ASSESSING QUALITY OF CORSnet-NSW INFRASTRUCTURE FOR USE IN REGIONAL NEW SOUTH WALES, AUSTRALIA

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ABSTRACT:

CORSnet-NSW is a network of Global Navigation Satellite System (GNSS) Continuously Operating Reference Stations (CORS) covering the state of NSW and providing centimetre-level real-time positioning. This research paper aims to determine the level of accuracy and precision of CORSnet-NSW in regional parts of the network and compare them to that of traditional RTK under identical conditions. It investigates what effects satellite geometry and proximity to a CORS station have on NRTK measurements. It also verifies the CORSnet-NSW claim of network wide 2cm accuracy. The claim was found to be true at the 68% Confidence Interval. Changes in satellite geometry were not found to affect the results for the most part. It was also found that CORSnet-NSW precision was affected by the proximity of the rover to the base/calibration points more than its proximity to a CORSnet-NSW station. However, even though the CORSnet-NSW results were better than expected, traditional RTK remains the most precise and consistent method. This research paper provides GNSS users in regional NSW with the evidence they need to make informed decisions regarding which type of RTK method is fit for their purposes.

1. INTRODUCTION

1.1 Background

Over the past couple of decades, surveyors have made increasing use of Global Navigation Satellite System (GNSS) technology. Traditionally, accurate GNSS measurements relied on using a Real Time Kinematic (RTK) base station to calculate corrections that provide the centimetre level accuracy needed for survey applications. These corrections are transmitted via a radio signal for use in a small area of operation surrounding the RTK base (Berber et al. 2012). To increase the ease of GNSS use, networks of Continually Operating Reverence Stations (CORS) have been developed with the aim of providing more accurate corrections over broader areas (Hu et al. 2003). The main advantage of these CORS networks is that they are able to model atmospheric error over large areas and therefore provide superior atmospheric corrections (Garrido et al. 2011).

CORSnet-NSW is a network of Global Navigation Satellite System (GNSS) Continuously Operating Reference Stations (CORS) covering the state of NSW and providing centimetre-level real-time positioning. CORSnet-NSW began providing CORS services in Sydney, New South Wales over a decade ago (Janssen et al. 2011) and is now widely available across the state. CORSnet-NSW claims an accuracy of 2cm is achievable wherever there is network coverage (NSW Government 2022a). This is very similar to the level of horizontal accuracy that traditional RTK provides, although its vertical accuracy is usually two to three times lower (Garrido et al. 2011; Berber et al. 2012). This suggests that CORSnet-NSW would provide similar accuracy to traditional RTK, but this claim must be evaluated in order to be relied upon.

Research comparing the vertical accuracy of CORS networks to traditional single base RTK has been conducted in several European countries. However, as errors are network dependent the results of these studies are not relevant beyond the network which they investigate. Janssen and Haasdyk (2011) undertook a detailed comparison of CORSnet-NSW and single base RTK, however, it was focused on areas closer to Sydney where the network was denser. Network density has a direct effect on the quality of correction provided. As the number of stations in a network increase, better corrections can be obtained (El-Mowafy 2012). Therefore, the level of accuracy achieved in this research was not a reflection of the accuracy in more remote areas at the time, and most certainly does not reflect the current level of network density.

In the years since 2011, CORSnet-NSW has been expanded and currently includes 202 base locations and a much denser rural network (NSW Government 2022c). However, no comparisons have since been carried out to help professionals choose between traditional RTK and CORSnet-NSW for elevation surveys (GNSS levelling) in rural areas. Additionally, the research by Janssen and Haasdyk (2011) is already eleven years old. A study by Dobelis and Zvirgzds (2016) found that modern GNSS receivers are more accurate than those used even a decade ago. These developments to both the network and technology since 2011 support the need for an up-to-date evaluation of CORSnet-NSW accuracy in regional areas.

The objective of this research paper is to determine the current vertical accuracy and precision of RTK GNSS in regional NSW. This was done by simultaneously collecting data using both CORSnet NSW and traditional RTK corrections. The results are also used to verify CORSnet-NSW's claim of network wide 2cm accuracy and explore how proximity to a CORSnet-NSW base affects vertical accuracy and precision. Connections are

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drawn between the variation of precision and changes in atmospheric satellite geometry over the course of a working day. By making a direct comparison of the two techniques under the same conditions, users will be able to make more informed decisions regarding their use of the technology.

The remainder of this paper is structured as follows. In Section 1.2, a thorough literature review has been done and research gaps explored. Research methods have been discussed in Section 2. The research findings are presented and summarised in Section 3, followed by a comprehensive analysis and discussion in Section 4. Section 5 concludes the paper and gives direction on limitations and future research.

