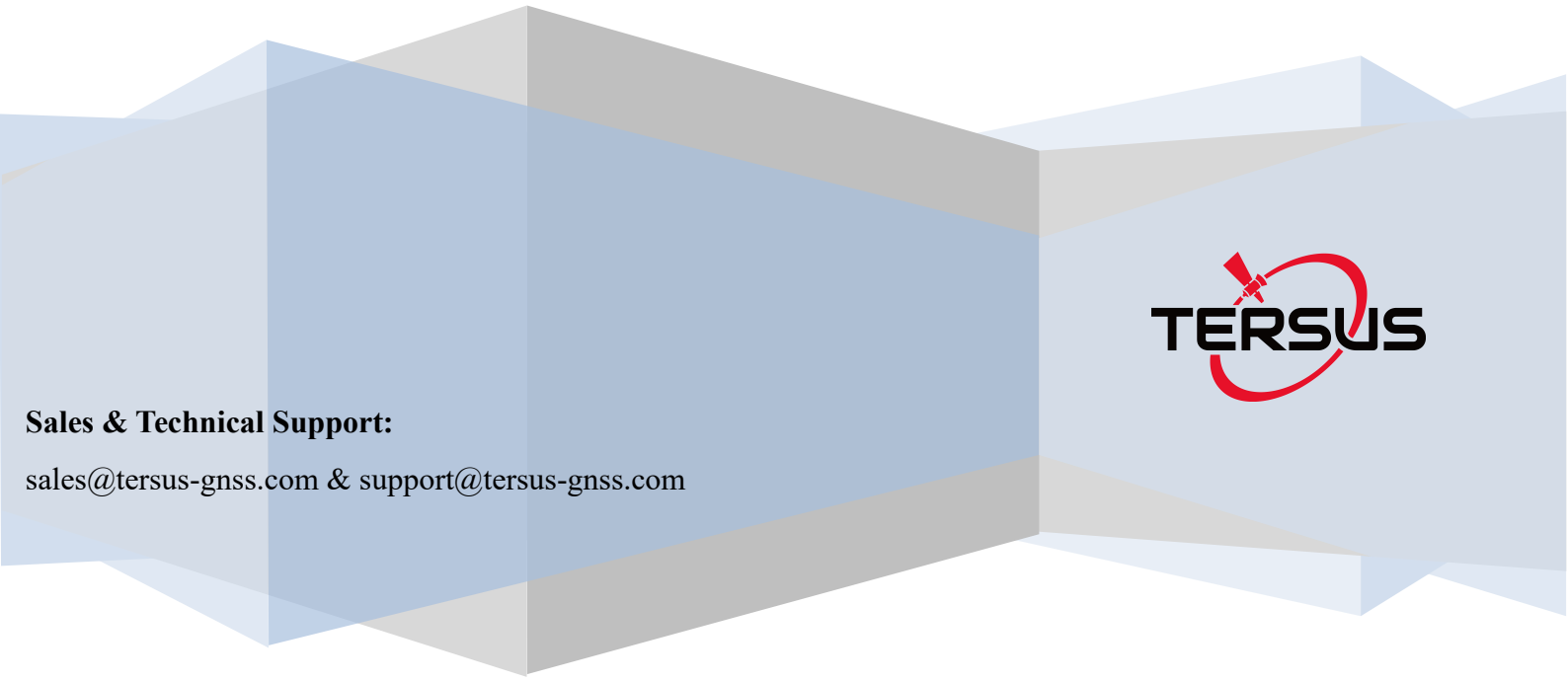
[TEST REPORT]

Tersus RTK Competitive Analysis —Apr 2018



Sales & Technical Support:

sales@tersus-gnss.com & support@tersus-gnss.com

Contents

1 Abstract....4

2 Test Set-up and Methodology....4

2.1 Test Equipment....4

2.2 Methodology....4

2.3 Test Items....5

3 Conclusion....6

4 Test Results....7

4.1 Short Baseline – Open sky Test Results....7

4.1.1 Test method and scene description....7

4.1.2 Test Result....8

4.2 Reliability of RTK (Open sky)....10

4.2.1 Test method and scene description....10

4.2.2 Test Results....11

4.3 Reliability of RTK (Partial Foliage)....13

4.3.1 Test method and scene description....13

4.3.2 Test Results....14

4.4 Reliability of RTK (Half sky)....20

4.4.1 Test method and scene description....20

4.4.2 Test Results....21

Table Contents

Table 1 Description of Test OEM boards....4

Table 2 RTK precision statistics of 5km baseline – open sky....8

Table 3 Horizontal Position and Vertical Position Error Scatter (<2km-open sky)....11

Table 4 Number of Fixed Solutions and Time to Fix (<2km-open sky)....12

Table 5 Horizontal Position and Vertical Position Error Scatter (<2km- Partial Foliage, scene A)....14

Table 6 Number of Fixed Solutions and Time to Fix (<2km- Partial Foliage, scene A)....15

Table 7 Horizontal Position and Vertical Position Error Scatter (<2km- Partial Foliage, scene B)....16

Table 8 Number of Fixed Solutions and Time to Fix (<2km- Partial Foliage, scene B)....17

Table 9 Horizontal Position and Vertical Position Error Scatter (<2km- Partial Foliage, scene C)....18

Table 10 Number of Fixed Solutions and Time to Fix (<2km- Partial Foliage, scene C)....19

Table 11 Horizontal Position and Vertical Position Error Scatter (<2km- half sky, scene A)....22

Table 12 Number of Fixed Solutions and Time to Fix (<2km- half sky, scene A).....22
Table 13 Horizontal Position and Vertical Position Error Scatter (<2km- half sky, scene B)... 24
Table 14 Number of Fixed Solutions and Time to Fix (<2km- half sky, scene B).....25

Figure Contents

Figure 1 Test-set up figure..... 5
Figure 2 Environment of Base Station..... 7
Figure 3 Environment of Rover Station (5km-open sky)..... 8
Figure 4 Position Error Time Sequence Diagrams and Horizontal Scatters (5km – open sky)10
Figure 5 Environment of Rover Station (<2km-open sky)..... 11
Figure 6 Position Error Time Sequence Diagrams and Horizontal Scatters (<2km-open sky) 13
Figure 7 Environment of Rover Station (<2km- Partial Foliage).....14
Figure 8 Position Error Time Sequence Diagrams and Horizontal Scatters (<2km- Partial Foliage, scene A)..... 16
Figure 9 Position Error Time Sequence Diagrams and Horizontal Scatters (<2km- Partial Foliage, scene B)..... 18
Figure 10 Position Error Time Sequence Diagrams and Horizontal Scatters (<2km- Partial Foliage, scene C)..... 20
Figure 11 Environment of Rover Station (<2km- Half sky).....21
Figure 12 Sky plot of scene A.....22
Figure 13 Position Error Time Sequence Diagrams and Horizontal Scatters (<2km- half sky, scene A).....24
Figure 14 Sky plot of scene B.....24
Figure 15 Position Error Time Sequence Diagrams and Horizontal Scatters (<2km- half sky, scene B).....26

1 Abstract

RTK performance varies depending on the environment in which the work is being performed. Tersus carried out some tests that compare the performance of our RTK engine with a number of competitor products. The objective of our testing was to quantify the RTK performance of Tersus OEM board. The paper demonstrates the usability and reliability of our products in the following test scenarios. The results show that Tersus OEM board provides available RTK positioning in real-world GNSS conditions.

2 Test Set-up and Methodology

2.1 Test Equipment

Table 1 Description of Test OEM boards

Item	Descriptions
OEM BOARDS	BX316 and other four OEM boards.
Antenna	Tersus AX3702

2.2 Methodology

Competitive testing was done by Tersus Inc. The tests were designed to simulate how users work with GNSS receivers in the field. All tests were static, on short baseline lengths of 500m to baseline lengths of 5 km. Four OEM boards from Competitors were tested along with Tersus BX316. NMEA logs from Competitors were collected and used for comparison and plotting.

- All OEM boards use the same Tersus AX3702 GNSS antenna, for identical antenna placement.
- All OEM boards receive the RTCMv3 messages broadcasted by the same brand OEM boards.

- RTK corrections were transmitted to the rover via GPRS/NTRIP .

  The test set-up is shown in Figure 1.

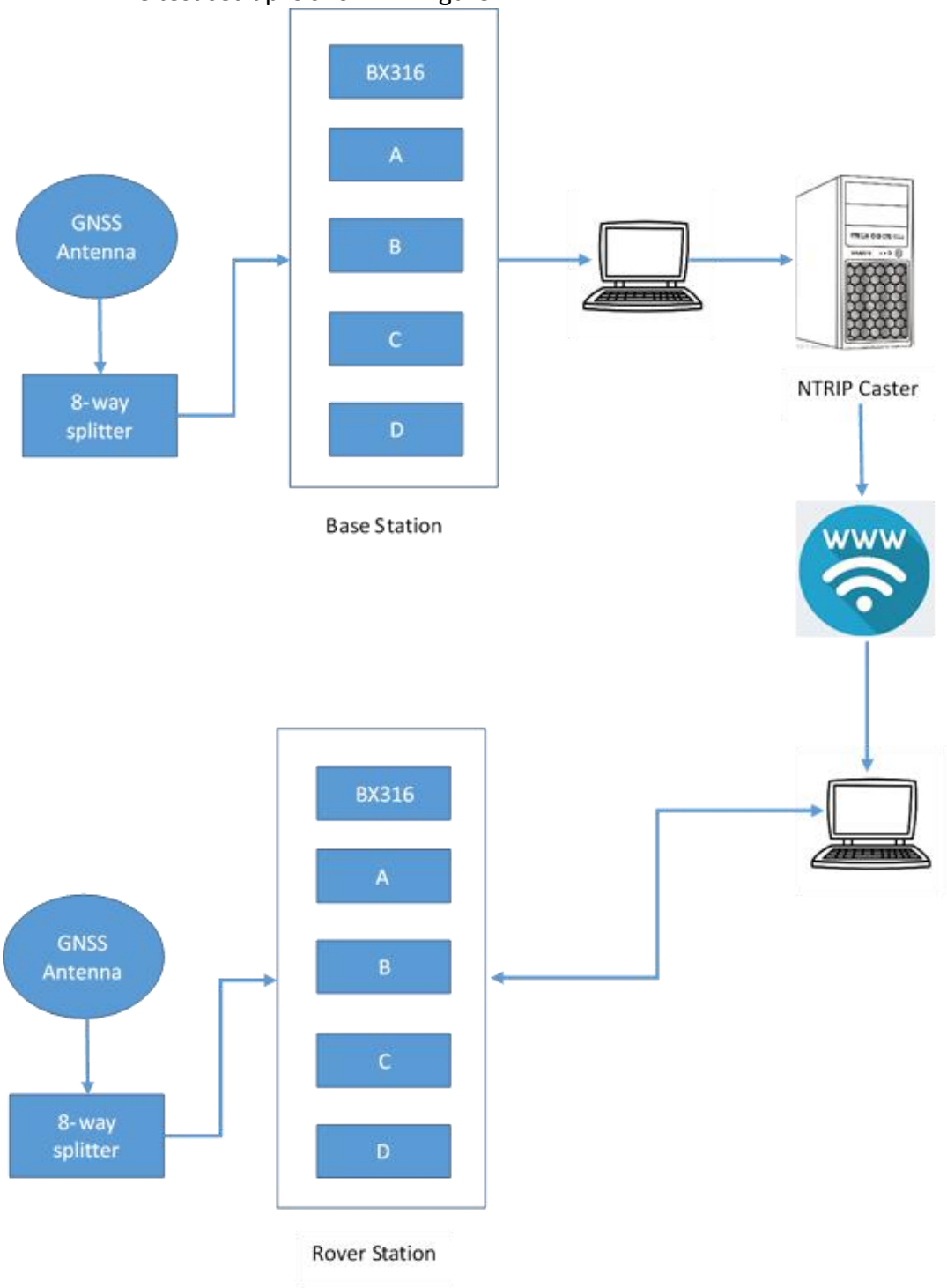


Figure 1 Test-set up figure

2.3 Test Items

The performance of the RTK engines was measured using the following criteria:

