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Author(s) / Submitter(s) ………China MSA………

BDS PPP offshore test and application suggestions

1 SUMMARY

In 2020, the BeiDou navigation satellite system (BDS) initiated a free of charge real-time service for precise point positioning (PPP) using the B2b signal for users in China and its surrounding areas.

Recently, China MSA conducted a test in the water of the Yangtze River estuary, both dynamic and static. Through the test, it is verified that BDS PPP-B2b can achieve a centimetre-level accuracy by using a single receiver. BDS-PPP can be used in the maritime field for high-precision applications.

1.1 Purpose of the document

This paper assessed the use of satellite high accuracy system for maritime navigation, in particular, analysed the compliance of BDS PPP position accuracy against the IMO A.915(22) high accuracy application requirements in the maritime operation.

As a means of satellite high-precision system to achieve high-precision positioning and ranging, Beidou PPP service is evaluated for the high-precision navigation application in the maritime field. Through actual tests, it is proved that BDS PPP service meets the positioning accuracy requirements for high-precision applications in IMO A.915(22) resolution.

The purpose of the document is to provide information for the Committee to review and consider the applications of BDS PPP service as a manner of high-accuracy positioning and ranging system in the maritime domain. Furthermore, this paper aims to provide reference for the committee to consider developing high-precision satellite guidelines.

1.2 Related documents

[1] IALA. Guideline G1127 Systems and Services for Highaccuracy Positionning and Ranging (Edition 2.0)

[2] ENG16-3.1.3.6 Introduction of BDS PPP Service

2 BACKGROUND

The IALA Guideline G1127 provides guidance on systems and services for high-precision positioning or ranging in waterways, in maritime traffic diversions, in traffic areas with limited maneuver space, in ports,

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and in congested waters where the risk of collision or grounding increases. Precision single-point positioning (PPP) is an important technology for satellite navigation systems to achieve wide-area high-precision positioning due to its wide signal coverage, uniform accuracy distribution, and small number of ground reference monitoring stations. Especially in the fields of autonomous unmanned ship automatic berthing, channel mapping, dredging, cargo loading and unloading, etc., decimetre or centimetre level positioning accuracy is very necessary. A new satellite PPP guideline is under consideration of IALA as described in its 2023-20274 work programme.

Beidou PPP services are provided by the PPP-B2B signal of the three GEO satellites in BDS. Users can achieve high-precision positioning through this service.

3 BDS PPP OVERVIEW

3.1 BDS PPP-B2b service structure

BDS PPP service works by using the space and ground segment facilities of BDS-3.The architecture is shown in figure 1.

a) Space segment: three BDS-3GEO located at longitudes 80°, 110.5 °, and 140 ° .

b) Ground segment: consists of the master control station (MCS), uplink stations (ULS), and monitoring stations (MS), which are well distributed in mainland China. The MS carries out continuous monitoring for all the visible satellites of the global navigation satellite systems (GNSS), forming pseudorange and carrier phase observations, and collecting meteorological data. After pre-processing, the raw data are sent to the MCS via a network. The quality verification and accuracy assessment for the raw data are carried out by the MCS for pre-processing. The raw data are compared with historical precise products for the overlapping arcs, and the user differential range error (UDRE) is evaluated. After pre-processing, the precise prediction satellite orbit and clock corrections are solved and fitted based on a dynamical smoothing process. According to the design protocol and format, the corrections and other related parameters such as mask and differential code bias (DCB) are attached to the augmentation navigation messages and then transferred to the ULS. The ULS transmits the augmentation navigation messages to the GEO satellites for broadcasting via PPP-B2b signals. Meanwhile, the MS and MCS retrieve the messages for closed-loop checking.

c)User segment: includes various receivers with PPP-B2b signal reception, augmentation navigation message demodulation, and PPP solution functions.

