BDS-3 Precise Point Positioning Featured Service on GEO B2b signal

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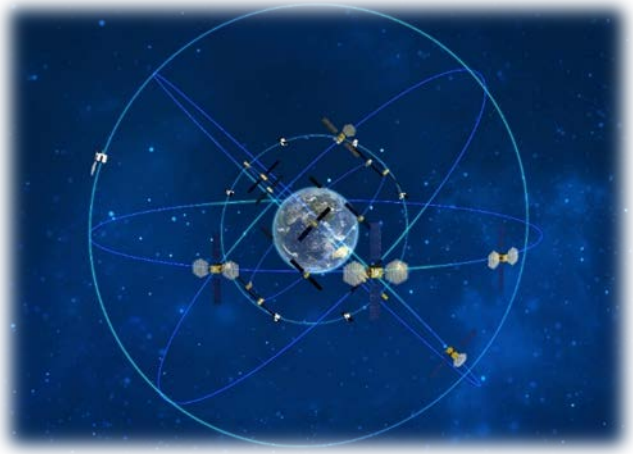
Contents

Background

◻ BDS-3 Services

- The full constellation of BDS-3 was officially put into service on July 31, 2020, consisting of 3 GEO, 3 IGSO and 24 MEO satellites to provide diversified services.



BDS-3 Constellation

Global Services

- Positioning, Navigation and Timing (RNSS)
- Global Short Message Communication (GSMC)
- International Search And Rescue (SAR)

Regional Services

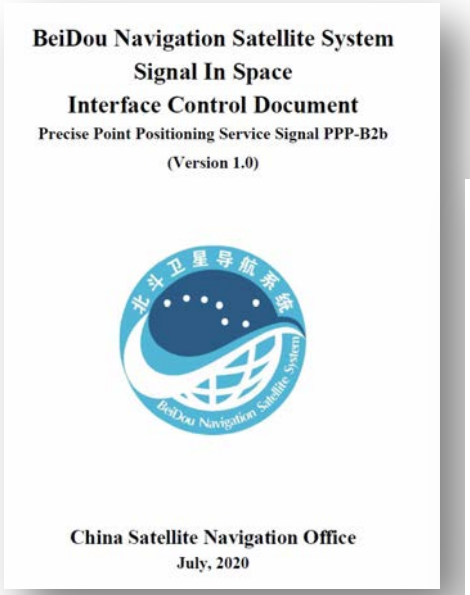
- Satellite-based Augmentation System (SBAS)
- Ground Augmentation System (GAS)
- Precise Point Positioning (PPP)
- Regional Short Message Communication (RSMC)

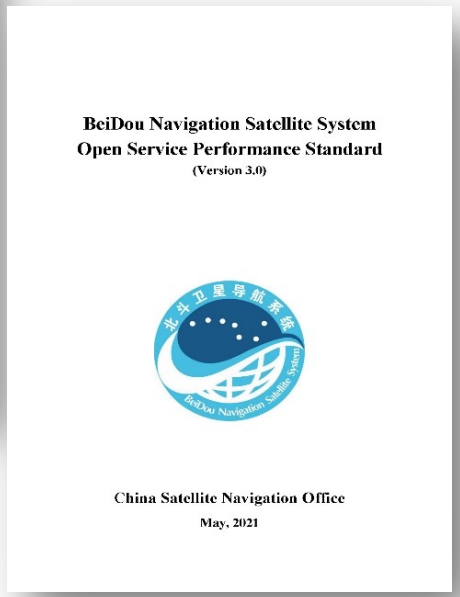
4 Services related to RNSS service

Background

◻ BDS-3 PPP Service

- The real-time PPP service is newly provided by BDS-3.
- Correction parameters, including satellite orbit, clock offset and DCB corrections, are transmitted by PPP-B2b signal from BDS-3 GEO satellites.
- PPP-B2b ICD was released in July 2020.
- Beidou SPS was released in May 2021.





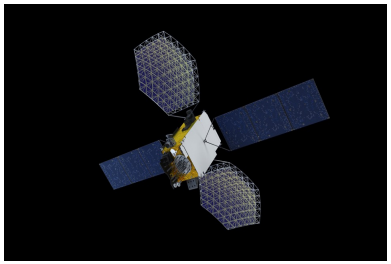
Constellation	HorizontalPositioning Accuracy (95%)	Vertical Positioning Accuracy (95%)	Convergence Time
BDS	≤0.3m	≤0.6m	≤30min
BDS+GPS	≤0.2m	≤0.4m	≤20min

