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Investigation of Virtual RINEX Data Quality

Volker Janssen
Survey Infrastructure and Geodesy, Land and Property Information
NSW Department of Finance & Services, Bathurst NSW 2795, Australia
Tel: +61-2-6332 8426, Fax: +61-2-6332 8479, Email: Volker.Janssen@lpi.nsw.gov.au

ABSTRACT

Network Real Time Kinematic (NRTK) Global Navigation Satellite System (GNSS) technology is being utilised for a wide range of positioning applications. The advantage of NRTK is its ability to provide corrections (accounting for atmospheric and satellite orbit errors) that are based on a Continuously Operating Reference Station (CORS) network rather than a single reference station. While most users employ NRTK for real-time applications, it is also possible to benefit from network-based GNSS corrections for post-processing applications. This is achieved through the provision of Virtual RINEX data, i.e. data that would have been observed at an imaginary, unoccupied (i.e. virtual) GNSS reference station whose location is specified by the user. This paper presents an initial investigation into the quality of Virtual RINEX data in regards to processing outcomes. An extensive 3-day dataset is used to compare static positioning results obtained with Virtual RINEX data generated by CORSnet-NSW and RINEX data observed at two test sites (incorporating small and large NRTK cells) in New South Wales, Australia. At each test site, data are analysed in three ways: (1) ‘zero’ baseline processing between virtual and observed data for session lengths ranging from 10 minutes to 24 hours, (2) AUSPOS processing using virtual and observed data for 2-hour, 6-hour and 24-hour sessions, and (3) baseline processing relative to surrounding CORS using virtual and observed data for session lengths of 10 minutes, 1 hour and 24 hours. It is found that ‘zero’ baselines vary from 1 mm (hz) and 2 mm (vt) for long observation sessions in a small NRTK cell to 15 mm (hz) and 40 mm (vt) for all observation windows investigated in a large NRTK cell. 24-hour AUSPOS solutions based on Virtual RINEX data agree with those using observed data at the 10 mm level or better, while 2-hour solutions show differences of up to about 20 mm (hz) and 40 mm (vt). Baseline processing to surrounding CORS reveals differences ranging from the few-mm level for short (10 km) baselines in a small NRTK cell to the few-cm level for long (70 km) baselines in a large NRTK cell. These results indicate that Virtual RINEX data are comparable to observed data for some applications, provided NRTK cell size, observation length and baseline length are taken into consideration.

KEYWORDS: GNSS, Virtual RINEX, Network RTK, CORSnet-NSW.

1. INTRODUCTION

Network Real Time Kinematic (NRTK) Global Navigation Satellite System (GNSS) technology is being utilised for a wide range of surveying, mapping, agriculture, mining and construction applications, providing users with instant and highly accurate position information over distances of several tens of kilometres. The advantage of NRTK is its ability to provide corrections (accounting for atmospheric and satellite orbit errors) that are based on a Continuously Operating Reference Station (CORS) network rather than a single reference station (e.g. Wang *et al*., 2010; Janssen and Haasdyk, 2011; Penna *et al*., 2012).

CORSnet-NSW is a rapidly growing network of GNSS CORS providing fundamental positioning infrastructure for New South Wales (NSW), Australia that is accurate, reliable and easy to use (Janssen *et al*., 2011, 2013). It is built, owned and operated by Land and Property Information (LPI), a division of the NSW Department of Finance and Services. CORSnet-NSW currently (June 2013) consists of 128 CORS tracking multiple satellite constellations, and efforts are underway to expand the network to over 150 stations by mid 2014 (Figure 1). Currently, 60% of the area of NSW (and 98% of the population) is covered by the single-base RTK service, while NRTK is available to 38% of the area of NSW (and 94% of the population).