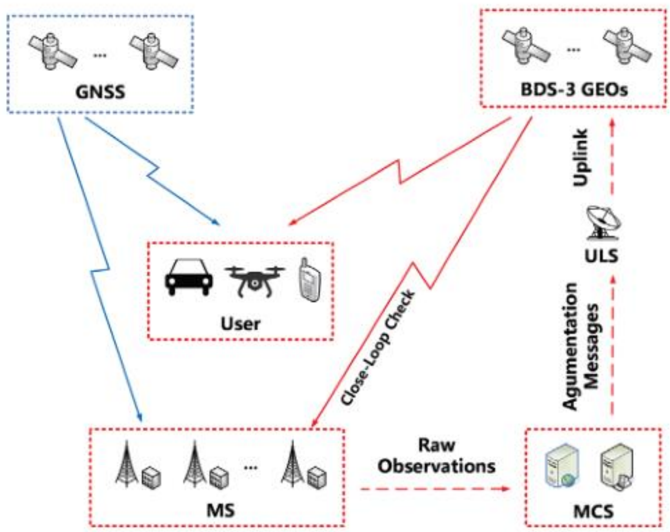

Figure 1 The BDS PPP architecture and Data processing flow

3.2 BDS PPP Performance Characteristics

3.3.1 Usage Constraint

The PPP service performance are based on the following user constraints:

a) The user receiver meets the relevant technical requirements specified in BDS-SIS-ICD-PPP-B2b-1.0, can track and correctly process the dual-frequency RNSS signals and the PPP-B2b signal, and use the augmentation information to complete the positioning calculation;

b) The service is based on BeiDou Navigation Satellite System Time (BDT) and BeiDou Coordinate System (BDCS);

c) Exclude errors of the signal transmission and the receiving terminal;

d) When the highest bit of the reserved flags is "1", the PPP information broadcast by the satellite should not be used.

3.3.2 Positioning Accuracy and Convergence Time

The main PPP performance standards include the positioning accuracy and the convergence time, etc.

The positioning accuracy refers to the statistical value of the difference between the user's reference position and the position determined by using the PPP service. The positioning accuracy includes the horizontal and vertical component respectively.

The convergence time is the time to meet the positioning accuracy requirements for the first time, under the condition that the receiver starts meeting the positioning accuracy and continues for 5 minutes.

3.3.3 Service Performance Standard

The augmentation service performance for using BDS only or the dual-system (BDS+GPS) are presented in Table 1

Table 1 The PPP Service Performance Standard

Constellation	Performance Characteristics	Performance Standard	Constraints
BDS	Horizontal Positioning Accuracy (95%)	⩽0.3m	The correction targets: PPP-B2b information is used to correct the CNAV1 NAV message of the BDS BIC signal and the LNAV NAV message of the GPS L1C/A signal;
	Vertical Positioning Accuracy (95%)	⩽0.6m	
	Convergence Time	⩽30min	Requirements for the correction targets: the BDS RNSS service performance meets the requirements of BeiDou Navigation Satellite System Open Service Performance Standard (Version 3.0); GPS service performance meets the requirements of "GPS Standard Positioning Service Performance Standard (Version 5.0)". Elevation mask is 10 degrees; Dual-frequency positioning; The statistical time interval is 7 days, and all points in the service area are averaged.
BDS+GPS	Horizontal Positioning Accuracy (95%)	⩽0.2m	
	Vertical Positioning Accuracy (95%)	⩽0.4m	
	Convergence Time	⩽20min	

4 BDS PPP TEST DETAIL

4.1 Test equipment and methods

This test includes static test and dynamic test. The static test installed the GNSS antenna at a fixed point on the roof of a 6-story building in Shanghai for data acquisition and calculation, while the dynamic test installed the equipment on a patrol vessel in the Yangtze River Estuary under the jurisdiction of the Shanghai Maritime Safety Administration.

For the data collection, the following equipment was used:

- 2 GNSS Receivers with the following characteristics:
  - BDS: B1I/B1C/B2a/B2b/B3I
  - GPS: L1/L2/L5
  - GLONASS: L1/L2
  - Galileo: E1/E5a/E5b
  - BDS PPP-B2b
  - BDS SBAS
  - RTK
- GNSS Antenna
- GNSS RF Recorder (Spirent 6450).
- Antenna feeder line (5 m).
- Splitter 1 In– 3 Out.

Figure 2 Test equipment

Receivers' mode set and data process in shown in figure 3.

Receiver 1:

- BDS SBAS Single Frequency (SF) real-time solution through BDSBAS-B1C signal for GPS L1 correction.

Receiver 2:

- BDS PPP real-time float solution through BDS PPP-B2b for combined systems of BDS B1C/B2a and GPS L1/L5.
- RTK Post process, used as the true value for the result comparison.

