Virtual RINEX: Science or fiction?

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Most high-precision Global Navigation Satellite System (GNSS) users regularly employ and enjoy Network Real Time Kinematic (NRTK) for a wide variety of applications. However, many users often forget that it is also possible to benefit from network-based GNSS corrections for old-fashioned post-processing applications.

This is achieved through the use of Virtual RINEX data. Simply put, Virtual RINEX is a method of archiving NRTK data to a file for post-processing instead of broadcasting the data in real time.

In this article we present an initial investigation into the quality of Virtual RINEX data using some classical baseline processing techniques. Our two study areas incorporate a small and a large NRTK cell that are often encountered in urban and rural Continuously Operating Reference Station (CORS) networks, respectively.

Virtual RINEX

The RINEX (Receiver INdependent EXchange) format was initially developed a quarter of a century ago by the University of Berne, Switzerland, for the easy exchange of data collected during the first large European GPS campaign (EUREF89). Since then, RINEX has evolved into an international standard for the exchange and archiving of GNSS data.

The latest version, RINEX 3.02, accommodates measurements from new GNSS systems, both fully operational or under construction. What may surprise some is that we now also talk about Virtual RINEX. So what is it?

Virtual RINEX is basically NRTK for post-processing applications. It provides the same standardised data that would have been observed at an imaginary, user-defined location within the area covered by a particular CORS network.

In theory, post-processing performance should be very similar to real-time operation, assuming that (a) Virtual 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.

Virtual RINEX data is of potential benefit to both everyday and upmarket boutique users. For the everyday user, it can provide a vital backup that provides workable results in those annoying communications black spot areas. In addition, it also provides the potential of forward and reverse post-processing to minimise the effects of GNSS data gaps and maximise performance.

For an infrastructure provider, it allows the option of the standardised generation of virtual GNSS reference stations, particularly along extended linear infrastructure projects (e.g. highways, railways and pipelines). This can provide cost savings, interoperability and simple commonality benefits.

For specialised users, Virtual RINEX data can also be useful for the establishment of reference stations in restricted or denied areas, and for boutique solutions that may require offshore or even airborne reference stations. Basically, the sky and your imagination are the only limit.

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

Luckily, for us mere mortals, it only requires an extra mouse click or two, the input of the position of the desired reference station (don't forget to use ellipsoidal heights) and a few more moments of our time as the system generates customised Virtual RINEX data to suit our specific needs.

Study areas

Regular Position readers will recall that CORSnet-NSW is a rapidly growing network of GNSS CORS providing fundamental positioning infrastructure for New South Wales (NSW) that is accurate, reliable and easy to use.

Some may even recall an earlier NRTK study (see *Position* 56, Dec 2011 and *Position* 57, Feb 2012), where we collected three consecutive days of GNSS data at several locations within eastern NSW in the summer of 2010/11.

While these original datasets were not specifically collected for the purpose of Virtual RINEX data testing, they are nevertheless able to provide a first indication of virtual data quality compared to observed data. Figure 1. illustrates the two study areas selected and the surrounding CORSnet-NSW sites used to generate each NRTK cell at the time.

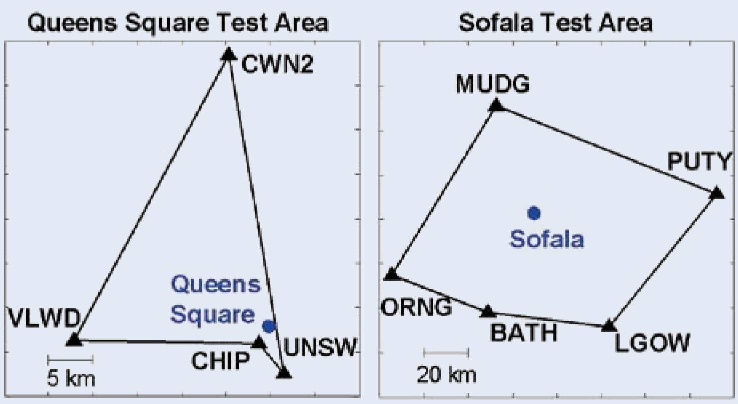

Figure 1: Location of the study areas and surrounding CORS at the time.