Contents

PPP-B2b product

☐ Advantages of BDS-3 PPP Service

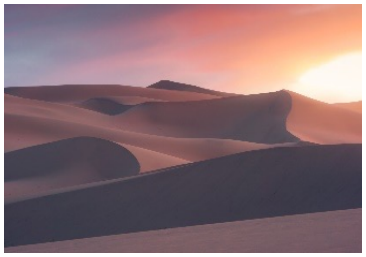
Satellite-based real-time PPP



Offshore oil drilling platforms

Offshore survey ships

Desert exploration



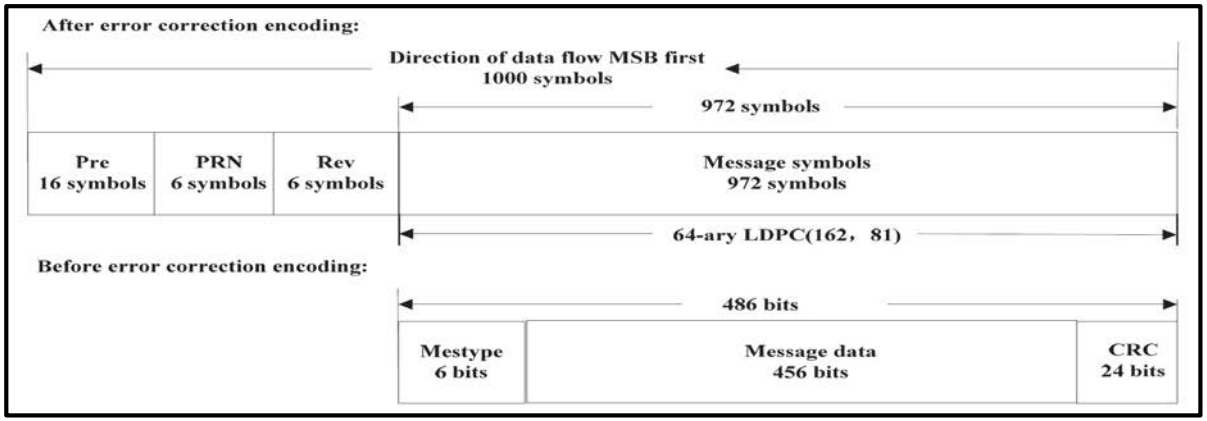
Satellite-based real-time PPP service	Typical type	Broadcast Link	Coverage Area	Characteristic
Commercial system	RTX	Skyterra satellite	Global	• Dedicated receiver • Paid service • Specific satellite
	OmniStar and StarFire	Inmarsat satellite		
GNSS system	BDS3 PPP-B2b	B2b, GEO	China and surrounding region	• Free • Embedded

PPP-B2b product

PPP-B2b Navigation Message Structure

- BDS-3 three GEO satellites broadcast PPP-B2b message by I-component.
- Each message has a length of 486 bits, including message type (6 bits), CRC (24 bits), message data and its specific contents (456 bits)
- The broadcast time of each frame is 1 s.

Signal	Component	Carrier frequency (MHz)	Band width (MHz)	Modulation	Symbol rate (sps)	GEOs
PPP-B2b	I	1207.14	246	BPSK(10)	1000	available



The PPP-B2b_I navigation message frame structure

PPP-B2b product

Message Type Definition

- The clock corrections are broadcast every 6 s, while the other messages are updated every 48 s.

Message types	Information content
1	Satellite mask
2	Satellite orbit correction and user range accuracy index
3	Differential code bias
4	Satellite clock correction
5	User range accuracy index
6	Clock correction and orbit correction - combination 1
7	Clock correction and orbit correction - combination 2
8-62	Reserved
63	Null message

Information content	Message type	Update interval	Nominal validity
Satellite mask	1	48s	-
Orbit correction	2,6,7	48s	96
Differential code bias	3	48s	86400
Clock correction	4,6,7	6s	12
User range accuracy index	2,5,6,7	48s	96