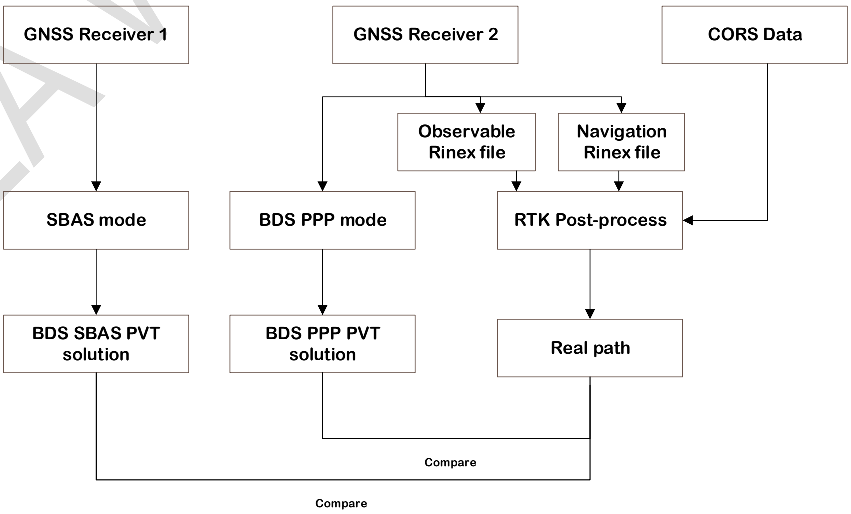

Figure 3 GNSS data process

The test mode of receiver 1 is set to BDS SBAS real-time solution mode, in which the receiver directly calculates and outputs the SBAS positioning results; The test mode of receiver 2 is set to BDS PPP real-time combined positioning float solution mode, and the observation data file and navigation data file of receiver 2 are stored synchronously for RTK post-processing as truth comparison. After processing, the data coordinates are unified into the current epoch of the BeiDou Coordinate System (BDCS), which is used to compare the positioning results of SBAS and PPP. This input document focuses on the comparison of the post-processing results of BDS PPP and RTK.

4.2 Dynamic test

4.2.1 Equipment installation

In order to assess the BDS PPP performance at user level in the maritime domain at coastal area in China, a text was carried out along the Yangtze River estuary waters on the 22th of August, 2023.
The vessel, departed from Wuhaogou dock in Yangtze river estuary at average speed of 10 knots and reached a position offshore of 25nm faraway, then returned to the start site at an average speed of 14 knots. Figure 4 4 shows the route followed by the patrol vessel along the mission.

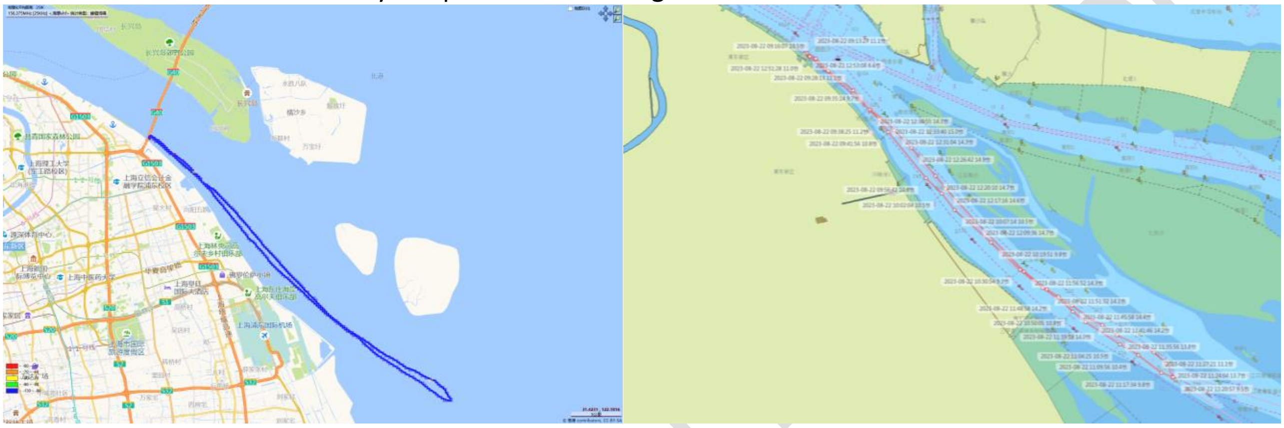

Figure 4 Data collection geographical path

The position of the GNSS antenna installed in the Haixun01053 patrol vessel is showed in figure 5.

