Cost Effective Positioning Using Australia and New Zealand SBAS Services

Eldar RUBINOV and Chris MARSHALL, Australia

Key words: SBAS, GNSS, positioning, low-cost, kinematic.

SUMMARY

This paper reports on some of the recent kinematic test results that were achieved using the L1 SBAS service from the Australian and New Zealand SBAS Test-bed. The paper specifically focuses on the performance of low-cost consumer-grade GNSS devices. Two devices, namely the u-blox M8N and SkyTraq Venus 838FLPx receivers were tested in walking and driving environments. The results showed that sub-metre positioning is attainable with the SBAS service and highlight the importance of matching the receiver kinematic mode to the intended use case. Additionally, these results indicate that the performance of any receiver can vary greatly depending on the combination of test environment and equipment configuration.

Cost Effective Positioning Using Australia and New Zealand SBAS Services

Eldar RUBINOV and Chris MARSHALL, Australia

1. INTRODUCTION

This paper reports on the kinematic testing results that were achieved using the Satellite Based Augmentation System (SBAS) service from the Australian and New Zealand (Aus-NZ) SBAS Test-bed that ran from 2017 to 2019. The paper specifically focuses on the performance of two consumer-grade GNSS devices, namely the u-blox M8N and SkyTraq Venus 838FLPx which were tested in a walking and driving environments.

SBAS is a correction service that can improve standalone Global Navigation Satellite System (GNSS) positioning in a number of ways to provide better accuracy, integrity and availability. The service works by computing corrections to the satellite orbits and clocks using a set of ground based continuously operating reference stations (CORS), uploading the corrections to a geostationary satellite (GEO) via an uplink station, and disseminating them to users. This process is shown graphically in Figure 1.

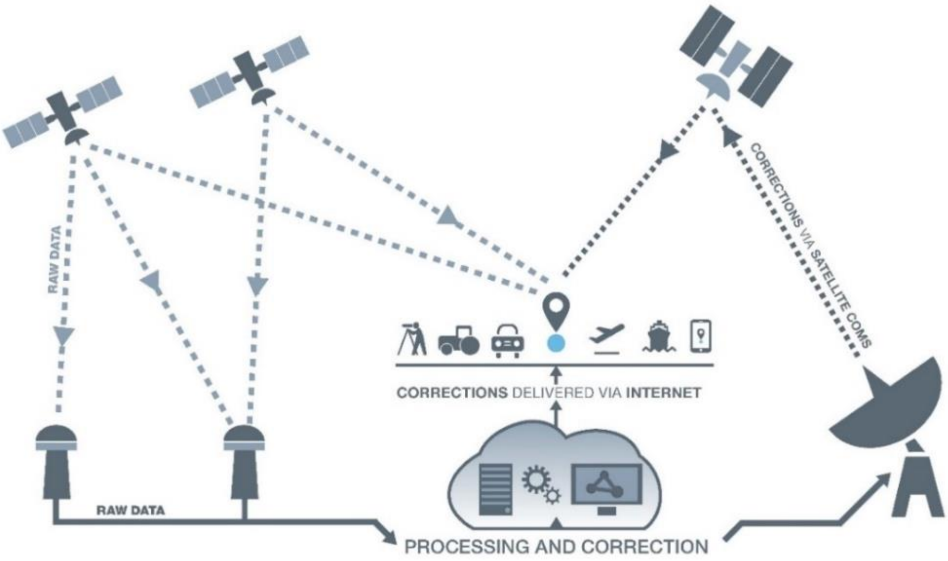

Figure 1. SBAS test-bed configuration (Dawson, 2018).

Originally designed to improve vertical guidance for safer aviation, SBAS has also been used for many non-aviation applications since its inception. Currently SBAS is implemented in several regions around the world including Wide Area Augmentation System (WAAS) in North America, European Geostationary Navigation Overlay Service (EGNOS) in Europe, GPS-Aided GEO Augmented Navigation (GAGAN) in India and Multi-functional Satellite Augmentation System (MSAS) in Japan. A number of other countries and regions are also in various stages of developing their own SBAS services including Russia, China, South Korea, Nigeria and South America.