PPP-B2b product

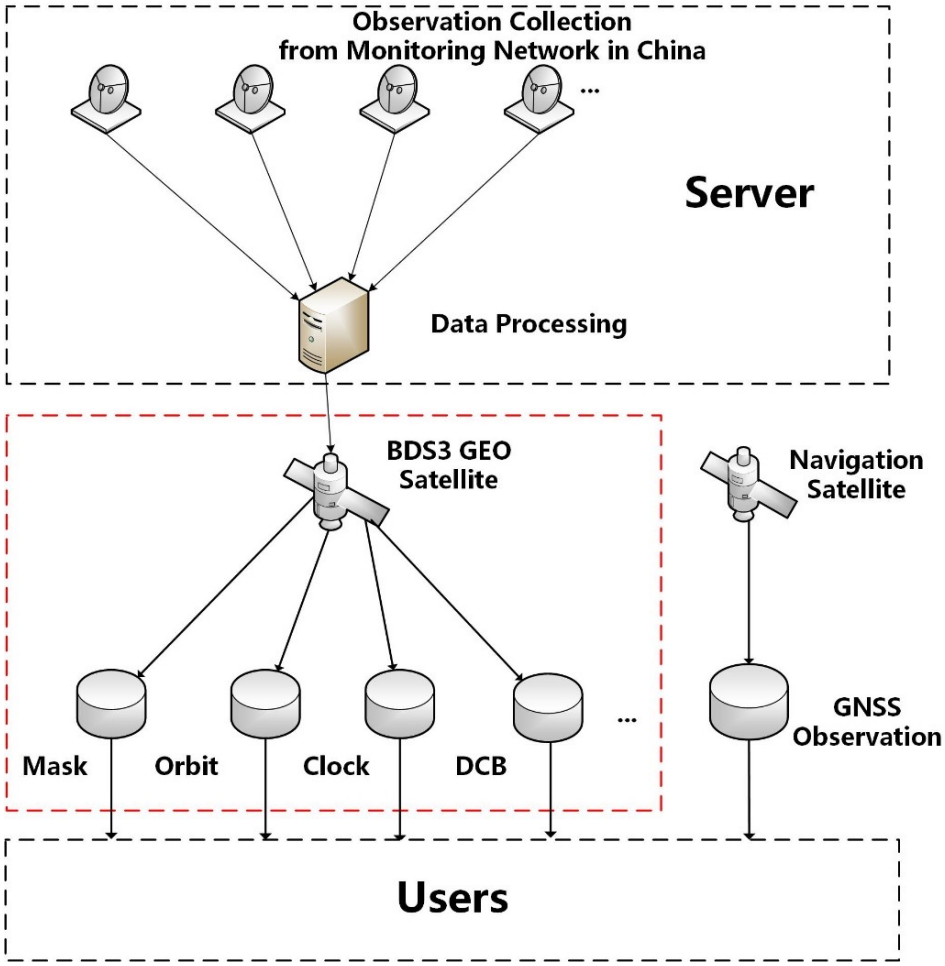
BDS3 PPP-B2b Procedure

Monitoring Network Observation Collection and Processing

Corrections Uploading

Corrections Broadcast

Corrections Acceptance



PPP-B2b product

User Algorithms

- **Differential Code Bias Correction**

$$\tilde{l}_{sig} = l_{sig} - DCB_{sig}$$

- **Orbit Correction**

$$\mathbf{X}_{orbit} = \mathbf{X}_{broadcast} - \delta\mathbf{X}$$

- **Clock Correction**

$$t_{satellite} = t_{broadcast} - \frac{C_0}{C}$$

User Algorithms	
Reference Broadcast Navigation Messages:	BDS CNAV1 of B1C GPS LNAV of L1C/A Galileo I/NAV (not available) GLONASS L1OCd (not available)
Coordinate System	BDCS
Time System	BDT
ARP/CoM	ARP
Clock datum	On B3I

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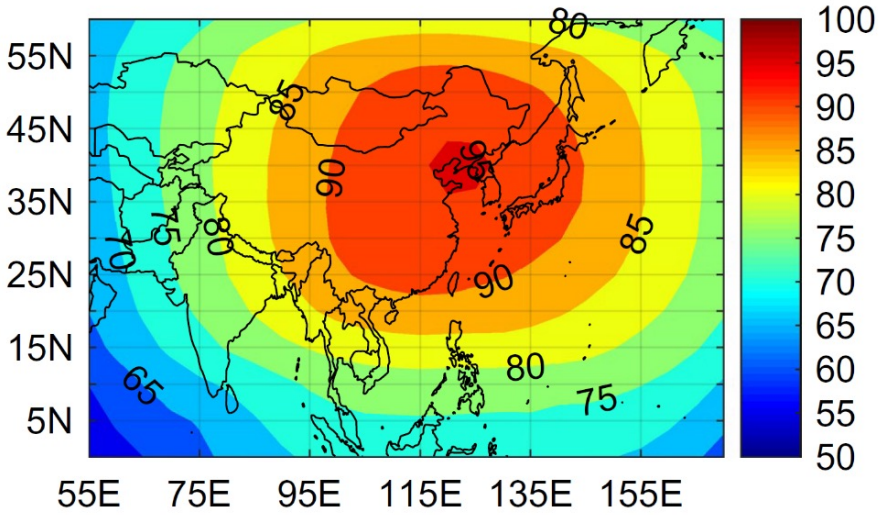
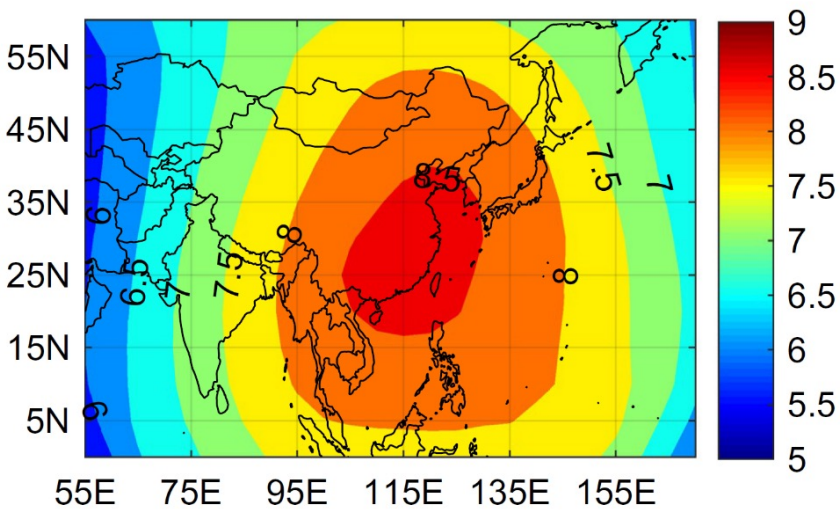
Performance assessment

☐ Availability of corrections

Empirical availability rate (EAR): the ratio of the length of the observation sub-arcs with available PPP-B2b corrections to the length of the total observation arcs.