1.2 Literature Review

There are theoretically two RTK alternatives to the base-rover method. One, using a single CORS station as the fixed base (in place of a single base of traditional RTK). Two, using the CORS Network Real Time Kinematic (NRTK) solutions. Both of these CORS alternatives deliver corrections to the rover via a cellular network (Dobelis & Zvirgzds 2016). To distinguish CORS single base RTK from personal base-rover RTK, this research will refer to the base-rover RTK method as traditional RTK.

CORSnet-NSW provides single base coverage up to 50km from a CORS station (NSW Government 2022a). This range theoretically covers most rural areas (as illustrated, in Figure 1, below).

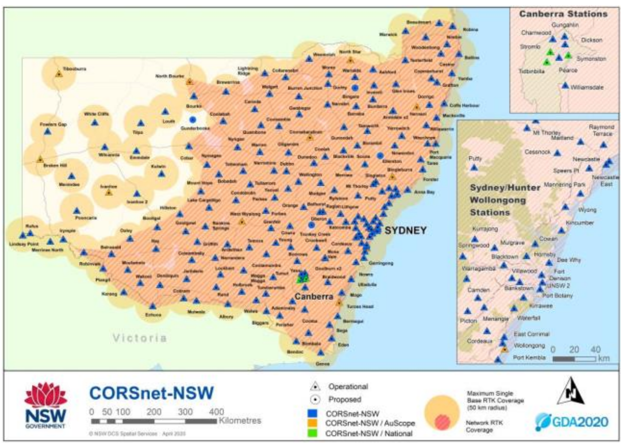

Figure 1: CORSnet-NSW Coverage Map (NSW Government 2022a). Note orange single base coverage.

The single base range set by CORSnet-NSW is validated by Janssen and Haasdyk's (2011) findings that acceptable accuracy may be achieved up to 50km from a base, but only under very good atmospheric conditions. Research carried out by Aykut et al. (2015) in Turkey confirms this limit. They found CORS single base RTK could provide good precision within a 50km radius of the base if conditions were good. However, the Intergovernmental Committee on Surveying and Mapping (2020) recommends that an RTK rover should not be more than 20km from the base, and CORSnetNSW claim of 2cm accuracy is only possible within 20km from a single base CORS station (NSW Government 2022a). As the vertical component of GNSS measurements are generally two to three times less accurate than the horizontal (Garrido et al. 2011; Berber et al. 2012; Gillins et al. 2019), GNSS levelling using a single CORS station would require conditions very favourable to achieve high accuracy vertical measurements using CORS single base RTK.

While 20km may be the generally accepted limit for single base RTK, it is preferable to stay even closer to the base. Hu et al. (2003), Aykut et al. (2015) and Zhang et al. (2006) recommended a range of less than 10km (15km maximum) due to the propagation of spatially correlated errors. Janssen and Haasdyk's (2011) results confirm a decrease in accuracy as distance from a single CORSnet-NSW base increased. As single base error increases with distance it is advisable to stay as close to the base station as possible. Most work in rural areas occurs at least 10-20km from a CORS station making CORS single base RTK impractical for high accuracy work in these locations. For this reason, the traditional base-rover method is the only viable single base RTK method in rural NSW as the base can be kept within a few km of the rover. This leaves CORSnet-NSW's NRTK as the only viable alternative to traditional RTK in rural NSW. CORSnet-NSW claim of 2cm accuracy wherever there is network coverage (NSW Government 2022a) does not specify whether it is referring to vertical or horizontal accuracy.

In order to better understand this, this project focuses on comparing the vertical accuracy and precision of CORSnet NSW to that of traditional RTK. In order to determine if CORSnet-NSW or traditional base-rover RTK is most accurate in the vertical component they must be directly compared. Studies comparing the vertical accuracy of NRTK to traditional RTK have been performed in various European countries such as Latvia (Dobelis & Zvirgzds 2016), Spain (Garrido et al. 2011) and Turkey (Gumus et al. 2016). However, as errors are network dependent the results of these studies cannot be applied to the CORSnet-NSW network. A study producing results for use in NSW must be based on the local CORSnet-NSW network. Furthermore, the traditional RTK used by Dobelis and Zvirgzds (2016) and Garrido et al. (2011) was a single CORS base, not the base-rover RTK that surveyors and civil contractors in the study area use. This is an important difference to note because both these studies found the NRTK levels to be more accurate than single base.