- RTK accuracy – Reliable centimeter-level accuracy is needed for high precision applications
- RTK consistence – RTK fixed solutions must be consistent no matter how many times the OEM board was power on.
- RTK initialization time – Faster RTK fixing leads to more productivity in the field

So the tests conducted include the following items:

1) Short baseline(5km) — open sky
2) Time consuming and reliability of RTK, and this item covers the following scenarios

   Short baseline (<2km) — open sky

   Short baseline (<2km) —Partial foliage

   Short baseline (<2km) — half sky

3 Conclusion

- In a short baseline (5 km) open sky environment, the positioning accuracy and the fixed rate of each OEM board are similar.
- In a short baseline (<2 km) open sky environment, BX316 fixes its ambiguities faster than Competitor B. The RTK solution of other Competitors were as accurate as BX316 without wrong integer fixes.
- In a short baseline (<2 km) moderate foliage survey environment, Competitor A proved to have the fastest initialization time. BX316 was the second fastest followed by Competitor A, however, sometimes fixed incorrectly. The overall performance is only superior to the Competitor B.
- In a short baseline (<2 km) half sky environment, of all the fixes BX316 and Competitor D's solutions show a higher degree of accuracy over that of other competitors. BX316 has certain competitiveness in RTK fixed time, however, due to poor satellite geometry it failed to achieve an RTK solution sometimes.

4 Test Results

4.1 Short Baseline – Open sky Test Results

4.1.1 Test method and scene description

The base antenna was placed on building rooftop with minimal multipath for ideal GNSS signal conditions (Figure 2). A 5 km baseline was selected for the open-sky RTK test. The rover antenna was placed on the ground as shown in Figure 3. All the OEM boards broadcasted RTCM v3 messages as follow:

LOG RTCM1074 ONTIME 1

LOG RTCM1084 ONTIME 1

LOG RTCM1124 ONTIME 1

LOG RTCM1005 ONTIME 10

Figure 2 Environment of Base Station

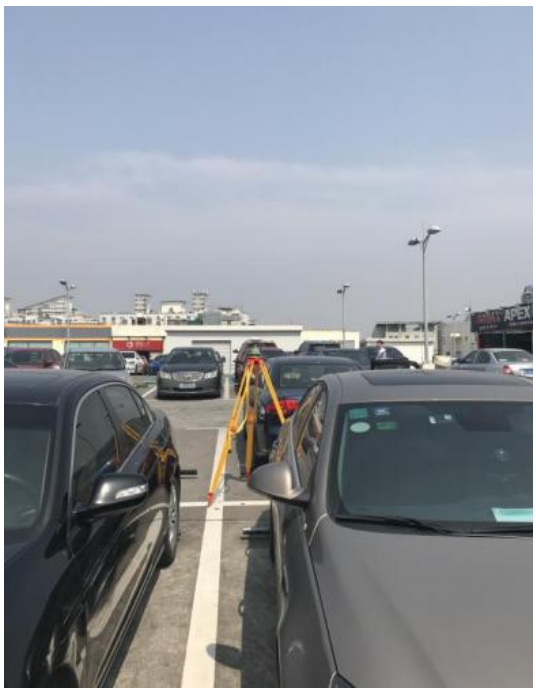


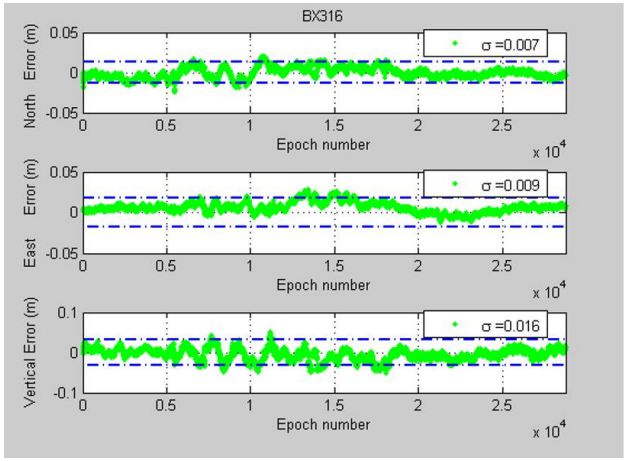
Figure 3 Environment of Rover Station (5km-open sky)

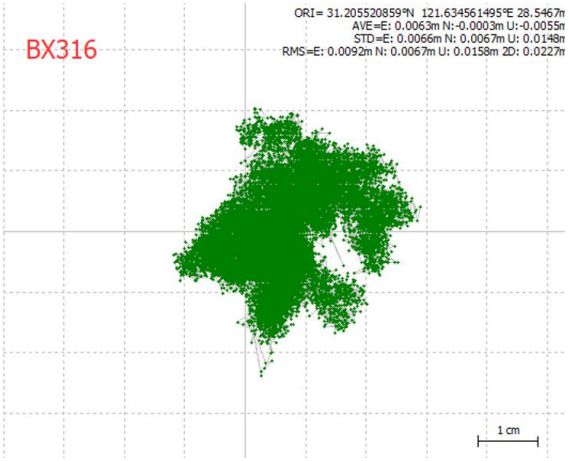
4.1.2 Test Result

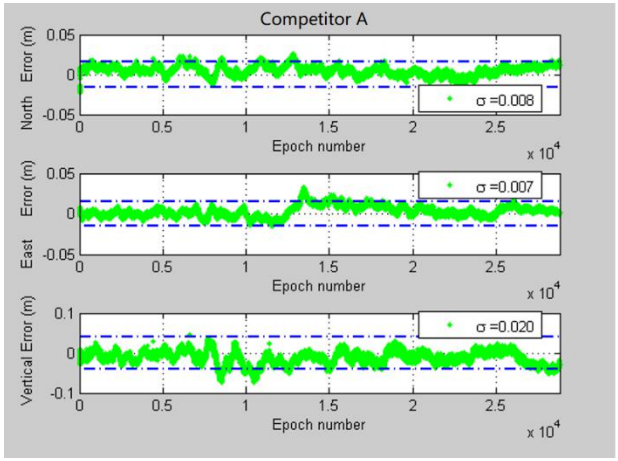
Data was collected on a short baseline (5 km) for nearly 8 hours. Mean value of the Competitor D's RTK fixed solutions is used as the reference value to calculate the external coincidence precision of the other OEM boards (not eliminating the gross error), as shown in Table 2. In order to better explain the positioning accuracy of RTK, figure 3 gives the time sequence diagrams of the difference between the RTK solutions of each board and the reference coordinates. RTKPLOT tool was used to document the horizontal position error and the corresponding statistical information was given as well.

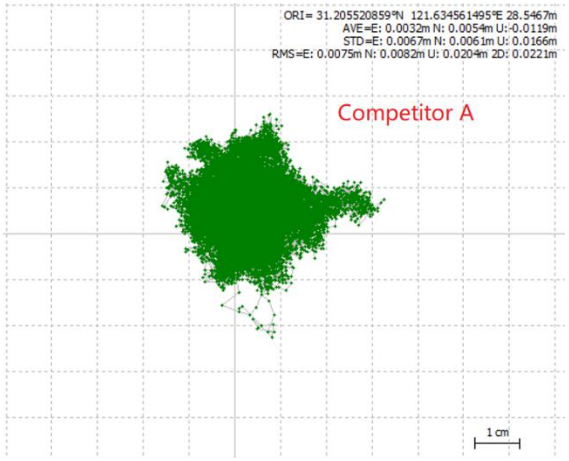
Table 2 RTK precision statistics of 5km baseline – open sky

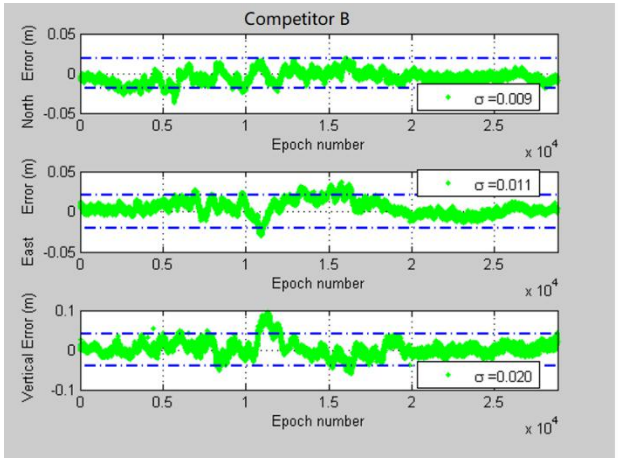
OEM Boards	RMS (cm)			# Fixed Solutions	Fix Rate
	N	E	U		
BX316	0.7	0.9	1.6	28771	99.9%
A	0.8	0.7	2.0	28831	100%
B	0.9	1.1	2.0	28786	99.8%
C	0.5	0.7	1.4	28788	100%
D	0.5	0.6	1.3	28770	99.9%