EAR of PPP-B2b correction in China and surrounding area.
The color bar represents the EAR value(unit : %)



Average number of **visible satellites**
The color bar represents the average number of satellites

In China: EAR>80%, visible satellites >7

Xu at el. 2021

Performance assessment

Assessment strategy

- **Receiver**: Femtomes-FB680
- **Time span**: 2020/8/1 – 2021/5/1
- **Reference**: GBM product
- **Assessment method of orbit**:

$$RMS = \sqrt{\frac{\sum(\Delta Orb)}{n}}$$

- **Assessment method of Clock**:

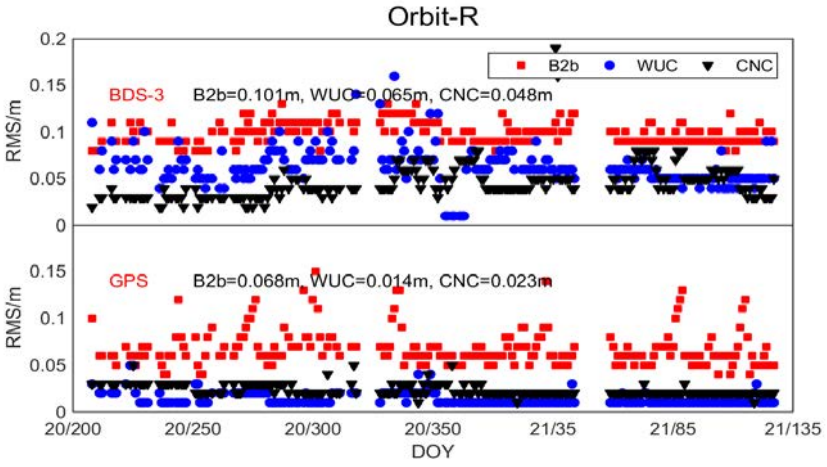
$$RMS = \sqrt{\frac{\sum(\nabla\Delta Clk)}{n}}, STD = \sqrt{\frac{\sum(\nabla\Delta Clk - avg_{\nabla\Delta Clk})}{n-1}}$$

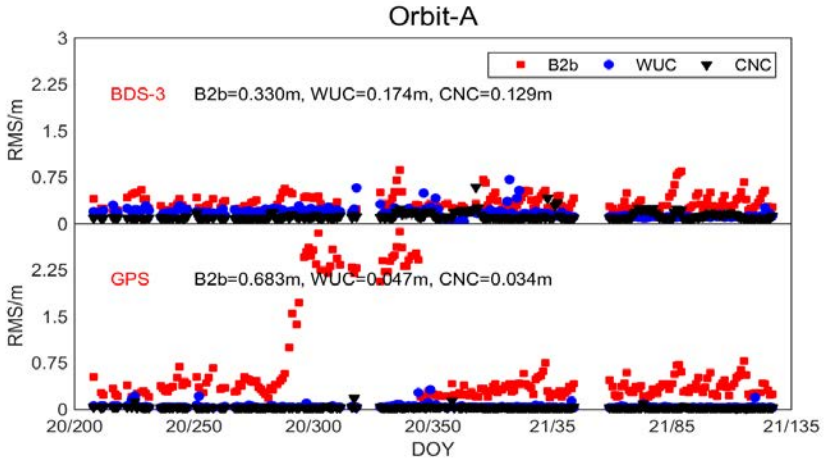
- **Assessment method of SISRE**:

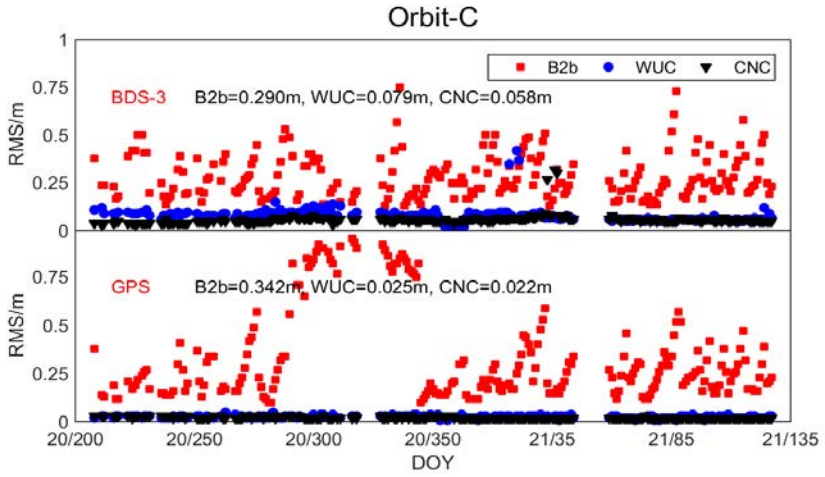
$$RMS = \sqrt{\frac{\sum(\Delta SISRE)}{n}}, STD = \sqrt{\frac{\sum(\Delta SISRE - avg_{\Delta SISRE})}{n-1}}$$