However, Gumus et al. (2016) found that 'classical' single base RTK levels were more accurate than NRTK. It appears that the 'classical' RTK in Gumus et al's study was a base-rover setup. These contrasting results suggest that, especially at shorter distances, base-rover RTK levels may be more accurate than those of NRTK. Janssen and Haasdyk (2011) undertook a comparison between CORSnet-NSW NRTK and single base RTK methods. Their study used CORS single base RTK and not base-rover RTK. The vertical results show virtually the same level of accuracy when the rover is very close to the base station. The accuracy of both NRTK and single base RTK decreased as the distance from the rover to a CORS station increased, but the NRTK results maintained a higher level of accuracy at the longer distances. These results are not surprising and confirm the theory that NRTK is more accurate than single base RTK at longer ranges. What this study does not consider is that on a rural site 20-30km from a CORS base, traditional base-rover RTK will be operating over much shorter baselines than NRTK and therefore may potentially provide much more accurate vertical results. Even though the base-rover RTK lacks advanced atmospheric error modelling, its close proximity to the rover could give it an advantage. It may be said Janssen and Haasdyk's (2011) results are sufficient to deductively draw the needed comparisons. Even if this were possible, they are now over a decade old, both technology and the CORSnet-NSW network have changed a lot since then. The network has grown

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from 68 CORS stations (Janssen et al. 2011) to 202 stations (NSW Government 2022c) greatly increasing the density in rural areas. There are now more GNSS satellites and satellite constellations in use which help to improve GNSS accuracy.

Since 2011, CORSnet-NSW has begun including corrections for three new satellite constellations, the European Space Agency's Galileo, China's BeiDou and Japan's QuasiZenith Satellite System (QZSS) (Janssen 2016). The new constellations have been in operation since 2020 and are now available to CORSnet-NSW users. Figure 2, below, shows the increased number of satellites these new constellations provide. New research is needed to understand the impact of these new constellations on CORSnet-NSW corrections. Even though the Janssen and Haasdyk (2011) comparison is different to this study and the results are no longer current, the study laid much of the groundwork for the methodology used in this project.

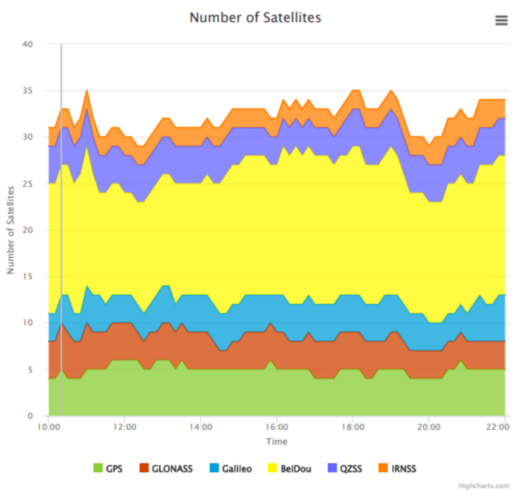

Figure 2: Number of visible GNSS satellites above 30^0 elevation in 2022 (Test sites)

Receiver technology has also advanced during the past few years. Research by Dobelis and Zvirgzds (2016) found that modern GNSS receivers were more accurate than those from only a few years earlier. While they didn't cite any particular factor, investigating the specifications of their equipment reveals that the older GNSS receiver that was returning less accurate results was dual frequency only. This project used modern triple frequency Trimble R10 and R8s receivers. Triple frequency GPS, which uses the L5 GPS signal, has been available for use since 2014. Although not yet fully operational, it is currently limited to the navigation message, traditional base-rover RTK can begin to make use of triple frequency GPS which was unavailable in earlier studies (US Government 2022). This is currently a point of comparison, because while CORSnet-NSW has begun supporting the L5 signal, its rollout was not complete at the time of field work. A check of the CORSnet-NSW Network Information page (NSW Government 2022b) at the time of field observation reveals stations such as Bathurst and Adaminaby track the L5 signal. However, it is not currently supported in many locations including those around the test area such as the Griffith and Narrandera CORS.

Berber et al. (2012) assessed the accuracy of base-rover RTK using triple frequency receivers, however, they compared it to other kinematic and static GNSS methods, not NRTK. Although they used triple frequency receivers the L5 signal was not being broadcast at the time. It is probable that they were using triple frequency capable receivers in a dual frequency capacity. Also, the Galileo and BeiDou constellations were not yet operational. Though this comparison is different to this project, some of the data analysis methodology used is relevant to this study and the base-rover RTK results could be used to verify the findings of this study. During the last decade, several researchers in NSW have conducted studies involving GNSS heights. Janssen and Watson (2010) evaluated GNSS derived AHD heights to compare the then new AUSGeoid09 model to the older AUSGeoid98 geoid. Sussanna et al. (2014) compared the same models but focused their study in mountainous areas. Janssen and Watson (2019) made similar comparisons between AUSgeoid09 and the current AUSgeoid2020. These three studies recognised CORS networks need of accurate geoid models to compute accurate AHD levels. They evaluated the improvements as new AUSGeoid models became available. This project used the AUSGeoid2020 but compared the RTK methods themselves and not the geoid models. These studies indicate that results from older studies using superseded geoid models are not the same as those expected when using the current version. Therefore, results from older evaluations of CORSnet-NSW can no longer be regarded as current.