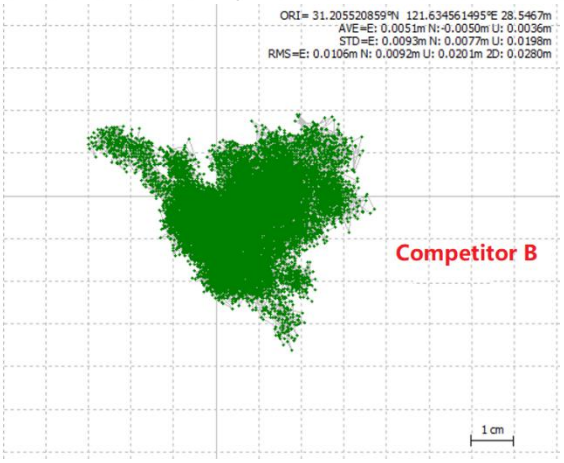

BX316
North Error (m)
σ =0.007
East Error (m)
σ =0.009
Vertical Error (m)
σ =0.016
Epoch number
x 10^4


ORI= 31.205520859°N 121.634561495°E 28.5467m
AVE=E: 0.0063m N:-0.0003m U:-0.0055m
STD=E: 0.0066m N: 0.0067m U: 0.0148m
RMS=E: 0.0092m N: 0.0067m U: 0.0158m 2D: 0.0227m
BX316
1 cm


Competitor A
North Error (m)
σ =0.008
East Error (m)
σ =0.007
Vertical Error (m)
σ =0.020
Epoch number
x 10^4


ORI= 31.205520859°N 121.634561495°E 28.5467m
AVE=E: 0.0032m N: 0.0054m U:-0.0119m
STD=E: 0.0067m N: 0.0061m U: 0.0166m
RMS=E: 0.0075m N: 0.0082m U: 0.0204m 2D: 0.0221m
Competitor A
1 cm


Competitor B
North Error (m)
σ =0.009
East Error (m)
σ =0.011
Vertical Error (m)
σ =0.020
Epoch number
x 10^4


ORI= 31.205520859°N 121.634561495°E 28.5467m
AVE=E: 0.0051m N:-0.0050m U: 0.0036m
STD=E: 0.0093m N: 0.0077m U: 0.0198m
RMS=E: 0.0106m N: 0.0092m U: 0.0201m 2D: 0.0280m
Competitor B
1 cm

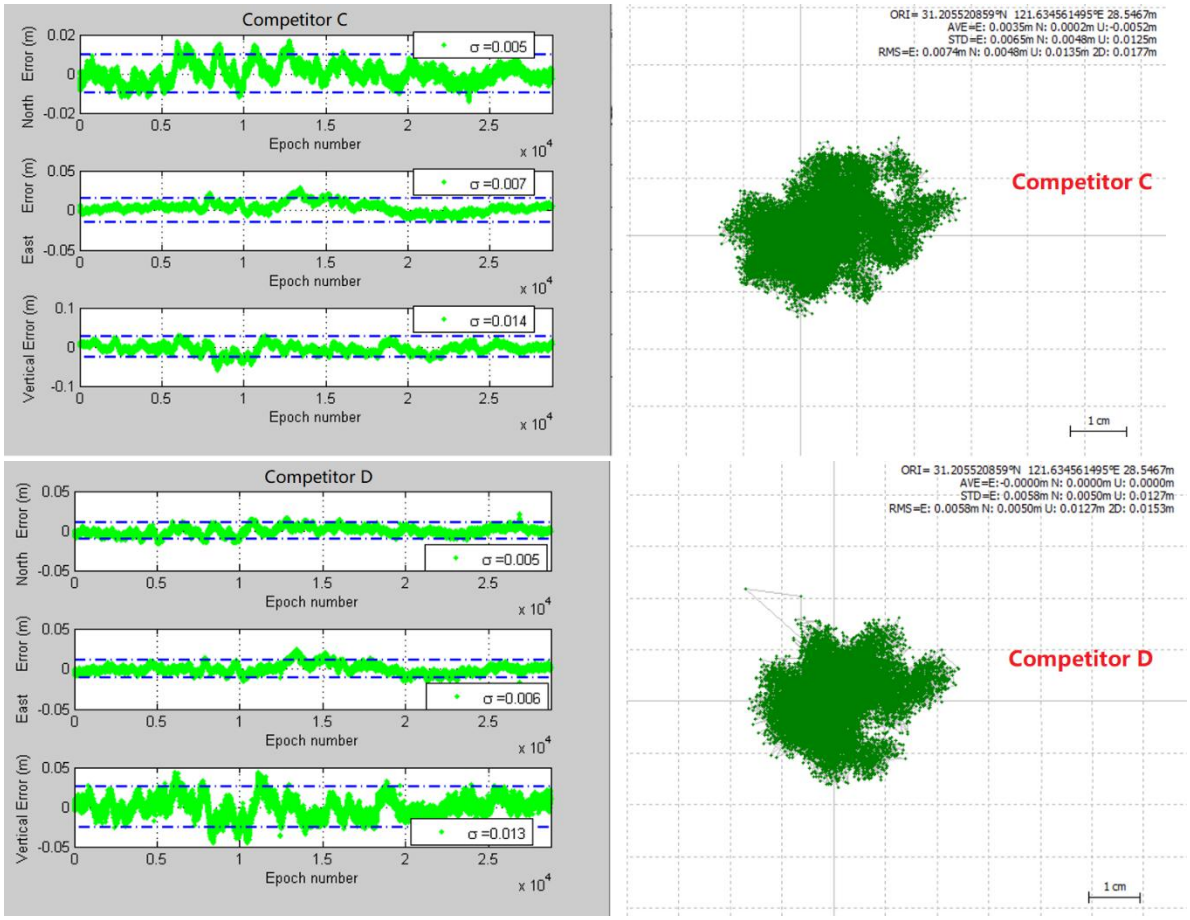


Figure 4 Position Error Time Sequence Diagrams and Horizontal Scatters (5km – open sky)

4.2 Reliability of RTK (Open sky)

4.2.1 Test method and scene description

The base station is as the same as the 4.1. In order to test the stability and reliability of RTK solutions of each OEM board, this test repeated for 30 times. The rover antenna was placed in the open sky environment as shown in Figure 5. The test was conducted as follow:

1) Configuring all OEM boards to output GGA logs automatically;
2) Power on all OEM boards;
3) Connecting the laptop PC to WIFI so as to get RTCM data after all the OEM boards obtained single point position solutions;
4) Storing all the GGA logs and waiting for about two minutes;
5) The above steps were repeated for 30 times;

Figure 5 Environment of Rover Station (<2km-open sky)

4.2.2 Test Results

The mean value of RTK fixed solutions of Competitor D was used as reference coordinates. We statistics the position accuracy in the direction of ENU (**excluding gross errors**), successful fixed times, number of fixed solutions and initial time of RTK. RTK initialization time refers to the time from the last single solution to the first fixed solution. In this test, the logs of Competitor C were not configured correctly, so Competitor C do not participate in this comparison.

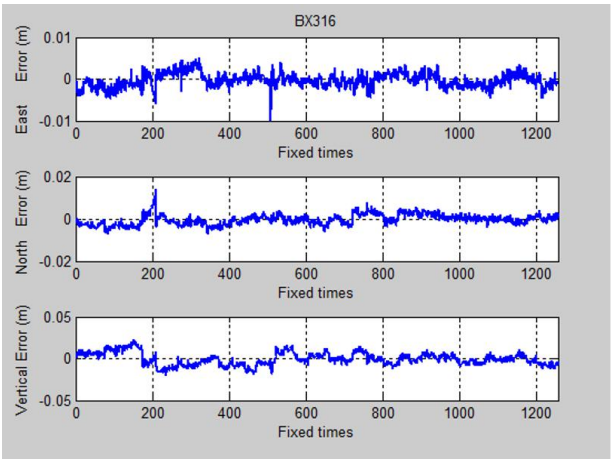
Table 3 shows all the OEM board produced similar accuracy. BX316 achieved 100% success rate. However its RTK initialization is only faster than Competitor B and it provided less RTK fixed solutions than Competitor A and D (Table 4). Figure 6 is the position error time sequence diagrams and horizontal scatters.

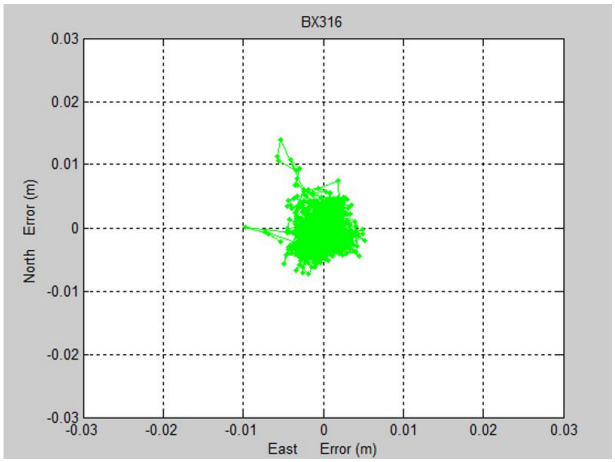
Table 3 Horizontal Position and Vertical Position Error Scatter (<2km-open sky)

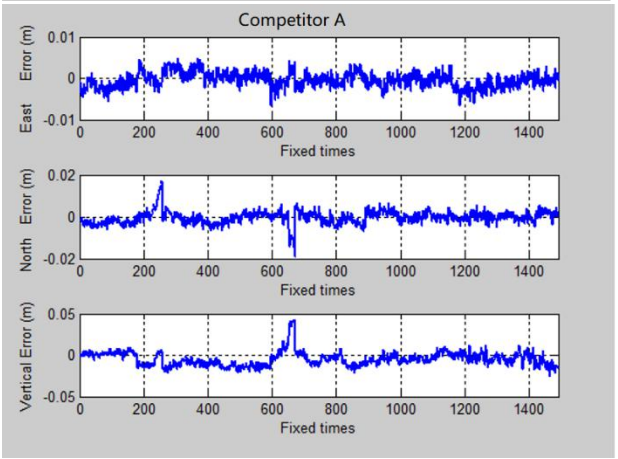
OEM Boards	**RMS(cm)**		
	E	**N**	**U**
BX316	0.2	0.3	0.8
A	0.2	0.3	0.9
B	0.3	0.3	0.8
D	0.2	0.3	0.7