The study areas chosen were GNSS friendly, with a clear sky-view and minimal obstructions. At Queens Square, one Leica Viva GNSS receiver observed raw data at a 1-second sampling rate. At Sofala, we operated four of these receivers next to each other. Not surprisingly, all four provided very consistent results, so we only present the results for one of these instruments here.

The small size of the Queens Square NRTK cell is typical for urban NSW, i.e. the Sydney, Wollongong and Newcastle metropolitan areas. The distances around the perimeter of the surrounding CORS are 25 km on average, with a maximum of 37 km.

The larger Sofala NRTK cell is common for regional NSW. It has inter-CORS distances of 75 km on average. This CORS density is still within the recommended maximum of about 90 km between CORS, with the exception of the baseline MUDG-PUTY (108 km). Note that the recent installation of Rylstone CORS in March 2013 (located between Mudgee and Putty) has since eliminated this longer baseline.

Virtual RINEX data generation

The Virtual RINEX data was generated by the Trimble VRS3Net CORS network management software (version 1.01) used by CORSnet-NSW at the time. This process requires the user to provide the location of the desired virtual GNSS reference station (in Cartesian coordinates or latitude, longitude and ellipsoidal height).

In practice, the user generally chooses this location to be somewhere in the vicinity of the survey area. However, in this case, we had to determine an exact location in order to allow comparisons between virtual and observed data at a specific (surveyed) location.

The exact location of the test points was determined by a least-squares adjustment of a good geometry network based on the observed 24-hour baselines to three surrounding CORSnet-NSW stations. The adjustment was constrained by the known coordinates of the CORS involved (Regulation 13 values).

Testing methods

At each test site, we analysed the datasets in three ways for various observation session lengths:

- 'Zero' baseline processing between virtual and observed data.
- AUSPOS processing using virtual and observed data.
- Baseline processing relative to surrounding CORS using virtual and observed data.

All baseline processing was performed using the Leica Geo Office software package, final precise satellite orbits and absolute antenna models, both provided by the International GNSS Service (IGS). We determined GPS-only solutions without any manual editing during processing (e.g. no deletion of particular satellites or tracked data). The 3-day datasets were truncated into smaller observation sessions as required.

'Zero' baselines

In the first analysis, 'zero' baselines were processed between virtual and observed data on each test point for various session lengths. Strictly speaking, this is not a zero baseline test as classically used to evaluate GNSS receiver performance, or as described in some best practice guidelines, because the data were not collected by one GNSS antenna feeding two receivers.

While a zero baseline may seem a bit bizarre at first glance, it does show the noise/variation in solutions over a perfectly known distance, i.e. zero metres. In this case, it can also help indicate the sensitivity of Virtual RINEX file generation to the input coordinates, and that changing them by just a few millimetres could change the content of the data file and therefore the resulting baseline.

In order to satisfy the strict RINEX standard, all data must be with respect to the phase centre of the physical antenna. Obviously, that's a bit of a challenge in regards to Virtual RINEX. There is no physical CORS, nor antenna.

Instead, data is generated with respect to the next best thing, i.e. the phase centre of the physical antenna of the nearest CORS. Note that this is completely different to the null antenna approach adopted in modern NRTK (see *Position* 51, Feb 2011), but that's a completely different story.

Nevertheless, provided that absolute antenna models are applied correctly, the baseline should be close to zero if the virtual and observed data can be assumed the same. Thus, the length of this baseline is used to investigate the quality of the Virtual RINEX data.

We analysed session lengths of 10 minutes, 30 minutes, 1 hour and 2 hours over one day, 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. a 10-minute or 30-minute observation window at the beginning of each hour. All sessions were processed using a traditional static baseline sampling rate of 30 seconds.

Figure 2: 'Zero' baseline results in the horizontal (hz) and vertical (vt) components for (a) Queens Square (small cell) and (b) Sofala (large cell).