Performance assessment

☐ Assessment result of PPP-B2b orbit





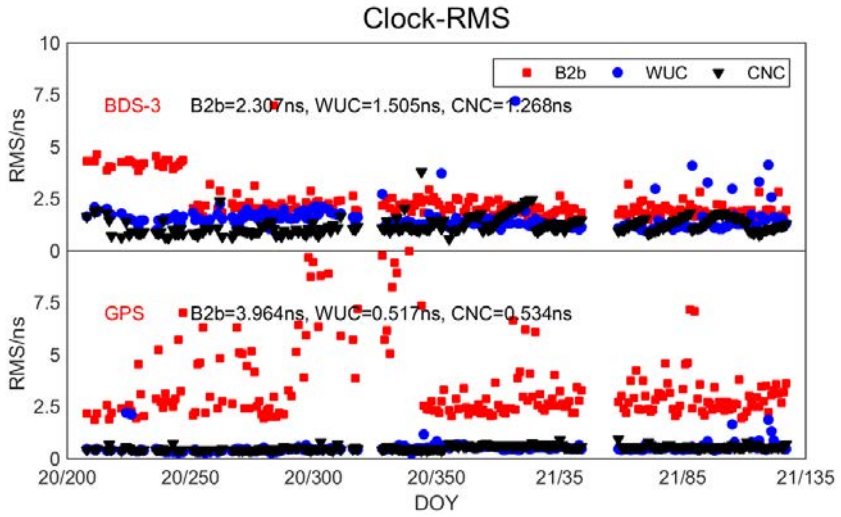


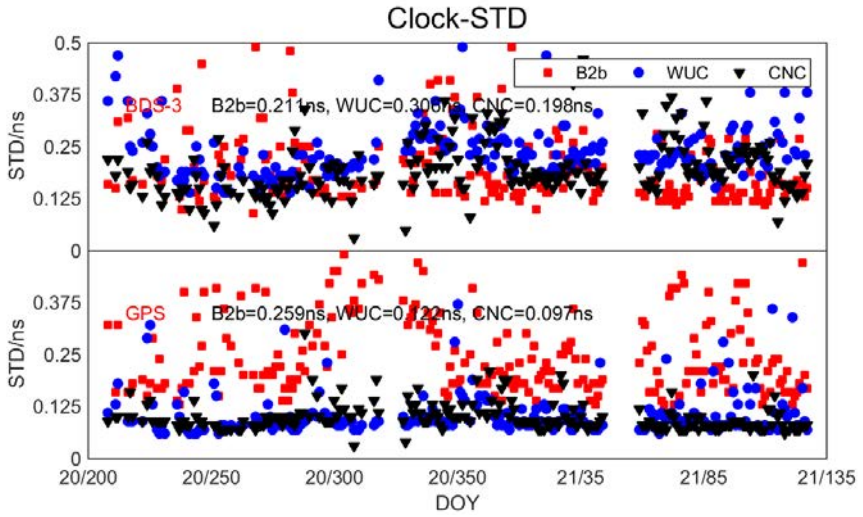
	B2b		WUC		CNES	
	BDS	GPS	BDS	GPS	BDS	GPS
R(cm)	10.1	6.8	6.5	1.4	4.8	2.3
A(cm)	33.0	68.3	17.4	4.7	12.9	3.4
C(cm)	29.0	34.2	7.9	2.5	5.8	2.2

BDS and GPS orbit RMS: decimeter level

Performance assessment

☐ Assessment result of PPP-B2b clock



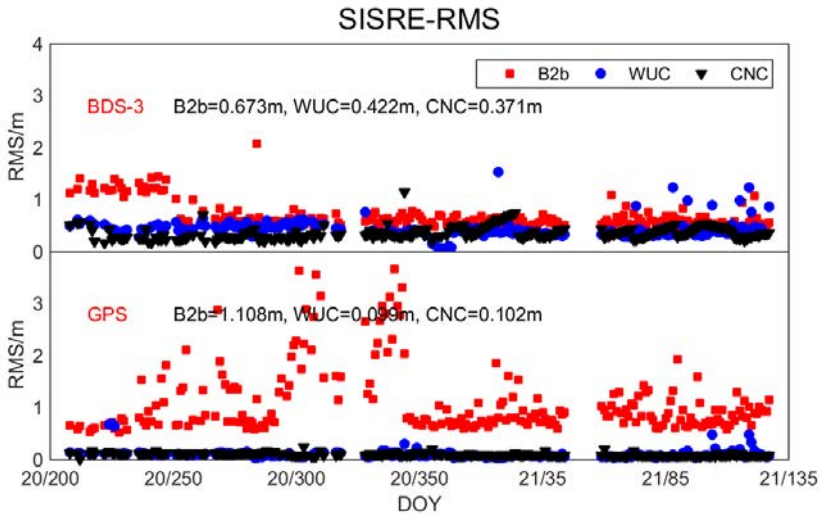


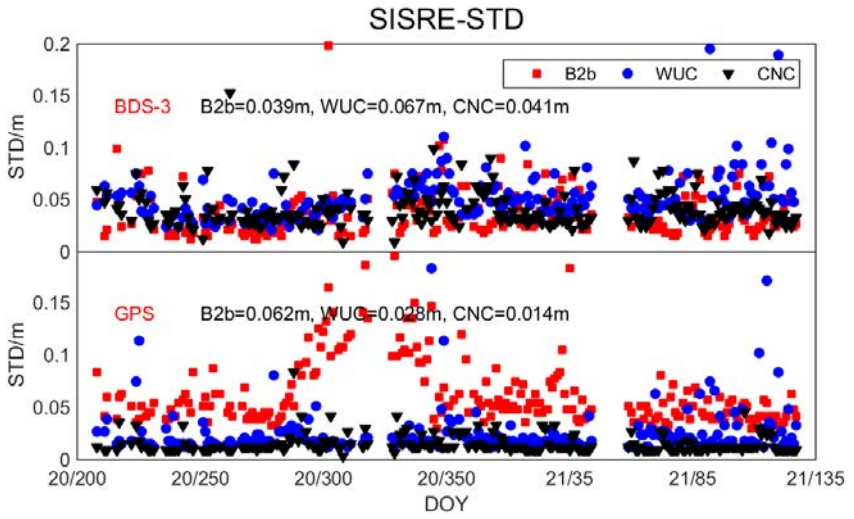
	B2b		WUC		CNES	
	BDS	GPS	BDS	GPS	BDS	GPS
RMS(ns)	2.307	3.964	1.505	0.517	1.268	0.534
STD(ns)	0.211	0.259	0.306	0.122	0.198	0.097