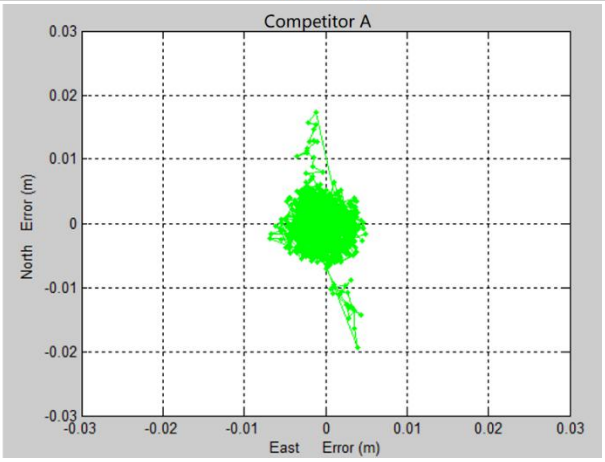
Table 4 Number of Fixed Solutions and Time to Fix (<2km-open sky)

OEM Boards	RTK Fix Success	Number of ALL Fixed Solutions	Time to Fix (unit: s)		
			Min Fix times	Max Fix Times	Mean Fix Times
BX316	30/30	1257	3	3	3
A	28/30	1491	1	1	1
B	28/30	1232	1	30	4.9
D	29/30	1350	1	4	1.5









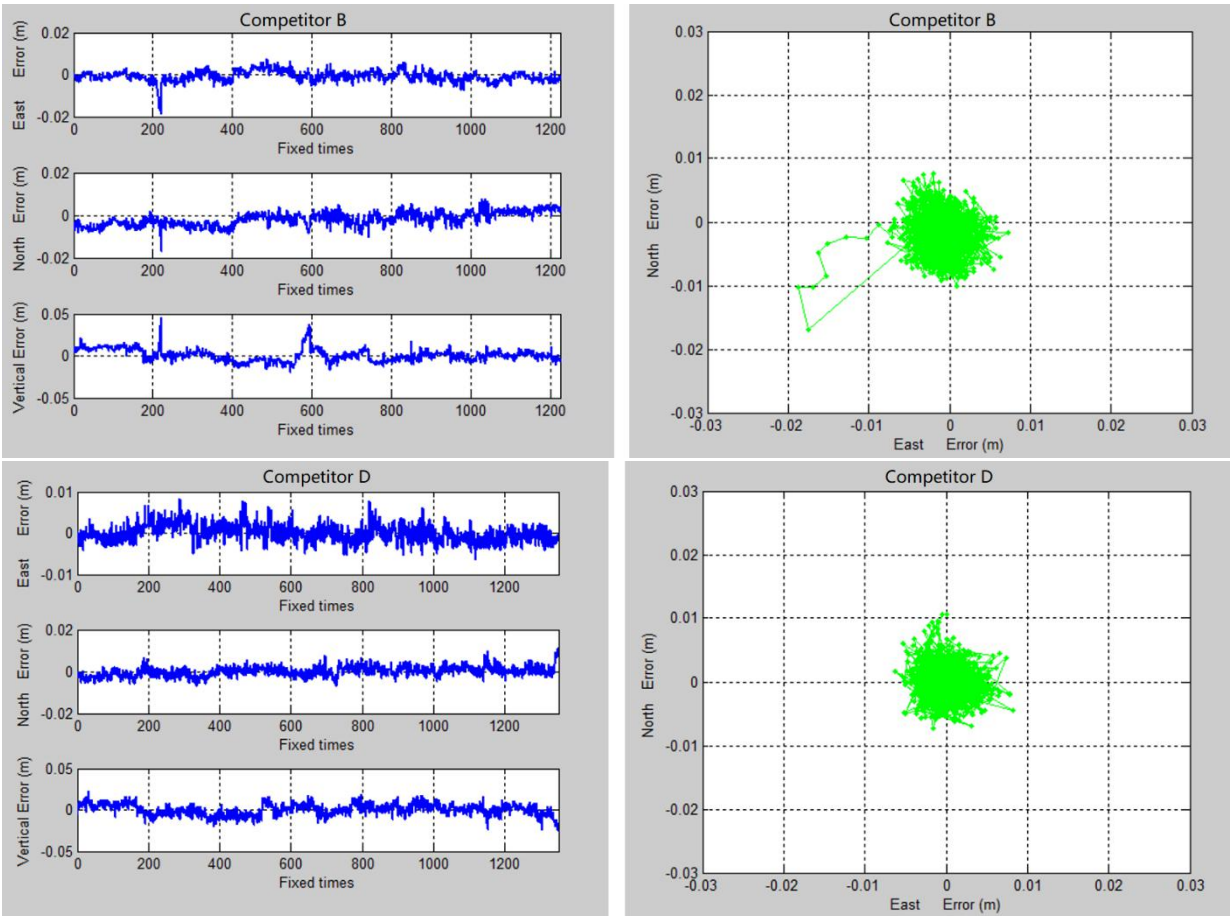


Figure 6 Position Error Time Sequence Diagrams and Horizontal Scatters (<2km-open sky)

4.3 Reliability of RTK (Partial Foliage)

4.3.1 Test method and scene description

GNSS users are rarely subject to the ideal conditions found in the open sky test. Buildings, trees and other obstructions limit the number of visible satellites and also reflect GNSS satellite signals, a phenomenon referred to as multipath propagation. These reflected signals interfere with the direct signal, degrading the GNSS measurement quality.

A similar set of tests were run in a moderate foliage survey environment. Three scenarios were contained as show in Figure 7, from left to right, respectively, as scene A, B and C. In each scene, the steps described in 4.2.1 were executed for 30 times.

Figure 7 Environment of Rover Station (<2km- Partial Foliage)

4.3.2 Test Results

The mean value of RTK fixed solutions of Competitor D was used as reference coordinates in each scene. The performance of each OEM board were evaluated using the following indicators: position accuracy in the direction of ENU (**excluding gross errors**), successful fixed times, number of fixed solutions and RTK initialization time. RTK initialization time refers to the time from the last single solution to the first fixed solution. In these tests, the logs of Competitor C were not configured correctly in scene A and B , so Competitor C do not participate in these comparisons.

4.3.2.1 Scene A

Table 5 and Table 6 show specific statistical values of the 30 sets of tests in the environment of scene A. Competitor A yielded the highest accuracy, while BX316 and Competitor B produced similar accuracy worse than others. BX316 achieved 100% success rate, and its RTK initialization is significantly faster than Competitor A and Competitor B. BX316 provided the higher number of fixed RTK solutions than Competitor A and Competitor B, however, it produced nearly 9% outliers as shown in Figure 8.

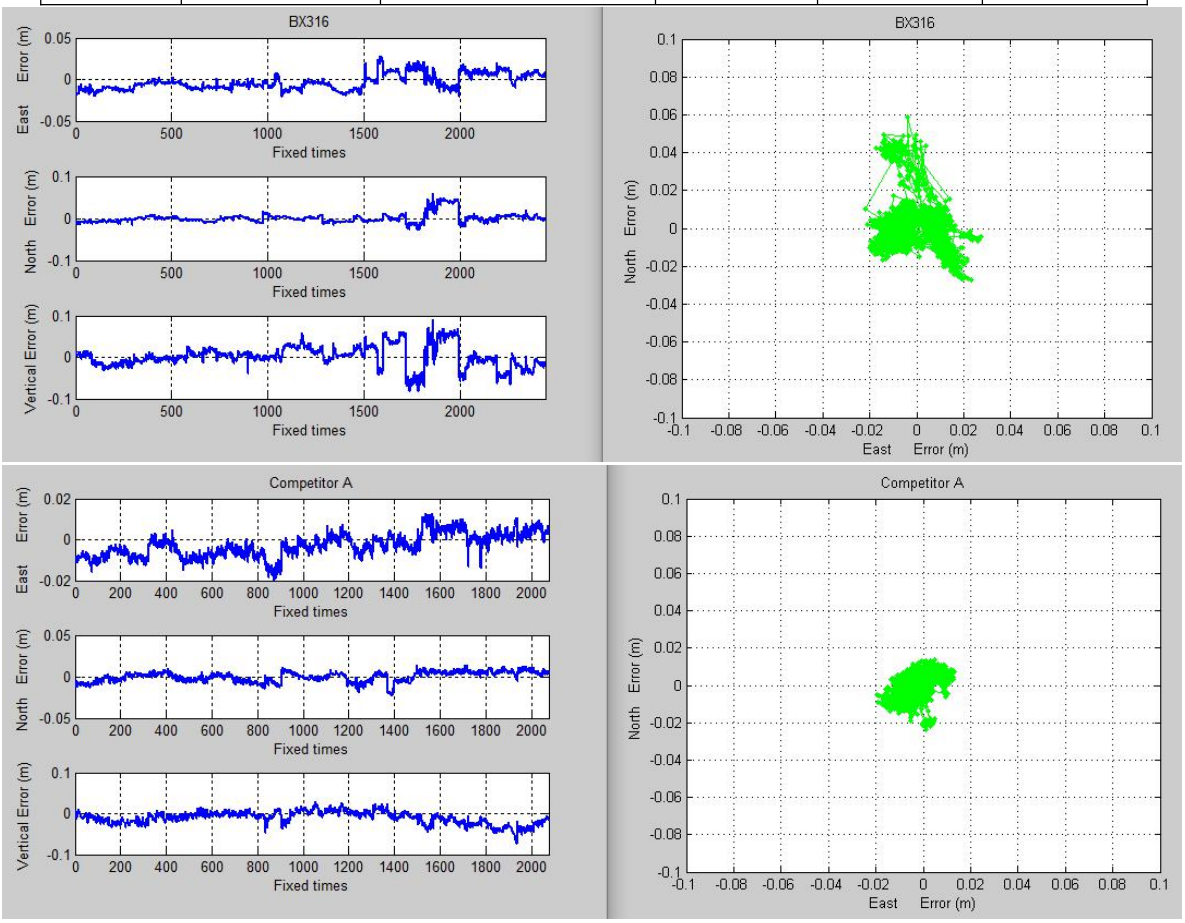
Table 5 Horizontal Position and Vertical Position Error Scatter (<2km- Partial Foliage, scene A)

OEM	**RMS(cm)**		
Boards	**E**	**N**	**U**
BX316	0.9	0.7	2.2

A	0.6	0.6	1.6
B	1.1	0.7	2.6
D	0.6	0.7	1.9

Table 6 Number of Fixed Solutions and Time to Fix (<2km- Partial Foliage, scene A)

OEM Boards	RTK Fix Success	Number of ALL Fixed Solutions	Time to Fix (unit: s)		
			Min Fix times	Max Fix Times	Mean Fix Times
BX316	30/30	2455	3	49	5.9
A	27/30	2075	1	310	28.9
B	24/30	1314	1	95	30.2
D	29/30	2588	1	10	2.7



