will be hosted by private industry. LPI collaborates with the ACT Planning and Land Authority to provide CORS services across the Australian Capital Territory. LPI also collaborates with the VIC Department of Sustainability and Environment, which operates Victoria's GPSnet (DSE, 2011), in order to ensure consistent positioning services in the border region between the two states. Currently 80% of CORSnet-NSW stations are hosted by our partners, and this percentage is expected to rise. As LPI progresses with the rollout of CORS, more users will have services available to them and the level of service may also improve from its current levels.

Single-Base RTK versus Network RTK

The traditional single-base RTK approach uses the GNSS data of a single reference station or CORS to model the distance dependent errors (i.e. the ionospheric and tropospheric delays and orbit errors) and provide corrections to the user. Since the corrections that model the offset between observed and corrected user position are based on the location of a single CORS, positioning quality decreases with increasing distance from the CORS. NRTK, on the other hand, enables reliable modelling of the distance dependent errors across the network and allows the correction data provided to a user to be optimised based on their location within the network, thereby providing a modelled offset that represents the actual conditions much better (Figure 2).

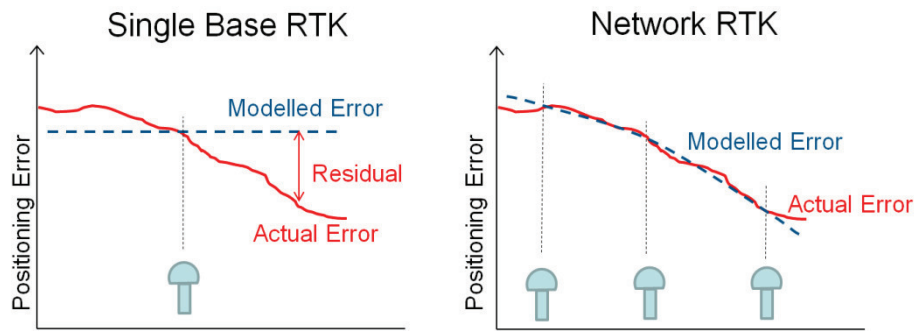


Figure 2: RTK vs. NRTK modelling of the distance dependent errors.

High-accuracy single-base RTK solutions are generally limited to a distance of 20 km (Zhang et al., 2006), although tests conducted by LPI have shown that acceptable results can be achieved over up to 50 km (McElroy, 2007). Providing high-accuracy GNSS solutions state-wide using single-base RTK would require many hundreds of CORS and is not feasible due to the extreme cost involved. The NRTK solution is generally based on between three and six of the closest reference stations with respect to the user and allows much greater inter-CORS distances (up to 70-90 km) while maintaining the same level of accuracy (Figure 3). CORSnet-NSW provides users with NRTK correction data according to both the Virtual Reference Station (VRS) approach and the Master-Auxiliary Concept (MAC). For a comparison of these two techniques the reader is referred to Janssen (2009a).

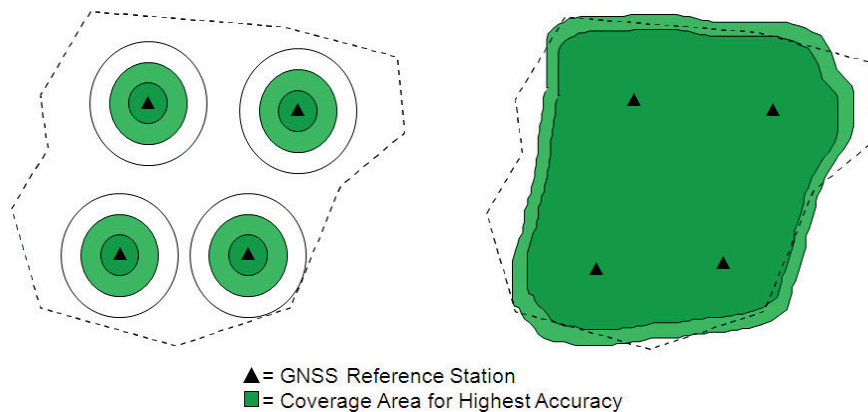


Figure 3: RTK vs. NRTK coverage.

A recent international study compared the performance of NRTK across the United Kingdom in order to quantify the achievable accuracy with VRS and MAC, and to provide a basis for NRTK best practice guidelines (Edwards et al., 2008; 2010). It was found that the two commercial NRTK systems investigated provided similar levels of overall accuracy, i.e. 10-20 mm in the horizontal component and 15-35 mm in the vertical component at the one-sigma level (68%). However, users were urged to pay close attention to coordinate quality (CQ) indicators provided by the GNSS rover equipment and to be aware that overly optimistic CQ values (by a factor of 3-5) can be obtained under limited satellite visibility and multipath conditions. The adoption of the mean of two 3-minute averaged observation windows separated by 20-45 minutes was shown to reduce errors by about 5 mm, particularly in the vertical component. The use of averaging (or windowing) techniques was also recommended if the height difference between the user and the nearest reference station(s) exceeds 250 m.

Wang et al. (2010) assessed the performance of NRTK in Australia when longer than recommended inter-CORS distances are utilised. It was found that it may be possible to offer

NRTK services to regional areas using larger than recommended inter-CORS distances. However, CORS operators and users need to be aware that the risk of incorrectly resolving integer ambiguities increases substantially when larger NRTK cell sizes are used. For some applications, these errors may be identified by multiple occupations. The authors also demonstrated that CQ values tend to be overly optimistic, especially under challenging conditions, and do not function well in regards to identifying incorrectly fixed integer ambiguities.