BDS and GPS clock RMS: nanosecond level,
clock STD: better than 0.3 ns

Performance assessment

☐ Assessment result of PPP-B2b SISRE





	B2b		WUC		CNES	
	BDS	GPS	BDS	GPS	BDS	GPS
RMS (cm)	67.3	110.8	42.2	9.9	37.1	10.2
STD (cm)	3.9	6.2	6.7	2.8	4.1	1.4

BDS and GPS SISRE RMS: decimeter and meter level, respectively
BDS and GPS SISRE STD: better than 7 cm

Performance assessment

☐ Data collection and processing strategy

Time span: 2020/7/26 - 2020/12/29

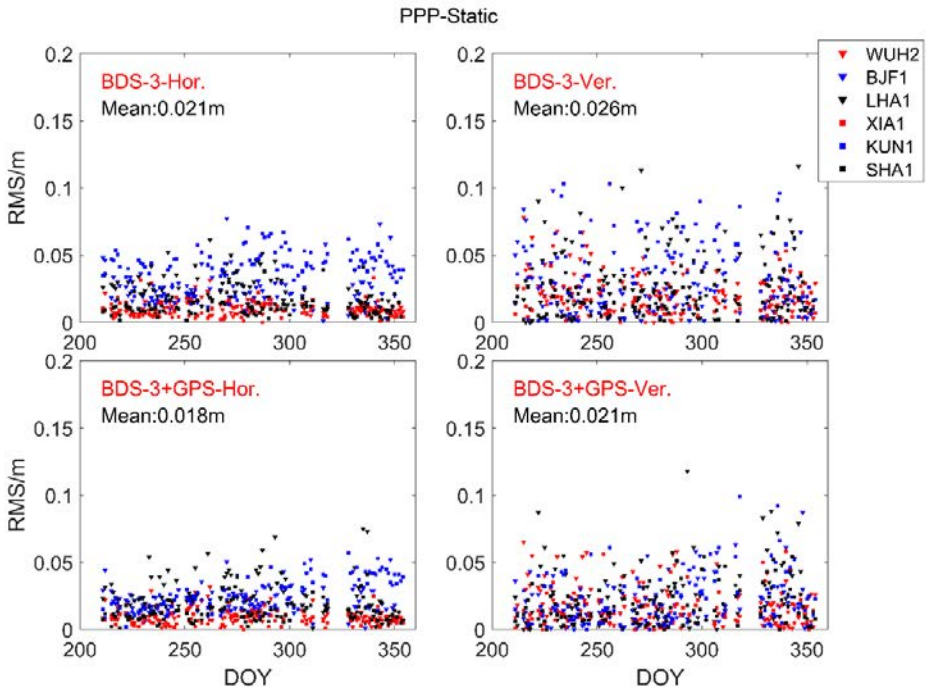
Station: 1 MGEX station + 5 IGMAS stations

Observations	Ionosphere-free combination of L1/L2 for GPS and B1I/B3I for BDS-3
Sampling interval	30 s
Elevation cutoff	7 degree
Weighting strategy	Elevation-dependent: 1 for elevation (E) $>30°$, otherwise 2sin(E) A-priori sigma: 3 mm and 3 m for the phase and code observation Weight ratio is 1:1 for GPS and BDS-3 satellite
Satellite PCO/PCV	igs14.atx
Receiver PCO/PCV	igs14.atx for GPS observations, use GPS values for BDS-3 observations
Phase wind-up effect	Corrected
Tide model	Solid tide; Polar tide; Ocean tide; IERS Conventions, 2010
Tropospheric model	ZHD corrected by GPT and Saastamoinen model
Mapping Function	GMF
Satellite orbit and clocks	Fix to PPP-B2b products
Receiver position	Static mode: daily constants Kinematic mode: epoch-wise parameter without constrains between epochs
ZWD	Random walk with constrains of 1.5 mm/$\sqrt{h}$
Receiver clock	White noise
Ambiguity	Float