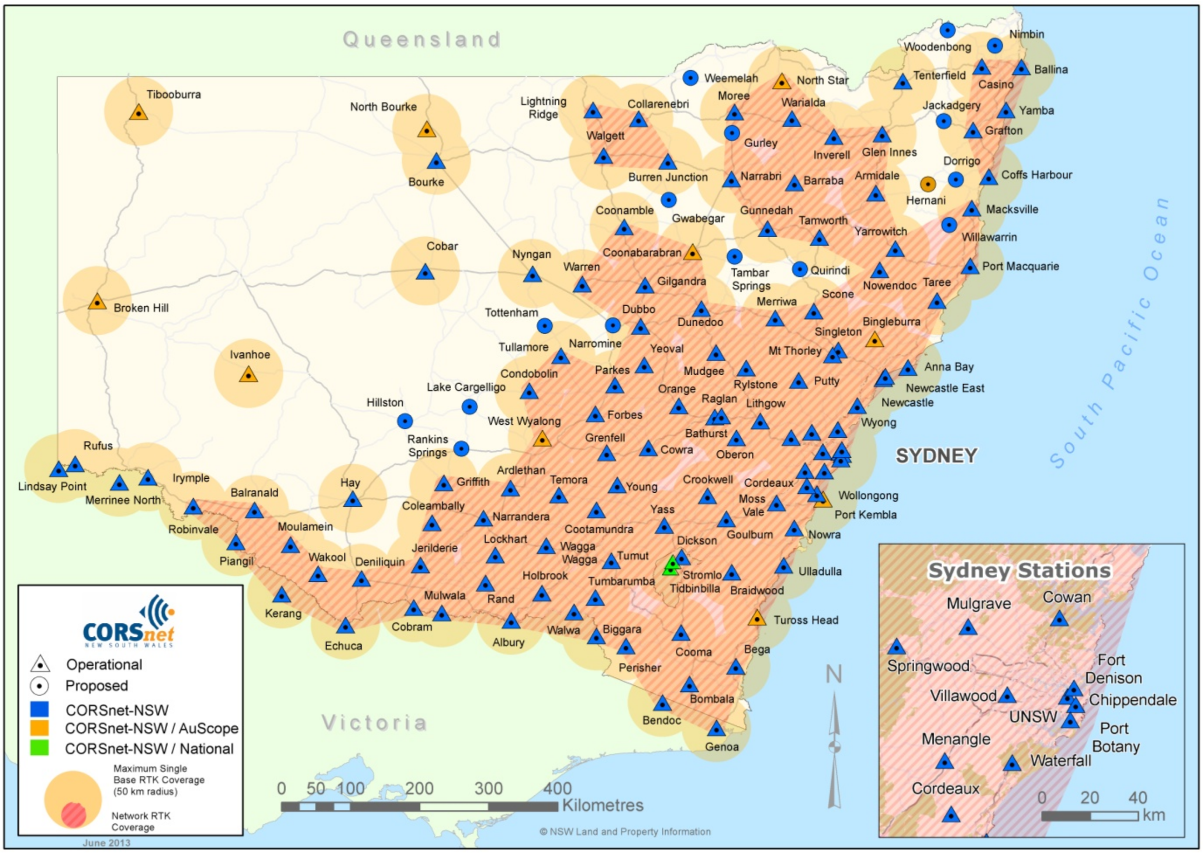

Figure 1: CORSnet-NSW network map as of June 2013 (LPI, 2013).

NRTK can significantly reduce the effect of the ionospheric delay, the largest error source affecting GNSS observations. It is worth noting that we are currently approaching a solar maximum. While initially predicted for early 2013, it is now forecast to occur in the second half of this year (NASA, 2013). As increased ionospheric disturbances are evident many months before and after the nominal solar maximum, GNSS users should already expect intermittent effects on positioning quality (Janssen, 2012).

To date, most users employ the NRTK technique for real-time GNSS applications. However, it is also possible to benefit from network-based GNSS corrections for post-processing applications. This is achieved through the provision of Virtual RINEX data, i.e. data that would have been observed at an imaginary, unoccupied (i.e. virtual) GNSS reference station whose location is specified by the user. The RINEX (Receiver INdependent EXchange) format was initially developed by the Astronomical Institute of the University of Berne, Switzerland for the easy exchange of data to be collected during the first large European GPS campaign EUREF89, which involved more than 60 GPS receivers from four different manufacturers. Since then, it has evolved into an international standard for the exchange and archiving of GNSS data (IGS and RTCM-SC104, 2013).

Simply put, Virtual RINEX is a method of archiving NRTK data to a RINEX file instead of broadcasting the data in real time. In theory, post-processing performance should be very similar to real-time operation, assuming that (a) RINEX files have the same content and accuracy/precision as broadcast NRTK data and (b) the processing software employs similar algorithms in both real-time operation and post-processing. The use of Virtual RINEX data is of potential benefit to a variety of applications, including the provision of a backup in case the NRTK communications link fails (provided raw data are collected at the rover), the standardised generation of GNSS reference stations along extended linear infrastructure projects (e.g. highways, railways and pipelines), the establishment of reference stations in restricted or denied areas, and boutique solutions that may require airborne or offshore reference stations.

Virtual RINEX data are generated by the CORS network management software for a user-defined location (and time span). This process involves the following steps:

- Determining atmospheric and satellite orbit errors by fixing the ambiguities of the baselines within the network.
- Generating network-based corrections for the given location using linear or higher-order interpolation models.
- Applying these corrections to the given location.
- Geometrically displacing (i.e. ‘shifting’) the observations of the nearest CORS onto the given location.