Between January 2017 and January 2019, the Australian and New Zealand governments ran a two year test-bed to examine the benefits of SBAS technology to the region. The SBAS signals were transmitted using PRN122 from the Inmarsat 4F1 satellite positioned at 143.5º East in a geostationary orbit. The Lockheed Martin uplink station at Uralla, NSW was used to uplink the SBAS messages to the satellite. GMV provided the server infrastructure to compute the SBAS corrections (Barrios et al., 2017; Barrios et al., 2018). The successful test-bed resulted in the governments of both countries agreeing fund an operational SBAS for shared benefit, which is currently scheduled for 2023.

Three different signals were transmitted as part of the test-bed: single-frequency L1 SBAS, Dual Frequency Multi Constellation (DFMC) SBAS and a Precise Point Positioning (PPP) service. An extensive testing campaign has been carried out to test the performance of all three services in a variety of different environments, including both static and kinematic use cases. Some results from the Aus-NZ Test-bed have been reported in Rubinov et al. (2019) and Marshall et al. (2019). This paper specifically concentrates on evaluating the L1 SBAS service on consumer-grade devices in a kinematic environment.

2. TEST DESCRIPTION AND METHODOLOGY

2.1 Receiver and antenna hardware

Two consumer-grade receivers were used in the testing described in this paper. These are SkyTraq Venus 838FLPx and u-blox M8N. These are popular consumer-grade GNSS chipsets that retail around $10-15. In this test evaluation kits were used for each model which enable direct antenna and power supply connections to the chipset, as well as data logging capabilities. Additionally a geodetic-grade Septentrio AsteRx-SB receiver was used to record data for post-processing and compute the reference trajectory against which the performance of both consumer-grade devices were tested. The receivers used in the testing are shown in Figure 2.

Figure 2. SkyTraq Venus 838FLPx (left), u-blox M8N (centre) and Septentrio AsteRx-SB (right).

A number of antennas were also used in the testing as it was previously shown that the antenna quality can have a significant impact on the resulting receiver performance. The antennas that were tested are shown in Figure 3 below. All antennas in the testing are multi-band and targeted at high-precision applications. The u-blox ANN-MB is a cost-effective antenna solution from u-blox with small size and which retails under $100. The Tallysman TW7972 is a compact geodetic antenna with a small form factor priced under the $500 price bracket. Finally, the Topcon G3-1A and Tallysman VP6000 are geodetic quality antennas designed for high precision applications and each cost over $1000.

Figure 3. From left to right – u-blox ANN-MB, Tallysman TW7972, Topcon G3-A1 and Tallysman VP600 antennas.

2.2 Test Description

Two separate kinematic tests were conducted in late 2019. The first was a driving test, measuring laps around the Albert Park Lake Grand Prix Circuit in Melbourne which presented an ideal scenario for a driving test. This is a public, one lane road with a mostly open sky environment, which made for a repeatable test track. There are some regions of the track that pass close to multi-story buildings, and some areas with overhanging canopy. Each lap took around eight minutes to complete. Three antennas were used in this test: ANN-MB, TW7972 and VP6000, with three laps using each antenna for a total of nine laps. All three receivers were connected to the same antenna through a passive DC-blocked signal splitter ensuring that all receivers were observing exactly the same signals, and that the antenna was powered correctly for the entire test. Each of the antennas were magnetically mounted to the same point on the centre of the roof of the test vehicle. All three receivers were logging SBAS data, and AsteRx-SB was also recording raw data, which was later post-processed using data from a nearby CORS to provide a reference trajectory with centimetre-level accuracy.

The second test was a walking test which was carried out in the Darebin Parklands in Melbourne’s north-east. The parklands offered a variety of environments from open-sky to a moderate tree canopy, with some significant height variation. A similar test methodology to the previous test was employed for this scenario, except this time all three receivers were connected to a Topcon G3-1A antenna mounted on a backpack pole. Three separate tracks were walked with an average of 10 minutes per track. The test locations are shown in Figure 4.