Performance assessment

☐ Static Mode

- Reference: post-processing mode result with GBM product



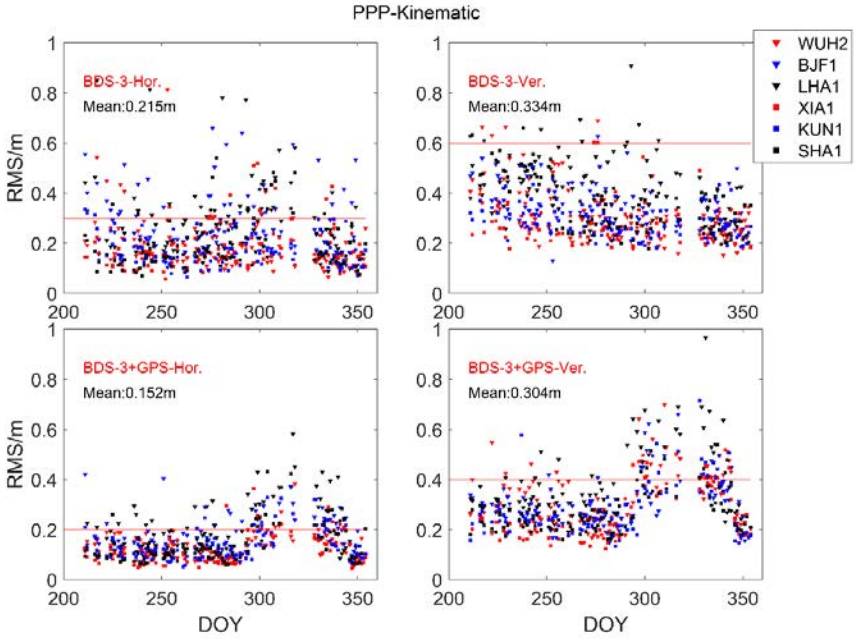
Stations	BDS-only		GPS+BDS	
	Hor. (cm)	Ver. (cm)	Hor. (cm)	Ver. (cm)
BJF1	1.1	2.4	1.1	2.2
LHA1	2.5	2.3	2.2	2.0
KUN1	2.5	3.1	2.7	2.7
WHU2	9	1.6	8	1.4
SHA1	4.2	4.0	2.6	2.4
XIA1	1.3	2.0	1.4	1.8
Mean	**2.1**	**2.6**	**1.8**	**2.1**

Hor. and Ver. RMS of BDS-only: 2.1 and 2.6 cm
Hor. and Ver. RMS of BDS+GPS: 1.8 and 2.1 cm

Performance assessment

☐ Kinematic Mode(accuracy)

- Reference: the static mode result with GBM products
- Convergence time: BDS-only (H: 0.3m, V: 0.6m); BDS+GPS (H: 0.2m, V:0.4m) for at least 10 minutes
- Accuracy indicator: 95% confidence



Stations	BDS-only (95%)		GPS+BDS (95%)	
	Hor. (cm)	Ver. (cm)	Hor. (cm)	Ver. (cm)
BJF1	27.4	34.2	17.6	32
LHA1	27.7	41.9	23	37.8
KUN1	17.0	29.0	13.9	28.6
WHU2	18.5	31.5	13.5	32.7
SHA1	19.8	35.6	14.2	27.2
XIA1	18.8	28.0	11.7	25.5
Mean	**21.5**	**33.4**	**15.2**	**33**

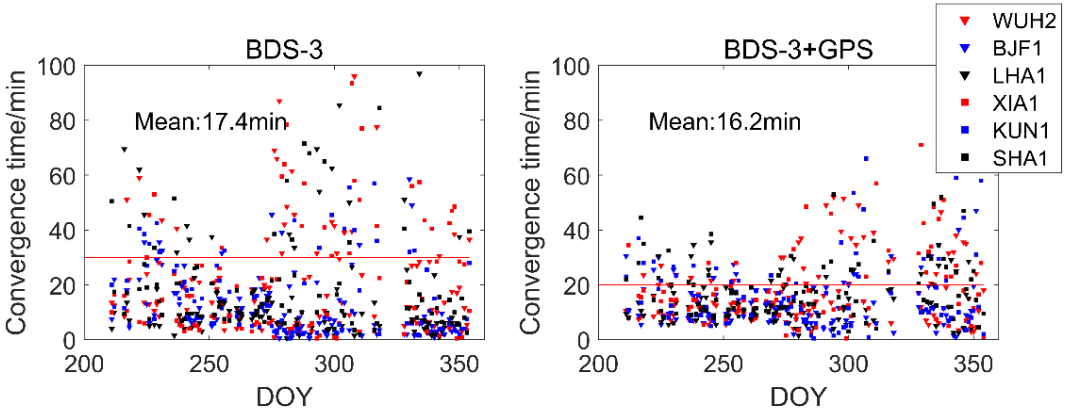
Hor. and Ver. RMS of BDS-only: 22 and 33 cm

Hor. and Ver. RMS of BDS+GPS: 15 and 33 cm

Performance assessment

☐ Kinematic Mode(convergency time)

- Reference: the static mode result with GBM products
- Convergence time: BDS-only (H: 0.3m, V: 0.6m); BDS+GPS (H: 0.2m, V:0.4m) for at least 10 minutes
- Accuracy indicator: 95% confidence



Convergency time result

Stations	Convergence time (min)	
	BDS	BDS+GPS
BJF1	12.2	13.2
LHA1	16.9	13.9
KUN1	14.5	15.9
WHU2	21.8	18.0
SHA1	19.3	18.3
XIA1	19.9	18.2
Mean	**17.4**	**16.2**

Convergency time of BDS-only: ~17 min

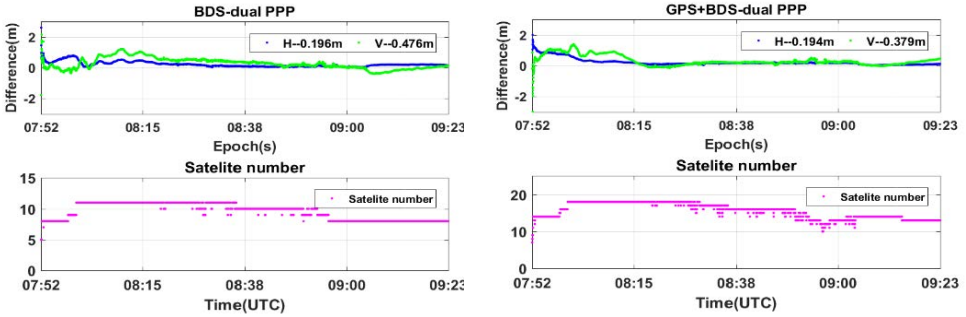
Convergency time of BDS+GPS: ~16 min

Performance assessment

☐ Kinematic mode for vehicle experiment

- Reference: RTK
- Convergence time: BDS-only (H: 0.3m, V: 0.6m); BDS+GPS (H: 0.2m, V:0.4m) for at least 10 minutes
- Accuracy indicator: 95% confidence