Allerton et al. (2015) performed a geoid comparison that was slightly different to those just mentioned which compared GNSS networks. They used NRTK observations in the field to obtain CORS derived AHD heights. However, although they were using a rover operating on CORSnet-NSW to measure heights, the results are unlike this study for the following two reasons. First, they compared the AUSGeoid98 and AUSGeoid09 models, neither of which remain the latest standard. Second, the comparison is between CORSnet-NSW derived AHD heights and published Survey Control Information Management System (SCIMS) heights. It is important to note that none of these four AUSGeoid studies compared calibrated NRTK heights to that of traditional RTK (or even CORS single base RTK) as in this project. Instead, they focus on uncalibrated AHD heights derived from CORSnet-NSW. These comparisons are between geoid models not RTK methods.

As this project is based on the CORSnet-NSW network, it provides a level of relevance for local users that the overseas studies cannot. In the past, most CORSnet-NSW studies involving height have, in some form, been the work of Janssen and Haasdyk (2011). While these have provided a good understanding of how the network was designed and operates, there is room for an independent evaluation of the now completed network. This project was also the first to evaluate the network's vertical accuracy and precision using the new AUSGeoid2020 model and newly available GNSS constellations. As the project is limited to a small area of the state's mid-west the results are limited to areas of similar topography and network density.

2. MATERIALS AND METHODS

This section covers the site selection, data collection and analysis methodology. It also discusses the GNSS errors which may affect the results and what has been done to minimise them. The traditional RTK used in this research project is the personal base-rover RTK method where a base station is set up over a known point to compute and transmit local corrections to a rover. The range of the rover is limited to the range of the radio signal and is therefore usually only a few kilometres from the base. This setup is currently used and trusted by land surveyors and civil contractors in rural NSW for the purposes of data collection and machine guidance etc. They usually own their own RTK base-rover kit and move it with them from site to site.

2.1 Test Sites

The study areas are located in the heart of the Murrumbidgee Irrigation Area which includes the towns of Griffith, Rankin Springs, Ardlethan, and Narrandera as shown in the Figures 3 and 4. A CORSnet-NSW station is located in each of these towns and The CORSnet-NSW station codes are illustrated in the Figure 4 as GFTH, RANK, ARDL, and NDRA respectively. Two test sites were selected at Leeton and Griffith close to CORS stations.

Figure 3: Location map of study area

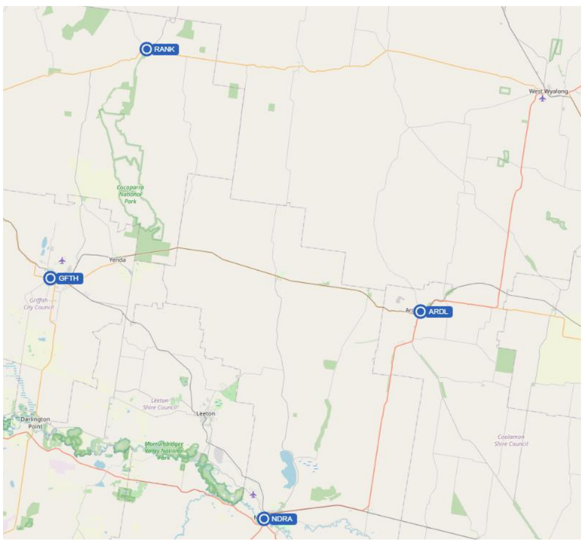

Figure 4: Map of CORS stations in study area

Previous NRTK research by Dobelis and Zvirgzds (2016) found a substantial increase in the precision of derived coordinates as the distance from a LatPos CORS station increased. This is confirmed by the results of Janssen and Haasdyk (2011) who found a decrease of precision linked to increased distance from a CORSnet-NSW station. This is because inter-CORS distances, the distance between any two CORS in the network, effect the accuracy of NRTK corrections. They stated that inter-CORS distances up to 70-90km were acceptable and that within this range it was possible to maintain the same results as high accuracy single base RTK. None of the Inter-CORS distances in the test area are greater than 81km.

Two test sites were selected at different distances from CORSnet-NSW stations to investigate how proximity to a CORSnet-NSW base affects vertical accuracy and precision. Using these sites, it was decided to create two test scenarios for evaluation. The Griffith site was chosen relatively close to a CORSnet-NSW base to simulate a high accuracy case and the Leeton site, at the maximum practical distance from a CORSnet-NSW station, to simulate a worst-case scenario. The Leeton site is over 28km away from the nearest CORS station, while the Griffith site is only 10km away.

To complete these test scenarios, the rovers were positioned 4km away from the traditional RTK base station/NRTK calibration point at the Leeton site and 1km away at the Griffith site (Figure 5). At each site, the two methods were tested simultaneously to expose them to the same conditions using two identical receivers, one connected to CORSnet-NSW and the other to a traditional RTK base. The proximity of each site to a CORSnet-NSW base is illustrated by the sketches, Figure 5 below.