Figure 4. Test locations, Albert Park Lake (left) and Darebin Parklands (right).

The consumer-grade devices can be configured for a number of navigation modes including stationary, pedestrian, automotive, airborne and more. These are shown in Figure 5 for each device. Each navigation mode enforces differing constraints on the positioning algorithm depending on the receiver’s application environment. For example, pedestrian mode assumes low acceleration and speed in both horizontal and vertical axes, whereas automotive (or car) mode is used for applications with dynamics equivalent to those of a passenger car (u-blox, 2019). The automotive modes assume a high maximum horizontal velocity and a significantly lower maximum vertical velocity and acceleration.

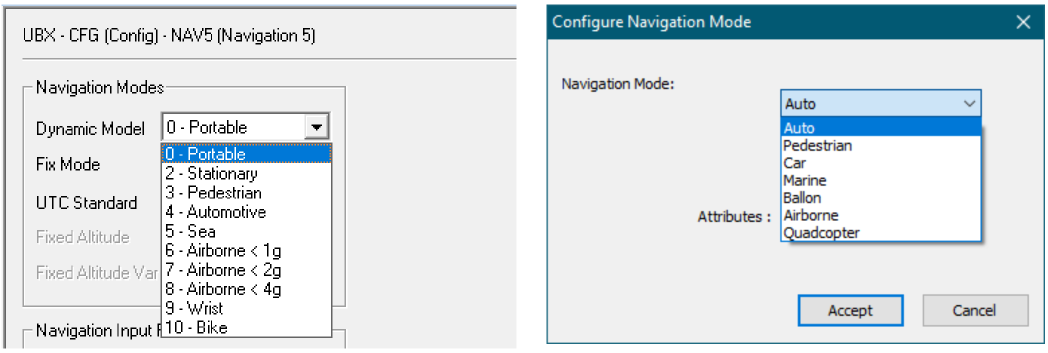

Figure 5. Navigation modes for u-blox (left) and SkyTraq (right).

3. RESULTS

This section presents the results of both tests. The primary objective of the investigation is to categorise the performance of the low-cost u-blox and SkyTraq devices. The geodetic-quality AsteRx-SB receiver was mainly used to log raw data for later post-processing, however it was also set up to log real-time SBAS data, so the SBAS results were also included as a point of comparison.

The results are reported in terms of mean, standard deviation and Root Mean Square (RMS) error. The RMS is a useful indicator which combines the effects of the mean and standard deviation, and provides an overall indicator of the quality of the solution, which is computed using the following formula:

$$x_{rms} = \sqrt{\frac{1}{n}\left(x_1^2 + x_2^2 + \cdots + x_n^2\right)} \tag{1}$$

The horizontal error is computed as the sum of squares of Easting and Northing errors as per the formula below:

$$Horizontal\ error = \sqrt{(dE^2 + \ dN^2)} \tag{2}$$

3.1 Driving Test Results

In total nine laps were driven around the Albert Park lake, three laps with each of the three antennas – Tallysman VP600, Tallysman TW7972 and u-blox ANN-MB. The horizontal results from all the laps are shown in Table 1 and the vertical results are shown in Table 2.

Albert Park Driving Test – Horizontal Errors									
Lap No	**Septentrio AsteRx-SB**			**u-blox M8N**			**SkyTraq Venus 838FLPx**		
	Mean (m)	**St Dev (m)**	**RMS (m)**	**Mean (m)**	**St Dev (m)**	**RMS (m)**	**Mean (m)**	**St Dev (m)**	**RMS (m)**
Tallysman VP6000 Antenna									
Lap 1	0.20	0.17	0.26	0.90	0.33	0.96	1.11	1.55	1.91
Lap 2	0.24	0.20	0.31	0.74	0.37	0.77	1.38	1.74	2.23
Lap 3	0.22	0.14	0.25	0.63	0.37	0.73	1.13	1.74	2.08
Tallysman TW7972 Antenna									
Lap 1	0.13	0.23	0.26	0.65	0.33	0.72	0.16	1.75	1.76
Lap 2	0.11	0.26	0.26	0.36	0.26	0.40	1.89	1.32	2.23
Lap 3	0.07	0.28	0.29	0.29	0.29	0.40	0.73	1.74	1.89
u-blox ANN-MB Antenna									
Lap 1	0.42	0.57	0.71	0.30	0.57	0.64	0.64	1.68	1.79
Lap 2	0.43	0.42	0.59	0.33	0.37	0.48	0.55	1.54	1.61
Lap 3	0.47	0.36	0.59	0.35	0.42	0.55	1.20	1.53	1.94