This paper presents an initial investigation into the quality of Virtual RINEX data. An extensive 3-day dataset is used to compare static positioning results obtained with Virtual RINEX data generated by CORSnet-NSW and observed RINEX data. At each of two test sites (incorporating small and large NRTK cells), data are analysed via ‘zero’ baseline processing between virtual and observed data, AUSPOS processing (GA, 2012a) using virtual and observed data, and baseline processing relative to surrounding CORS using virtual and observed data. It is shown that Virtual RINEX data can be comparable to observed data for some applications, provided NRTK cell size, observation length and baseline length are taken into consideration.

2. STUDY AREAS AND METHODOLOGY

The quality of Virtual RINEX data was investigated by collecting three consecutive days of GNSS data at two locations within eastern NSW between December 2010 and January 2011. It should be noted that the data analysed in this study were collected in conjunction with a larger dataset previously used to investigate NRTK performance in real time (Janssen and Haasdyk, 2011). While this dataset was not specifically collected for the purpose of Virtual RINEX data testing, it is nevertheless able to provide a first indication of the quality of virtual data compared to observed data. Figure 2 illustrates the two study areas including the surrounding CORSnet-NSW sites used to generate each NRTK cell at that time.

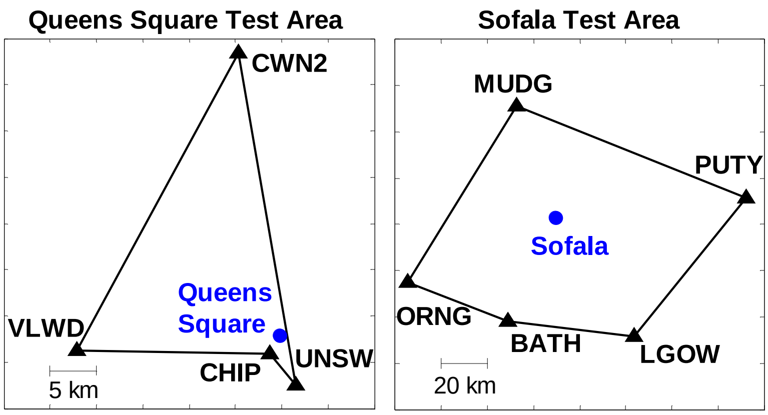

Figure 2: Location of the study areas and surrounding CORS.

The two study areas were chosen to exhibit a clear skyview with minimal obstructions. At the Queens Square test site, one Leica Viva GNSS receiver was used to observe raw GNSS data at a 1-second sampling rate. At Sofala, four of these receivers were employed next to each other. However, since very consistent results were obtained for these four receivers, this paper presents the analyses for one of these instruments only. The average and maximum inter-CORS distances around the perimeter of each NRTK cell (as it existed at the time of data collection) are listed in Table 1. Inter-CORS distances in the Queens Square test area are typical of NRTK cells found in the Sydney metropolitan area. The Sofala test area exhibits larger inter-CORS distances that are still within the recommended maximum of about 90 km (typical for regional NRTK areas in NSW), with the exception of the baseline MUDG-PUTY (108 km). It should be noted that the recent installation of Rylstone CORS, located between Mudgee and Putty, has since eliminated this longer baseline (see Figure 1).

Table 1: Inter-CORS distances in each test area.

Test Area	Inter-CORS Distance (km)	
	Average	Maximum
Queens Square	25	37
Sofala	75	108

The Virtual RINEX data used in this study were generated by the Trimble VRS^{3}Net CORS network management software (version 1.01). This process requires the user to provide the location of the desired virtual GNSS reference station (in latitude, longitude and ellipsoidal height or in Cartesian coordinates). In practice, the user generally chooses this location to be somewhere in the vicinity of the survey area. However, in this case, it was necessary to determine an exact location in order to allow comparisons with observed RINEX data at a given location. This given location was determined by a good-geometry GeoLab least squares network adjustment based on the observed 24-hour baselines to three surrounding CORSnet-NSW stations. The adjustment was constrained by the Regulation 13 values (GA, 2012b) of the CORS involved. It should be noted that all baseline processing in this study was performed using the Leica Geo Office software package (version 7.01), final precise satellite orbits, absolute antenna models provided by the International GNSS Service (IGS) and GPS-only solutions without any manual editing (e.g. no deletion of particular satellites) during processing. As indicated in the following sections, the 3-day datasets were truncated into smaller observation sessions as required.