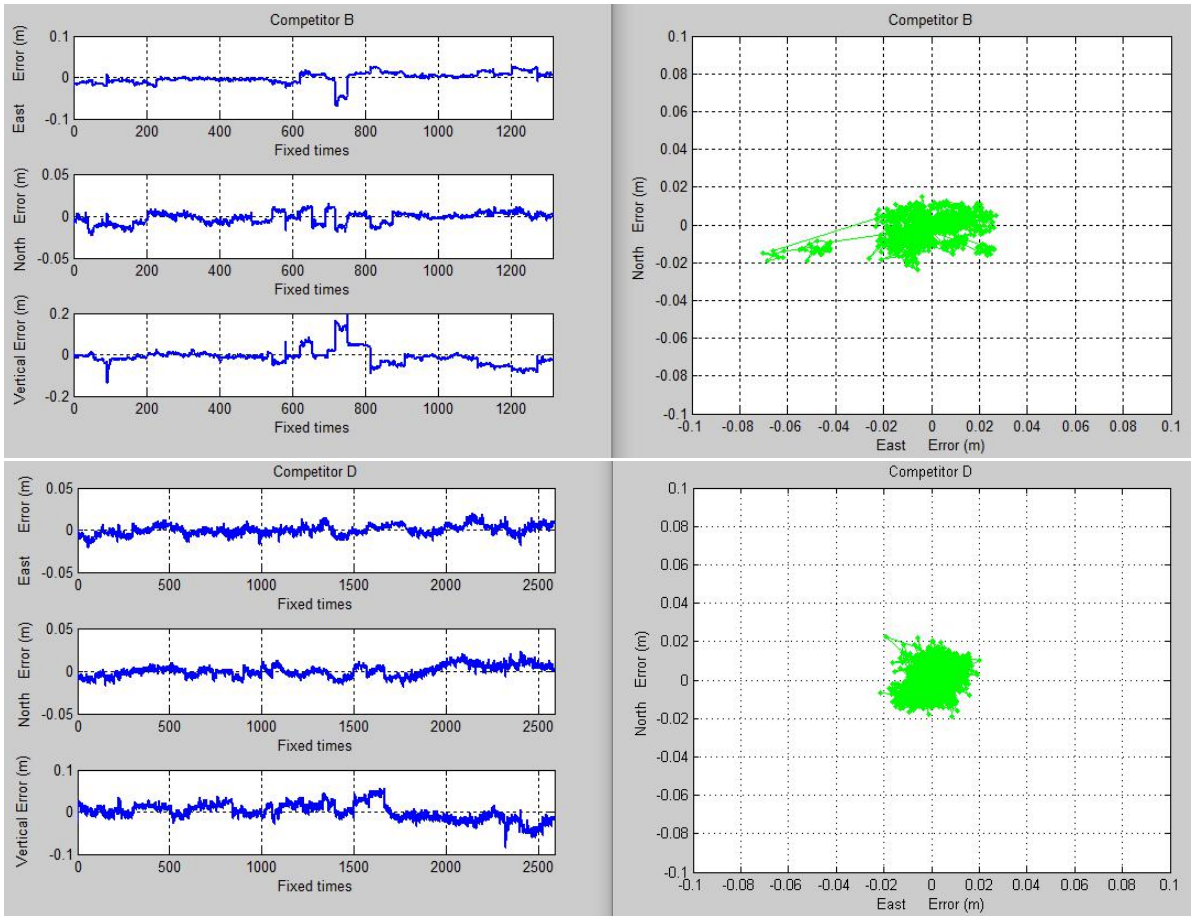


Figure 8 Position Error Time Sequence Diagrams and Horizontal Scatters (<2km- Partial Foliage, scene A)

4.3.2.2 Scene B

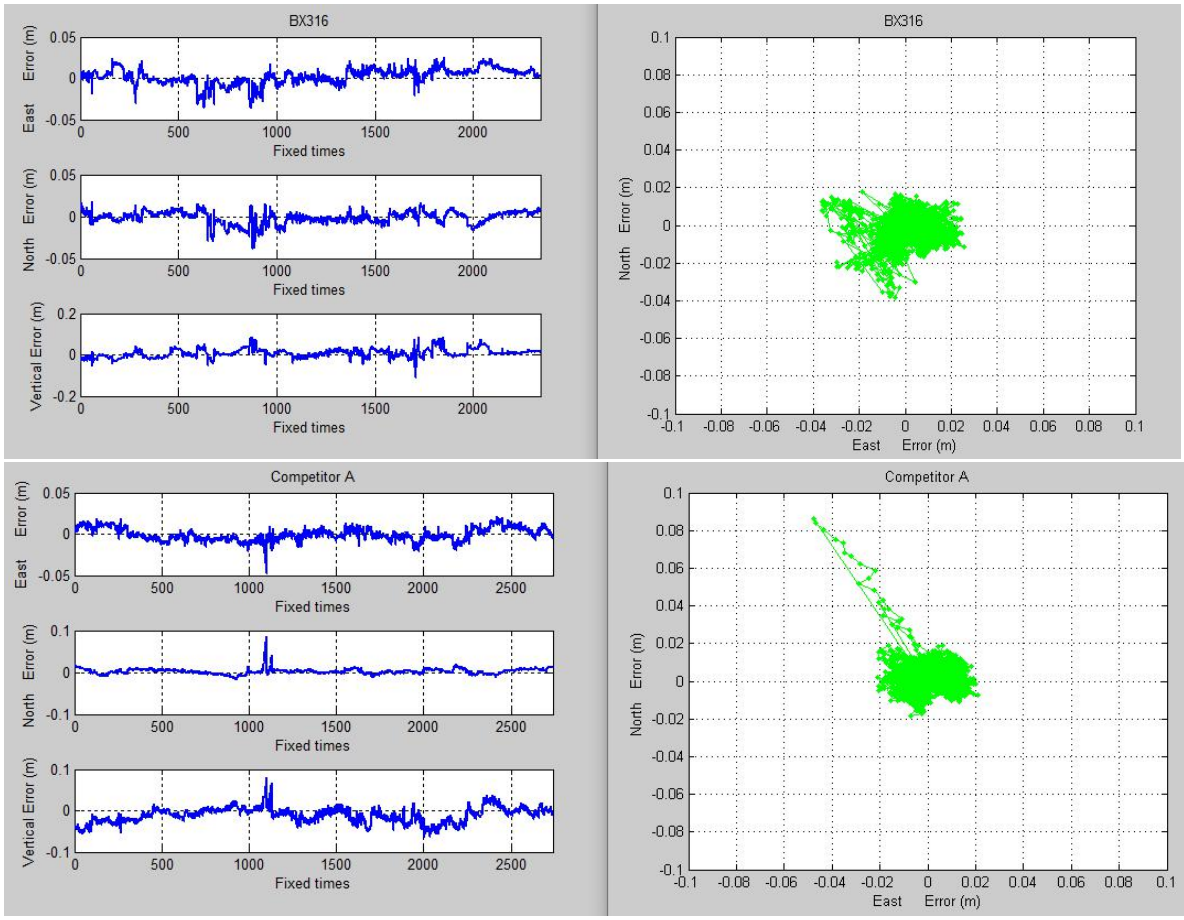
As shown in Table 7, the accuracy of Competitor B is not as good as other OEM boards. Competitor D proved to have the fastest initialization time and BX316 is second only to it (Table 8). Competitors B had difficulties fixing throughout the test and provided the slowest time to fix their RTK solution. However, BX316 produced nearly 18% outliers during this test (Figure 9).

Table 7 Horizontal Position and Vertical Position Error Scatter (<2km- Partial Foliage, scene B)

OEM Boards	RMS(cm)		
	E	N	U
BX316	0.9	0.8	1.8
A	0.8	0.6	1.8
B	1.0	0.6	2.4
D	0.8	0.6	1.8

Table 8 Number of Fixed Solutions and Time to Fix (<2km- Partial Foliage, scene B)

OEM Boards	RTK Fix Success	Number of ALL Fixed Solutions	Time to Fix (unit: s)		
			Min Fix times	Max Fix Times	Mean Fix Times
BX316	27/30	2223	3	184	12.1
A	29/30	2739	1	218	18.5
B	27/30	1834	3	112	30.3
D	30/30	2875	1	7	2.2



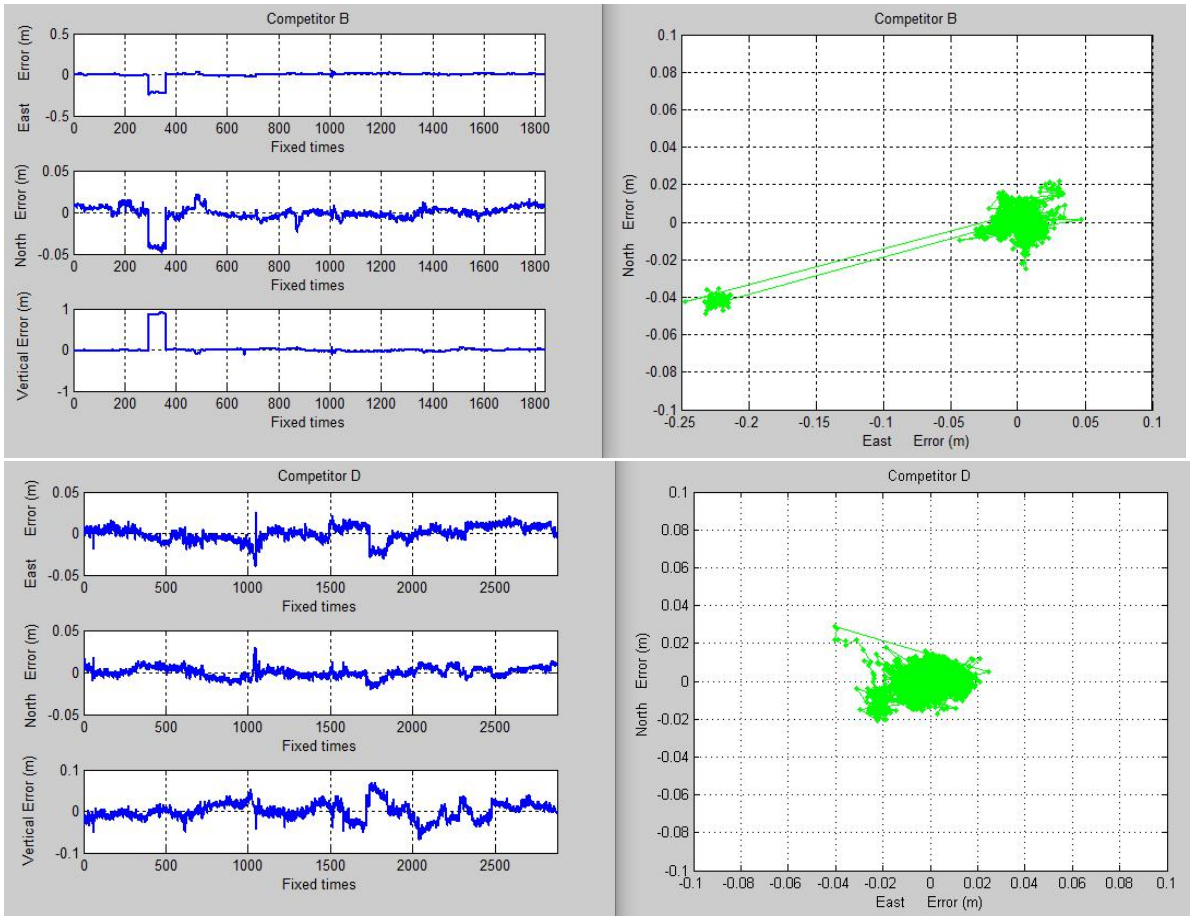


Figure 9 Position Error Time Sequence Diagrams and Horizontal Scatters (<2km- Partial Foliage, scene B)

4.3.2.3 Scene C

Competitor C were configured correctly in this scene, so it participated in the comparisons in these tests. BX316 provided the least RTK fixed solutions with the highest accuracy. The BX316 and Competitor B failed to achieve an RTK solution in 8 of 30 iterations. Competitor B provided solutions with lower accuracy and occasional outlier (Figure 10).