Table 1. Albert Park driving test results – Horizontal Error.

Albert Park Driving Test – Vertical Errors									
Lap No	**Septentrio AsteRx-SB**			**u-blox M8N**			**SkyTraq Venus 838FLPx**		
	Mean (m)	**St Dev (m)**	**RMS (m)**	**Mean (m)**	**St Dev (m)**	**RMS (m)**	**Mean (m)**	**St Dev (m)**	**RMS (m)**
Tallysman VP6000 Antenna									
Lap 1	0.70	0.27	0.75	1.00	0.51	1.12	2.51	0.86	2.65
Lap 2	0.65	0.27	0.70	1.08	0.54	1.21	-0.10	1.25	1.25
Lap 3	0.64	0.19	0.66	1.12	0.58	1.27	-2.13	1.15	2.42
Tallysman TW7972 Antenna									

Lap 1	0.95	0.42	1.04	0.08	0.80	0.80	0.85	1.66	1.86
Lap 2	0.93	0.28	0.97	0.10	0.68	0.69	-2.49	0.90	2.65
Lap 3	0.53	0.21	0.57	-0.35	0.41	0.54	1.73	1.59	2.35
u-blox ANN-MB Antenna									
Lap 1	0.75	0.35	0.83	0.24	0.69	0.73	0.02	1.09	1.09
Lap 2	0.88	0.28	0.93	0.55	0.44	0.70	0.00	1.88	1.87
Lap 3	0.70	0.29	0.76	0.64	0.51	0.82	-2.10	1.08	2.36

Table 2. Albert Park driving test results – Vertical Error.

From Table 1 it follows that the u-blox M8N receiver has achieved very good horizontal performance in a driving scenario, maintaining a sub-metre horizontal RMS in all tests, and even under 0.5m in some cases, which is an outstanding performance for consumer-grade equipment. What was also interesting is that the choice of the antenna did not affect the quality of positioning, in fact the results with the ANN-MB antenna were only marginally worse than the TW7972, and better than the VP6000 antenna, which was the highest quality antenna used in this test. This suggests that the ANN-MB antenna was specifically designed for highest integration with u-blox GNSS receivers, thus providing high-quality results.

The SkyTraq was not able to achieve the same quality of results in the driving tests with the horizontal RMS ranging between 1.5-2.5m. Additionally, the AsteRx-SB has performed at under 0.3m RMS with both TW7972 and VP6000 antennas, but the quality was reduced to 0.6-0.7m when the ANN-MB antenna was used.

Vertically, the u-blox receiver performed slightly worse than in horizontal domain with the RMS error ranging between 0.7-1.2m on all laps apart from one (lap 3 with TW7972 antenna) where it was able to achieve 0.54m RMS. SkyTraq similarly performed slightly worse in the vertical domain with the RMS ranging between 1.8-2.7m on most laps. There were two notable exceptions (lap 2 with VP6000 and lap 1 with ANN-MB antennas) where it was able to achieve 1.25m and 1.09m RMS, which was in fact much lower than the horizontal RMS during the same laps.

The horizontal results are shown graphically in Figures 6-8. One lap is shown for each u-blox and SkyTraq receivers with each of the three antennas. Note that the legend range is different in each case depending on the receiver performance. It is also worth noting that the driving was done in an anti-clockwise direction.