CORSnet-NSW Network RTK Performance Testing

Extensive tests were carried out at several locations in eastern NSW to investigate the performance of the CORSnet-NSW NRTK service outside the Sydney metropolitan area, and with larger inter-CORS distances than those found in Sydney (25 km on average). This paper presents initial results obtained from a selected sample of the data, collected in NRTK cells within the recommended size. Comparisons are made between NRTK and single-base RTK operation to illustrate the performance of NRTK in the study areas. The achievable precision was investigated during a 3-day test, while the achievable accuracy was determined by comparison to established marks contained in the Survey Control Information Management System (SCIMS) database (LPMA, 2011b).

Test 1: Long-Term Precision

Test 1: Methodology

The long-term precision (i.e. repeatability) of NRTK and single-base RTK solutions was investigated by collecting three days of real-time GNSS data at multiple locations within eastern NSW. The results presented here are from the roof of a building at Macquarie University, collected on 4-6 January 2011. Figure 4 shows the study area including the surrounding CORSnet-NSW sites. The average inter-CORS spacing around the perimeter of the four closest CORS was 29 km (with a maximum of 33 km), i.e. well within the recommended maximum. Six Leica Viva GNSS receivers were set up next to each other, observing in NRTK mode (VRS and MAC) utilising data from the surrounding CORSnet-NSW sites, in single-base RTK mode connected to three different CORS (CHIP, MGRV and the more distant WFAL), and in DGPS mode. All receivers collected real-time data at a 1-second interval. Due to the very close proximity of the receivers (using equipment of the same type), it can be assumed that all datasets were exposed to the same conditions. This paper focuses on the results obtained by NRTK (utilising the VRS concept) and single-base RTK connected to CHIP (the closest CORSnet-NSW site, 15 km away).

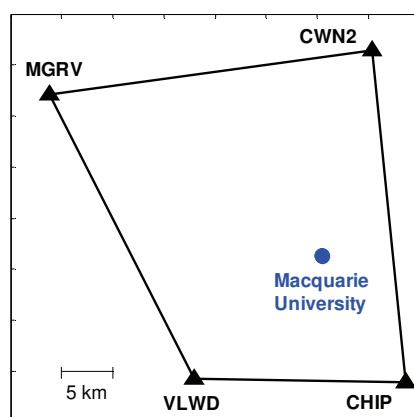


Figure 4: Location of the Macquarie University study area and surrounding CORSnet-NSW stations.

Test 1: Results

A real-time coordinate solution (Easting, Northing, and Ellipsoidal Height) was determined for each second over this 3-day observation period. In order to simulate a situation generally encountered in practice, a coordinate quality indicator that can be set in the GNSS rover equipment was applied to the collected data. In the Leica software, this indicator is referred to as CQ. It is calculated at the rover as the root mean square (RMS) of coordinate errors, based on ambiguity-fixed double-differenced observations, and indicates how much the computed position is likely to deviate from the ‘true’ value (Leica Geosystems, 2009). In other words, the lower the reported CQ, the higher the estimated quality of the coordinates.

Our analysis only considers data within a CQ value of 50 mm for position & height, i.e. the default value recommended by the manufacturer. This resulted in a small amount of data being discarded due to insufficient quality (as determined by the GNSS rover software). Table 1 lists the percentage of the 3-day dataset that was within specifications as well as the resulting RMS relative to the mean of the remaining data for both NRTK and single-base RTK. It should be emphasised that all remaining figures and tables in this paper represent data that has passed this ‘CQ filter’.

Table 1: Statistics of the 3-day dataset at Macquarie University.

	NRTK (VRS)	RTK (CHIP)
Data within specifications (%)	99.6	99.8
Horizontal RMS (mm)	12.3	15.4
Vertical RMS (mm)	21.2	30.8

It is evident that a slightly larger amount of data was found to be of insufficient quality in the case of NRTK. The RMS provides a measure of the precision achieved over the 3-day test. NRTK performs better in both the horizontal component (i.e. distance from mean coordinate) and the vertical component, reaching about 12 mm and 21 mm respectively. Figure 5 illustrates the higher precision of NRTK in regards to horizontal position compared to single-base RTK. The histograms along the coordinate axes indicate the number of points involved in each millimetre bin from the mean. It should be noted that the figure does not show the small number of outliers that passed the CQ filter but still deviated by more than 50 mm from the mean value (see Table 2). There were 18 such outliers out of 264,524 observations for NRTK, and 451 outliers out of 267,423 observations for single-base RTK.

The cumulative distribution of the analysed data allows us to quantify the precision achieved by a given proportion of the data. Table 2 compares the number of observations that were outside specified quality bins of up to 500 mm. It is clearly evident that performs better than single-base RTK, showing significantly fewer observations outside each quality bin. Note in particular the large difference between the two methods for observations outside 50 mm from the mean, both in horizontal position and the height component. While it is recognised that the initial CQ filter may have been more effective in eliminating outlier observations for NRTK than for single-base RTK, this only accounts for about 0.2% of the difference between the two methods (cf. Table 1).

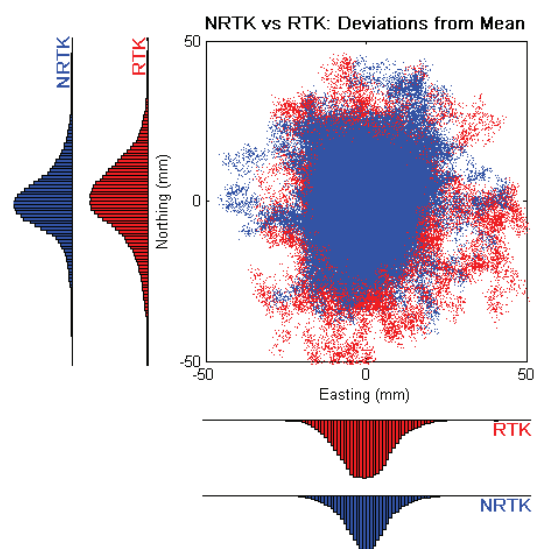


Figure 5: Horizontal precision of NRTK (blue) vs. RTK (red).