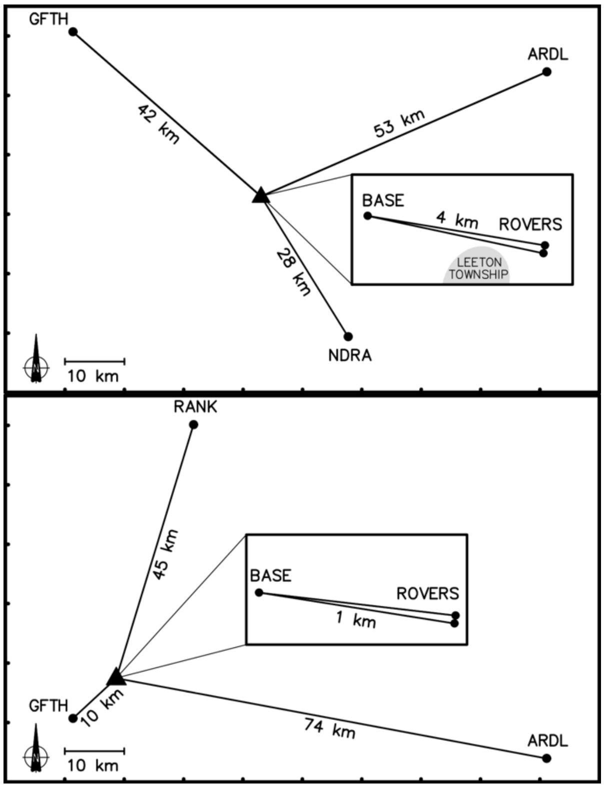

Figure 5: Proximity of Leeton test site and Griffith test site to CORS stations

In order to determine accuracy, a comparison must be made between the observed and known values of a given point. Edwards et al. (2010) assessed the accuracy of NRTK by comparing the published values of reference stations to their observations. The resulting coordinate difference became the measure of accuracy.

Three temporary benchmarks were installed at each site, one for the base station and one for each rover. The AHD level from a nearby permanent survey mark (PSM) was transferred to the base station. The height difference between the base and rover points was derived by third order differential levelling to establish their 'true height' in relation to the base point. Each day, the CORSnet-NSW rover was calibrated on the same base point occupied by the traditional RTK base station. Accuracy was then derived by comparing the true levelled height to that obtained using GNSS. While no measurement can be made with absolute certainty, the term 'true height', when used in this paper, refers to the height via differential levelling which is the best estimate of the true height. At the Leeton site, the base and rover points are 4km apart. Here, two SCIMS marks on the same adjustment with 10mm relative vertical accuracy were used. This reduced the amount of levelling required to about 50m at either end to connect to the base and rover points.

2.2 Data Sources

This section discusses how the data for this research was acquired. Primary data is first-hand data collected by the researcher, and secondary data is sourced from third parties who publish information either publicly or privately (Dudovskiy 2022).

2.2.1 Primary data sources

The primary data source for this study was GNSS field observations. Data from each RTK method was collected simultaneously as illustrated in the Figure 6.

Figure 6: Field data collection using GNSS receivers

While GNSS errors can be managed, a certain amount of error will always remain in the recorded measurements. Because satellite geometry and atmospheric conditions are constantly changing, the errors they create cause continual variance in GNSS precision. Therefore, if accuracy was determined over a short period of time when conditions are good, it would not be a true indication of general performance when conditions are less favourable. To ensure the results of this project are a true indication of real-world accuracy, data must be collected over an extended period of time. Previous studies have collected data samples for various lengths of time. Janssen and Haasdyk (2011) collected data continuously over three days, Edwards et al. (2010) for six hours and Gumus et al. (2016) for eight hours. In order to collect a sufficient quantity of data to investigate trends and changes to accuracy over time, observations were stored at one second epochs for the duration of a seven-hour day generating a sample of over 25,000 observations. Gumus et al. (2016) recommend that measurements should be taken at each test site on at least three separate days to ensure repeatability and data redundancy. This seems to be standard practice as it is also the length of testing used by Janssen and Haasdyk (2011) and Allerton et al. (2015). Data was collected for three days at each site the months of July to September 2020 with at least one week between revisiting each site (See Tables 2 and 4).

2.2.2 Secondary data sources

The secondary data used in this project was the published heights of SCIMS marks, GNSS planning charts and manufacture specifications. Because this study focuses on relative accuracy, the height difference between the base and rover is the critical value. Therefore, SCIMS marks with high order levels were not required, so long as the level was accurate enough that the AUSGeoid values were not affected.