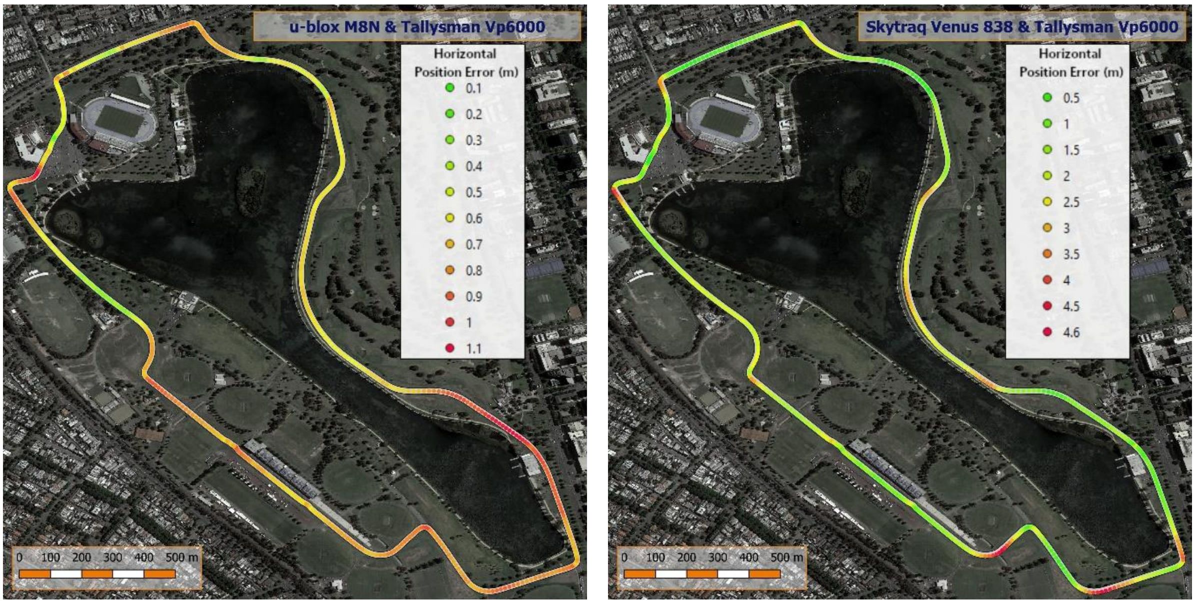

Figure 6. u-blox (left) and SkyTraq (right) Albert Park test with Tallysman VP6000 antenna.

Figure 7. u-blox (left) and SkyTraq (right) Albert Park test with Tallysman TW7972 antenna.