Table 2: Selected quality bins for NRTK and single-base RTK.

Quality Bin	NRTK (VRS)				RTK (CHIP)			
	Distance		Height		Distance		Height	
# > 500 mm	0	0.00%	18	0.01%	0	0.00%	0	0.00%
# > 200 mm	0	0.00%	18	0.01%	39	0.02%	28	0.01%
# > 100 mm	18	0.01%	449	0.17%	49	0.02%	2,051	0.77%
# > 50 mm	18	0.01%	4,954	1.87%	451	0.17%	25,291	9.46%
# > 40 mm	998	0.38%	11,987	4.53%	3,800	1.42%	42,484	15.89%
# > 30 mm	5,696	2.15%	32,543	12.30%	12,485	4.67%	69,630	26.04%
# > 20 mm	23,226	8.78%	77,312	29.23%	41,553	15.54%	116,755	43.66%
# > 10 mm	105,270	39.80%	153,580	58.06%	144,835	54.16%	183,800	68.73%
# > 0 mm	264,524	100.00%	264,524	100.00%	267,423	100.00%	267,423	100.00%

Figure 6 visualises the cumulative distribution in regards to the horizontal position (i.e. distance from mean position) and height for NRTK and single-base RTK. For instance, it can be seen that, for NRTK, 95% of the horizontal positions are within 25 mm of the horizontal mean and within 40 mm of the vertical mean. For single-base RTK, 95% of the positions are within about 30 mm and 60 mm of the mean, respectively. This again shows that NRTK performs better. It should be noted that the figure does not display all of the outliers that have slipped through the CQ filter (cf. >50 mm bin in Table 2). The cumulative distribution does however take these outliers into account.

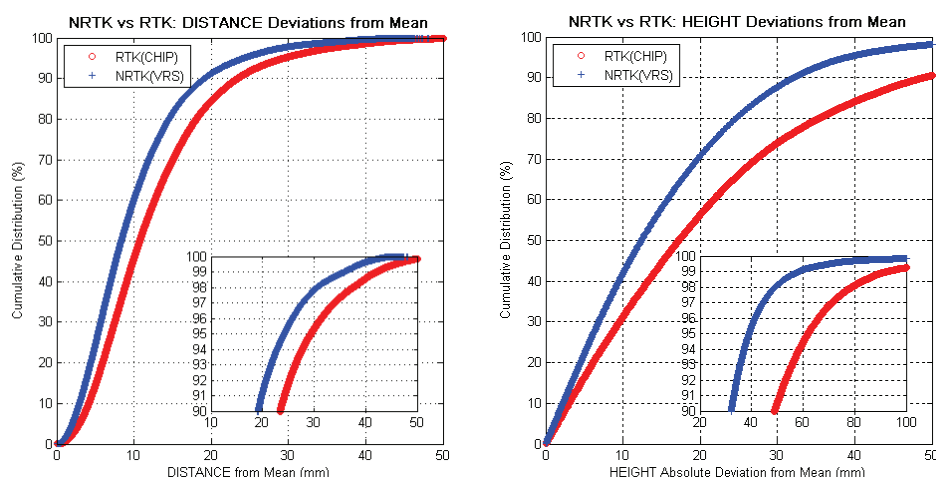


Figure 6: Cumulative distribution in horizontal position (left) and height (right) for NRTK and single-base RTK.

The NRTK time series showing the epoch-by-epoch difference from the mean in horizontal position and height for the first day is depicted in Figure 7. The following days produced similar figures. In addition to the original single-epoch (1 second) data, a smoothed time series obtained by applying a moving average of 5 minutes (i.e. 300 epochs) is also shown, to indicate the effects of windowing. Windowing is achieved by determining the average of several epochs observed at a point and is a method commonly employed in the field. It increases the reliability of an observed position by eliminating extreme fluctuations. Obviously, a larger window will produce a smoother time series, but the resulting coordinates still follow the main trend of the time series. This emphasises the importance of re-occupying a point (i.e. double occupation) for high-accuracy applications, even when the windowing technique is employed. Visual inspection of the time series indicates that a small window (i.e. an observation period of several seconds) may produce results that are still significantly offset from the mean, while a larger window increases the time in the field but further reduces the effect of outlier observations.