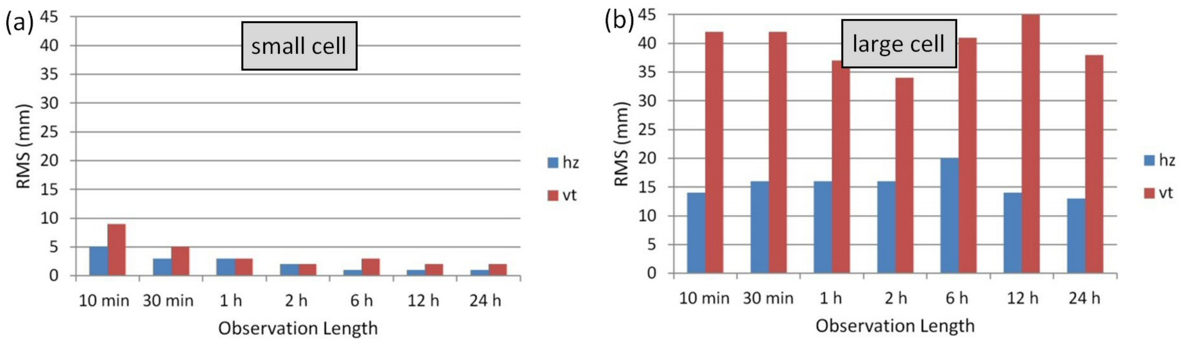

Figure 2. illustrates the resulting Root Mean Square (RMS) values for the horizontal (hz) and vertical (vt) position components. In general, 'zero' baselines vary from 1 mm (hz) and 2 mm (vt) for long observation sessions in a small NRTK cell to about 15 mm (hz) and 40 mm (vt) for all observation windows investigated in a large NRTK cell.

Let's investigate Figure 2a. in more detail. In a small NRTK cell, we obtained 'zero' baselines of 5 mm (hz) and 9 mm (vt) 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 very good agreement between virtual and observed data. Furthermore, these results are similar to those typically found for zero baseline tests for classic static, RTK and NRTK, indicating that Virtual RINEX is a viable tool in small cells.

The trend of improving results by increasing the observation time is not evident in the large NRTK cell (Figure 2b.).

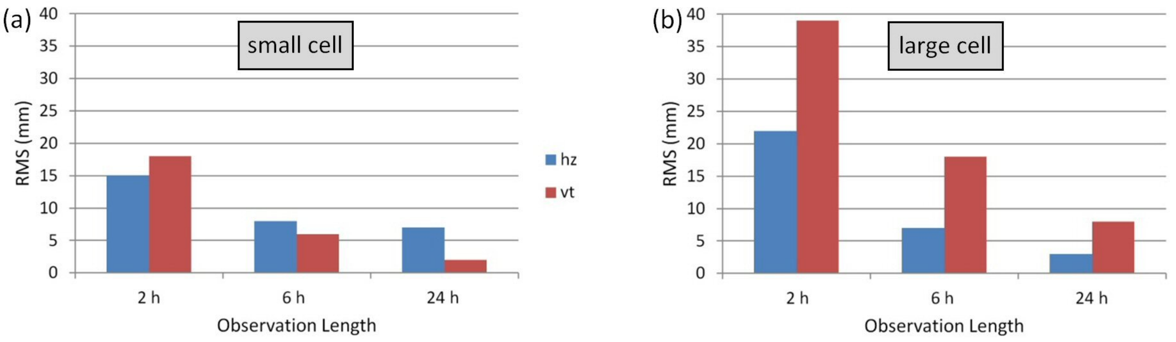

Figure 3: AUSPOS results in the horizontal (hz) and vertical (vt) components for (a) Queens Square (small cell) and (b) Sofala (large cell).

Instead, we obtained 'zero' baselines of about 15 mm (hz) and 40 mm (vt) across 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. Consequently, users would need to consider and accept both a horizontal and height limitation (or threshold) when employing Virtual RINEX in rural areas.

AUSPOS processing

The second analysis was based on AUSPOS, Geoscience Australia's free online GPS processing service. We determined the position of each test point using 30-second virtual and observed data for 2-hour, 6-hour and 24-hour sessions over three days.

AUSPOS was selected as it shows what is achievable with a processing engine that uses the latest and greatest modelling and processing algorithms (i.e. the scientific Bernese GPS processing software). In this case, solutions were based on connections to 13 or 14 surrounding CORS.

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)

Table 1: CORS utilised and baseline lengths processed in each test area.