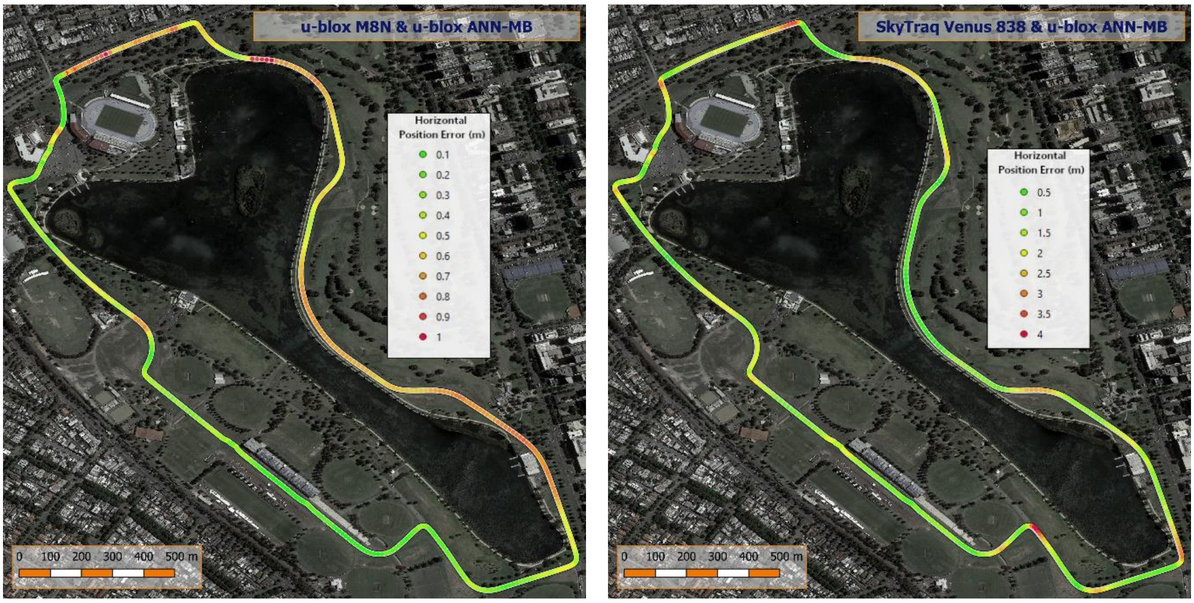

Figure 8. u-blox (left) and SkyTraq (right) Albert Park test with u-blox ANN-MB antenna.

The maps above tell an interesting story. The u-blox receiver was very stable with the quality of horizontal positioning remaining at sub-metre level throughout the drive. The SkyTraq on the other hand was also keeping to sub-metre for most of the drive, however after each turn, the horizontal positioning error was thrown out to a few metres settling shortly after. The SkyTraq also dropped to ~2m accuracy level during some sweeping turns, and towards the end of some straight sections. This suggests that the SkyTraq does not handle acceleration changes adequately, even when the receiver is configured for the kinematics of a car.

3.2 Walking Test Results

In total, three walking tests were conducted in the Darebin Parklands, each covering a different area of the park, with some variation in elevation and canopy density. A backpack was carried with the u-blox and SkyTraq receivers along with the AsteRx-SB used for the reference similarly to the previous test. A Topcon G3-A1 antenna was mounted on a pole with the antenna situated above head-level for each tested track. The horizontal results of each test are displayed in **Fejl! Henvisningskilde ikke fundet.**, and the vertical results in Table 4 below.

Darebin Parklands walking Test – Horizontal Errors									
Track No	**Septentrio AsteRx-SB**			**u-blox M8N**			**SkyTraq Venus 838FLPx**		
	Mean (m)	**St Dev (m)**	**RMS (m)**	**Mean (m)**	**St Dev (m)**	**RMS (m)**	**Mean (m)**	**St Dev (m)**	**RMS (m)**
Track 1	0.20	0.41	0.45	1.53	1.07	1.87	0.80	0.59	1.00
Track 2	0.29	0.45	0.53	1.62	2.70	3.15	0.75	0.88	1.16
Track 3	0.37	0.38	0.53	1.80	2.15	2.80	0.84	0.58	1.02

Table 3. Darebin Parklands walking test results – Horizontal Error.

Darebin Parklands walking Test – Vertical Errors			
	Septentrio AsteRx-SB	**u-blox M8N**	**SkyTraq Venus 838FLPx**

Track No	Mean (m)	St Dev (m)	RMS (m)	Mean (m)	St Dev (m)	RMS (m)	Mean (m)	St Dev (m)	RMS (m)
Track 1	1.45	0.88	1.69	2.27	0.76	2.39	2.90	0.68	2.98
Track 2	1.40	1.21	1.85	0.92	1.39	1.67	0.02	2.16	2.15
Track 3	0.66	1.27	1.43	-0.01	0.71	0.71	2.18	0.78	2.31

Table 4. Darebin Parklands walking test results – Vertical Error.

From the horizontal results in **Fejl! Henvisningskilde ikke fundet.** it follows that in a walking test case, it was the SkyTraq receiver that was able to produce superior results at ~1m RMS. The u-blox receiver on the other hand could not reproduce a similar performance to the driving test case, achieving a 1.8-3.2m RMS in a pedestrian mode.