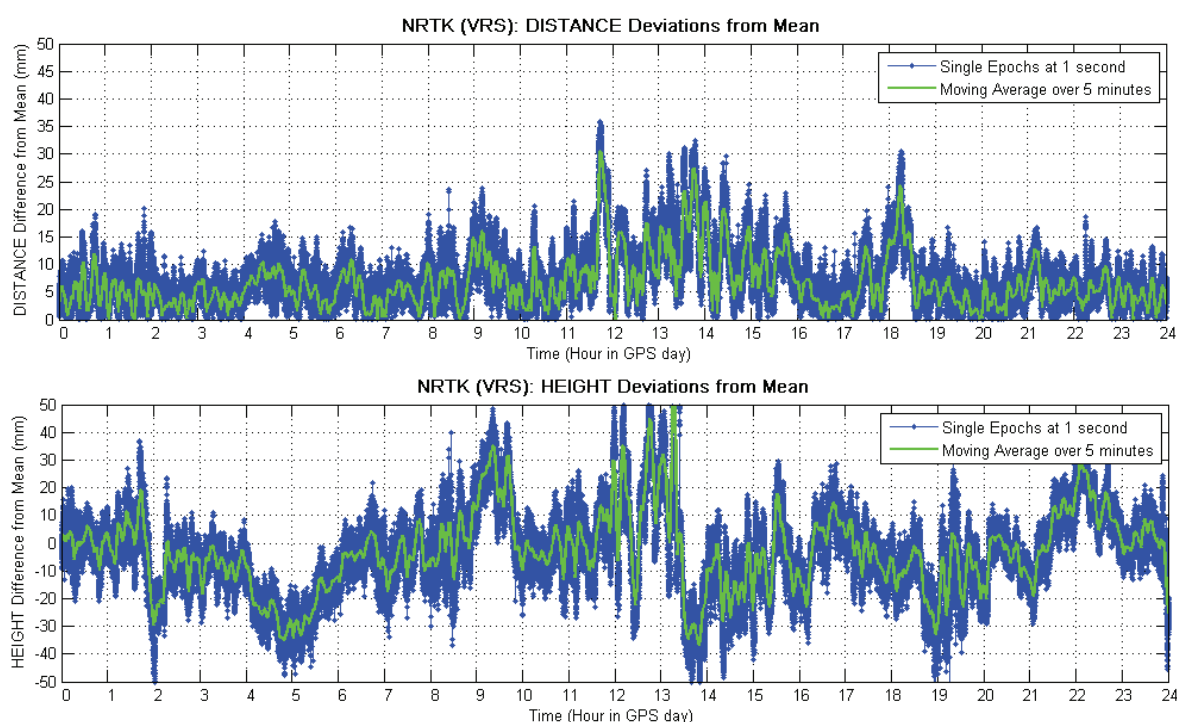


Figure 7: NRTK precision time series of the horizontal component (top) and vertical component (bottom) on 4 January 2011.

How long should a user spend on a mark in order to benefit from windowing without sacrificing productivity? We investigated the present 3-day dataset in regards to the RMS and the range of the difference from the mean for both coordinate components, utilising observation windows of varying length. While windowing provides a relatively small improvement in the RMS, it significantly reduces the range of the differences from the mean (Figure 8). This reduces the risk of obtaining a coordinate result that disagrees with the mean by a large amount. The results reveal that a 1-minute window substantially reduces the effects of individual coordinate solution variations and removes potential outliers as much as possible in a short time frame. While one minute may seem like an eternity for some users in the field, it is generally feasible for most applications, considering that the time can be spent filling out the field book, taking site photos, and looking up the next point to be occupied. For applications requiring the GNSS rover to be in motion, more sophisticated techniques would need to be employed. It is important to note that a huge improvement is achieved between

observing for 1 second, 30 seconds and 60 seconds, while observing for longer than 1 minute does generally not provide any significant improvement.

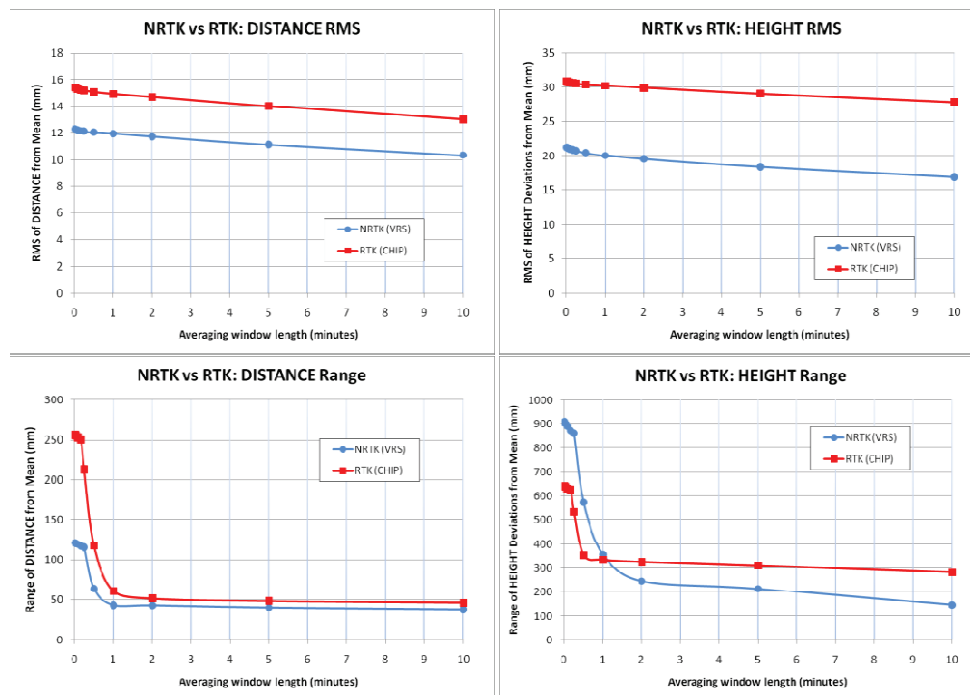


Figure 8: RMS and range of differences from the mean for horizontal position (left) and height (right). NRTK (blue) and single-base RTK (red) results are shown.

How long should a user wait until re-observing with the assumption that both occupations are sufficiently independent? In order to answer this question, the difference in horizontal position (and separately in height) was determined between every pair of epochs in the 3-day dataset that were a specified time apart. For example, comparing all epochs that are 300 seconds apart represents on average the effect of re-occupying the point after 5 minutes. This was repeated for every possible time separation up to 2 hours. Figure 9 illustrates the RMS of the resulting horizontal distance and height difference between two occupations undertaken a specified time apart. Our dataset indicates that two occupations can be assumed sufficiently independent from each other if they are taken 20-40 minutes apart, while waiting longer to re-observe is not likely, on average, to improve positioning results any further. While these findings agree very well with the recommendations made by Edwards et al. (2010), pending analysis of the remaining two long-term datasets collected by LPI will contribute to a more detailed answer.