Figure 3. illustrates the RMS values of the differences between virtual and observed solutions for the horizontal and vertical position components. 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.

At the other end of the spectrum, 24-hour AUSPOS solutions using Virtual RINEX data agree with those based on 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.

Unfortunately, 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 our input of corrupted Virtual RINEX data in the second half of the day. This resulted in a higher than expected horizontal RMS based on the comparison of only two 24-hour solutions. The same issue affected two 6-hour and six 2-hour sessions that were therefore also excluded from the analysis.

Baselines relative to CORS

The third and most traditional analysis involved baseline processing of 30-second data relative to four surrounding CORS (fixed to their Regulation 13 positions) using standard commercial off-the-shelf software with default settings. We processed 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.

Table 1. shows the CORSnet-NSW stations involved and the baseline lengths processed. The resulting RMS values of the differences between virtual and observed solutions for the horizontal and vertical position components are illustrated in Figure 4.

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. Again, 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 for longer observation sessions due to the larger amount of data included in the computation. This is particularly evident for longer baselines. Furthermore, the modelling performed during Virtual RINEX data generation 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.

Summary of results

These initial test results indicate that Virtual RINEX data have the capability of being comparable to observed data, provided NRTK cell size, observation length and baseline length are taken into consideration.

We have shown that 'zero' baselines vary from 1-2 mm (RMS) 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 agreed with those using observed data at the 10 mm level or better (i.e. at the current accuracy limit of the AUSPOS service). 2-hour solutions resulted in differences of up to about 20 mm (hz) and 40 mm (vt).

Baseline processing to surrounding CORS revealed differences ranging from the few-mm level for short baselines in a small NRTK cell to the few-cm level for long baselines in a large NRTK cell.

We discovered a number of issues related to the generated Virtual RINEX data during the course of this study and prior testing. These issues were reported to the manufacturer and some have since been fixed in later versions of the CORS network management software, highlighting the benefit of performing such independent tests and analyses.

Conclusion

In small NRTK cells, such as those found in urban areas, Virtual RINEX appears to perform well and be on par with results from tried and tested techniques like RTK/NRTK and classic static. In rural areas, Virtual RINEX certainly works but is a bit less accurate, particularly in the vertical. Users need to consider and accept these limitations when employing it in rural areas.

As with any other new technique or tool, GNSS users are advised to confirm whether using Virtual RINEX data is a viable alternative for a particular practical application on a case-by-case basis. This should include careful consideration of the associated accuracy requirements. Naturally, best practice field procedures should also be followed.

So, is Virtual RINEX science or fiction? Is it smoke and mirrors or another great tool? It only depends on you, your application and your imagination. We think it works.

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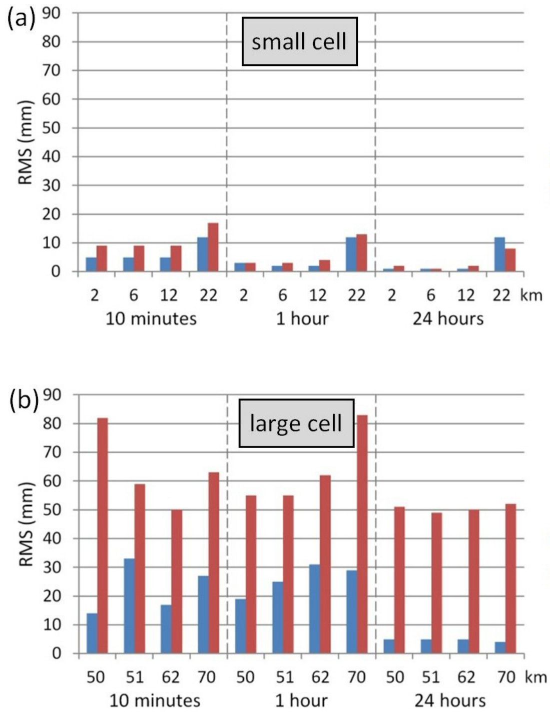

Figure 4: Baseline results for increasing observation windows and different baseline lengths in the horizontal (hz) and vertical (vt) components for (a) Queens Square (small cell) and (b) Sofala (large cell).