Figure 5 Antenna position in patrol vessel Haixun01053

4.2.2 Test results

Positioning at Yangtze river estuary is an open sky environment that is less affected by the shielding of buildings, and it the number of visible satellites received at mask angle 10° is showed as figure 6. It can be seen that the number of visible satellites of GPS, BDS, GLONASS and GALILEO are in good condition.

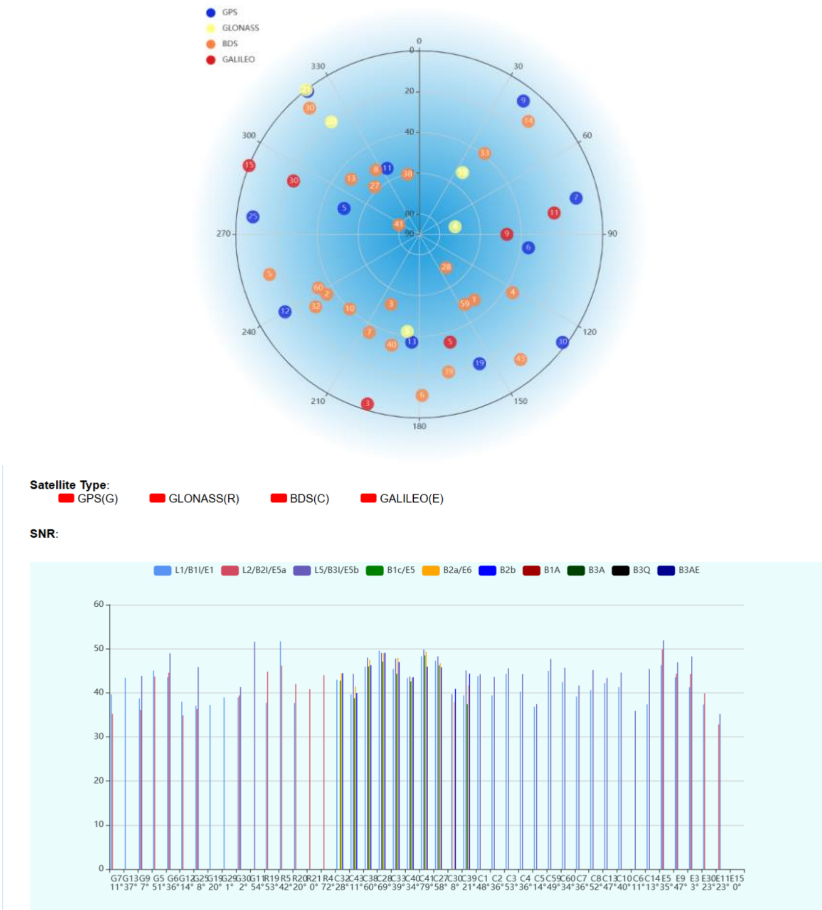

Figure 6 Real-time tracking of satellites by receiver

According to the receiving condition of receiver 2, BDS 3-PPP works in the float solution mode, and the combined DOP value of BDS and GPS is shown in figure 7. The mean value of PDOP is 1.809 (maximum value 4.2, minimum value 1.2), the mean value of HDOP is 0.954, and the mean value of VDOP is 1.537.