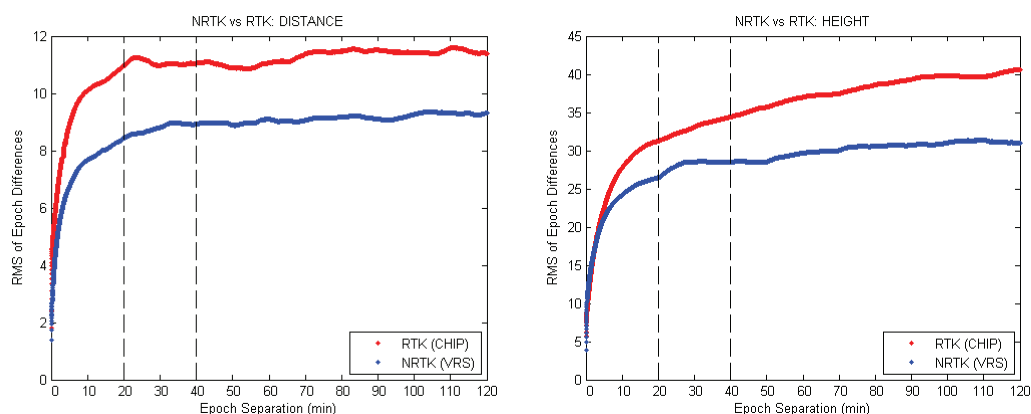


Figure 9: RMS of horizontal position (left) and height (right) for increasing observation windows. NRTK (blue) and single-base RTK (red) results are shown.

Recent studies have shown that users should be aware of overly optimistic CQ values, especially under limited satellite visibility and poor multipath conditions (Edwards et al., 2010; Wang et al., 2010). The present dataset is well suited to investigate the agreement between the CQ values calculated at the GNSS rover and the actual precision achieved over the 3-day period. Figure 10 visualises this relationship in regards to the horizontal position for NRTK and single-base RTK, and Figure 11 displays the same data for the NRTK solution, as the distance and height from the mean, coloured according to the CQ value. In addition to the already mentioned smaller spread of the NRTK solutions, NRTK also exhibits smaller CQ values (not shown), suggesting a better quality of the position solutions. It is important to note that for both NRTK and RTK there are instances where a low CQ value is reported, indicating a high-quality solution, even though the coordinate solution is significantly different from the mean. Obviously this is of more concern to the user than the reverse scenario, also shown, where a high CQ value is reported for an epoch with good agreement with the mean.

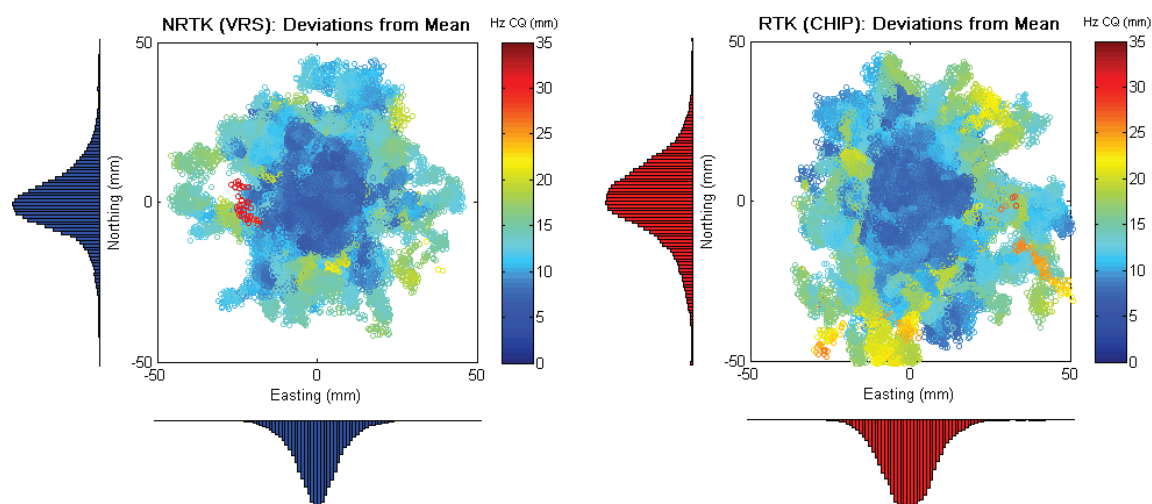


Figure 10: Horizontal precision vs. CQ value for NRTK (left) and RTK (right).
Deviations larger than 50 mm are not shown.

Figure 11 clearly shows that a specified CQ value does not necessarily represent the actual precision of the coordinate solution, both in the horizontal and vertical component. In fact, the actual precision is often a lot lower than indicated by the CQ, by up to a factor of 5 in the horizontal component and a factor of 7 in vertical component, *even under the favourable satellite visibility and multipath conditions encountered during this test*. It should be remembered that a CQ filter of 50 mm was applied to the data, so higher CQ values are not shown. It can be seen that CQ values have a minimum value of 5 mm in the horizontal component and 8 mm in the vertical component in this case. It is also evident that a small number of large outliers (the same 18 NRTK epochs in both the horizontal and vertical components) are presumably caused by incorrect ambiguity resolution and cannot be detected by the CQ filter. These findings show that CQ values are prone to be overly optimistic and should be used with caution, confirming results by Edwards et al. (2010) and Wang et al. (2010).

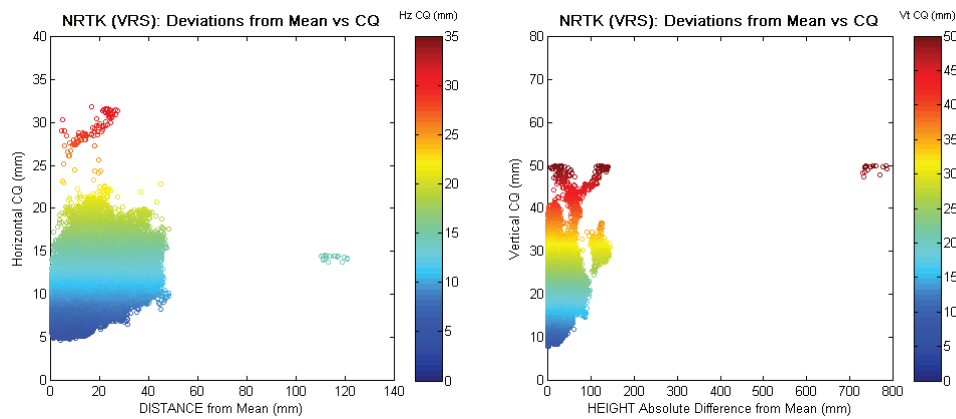


Figure 11: NRTK precision vs. CQ value for the horizontal component (left) and vertical component (right).