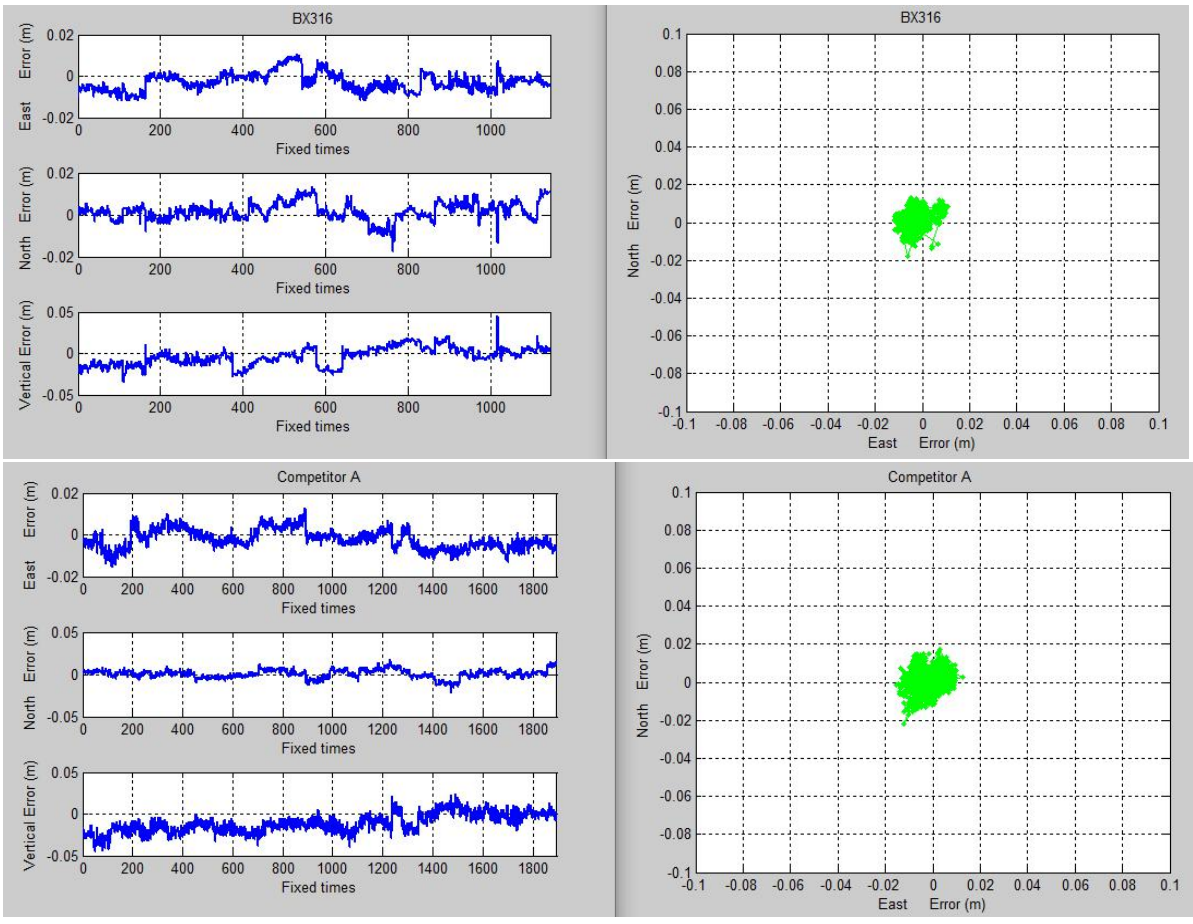
Table 9 Horizontal Position and Vertical Position Error Scatter (<2km- Partial Foliage, scene C)

OEM Boards	RMS(cm)		
	E	N	U
BX316	0.4	0.4	1.1
A	0.5	0.5	1.1
B	0.6	0.8	1.9
C	0.5	0.6	1.5

D	0.5	0.7	1.3

Table 10 Number of Fixed Solutions and Time to Fix (<2km- Partial Foliage, scene C)

OEM Boards	RTK Fix Success	Number of ALL Fixed Solutions	Time to Fix (unit: s)		
			Min Fix times	Max Fix Times	Mean Fix Times
BX316	22/30	1144	3	6	3.1
A	29/30	1896	1	70	3.7
B	22/30	1474	3	170	22.2
C	29/30	1636	1	49	5.1
D	29/30	1844	1	4	2.2



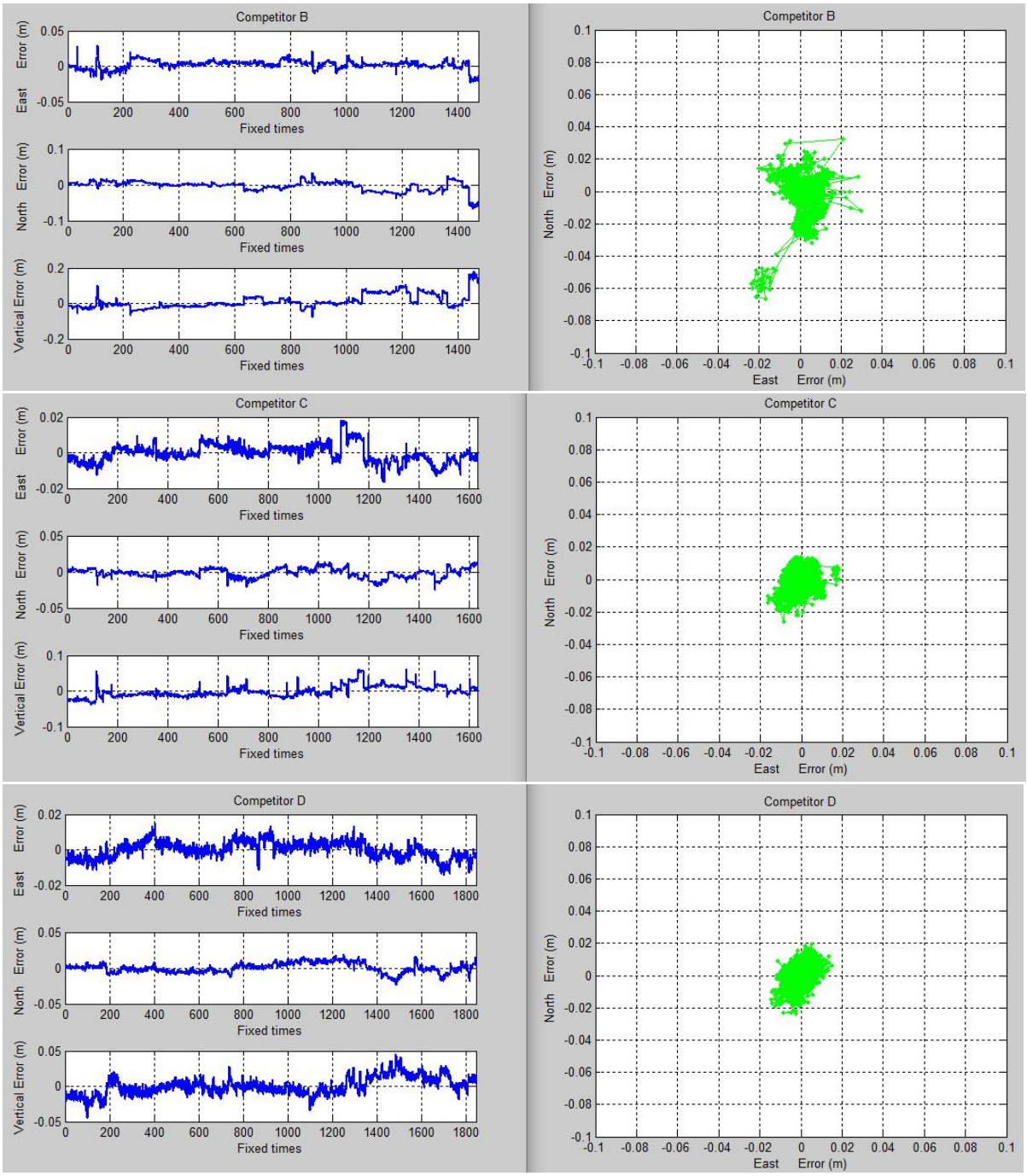


Figure 10 Position Error Time Sequence Diagrams and Horizontal Scatters (<2km- Partial Foliage, scene C)

4.4 Reliability of RTK (Half sky)

4.4.1 Test method and scene description

The RTK performance of each OEM board was tested under rigorous environment as shown in Figure 11 (from left to right, respectively, as scene A and B).

These scenarios limited the number of visible satellites, and the poor satellite geometry made it difficult for OEM boards to fix correctly.

Figure 11 Environment of Rover Station (<2km- Half sky)

4.4.2 Test Results

The steps described in 4.2.1 were executed for 30 times in each scene. The mean value of RTK fixed solutions of Competitor D was used as reference coordinates. The performance of each OEM boards were evaluated using the following indicators: position accuracy in the direction of ENU (**excluding gross errors**), successful fixed times, number of fixed solutions and initial time of RTK. RTK initialization time refers to the time from the last single solution to the first fixed solution.