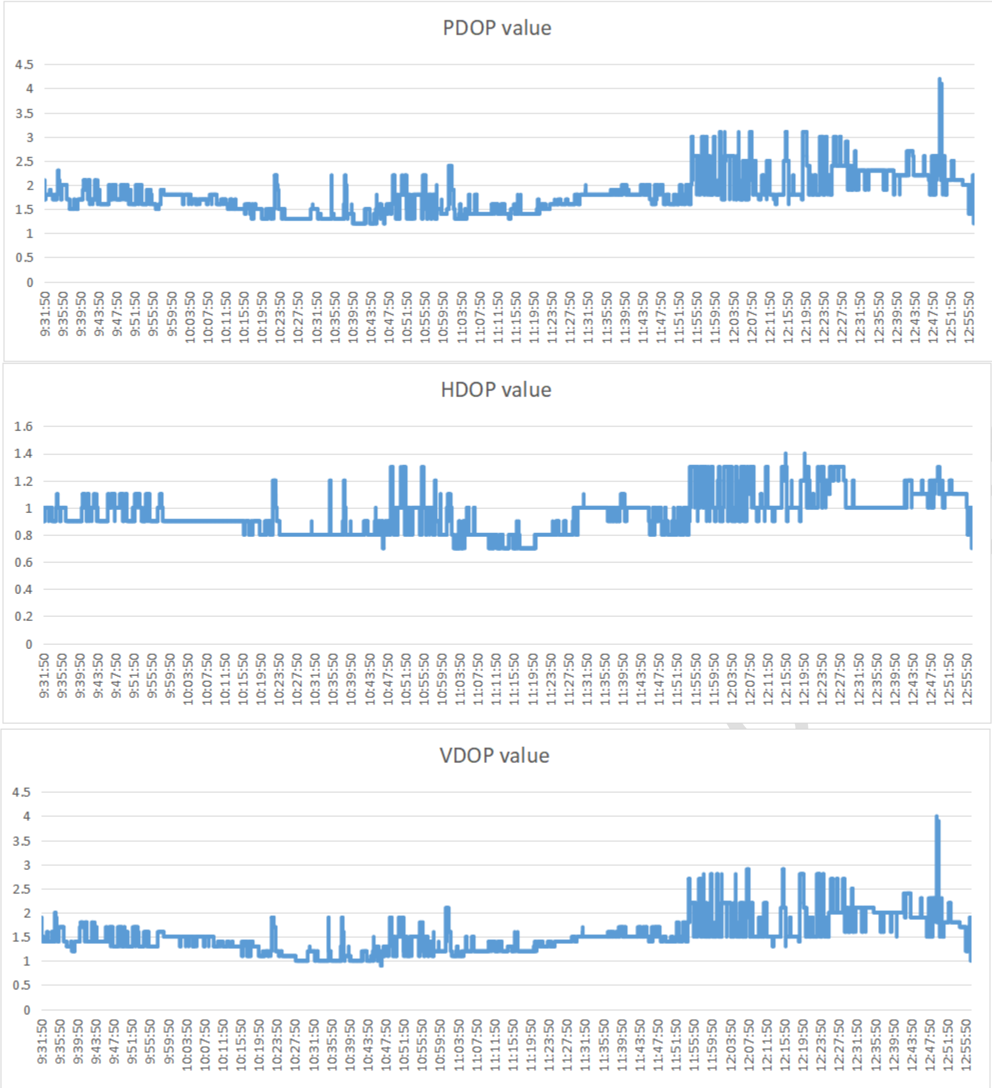

Figure 7 BDS PPP combined (BDS+GPS) float solution DOP value

Through the analysis of dynamic test results, the convergence time of BDS PPP float solution is about 30mins, and the positioning accuracy of BDS-PPP is compared with the post-RTK between the test time 9:17-12:57. It can be seen that the average horizontal positioning accuracy after convergence is 9.683cm and the average vertical positioning accuracy is 6.117cm as shown in figure 8. The positioning accuracy is better at a low speed. It can be seen that the accuracy is within the specification values.