Test 2: NRTK Performance in Practice

Test 2: Methodology

In order to investigate the achievable real-time agreement with SCIMS in a practical scenario, NRTK and single-base RTK solutions on a number of established marks were compared to their official SCIMS values. This test was performed at seven study sites throughout eastern NSW. All observations were performed with a tripod for stability, using Leica Viva GNSS receivers.

As CORSnet-NSW operates in the GDA94(2010) realisation of the national datum, a site calibration (also known as localisation or local transformation) is required to relate surveys utilising CORSnet-NSW to the local survey control network (Janssen and McElroy, 2010). The site calibration points were chosen to be of the highest class and order possible, i.e. A1 horizontal and LCL3 vertical, or better. Detailed definitions of the terms class and order can be found in ICSM (2007). In order to ensure that the site calibration does not contaminate the test results, it was decided to observe for 5 minutes at each site calibration point. This is far beyond recommended best practice but ensured that a reliable, high-quality local transformation between the CORSnet-NSW reference frame, i.e. GDA94(2010), and the local ground control network, i.e. GDA94(1997), could be determined. One site calibration was performed using NRTK, another using single-base RTK to the closest CORSnet-NSW site. Absolute antenna modelling was applied to the GNSS rovers involved in all tests (Janssen and Haasdyk, 2011). It should be noted that the site calibration used a direct 3-dimensional, 7-parameter transformation without the use of a geoid model, i.e. the geoid-ellipsoid separation was considered as part of the similarity transformation parameters between GDA94(2010) and GDA94(1997). This procedure is acceptable for research purposes only. The threshold for acceptance of the site calibration was set to 20 mm in Easting and Northing, and 50 mm in Height.

Within the area surrounded by the site calibration points, a number of high-quality established marks (B2 hz. and LCL3 vt., or B2 hz. and B2 vt. if not optically levelled, or better) were selected as test points. The test points were chosen to exhibit ‘typical’ conditions accepted for GNSS surveys, i.e. a good skyview with low to moderate obstructions. Test points were observed for 1 minute using NRTK (applying the NRTK-derived site calibration) and, following immediately after re-initialisation (without re-setting the tripod), using single-base RTK relative to the closest CORSnet-NSW site (applying the site calibration derived by single-base RTK). After all test points were occupied once, the procedure was repeated to obtain 10 rounds of observations on each test point at different times of day over several days.

While the extensive testing conducted by LPI involved seven test areas across eastern NSW, this paper presents results obtained in two study areas, Albion Park in the Illawarra (Figure 12) and Cessnock in the Lower Hunter region (Figure 13). The figures illustrate the location of the test points, surrounded by the site calibration points and the closest CORSnet-NSW sites. The average inter-CORS distance around the perimeter of the four closest CORS was 37 km (with a maximum of 52 km) for Albion Park and 66 km (with a maximum of 80 km) for Cessnock, i.e. within the recommended maximum for inter-CORS distances of 70-90 km. Single-base RTK operation utilised the closest CORSnet-NSW site, i.e. Port Kembla (PTKL) in Albion Park (16 km away) and Singleton (SNGO) in Cessnock (34 km away). The fieldwork was conducted over several days in January and February 2011.

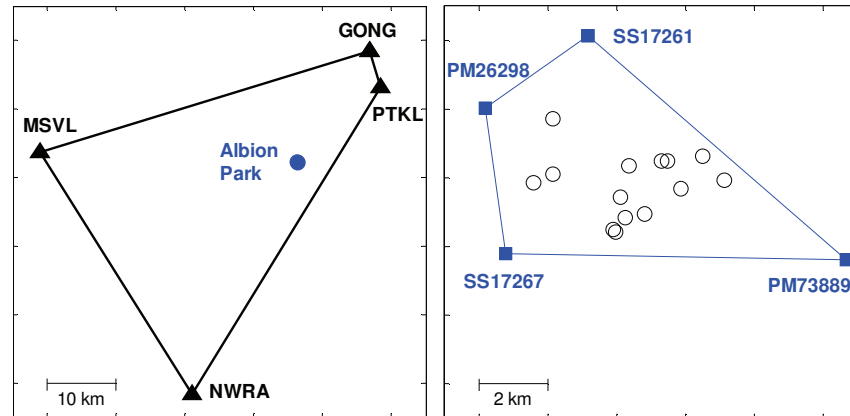


Figure 12: Location of the Albion Park test area and surrounding CORSnet-NSW stations. Site calibration points are shown as blue squares, and test points as black circles.

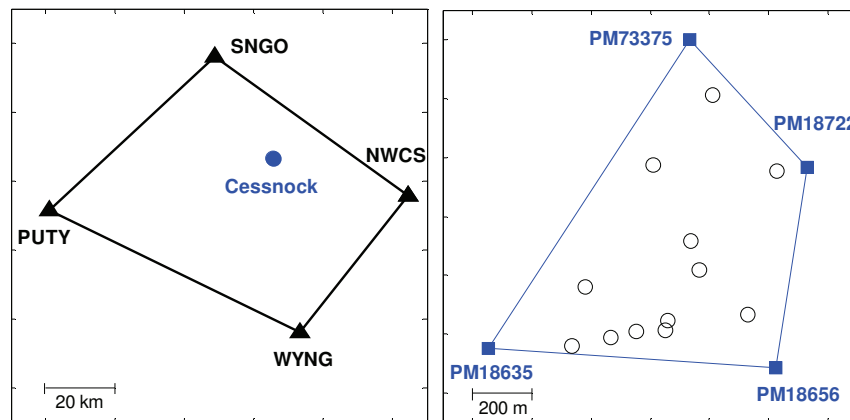


Figure 13: Location of the Cessnock test area and surrounding CORSnet-NSW stations. Site calibration points are shown as blue squares, and test points as black circles.