3. RESULTS

There are three standard metrics for comparing the accuracy and precision of GNSS derived data. First, the Root Mean Square error (RMSe) is the generally used method of evaluating precision and was used for this purpose by Janssen et al. (2011), Edwards et al. (2010), Gillins et al. (2019), ElMowafy (2012) and Berber et al. (2012). Second, the mean or average of the data set is used to evaluate accuracy. The difference between the mean and the known value gives the measure of accuracy (Edwards et al. 2010) (El-Mowafy 2012). Third, the maximum deviation from the mean is a useful indication of the magnitude of outliers (Dobelis & Zvirgzds 2016) (El-Mowafy 2012). The tables below display the project's results according to these metrics. The metrics were calculated individually for each dataset. The results presented are an average of these three daily results at each site. The RMSe of this project has been calculated at both the 68% CI for comparison to previous research and 95% CI as the official result of this project in accordance with the ICSM Special Publication 1 (SP1) guidelines (Intergovernmental Committee on Surveying and Mapping 2020). Accuracy was derived by calculating the difference from the true height to the GNSS derived height. The height differences are the measure of accuracy. In addition to the standard metrics, a table showing the average Vertical Dilution of Precision (VDOP) for each method on each day has also been prepared to support the analysis of precision.

Station Name	NRTK (CORSnet-NSW)	Traditional RTK
Griffith Vertical RMS @ 68%	9.2mm	4.3mm
Griffith Vertical RMS @ 95%	18.1mm	8.4mm
Leeton Vertical RMS @ 68%	14.3mm	7.6mm
Leeton Vertical RMS @ 95%	28.0mm	14.9mm

Table 1: RMSe at both Confidence Intervals

Table 1 above, shows the vertical RMSe values at both the 68% and 95% confidence intervals (CI). These results show that at the 95% CI, traditional RTK is up to two times more precise than CORSnetNSW NRTK. The precision of both methods is higher at the Griffith site by a similar margin.

Station Name	02/08/2020	09/08/2020	16/08/2020	30/08/2020	06/09/2020	20/09/2020
Griffith RTK		0.9	1.0		1.0	
Griffith NRTK		1.3	1.2		1.3	
Leeton RTK	1.0			1.0		0.9
Leeton NRTK	1.3			1.3		1.1

Table 2: VDOP values

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Table 2, above, shows the daily average VDOP value for each method over the course of this study. In general, the VDOP value of NRTK was about 0.3 higher than that of traditional RTK.

Station Name	Height (Differential levelling)	Height (GNSS)	Accuracy (Height difference)
Griffith RTK	128.105	128.108	+3mm
Griffith NRTK	128.116	128.110	-6mm
Leeton RTK	135.277	135.278	+1mm
Leeton NRTK	135.285	135.276	-9mm

Table 3: Accuracy, difference from true height

Table 3, above, compares the GNSS derived heights to the height derived via differential levelling which was adopted as the 'true' height. The GNSS heights are mean height at each site and accuracy is expressed as their difference from the true height. Importantly, the height difference between different methods at the same site is about 1cm.

Station Name	02/08/2020	09/08/2020	16/08/2020	30/08/2020	06/09/2020	20/09/2020
Griffith RTK		14mm	24mm		16mm	
Griffith NRTK		31mm	48mm		43mm	
Leeton RTK	19mm			36mm		41mm
Leeton NRTK	52mm			41mm		57mm

Table 4: Maximum height difference for each day of observations

Table 4, above, shows the maximum difference from the mean for each day of observations. These outliers are significantly greater for NRTK than they are for traditional RTK'.

4. ANALYSIS AND DISCUSSION

This section analyses the results from the previous section in relation to the objectives of this research project. Preliminary windowing tests showed a 2mm improvement in RMSe for a two- 14-minute window compared to a five second window. This agreed with the research by Bein (2015) and shows the increased precision of newer constellations and receivers translating to efficiency gains. As it agrees with previous research, the difference is less than the setup error budget and it is the length of a typical topo shot in the field, the five second window was chosen to be the standard observation length for this study.

4.1 Precision

Before the precision results can be used for analysis, it is necessary to ensure they lie within the tolerance ranges of the manufactures specifications of the rover. The expected level of precision for each site and method has been calculated below using the manufactures specifications (Trimble inc., 2018):

- Leeton RTK = (0.015m+1ppm * 4000m) * 1.96 = 37mm RMS
- Leeton NRTK = (0.015m+0.5ppm * 4000m) * 1.96 = 33mm RMS 325
- Griffith RTK = (0.015m+1ppm * 1000m) * 1.96 = 31mm RMS
- Griffith NRTK = (0.015m+0.5ppm * 1000m) * 1.96 = 30mm RMS

Most of the values in Table 1 are well below these limits of precision. However, at 4km from the calibration point, the Leeton NRTK is getting close to its limit.

4.2 NRTK vs Traditional RTK

This section compares the results of both GNSS methods in terms of both precision and accuracy. It also discusses the reason behind the different VDOP values and compares accuracy in relation to true height.