2.1 'Zero' Baseline Processing

In the first analysis, 'zero' baselines were processed between virtual and observed data on each test point for various session lengths. It is important to note that, strictly speaking, this is not a zero baseline test as routinely used to evaluate GNSS receiver performance because the data were not collected using one GNSS antenna feeding two receivers. In order to satisfy the RINEX standard, the Virtual RINEX datasets are generated with respect to the physical antenna type of the nearest CORS, which is different from the antenna type used to observe the test data in the field. Nevertheless, provided that absolute antenna models are applied correctly, the baseline should be close to zero if the virtual and observed RINEX data can be assumed the same. Thus, the length of this baseline is used to investigate the quality of the Virtual RINEX data. Session lengths of 10 minutes, 30 minutes, 1 hour and 2 hours over one day were analysed, as well as 6-hour, 12-hour and 24-hour sessions over three days. In order to reduce the processing overhead, the 1-day analysis included a maximum of 24 solutions, i.e. using a 10-minute or 30-minute observation window at the beginning of each hour. All sessions were processed using a sampling rate of 30 seconds.

2.2 AUSPOS Processing

The second analysis was based on AUSPOS, Geoscience Australia's online GPS processing service (GA, 2012a). The position of each test point was determined using 30-second virtual and observed data for 2-hour, 6-hour and 24-hour sessions over three days. AUSPOS utilises the Bernese GPS software version 5.0 (Dach *et al*., 2007), and in this case solutions were based on connections to 13 or 14 surrounding CORS. The differences in the resulting coordinates were compared in order to investigate Virtual RINEX data quality.

2.3 CORS Baseline Processing

In the third analysis, baseline processing was performed relative to four surrounding CORS (fixed to their Regulation 13 positions) using virtual and observed data for 10-minute and 1-hour sessions over one day, as well as 24-hour sessions over three days. Again, the 1-day analysis included a maximum of 24 solutions, i.e. using a 10-minute observation window at the beginning of each hour. All sessions were processed using a sampling rate of 30 seconds, while the 10-minute sessions were also processed using 1-second data. For each test area, Table 2 shows the CORSnet-NSW stations involved and the baseline lengths processed. The solutions obtained using Virtual RINEX and observed data were compared against each other and against the 'true' coordinates of the test point (i.e. the adjusted coordinates used for Virtual RINEX data generation).

Table 2: CORS utilised and baseline lengths processed in each test area.

Test Area	Baseline Processing: CORS Used and Baseline Distance (km)			
Queens Square	CHIP (2)	UNSW (6)	PBOT (12)	VLWD (22)
Sofala	BATH (50)	MUDG (51)	LGOW (62)	ORNG (70)

3. DATA ANALYSIS AND RESULTS

3.1 'Zero' Baseline Analysis

On each test point, 'zero' baselines were processed between virtual and observed 30-second data for session lengths of 10 minutes, 30 minutes, 1 hour and 2 hours over one day, as well as for 6-hour, 12-hour and 24-hour sessions over three days. The resulting Root Mean Square (RMS) values for the horizontal and vertical components based on a maximum of 24 solutions are shown in Figure 3. In general, it can be seen that 'zero' baselines vary from 1 mm (hz) and 2 mm (vt) for long observation sessions in a small NRTK cell to about 15 mm (hz) and 40 mm (vt) for all observation windows investigated in a large NRTK cell.

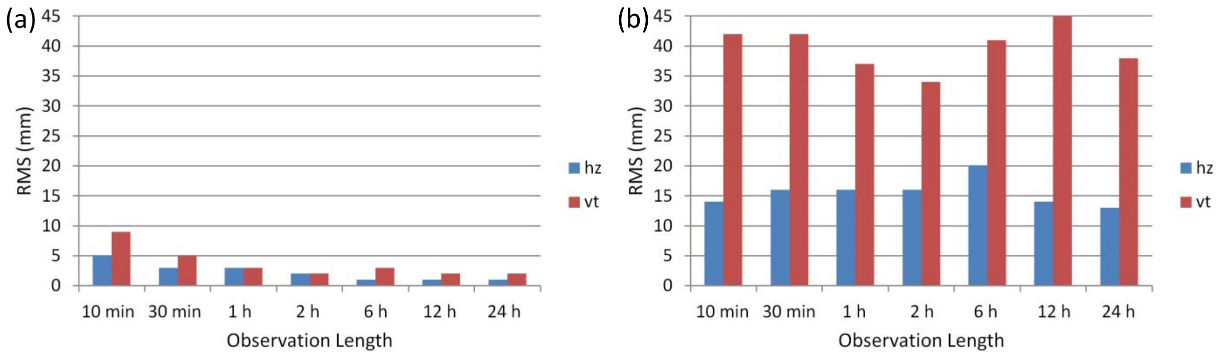

Figure 3: 'Zero' baseline results in the horizontal (hz) and vertical (vt) components for (a) Queens Square (small cell) and (b) Sofala (large cell).