Test 2: Results

In order to quantify the achievable accuracy of NRTK and single-base RTK, real-time observations on established marks in two study areas were compared against their published SCIMS coordinates. The resulting deviations from SCIMS in the horizontal and vertical component are shown in Figure 14 (Albion Park) and Figure 15 (Cessnock). For every test point surveyed, each 1-minute occupation is represented individually. It is evident that NRTK generally produces a better agreement with SCIMS (after a site calibration) with a smaller spread among re-occupations. This is particularly clear in the Cessnock test area, showing that NRTK provides a substantial improvement on single-base RTK in larger cells.

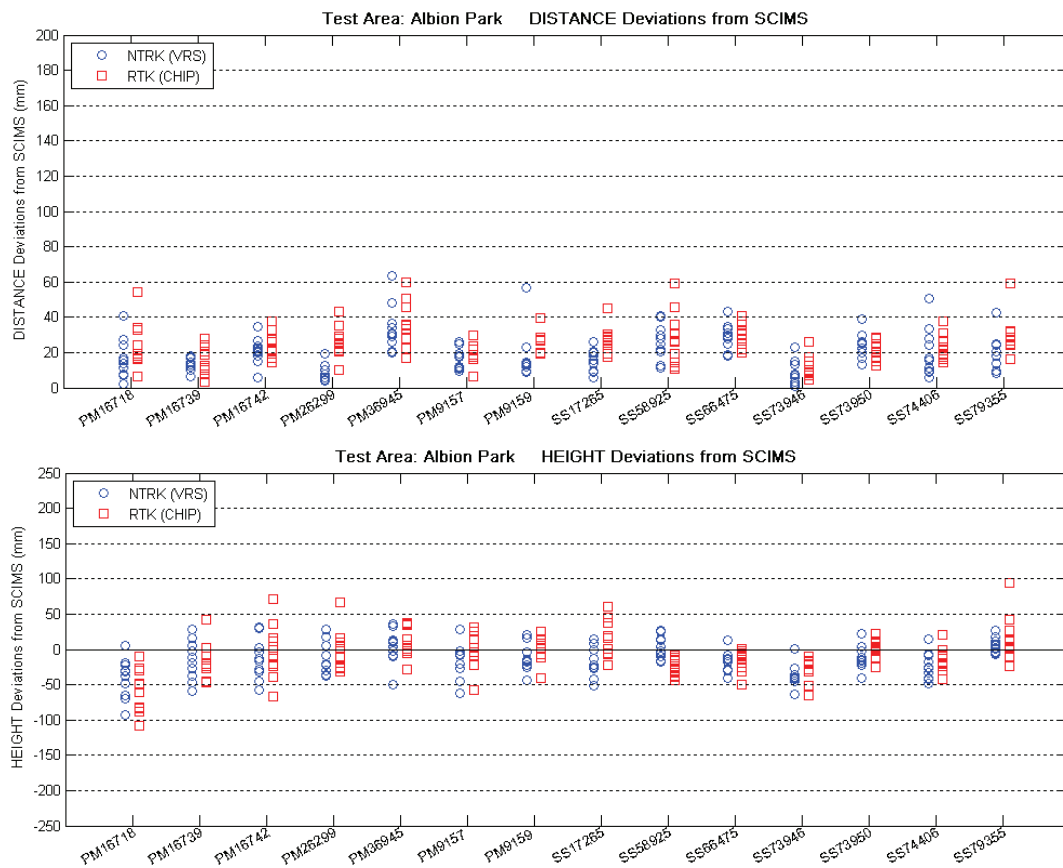


Figure 14: Horizontal and vertical accuracy vs. SCIMS in Albion Park.
NRTK (blue) and single-base RTK (red) results are shown.