Vehicle test scenario



BDS-only (left) and BDS+GPS (right) kinematic PPP results for test

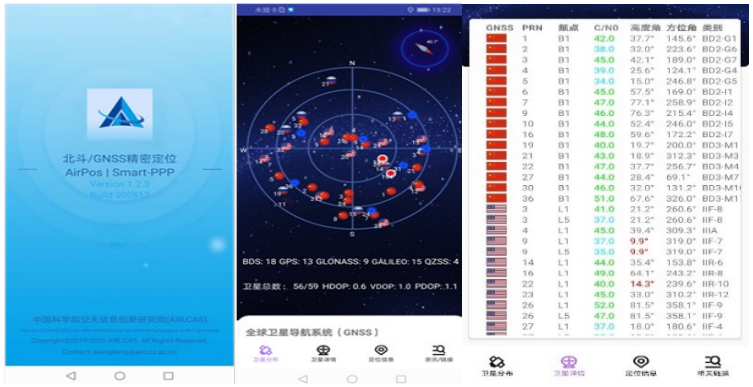
	BDS	BDS+GPS
Hor. (cm)	19.6	19.4
Ver. (cm)	47.6	37.9
Con. (min)	27.1	19.9

The positioning accuracy and convergence time are in accordance with the claim of convergence time in the performance specifications for BDS-3 open service.

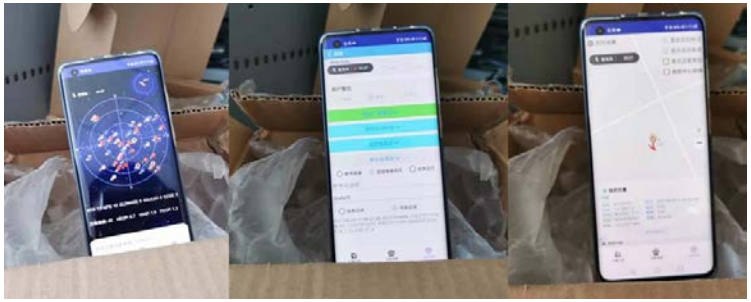
Performance assessment

☐ Smart terminal positioning test

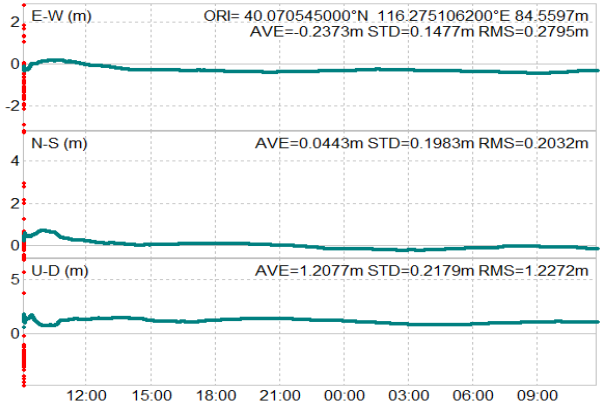
Smart terminal PPP-B2b positioning software



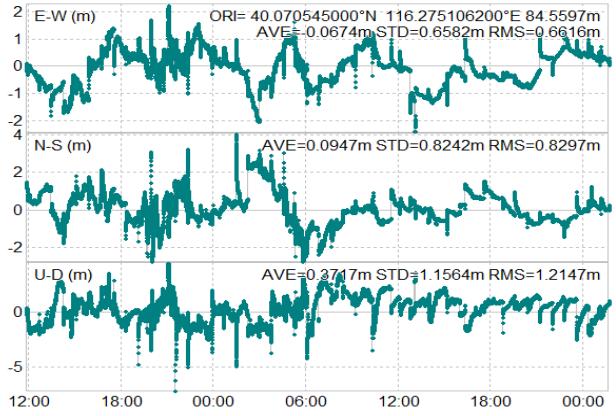
Smart terminal



Static mode



Kinematic mode



Performance Analysis (**Single Frequency**)

Type	E(m)	N(m)	U(m)
Static	0.28	0.20	1.22
Kinematic	0.66	0.83	1.21

Smart terminal single-frequency PPP: ~1m

Contents

Conclusions

- **EAR**

  better than 80% and maximum is up to 95%

- **Orbit Accuracy**

  RMS: decimeter level

- **Clock Accuracy**

  RMS: nanosecond level

  STD: better than 0.3 ns

- **SISRE Accuracy**

  RMS: decimeter and meter level

  STD: better than 7 cm

- **PPP Accuracy**

  static centimeter-level and kinematic decimeter-level

Prospects

The test results of BDS PPP-B2b service achieve the proposed service accuracy in the BDS Open Service Performance Standard.

- Service optimization: more global navigation system, wider service area, better accuracy and convergence time.

- More application: Expanding from professional field to mass consumption field.

Thank you !