Investigating Figure 3a in more detail, it is evident that in a small NRTK cell 'zero' baselines of 5 mm (hz) and 9 mm (vt) were obtained for a short observation window of 10 minutes. As expected, longer observation sessions improved the results – in this case to 3 mm (hz) and 3 mm (vt) for a medium observation window of 1 hour, and 1 mm (hz) and 2 mm (vt) for a long observation window of 12 hours. This indicates a very good agreement between virtual and observed data. The trend of improving results by increasing the observation time is not evident in the large NRTK cell (Figure 3b). Here, 'zero' baselines of about 15 mm (hz) and 40 mm (vt) were obtained for all observation windows investigated. This can be explained by the less accurate modelling of the atmospheric conditions (particularly the effects of the ionosphere) over larger inter-CORS distances.

3.2 AUSPOS Analysis

AUSPOS solutions were obtained on each test point, based on virtual and observed 30-second data for session lengths of 2 hours, 6 hours and 24 hours over three days. The RMS values of the differences between virtual and observed solutions for the horizontal and vertical position components are shown in Figure 4. It is evident that 2-hour solutions show differences of about 15 mm (hz) and 20 mm (vt) in a small NRTK cell, and about 20 mm (hz) and 40 mm (vt) in a large NRTK cell. 6-hour solutions show agreement of better than 10 mm (hz & vt) in a small NRTK cell, and better than 10 mm (hz) and 20 mm (vt) in a large NRTK cell. 24-hour AUSPOS solutions based on Virtual RINEX data agree with those using observed data to better than 10 mm (hz & vt) across both cell sizes – this is equivalent to the current accuracy limit of the AUSPOS service. The expected trend of improved agreement with increasing observation length is visible at both test sites.

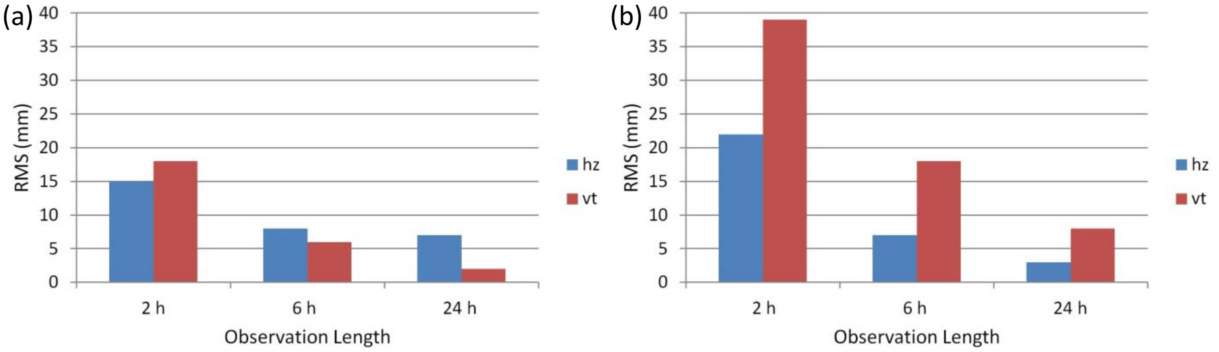

Figure 4: AUSPOS results in the horizontal (hz) and vertical (vt) components for (a) Queens Square (small cell) and (b) Sofala (large cell).

It should be noted that the first 24-hour session at Queens Square did not return a result for the virtual dataset due to an AUSPOS processing error caused by corrupted Virtual RINEX data in the second half of the day. This resulted in a higher than expected horizontal RMS value based on the comparison of only two 24-hour solutions (Figure 4a). The same issue affected two 6-hour and six 2-hour AUSPOS solutions that were therefore excluded from the analysis.

3.3 CORS Baseline Analysis

The position of each test point was precisely determined by GPS baseline processing relative to four surrounding CORS at varying distances (see Table 2). For each baseline, the CORS coordinates were fixed to their Regulation 13 values, and processing was performed using 30-second virtual and observed data for 10-minute and 1-hour observation sessions over one day, as well as 24-hour sessions over three days. The RMS values of the differences between virtual and observed solutions for the horizontal and vertical position components are illustrated in Figure 5.