4.2.1 Precision

Results at the 95% CI clearly show that traditional RTK is almost twice as precise at both test sites. However, while this is a large margin, the significance is relatively small given the usual tolerances of GNSS measurements. Precision was only 10-12mm worse when using CORSnet-NSW than traditional RTK. So, while CORSnet-NSW is less precise, it is not by a great margin. The sub 3cm precision of CORSnet-NSW will still be within the limits of many projects where GNSS is used for levelling.

4.2.2 Accuracy

Accuracy results show traditional RTK to be two times more accurate than NRTK. However, there is a definite bias of CORSnet-NSW to be several millimetres below the true value while traditional RTK is a few millimetres above it. This trend was distinctly repeated at both sites and on each day of testing. This difference is important to consider, because even though the accuracy for each method is similar at both sites, results derived using the different methods will be up to 1cm different. because of the biases. This difference is shown on the graph, Figure 7, below.

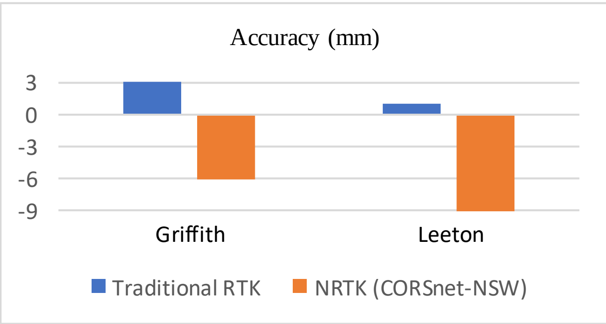

Figure 7: Accuracy in relation to true height

There is no avoiding the fact that traditional RTK is both more precise and accurate than NRTK. When absolute precision is the most critical factor, traditional RTK is still the best solution.However, CORSnet-NSW has come a long way, and the vertical accuracy and precision it can now achieve makes it suitable for many uses.

4.2.3 VDOP

During testing it was found that the traditional RTK rover tracks more satellites and therefore has lower VDOP, as illustrated in Table 2, than the rover using CORSnet-NSW corrections. CORSnet-NSW consistently tracked about two thirds the number of satellites being tracked by the traditional RTK rover beside it. This is most likely due to the fact that even though the extra third is visible to the rover, it cannot use them in its solution because they are not visible from enough CORS sites to make a CORSnet-NSW correction available at the rover's location.

4.3 Proximity to CORS Station

The precision of the CORSnet-NSW results at the Griffith site are significantly higher than at Leeton. Initially it seemed this was because the Griffith site is 18km closer to a CORS station. However, upon closer examination it is seen that the traditional RTK results improved by a similar margin, as illustrated in Figure 8 below

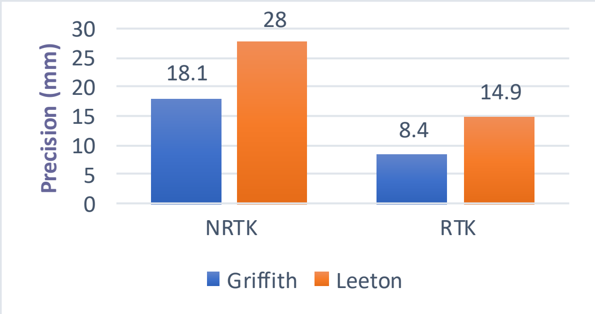

Figure 8: Precision of each method at different sites

This suggests that the increased precision is predominantly because the rovers were only 1km from the calibration/base point and not 4km as at Leeton. This result is not unusual given that RTK GNSS errors are spatially correlated, meaning they increase as in proportion to the distance of the baseline. The traditional RTK and NRTK precisions improved by a ratio of 1/1.77 and 1/1.54 respectively. This suggests that the proximity to a CORS station does have some affect, but it is not as great as the effect of baseline length. Further research needs to be conducted to determine the exact proportion that each of these factors contribute. Accuracy is very similar at both sites for each method. The small differences may be the result of random error in the control survey. Regardless, it is safe to say that there is no notable improvement in accuracy arising from proximity to the CORS station.

4.4 CORSnet-NSW Claim

One of the objectives of this study was to evaluate CORSnet-NSW claim of network wide 2cm vertical 'accuracy'. It is important to note that this claim, used for marketing, actually refers to precision rather than accuracy in the technical sense. It is assumed that this claim of 2cm precision is based on the work of CORSnet-NSW employees Janssen and Haasdyk (2011). As their results were calculated at the optimistic one sigma (68% CI) level, the results of this project must be calculated at 68% CI for comparison. The results from Table 1 show that this claim is definitely achievable, even when the rover is quite far from a CORS station and 4km from the calibration point. Results calculated at the more realistic 95% CI show sub 3cm 'accuracy' to be more probable. This is still an impressive outcome for an RTK method which can be used so far away from a base station.