4.4.2.1 Scene A

All the satellites in the northern sky are obscured in this scene (Figure 12). There is no obvious difference in the accuracy (excluding gross errors) of each OEM board (Table 11). BX316's RTK initializations were achieved in less than 20 seconds, however, due to poor satellite geometry it failed to achieve an RTK solution in 5 of 30 iterations. Competitor B had difficulties fixing throughout the test and provided the slower time to fix their RTK solution and produced some incorrect results (Figure 13).

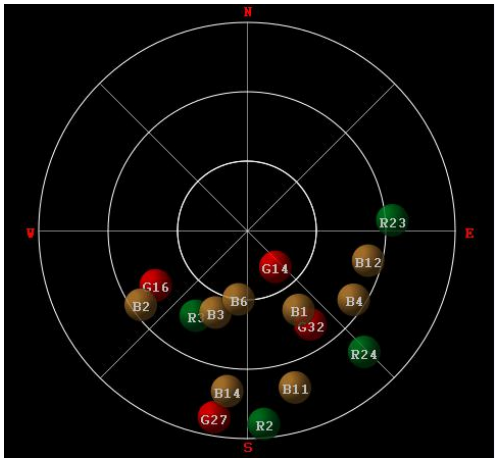


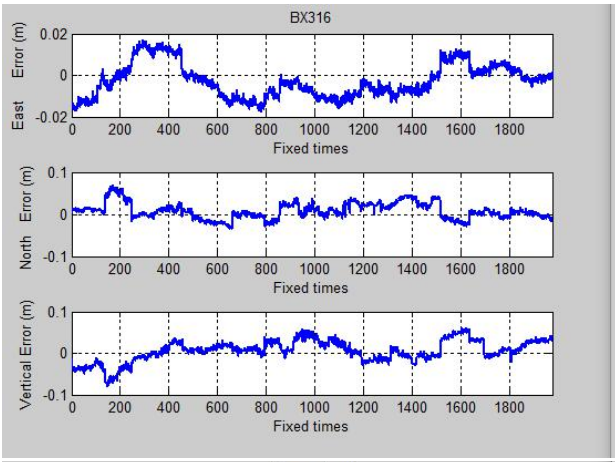
Figure 12 Sky plot of scene A

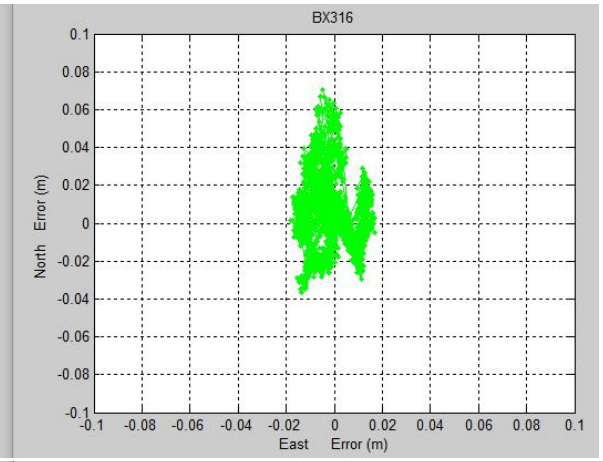
Table 11 Horizontal Position and Vertical Position Error Scatter (<2km- half sky, scene A)

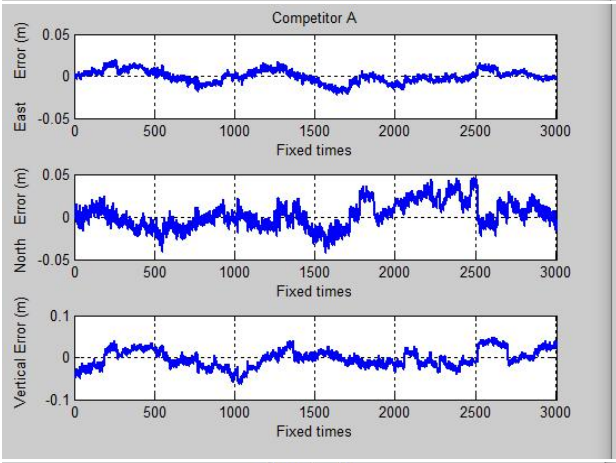
OEM Boards	RMS(cm)		
	E	N	U
BX316	0.8	1.3	2.1
A	0.7	1.4	2.1
B	0.7	1.6	1.9
C	0.8	1.5	1.9
D	0.8	1.6	1.9

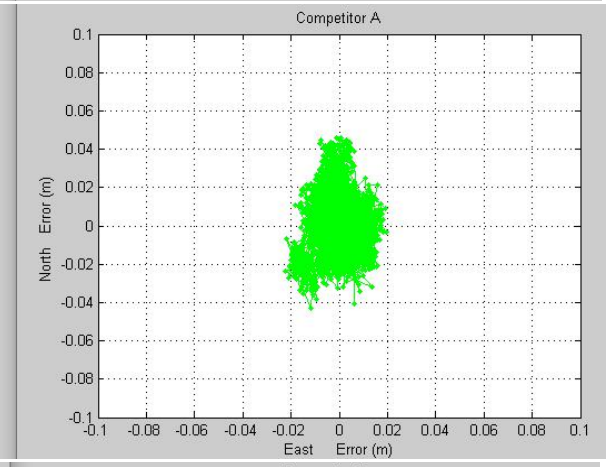
Table 12 Number of Fixed Solutions and Time to Fix (<2km- half sky, scene A)

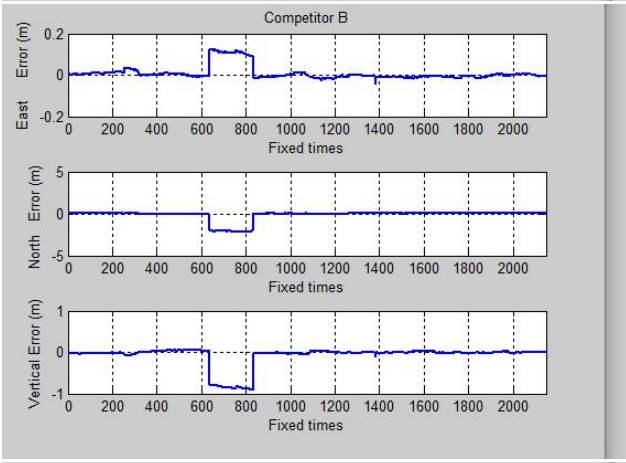
OEM Boards	RTK Fix Success	Number of ALL Fixed Solutions	Time to Fix (unit: s)		
			Min Fix times	Max Fix Times	Mean Fix Times
BX316	25/30	1977	3	17	4.0
A	30/30	3005	1	104	5.1
B	21/30	2148	3	49	8.9
C	28/30	2894	1	18	3.2
D	26/30	2050	1	246	14.0

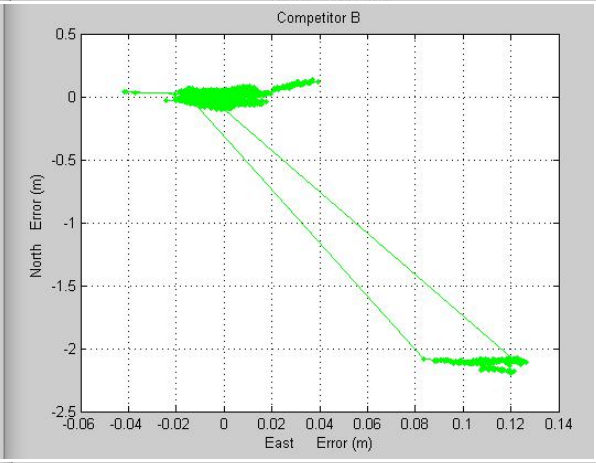

BX316
East Error (m)
North Error (m)
Vertical Error (m)
Fixed times

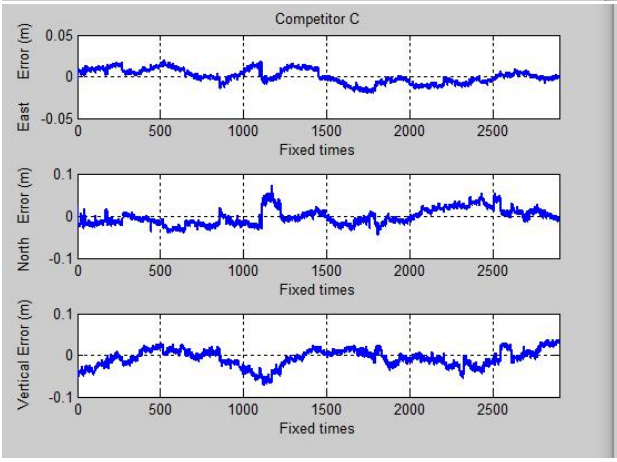

BX316
North Error (m)
East Error (m)

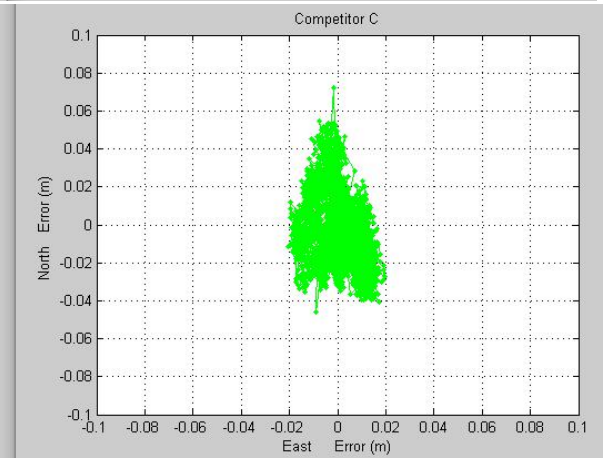

Competitor A
East Error (m)
North Error (m)
Vertical Error (m)
Fixed times


Competitor A
North Error (m)
East Error (m)


Competitor B
East Error (m)
North Error (m)
Vertical Error (m)
Fixed times


Competitor B
North Error (m)
East Error (m)


Competitor C
East Error (m)
North Error (m)
Vertical Error (m)
Fixed times


Competitor C
North Error (m)
East Error (m)