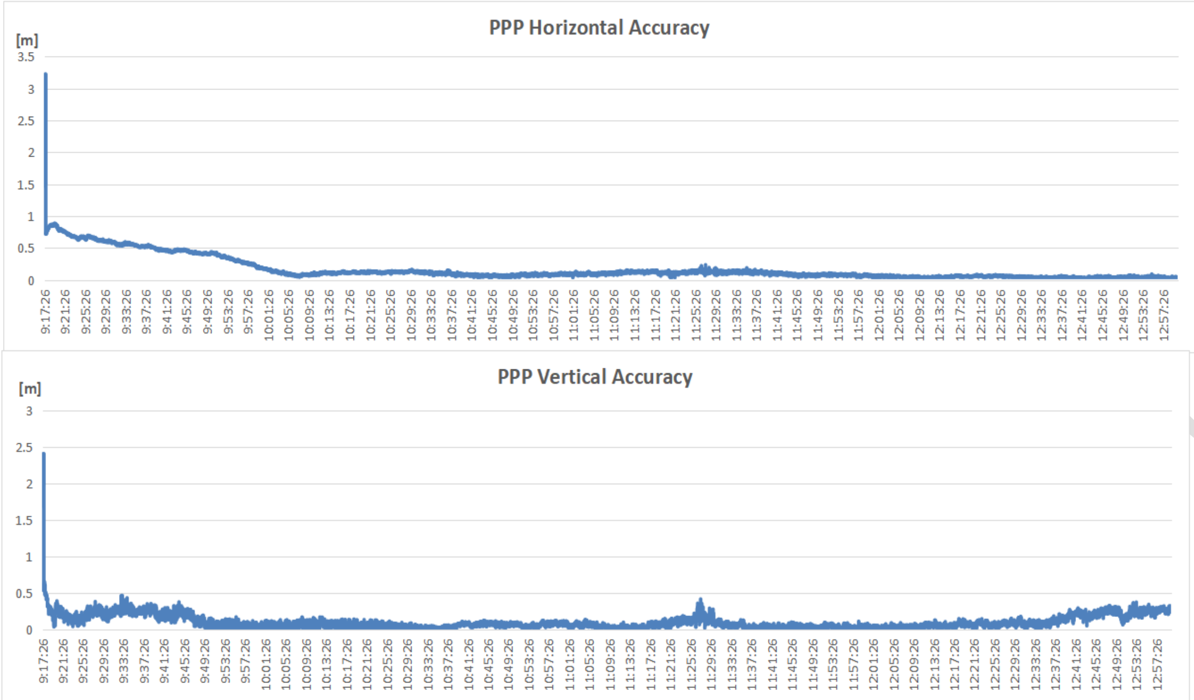

Figure 8 BDS PPP combined (BDS+GPS) float solution accuracy（Dynamic）

The comparison of positioning accuracy of BDS SBAS with post-RTK is shown in figure 9. It can be seen that the average horizontal positioning accuracy of BDS SBAS is 1.844m and the average vertical positioning accuracy is 1.640m during the test time from 9:17 to 12:57.

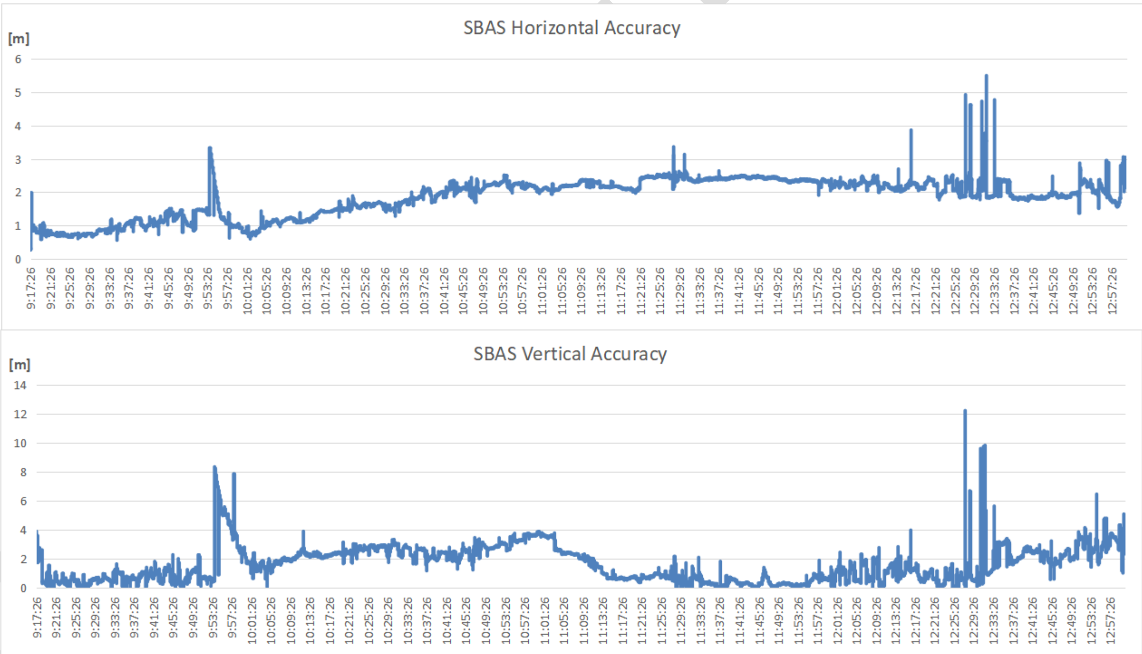

Figure 9 BDS SBAS solution accuracy（Dynamic）

The trace of the ship's movement is shown in the figure 10. The accuracy evaluation was performed by using the observation data collected by the shipborne receivers, using the highly accurate positioning results by RTK Post-process as the true value（yellow line）, and comparing the positioning results by BDS PPP (green line) and SBAS (red line). It can be seen that there is obvious deviation between SBAS and RTK post-processing positioning results, and there is basically no deviation between PPP and RTK post-processing accuracy.