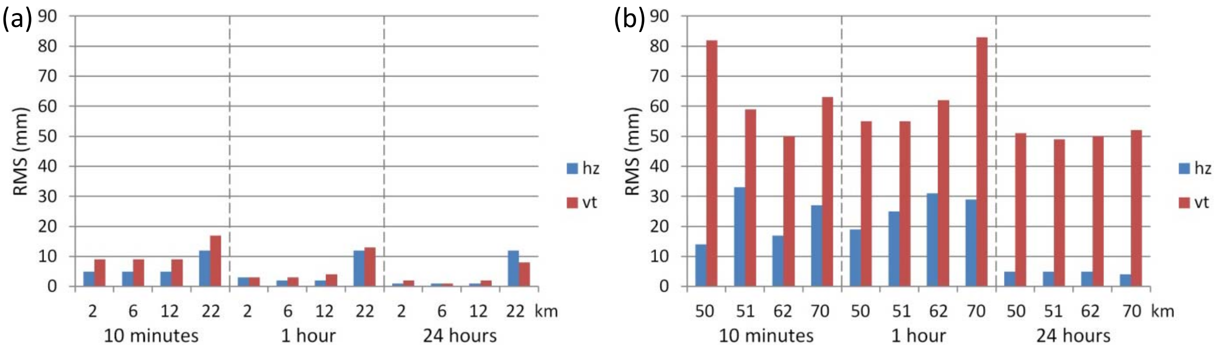

Figure 5: Baseline results for increasing observation windows and different baseline lengths in the horizontal (hz) and vertical (vt) components for (a) Queens Square (small cell) and (b) Sofala (large cell).

In general, agreement varies from the few-mm level for short (10 km) baselines in a small NRTK cell to the few-cm level for long (70 km) baselines in a large NRTK cell. This can be explained by the increased quality and reliability of atmospheric modelling during the generation of Virtual RINEX data in a small NRTK cell. As expected, the level of agreement improves significantly when longer observation sessions are employed due to the larger amount of data included in the computation, particularly for longer baselines. In addition, the modelling process performed during the generation of Virtual RINEX data is more successful in accounting for atmospheric variations over a 24-hour period than for a short 10-minute observation window because local variations have a much lesser impact on the positioning result.

Additional baseline processing of the 10-minute sessions using a 1-second sampling rate confirmed the results obtained with 30-second data in the small NRTK cell. The increased sampling rate did not improve the agreement between the solutions obtained using virtual and observed data. On the contrary, in the Sofala test area (i.e. for long baselines in a large NRTK cell) agreement generally decreased by about 20 mm in both the horizontal and vertical components for the 1-second results.

The 10-minute and 1-hour solutions obtained using Virtual RINEX and observed data were also compared against the 'true' coordinates of the test point, i.e. the adjusted coordinates used for Virtual RINEX data generation (Figure 6). Generally, the virtual results show a higher level of agreement with the 'true' coordinates. This is not surprising, as the virtual position approximates the actual location of the receiver, which is affected by local atmospheric variations that were 'averaged out' during the least squares network adjustment used to determine the 'true' position. As expected, higher agreement is achieved when employing the longer observation session.