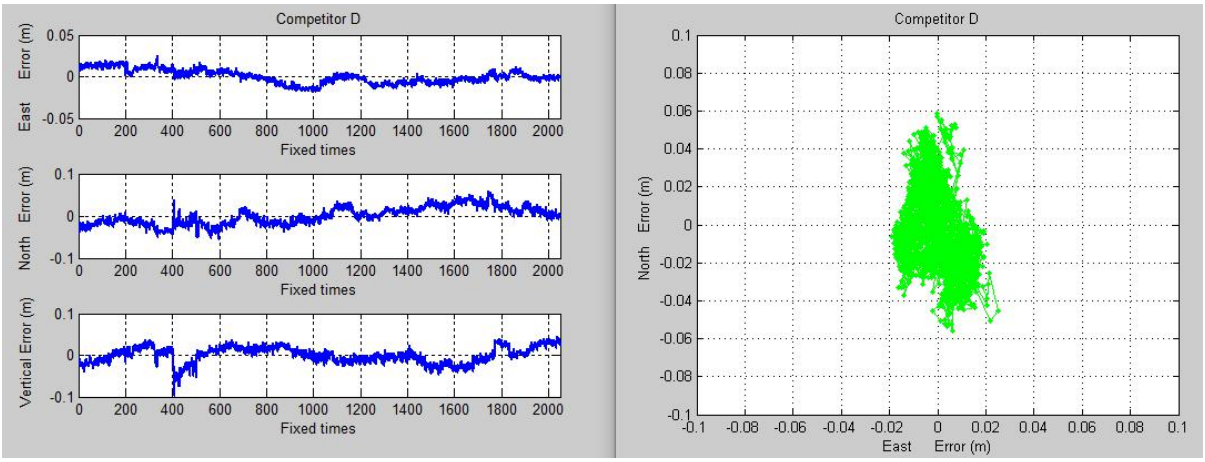


Figure 13 Position Error Time Sequence Diagrams and Horizontal Scatters (<2km- half sky, scene A)

4.4.2.2 Scene B

All the satellites in the southern sky are obscured in this scene (Figure 14). Of all the fixes BX316 and Competitor D's solutions show a higher degree of accuracy over that of other competitors (Figure 15). BX316 has certain competitiveness in RTK fixed time, however, due to poor satellite geometry it failed to achieve an RTK solution sometimes (Table 14).

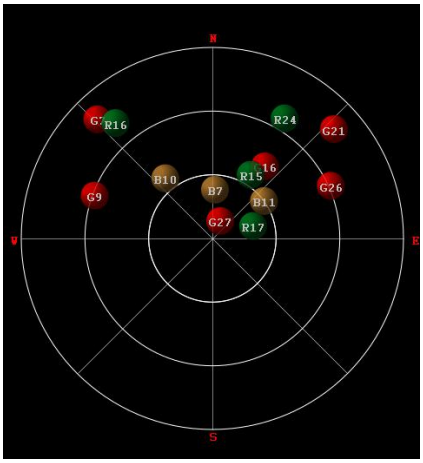


Figure 14 Sky plot of scene B

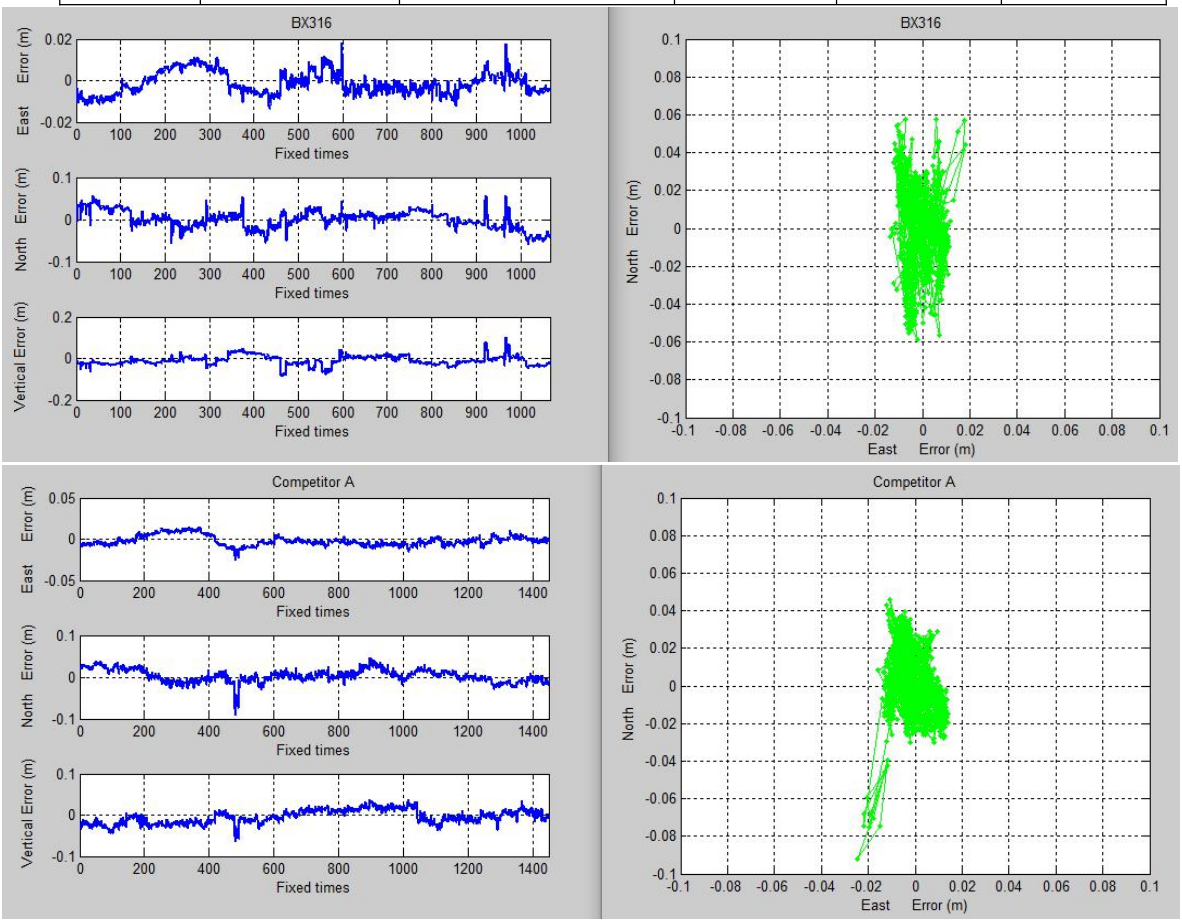
Table 13 Horizontal Position and Vertical Position Error Scatter (<2km- half sky, scene B)

OEM Boards	RMS(cm)		
	E	N	U
BX316	0.5	1.5	2.2
A	0.6	1.3	1.6
B	0.7	1.4	1.5

C	0.6	1.6	1.8
D	0.6	1.5	1.8

Table 14 Number of Fixed Solutions and Time to Fix (<2km- half sky, scene B)

OEM Boards	RTK Fix Success	Number of ALL Fixed Solutions	Time to Fix (unit: s)		
			Min Fix times	Max Fix Times	Mean Fix Times
BX316	26/30	1114	3	61	8.4
A	29/30	1449	1	37	3.7
B	29/30	1206	3	56	13.9
C	28/30	1369	1	48	7.9
D	29/30	1381	1	4	1.9



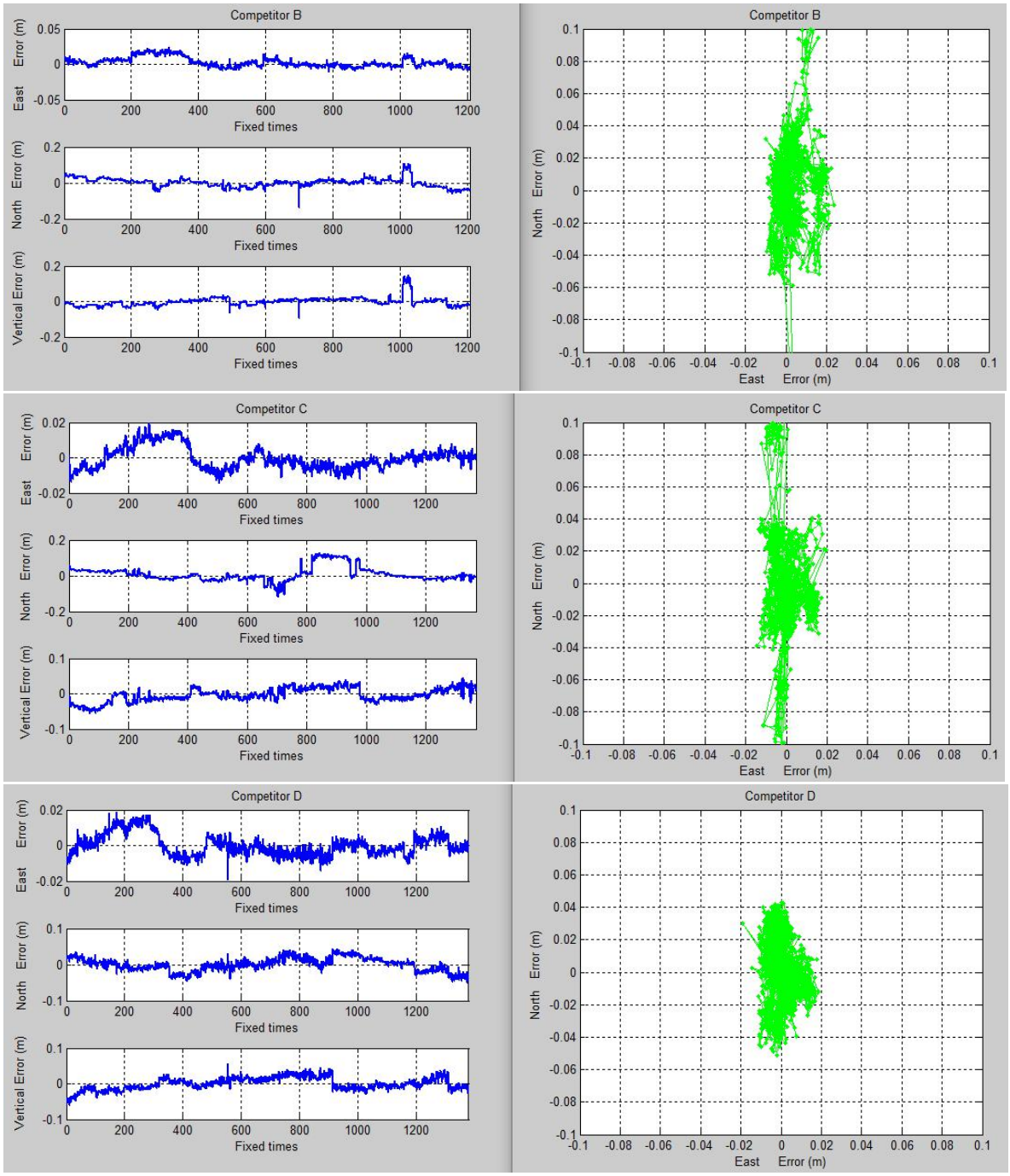


Figure 15 Position Error Time Sequence Diagrams and Horizontal Scatters (<2km- half sky, scene B)