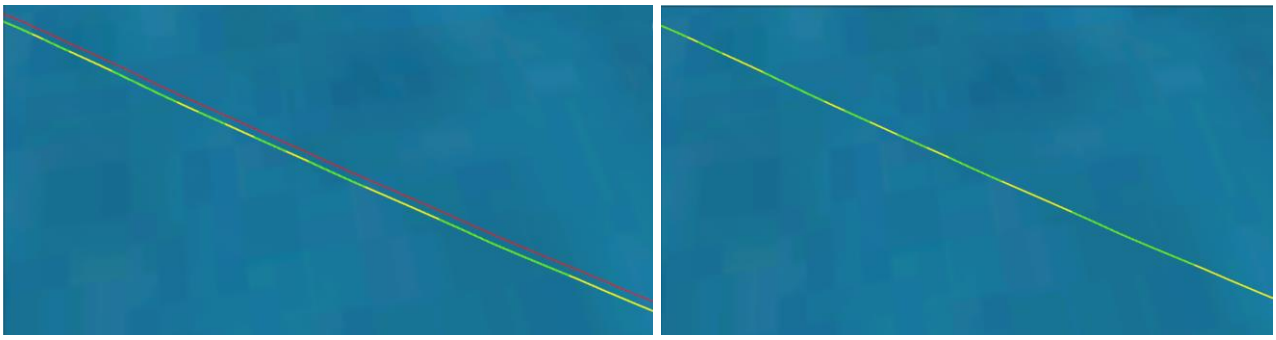

Figure 10 Vessel trace line (Yellow: Post RTK, true value; Green: BDS PPP; Red: BDS SBAS)

4.3 Static test

Unlike dynamic tests, which are installed on a ship, the static test GNSS antenna is set at a fixed point in an open space on a roof, and the receiver test mode is the same as the dynamic test. In static test, the convergence time of BDS PPP is about 20 minutes. It can be seen that after convergence, the average static horizontal positioning accuracy of BDS PPP service is 8.324cm and the average vertical positioning accuracy is 1.514cm between the test hours of 9:00 and 20:54 as shown in figure 11 .

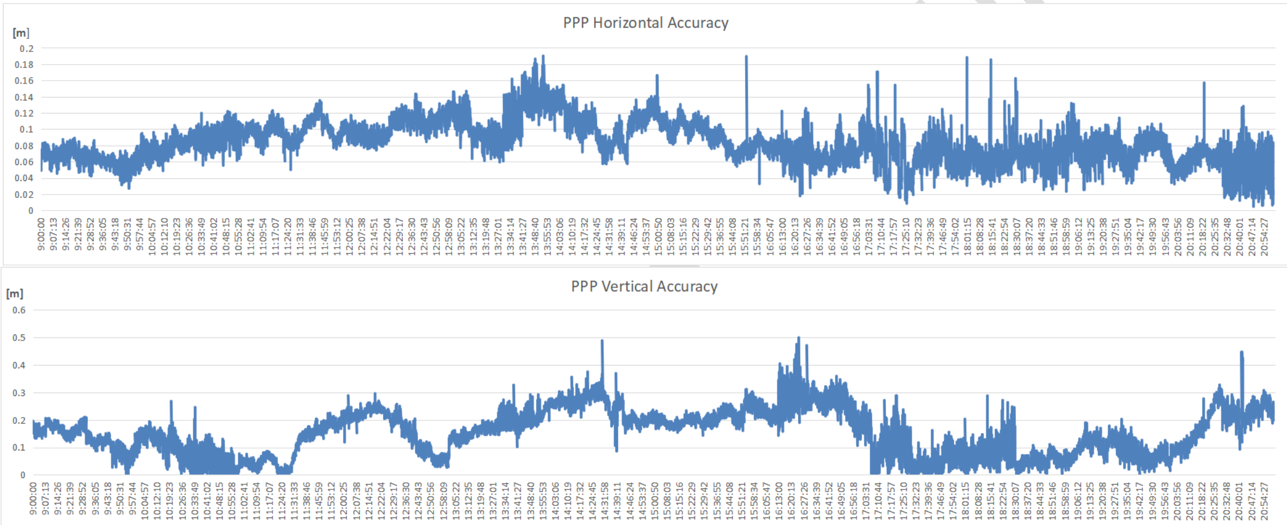

Figure 11 BDS PPP combined (BDS+GPS) float solution accuracy（Static）

The average horizontal positioning accuracy of the static test BDS SBAS was 1.188m and the average vertical positioning accuracy was 1.320m between 9:00-20:54 as figure 12.