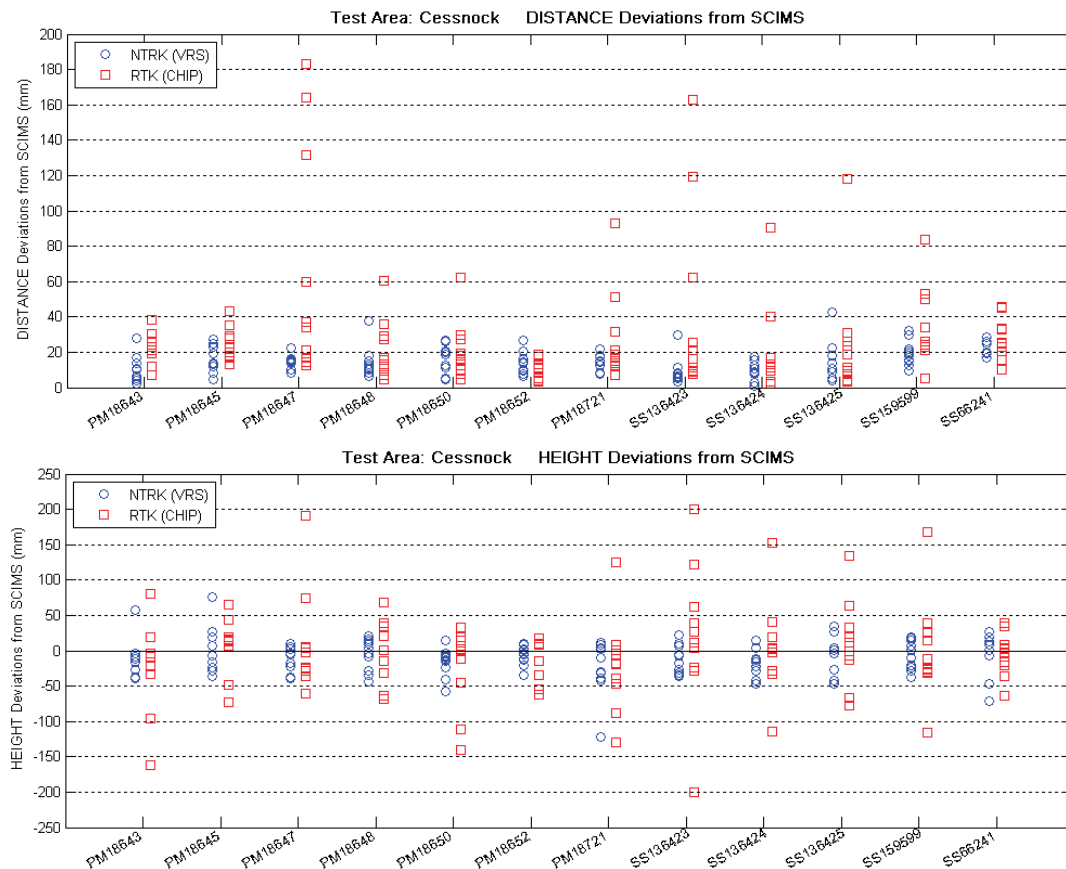


Figure 15: Horizontal and vertical accuracy vs. SCIMS in Cessnock.
NRTK (blue) and single-base RTK (red) results are shown.

In order to quantify the overall agreement with SCIMS in each test area, the RMS in the horizontal and vertical component was calculated across all occupations on all test points (Figure 16). Clearly, NRTK produced better results, especially if compared to single-base RTK over a longer distance. In Cessnock, the RMS obtained with NRTK improves on single-base RTK by a factor of 2.6 in the horizontal component and 2.3 in the vertical component.

In both test areas NRTK produces comparable agreement with SCIMS (RMS at 1σ) of about 20 mm in the horizontal and better than 30 mm in the vertical component, while single-base RTK accuracy degrades significantly with increasing baseline length, as expected. While pending analysis of the remaining five test areas will enable us to investigate NRTK performance in more detail, the presented results agree very well with findings presented by Edwards et al. (2010).

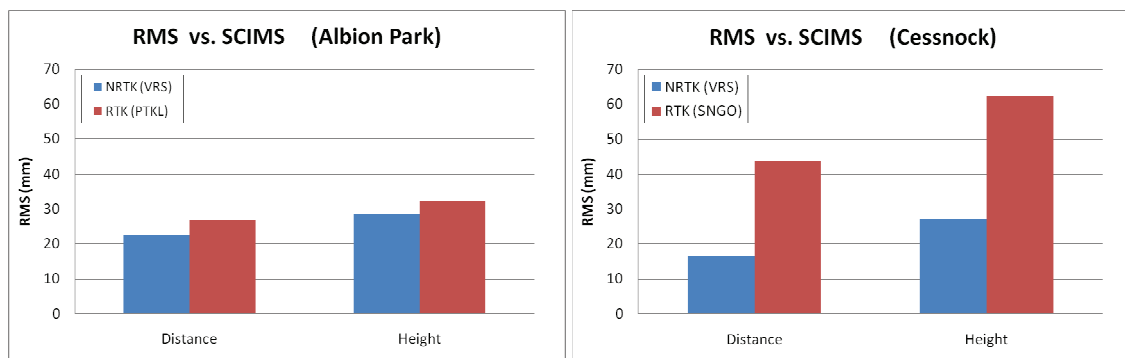


Figure 16: RMS of NRTK (blue) and single-base RTK (red) positioning vs. SCIMS. Single-base RTK was observed over distances of about 16 km (PTKL) and 34 km (SNGO) respectively.

Concluding Remarks

This paper has outlined the current status of CORSnet-NSW and briefly described the fundamental differences between the single-base RTK and NRTK concepts. In order to investigate the performance of the NRTK service outside the Sydney metropolitan area with larger inter-CORS distances, extensive tests have been carried out at several locations in eastern NSW. The achievable precision (i.e. repeatability) was investigated during 3-day tests, while the achievable accuracy was investigated by comparison to established marks contained in the SCIMS database.

We have presented promising results obtained from the analysis of a subset of the data collected. Further analysis of the extensive data collected by LPI will provide more insight into the performance of NRTK in NSW. At this stage we recommend the following in regards to NRTK observations utilising CORSnet-NSW for high-accuracy applications:

- Observe for 60 seconds to obtain an averaged position. This averaging (windowing) technique will reduce the effects of individual coordinate solution outliers.
- Averaging for 60 seconds rather than 15 seconds delivers a huge improvement in positioning quality, while averaging for longer than one minute is generally not expected to provide substantial further improvement.
- Re-observe each point after waiting 20-40 minutes. Waiting any longer is not likely to provide any further benefits other than perhaps logistic convenience.
- Be aware that coordinate quality (CQ) indicators provided by the GNSS rover equipment are often overly optimistic, even under favourable satellite visibility and multipath conditions.

- NRTK has the same ‘look and feel’ as single-base RTK but provides better precision and agreement with SCIMS, especially in larger NRTK cells that would require longer single-base RTK baselines but are still within the recommended limit for inter-CORS distances.
- NRTK can deliver precisions of about 12 mm in the horizontal component and about 21 mm in the vertical component (RMS at 1σ) when inter-CORS distances are approximately 30 km.
- In the two test areas investigated so far, consistent accuracies (against SCIMS) of about 20 mm in the horizontal and better than 30 mm in the vertical component (RMS at 1σ) can be achieved with NRTK, while single-base RTK accuracy degrades significantly with increasing baseline length.
- The findings of our NRTK testing will form the basis of future updates of regulations, Surveyor General’s directions, standards and best practice guidelines.

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