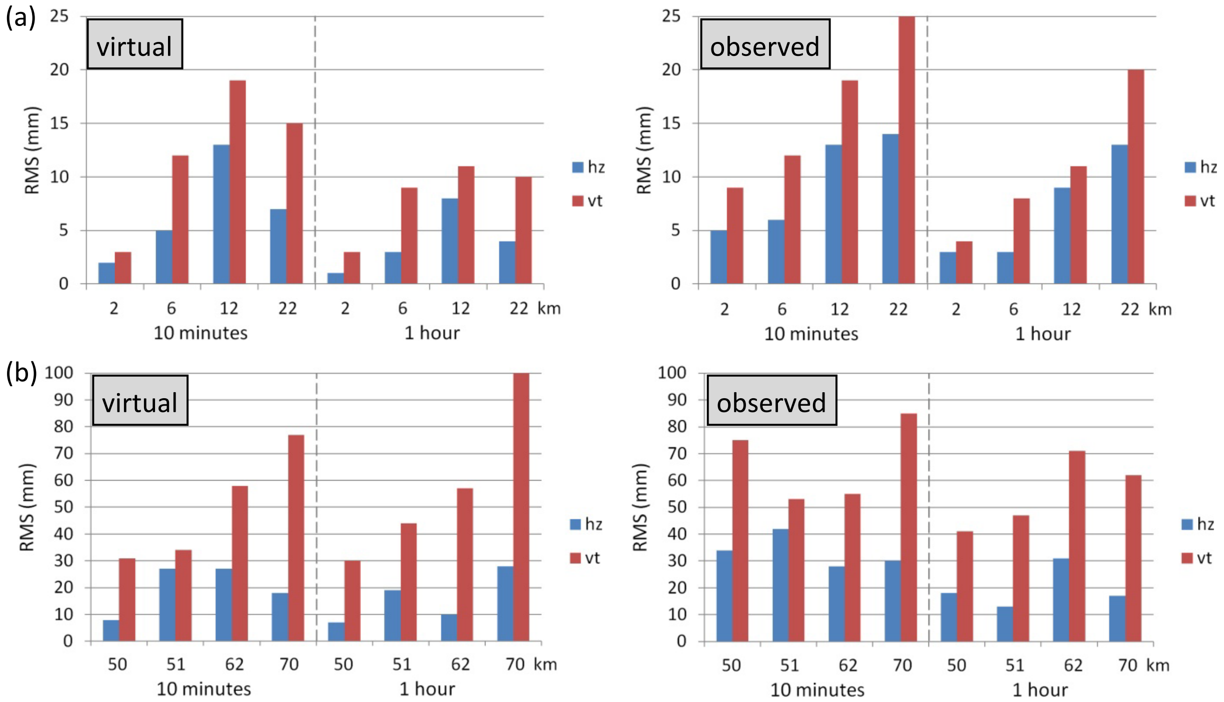

Figure 6: Comparison of virtual and observed baseline results against the 'true' position for two observation windows and different baseline lengths in the horizontal (hz) and vertical (vt) components for (a) Queens Square (small cell) and (b) Sofala (large cell).

3.4 Summary of Results

The results obtained indicate that Virtual RINEX data can be comparable to observed data for some applications if NRTK cell size, observation length and baseline length are taken into consideration. ‘Zero’ baseline processing has shown that the positions obtained using Virtual RINEX data agree with those based on observed data at the 1-2 mm level (RMS) for long observation sessions in a small NRTK cell. For various observation windows investigated in a large NRTK cell, differences between the two approaches amount to about 15 mm (hz) and 40 mm (vt). AUSPOS processing has shown that 24-hour solutions are comparable at the 10 mm level or better (i.e. at the current accuracy limit of the AUSPOS service), while 2-hour solutions show differences of up to about 20 mm (hz) and 40 mm (vt). Baseline processing to surrounding CORS has revealed differences ranging from the few-mm level for short (10 km) baselines in a small NRTK cell to the few-cm level for long (70 km) baselines in a large NRTK cell.

A number of issues related to the generated Virtual RINEX data were found during the course of this study and prior testing. These issues were reported to the manufacturer and some have been fixed in later versions of the CORS network management software, highlighting the benefit of performing the tests and analyses presented in this paper. GNSS users are advised to adopt best practice field procedures (e.g. LPI, 2012a, 2012b) and confirm whether utilising Virtual RINEX data is a viable alternative for a particular practical application on a case-by-case basis, carefully considering the associated accuracy requirements. It is hoped that the results presented in this paper will provide useful information in this regard.

4. FUTURE RESEARCH

It is recognised that most users will be interested mainly in the quality of the final positions obtained with Virtual RINEX data for various practical applications. This will generally involve short-range post-processing relative to a virtual GNSS reference station located on a known mark or an arbitrary (unmarked) point. This study has given users an indication of the capabilities Virtual RINEX data can provide. Based on the results presented here, it is recommended to extend this research in order to demonstrate potential benefits for particular practical applications and user groups. For example, this may include:

- Employing Virtual RINEX data instead of a local GNSS reference station for regular survey work, along extended linear infrastructure corridors and during aerial photography or airborne LiDAR surveys.
- Evaluating the backup function of Virtual RINEX data, e.g. by comparing results obtained for short observation sessions (i.e. 1-2 minutes) using Virtual RINEX data with real-time NRTK solutions observed at the same time.
- Evaluating the benefit of employing short observation sessions (i.e. 1-2 minutes) relative to Virtual RINEX data from an imaginary reference station in close proximity rather than longer observation sessions (i.e. 10-20 minutes) relative to a physical reference station at some distance (e.g. 20-50 km).
- Evaluating the feasibility of determining a site transformation (e.g. Haasdyk and Janssen, 2012) by processing the baseline between Virtual RINEX data and observed data collected on a given ground control mark with nominated SCIMS coordinates (e.g. Kinlyside, 2013).
- Investigating the dependence of GNSS solutions utilising Virtual RINEX data on the algorithms used in other commercial off-the-shelf post-processing software.

It is also useful to analyse the 'raw' Virtual RINEX data in regards to signal reception and quality parameters on all frequencies and observables (including Doppler data). This may include investigating multipath with respect to elevation, the ratio of recorded to available observations, the number, elevation and duration of loss-of-lock and cycle-slip events, and the variation of signal-to-noise (SNR) ratios with satellite elevation.