4.5 Changes Over Time

The graphs below, Figure 9 and 10, compare CORSnet-NSW precision over the course of one day of testing at the Griffith site and VDOP values provided by (Trimble Inc. 2020). Common points on the graphs have been marked to show the correlation between VDOP values and poor GNSS precision. Lines on the graph below, Figure 9, show the upper and lower limits of the RMSe range at the 95% CI.

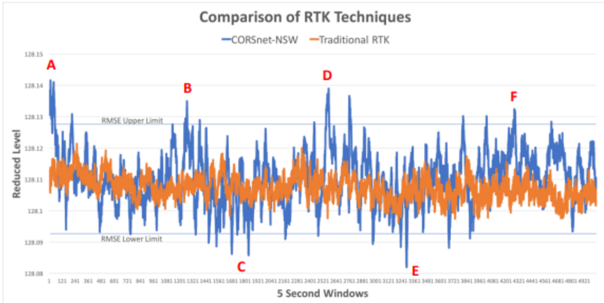

Figure 9: Comparison of levels over 7hrs using of both RTK techniques. Note: RMSe limits are at 95% CI

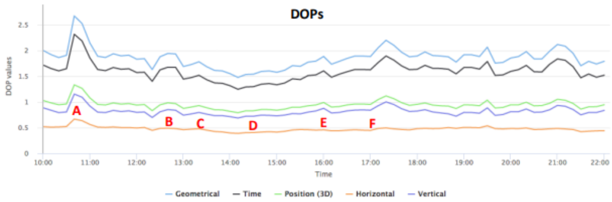

Figure 10: GNSS planning chart showing VDOP values during data collection.

There is no link between random movement within the RMSe range and the predicted VDOP values. This continual random movement is not unusual and is caused by the constantly changing satellite geometry. However, it is apparent that most outliers occur when the VDOP increases. This is because there are not enough satellites available to maintain a good level of precision. In this study.

this was found to occur when the number of satellites used in the solution dropped below about 18. Based on these observations, it is recommended users check the VDOP and number of tracked satellites before relying on their results. Further research would be required to determine what is an acceptable level of VDOP in the field. If the accuracy of levels is critical, it is important to reoccupy the position a few minutes later as a check against outliers. The average of the two measurements can then be adopted. This practice was recommended by Edwards et al. (2010) and confirmed by Janssen and Haasdyk (2011) and Bein (2015). However, they all specify that reoccupation should occur after 10-30 minutes to allow for changes in satellite geometry. Examination of the peaks in Figure 9 reveals cycles of 5-10 minutes. This indicates that optimal reoccupation times are currently less than 10 minutes. This is not surprising given the fact that there are many more satellites available now leading to faster geometry changes. However, further research is required to confirm this theory.

5. CONCLUSIONS

This research paper has compared the vertical accuracy and precision of CORSnet-NSW and traditional RTK in regional NSW. The comparison sought to replicate real world survey scenarios to make the results relevant to the end user. Tests were repeated over several days in varying weather conditions at two different sites. Standard survey equipment and practical methods were used, making the results possible to be repeated by any other surveyor or GNSS users in the region. The windowing technique, proved by previous researchers, was used to reduce the effect of outliers.

The vertical accuracy difference between traditional RTK and CORSnet-NSW was minimal and is negligible for most uses.

However, traditional RTK was found to be significantly more precise than CORSnet-NSW. It was confirmed that CORSnet-NSW does live up to its claim of network wide 2cm 'accuracy' (68% CI), even in the vertical component. More reliably though it was found to have 3cm 'accuracy' at the 95% CI. It was found that the usual changes in satellite geometry had no significant effect on the CORSnet-NSW precision or caused it to move beyond the range of the RMSe. Precision only exceeded these limits when the number of satellites being tracked dipped into the mid-teens, and the affected measurements were identified with high VDOP.

It was found that CORSnet-NSW precision was affected by the proximity of the rover to the base/calibration point more than its proximity to a CORSnet-NSW station. It is of critical importance that GNSS users stop and consider their current estimation of GNSS precision. Even though traditional RTK is still more precise than CORSnet-NSW the level of precision of both techniques has improved dramatically in recent years. Recent improvements mean that CORSnet-NSW can now achieve the same level of precision that was expected of traditional RTK only a few years ago.

Due to time constraints, it was not possible to investigate the distance of the rover to the calibration point at each site. Further research should test different distances between the rover and calibration point without changing the proximity to the CORS station. In this study, traditional RTK had the slight advantage of using triple frequency GPS although in its limited form. CORSnet-NSW was in the process of switching on these corrections in the study area at the time of this project. Although they were not available for use in this study, further research is recommended to investigate the improvements it provides once the L5 signal is in full operation.

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