Vertically, the SkyTraq performed at 2.1-3.0m RMS, while the u-blox receiver produced some surprising results on laps 2 and 3, with vertical RMS errors of 1.67m and 0.71m, which are much smaller than the corresponding horizontal errors on the same laps; 3.15m and 2.80m respectively. A number of further tests were carried out producing similar figures, suggesting that this performance is the result of the pedestrian navigation mode algorithm utilised by the u-blox receiver.

The horizontal results are also shown graphically in Figures 9-11. The white track on the images represents the reference trajectory computed from the AsteRx-SB receiver.

Figure 9. u-blox (left) and SkyTraq (right) Darebin Parklands test Lap 1.

Figure 10. u-blox (left) and SkyTraq (right) Darebin Parklands test Lap 2.

Figure 11. u-blox (left) and SkyTraq (right) Darebin Parklands test Lap 3.

From these figures it can be observed that the SkyTraq was able to follow the reference trajectory very closely even through sharp corners, zig-zags and gradual bends where the u-blox could not successfully follow. The u-blox diverged from the reference trajectory more than 6m in a number of areas, producing less than optimal results for the pedestrian tests. The SkyTraq maintained a horizontal RMS error close to 1m for each pedestrian test track, while the u-blox maintained 2-3m horizontal RMS error under identical conditions.

4. CONCLUSION

In this paper the performance of two common consumer-grade GNSS devices using the Australia and New Zealand SBAS L1 service was investigated. The two devices; u-blox M8N and SkyTraq Venus 838FLPx were evaluated in a walking and driving kinematic environments with a range of different antennas. A geodetic-grade receiver was used to provide a centimetre-level accurate reference trajectory for an epoch-by-epoch comparison to the SBAS receivers. It was shown that the u-blox receiver has provided excellent positioning in a driving environment which ranged between 0.5-1.0m horizontal RMS, whereas under pedestrian kinematics the SkyTraq was able to provide superior results to the u-blox, maintaining positioning at ~1.0m horizontal RMS level. Vertically both receivers produced worse RMS values ranging by a factor from 1 to 3 in most cases except the u-blox receiver in the walking test, which produced superior vertical performance than the horizontal while using the pedestrian navigation mode.

REFERENCES

Barrios, J., Caro, J., Calle, J.D., Carbonell, E., Rodríguez, I., Romay, M.M., Jackson, R., Reddan, P.E., Bunce, D. and Soddu, C. (2017) Australian and New Zealand second generation satellite positioning augmentation system supporting global SBAS concept, *Proceedings of ION GNSS+*, Portland, Oregon, 25-29 September, 979-996.

Barrios, J., Caro, J., Calle, J.D., Carbonell, E., Pericacho, J.G., Fernández, G., Esteban, V.M., Fernández, M.A., Bravo, F., Torres, B., Calabrese, A., Diaz, A., Rodríguez, I., Laínez, M.D., Romay, M.M., Jackson, R., Reddan, P.E., Bunce, D. and Soddu, C. (2018). Update on Australia and New Zealand DFMC SBAS and PPP system results, *Proceedings of ION GNSS+*, Miami, Florida, 24-28 September, 1038-1067.

Dawson, J. (2018) Positioning Australia for the future, *Proceedings of Multi-GNSS Asia*, Melbourne, Australia, 23-25 October 2018.

Marshall, C., Ng, L. and Rubinov, E. (2019) SBAS Test-bed Technical Report, https://frontiersi.com.au/project/sbas/, accessed on 11 February 2020.

Rubinov, E., Marshall, C., Ng, L. and Tengku, A.R. (2019). Positioning performance of SBAS and PPP technology from the Australia and New Zealand SBAS Test-bed, *Proceedings of South East Asia Survey Congress*, Darwin, Australia, 15-18 August 2019.

CONTACTS

Dr Eldar Rubinov
FrontierSI
Melbourne
AUSTRALIA
Email: erubinov@frontiersi.com.au
Web site: www.frontiersi.com.au

Mr Christopher Marshall
FrontierSI
Melbourne

AUSTRALIA
Email: cmarshall@frontiersi.com.au
Web site: www.frontiersi.com.au