5. CONCLUSIONS

NRTK technology is being utilised for a wide range of applications, allowing GNSS users to obtain highly accurate position information over distances of several tens of kilometres in real time. Through the provision of Virtual RINEX data, it is also possible to benefit from network-based corrections for post-processing applications in both standard and boutique scenarios. This paper has investigated the quality of Virtual RINEX data in regards to baseline processing outcomes. Based on an extensive dataset consisting of 3-day observations in two study areas incorporating small and large NRTK cells, static positioning results obtained with Virtual RINEX data generated by CORSnet-NSW and observed RINEX data were compared. While this dataset was not specifically collected for the purpose of this study, it has been able to provide a first indication of the quality of virtual data compared to observed data.

The analysis included 'zero' baseline processing between virtual and observed data, AUSPOS processing, and baseline processing relative to surrounding CORS. It was shown that positioning results using Virtual RINEX data can be comparable (at the few-mm level to the few-cm level) to those based on observed data. Based on these findings, GNSS users are advised to confirm the viability of using Virtual RINEX data for a particular application on a case-by-case basis, under consideration of the NRTK cell size, observation length and baseline length in conjunction with the associated accuracy requirements. Naturally, best practice field procedures should also be followed.

REFERENCES

Dach R, Hugentobler U, Fridez P, Meindl M (2007) Bernese GPS software version 5.0 user manual, Astronomical Institute, University of Berne, Switzerland, 612pp.

GA (2012a) AUSPOS – Online GPS processing service, http://www.ga.gov.au/earth-monitoring/geodesy/auspos-online-gps-processing-service.html (accessed June 2013).

GA (2012b) Regulation 13 certificates, http://www.ga.gov.au/earth-monitoring/geodesy/regulation-13-certificates.html (accessed June 2013).

Haasdyk J, Janssen V (2012) Site transformations: A block shift in thinking, *Proceedings of Association of Public Authority Surveyors Conference (APAS2012)*, Wollongong, Australia, 19-21 March, 29-47.

IGS, RTCM-SC104 (2013) RINEX: The Receiver Independent Exchange format version 3.02, http://igscb.jpl.nasa.gov/igscb/data/format/rinex302.pdf (accessed June 2013).

Janssen V (2012) Likely impact of the approaching solar maximum on GNSS surveys: Be alert but not alarmed, *Proceedings of Association of Public Authority Surveyors Conference (APAS2012)*, Wollongong, Australia, 19-21 March, 66-82.

Janssen V, Commins R, Watson P, McElroy S (2013) Using GNSS CORS to augment long-term tide gauge observations in NSW, *Proceedings of Surveying & Spatial Sciences Conference (SSSC2013)*, Canberra, Australia, 15-19 April, 12pp.

Janssen V, Haasdyk J (2011) Assessment of Network RTK performance using CORSnet-NSW, *Proceedings of International Global Navigation Satellite Systems Society Symposium (IGNSS2011)*, Sydney, Australia, 15-17 November, 18pp.

Janssen V, Haasdyk J, McElroy S, Kinlyside D (2011) CORSnet-NSW: Improving positioning infrastructure for New South Wales, *Proceedings of Surveying & Spatial Sciences Biennial Conference (SSSC2011)*, Wellington, New Zealand, 21-25 November, 395-409.

Kinlyside D (2013) SCIMS3: The next generation Survey Control Information Management System, *Proceedings of Association of Public Authority Surveyors Conference (APAS2013)*, Canberra, Australia, 12-14 March, 174-186.

LPI (2012a) Surveyor General's Direction No. 9: GNSS for cadastral and mining surveys (draft), available at http://www.lpi.nsw.gov.au/surveying/publications/surveyor_generals_directions (accessed June 2013).

LPI (2012b) Surveyor General's Direction No. 12: Control Surveys and SCIMS, available at http://www.lpi.nsw.gov.au/surveying/publications/surveyor_generals_directions (accessed June 2013).

LPI (2013) CORSnet-NSW, http://www.corsnet.com.au/ (accessed June 2013).

NASA (2013) Solar cycle prediction, http://solarscience.msfc.nasa.gov/predict.shtml (accessed June 2013).

Penna N, Clarke P, Edwards S, King M (2012) Further testing of commercial Network RTK GNSS services in Great Britain, *Report*, The Survey Association and Newcastle University, http://tsa-uk.org.uk/index.php/for-clients/guidance-notes/ (accessed June 2013).

Wang C, Feng Y, Higgins M, Cowie B (2010) Assessment of commercial Network RTK user positioning performance over long inter-station distances, *Journal of Global Positioning Systems* 9(2): 78-89.