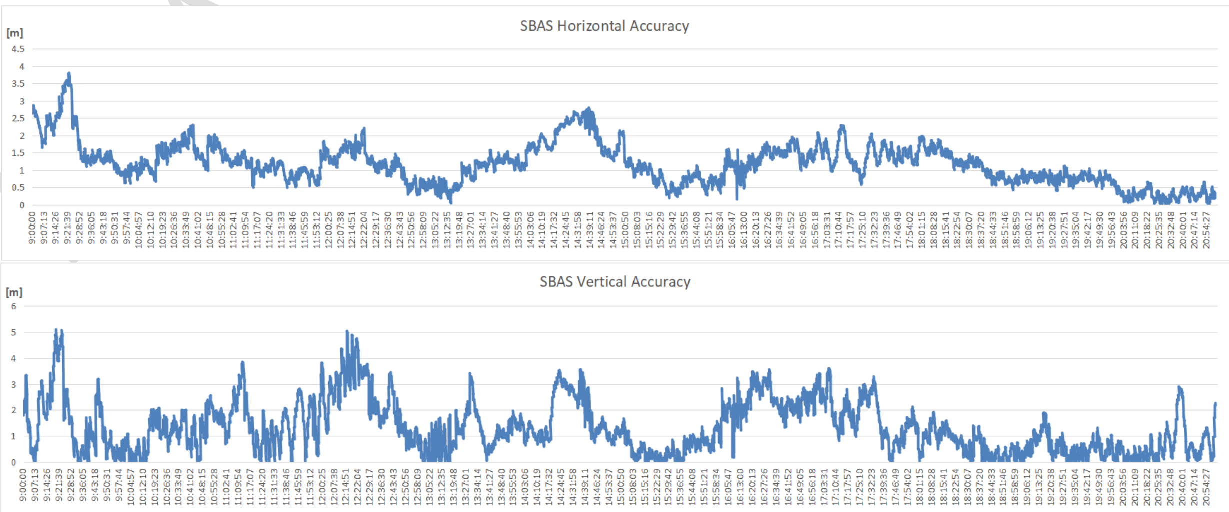

Figure 12 BDS SBAS solution accuracy（Static）

5 CONCLUSION

Through dynamic and static tests, the positioning accuracy of BDS PPP and SBAS during the test time is shown in table 2. BDS PPP achieves higher precision positioning and navigation performance under static and dynamic conditions.

Table 2 Test results

	BDS PPP (average)		BDS SBAS (average)		note
	Horizontal accuracy	Vertical accuracy	Horizontal accuracy	Vertical accuracy	Compared with RTK post-process
Dynamic test	9.683cm	6.117cm	1.844m	1.640m	
Static test	8.324cm	1.514cm	1.188m	1.320m	

6 REFERENCES

[1] BeiDou Navigation Satellite System Signal In Space Interface Control Document Precise Point Positioning Service Signal PPP-B2b(Version 1.0), July, 2020

[2] BeiDou Navigation Satellite System Signal In Space Interface Control Document Satellite Based Augmentation System Service Signal BDSBAS-B1C (Version 1.0) , July, 2020

[3] http://www.beidou.gov.cn/xt/gfxz/202008/P020200803362062482940.pdf

[4] BeiDou Navigation Satellite System Open Service Performance Standard (Version 3.0), May, 2021

[5] http://www.beidou.gov.cn/xt/gfxz/202105/P020210526216231136238.pdfPlease add details

7 ACTION REQUESTED OF THE COMMITTEE

The Committee is requested to:

1 note the information provided in this paper in relation to the performances achieved with BDS PPP for maritime navigation.

2 consider to develop a new guideline of PPP technology with other HAS providers.

3 discuss how high accuracy positioning systems can be used in maritime field.