16th Meeting of the International Committee on
Global Navigation Satellite Systems

BeiDou Coordinate System(BDCS) Status and Precise Transfer

Shanshi ZHOU[1] Li LIU[2] Junyi XU[2] Weijing Qu[1] Haifeng ZHANG[1] Yufei YANG[2]
XiaogongHU[1] Fengyu XIA[1]

1. Shanghai Astronomical Observatory, Chinese Academy of Sciences
2. Beijing Satellite Navigation Center

2022-10-11

CONTENTS

BDCS STATUS

REALIZATION AND MAINTENANCE

01

BDCS Definition

Definition:

Origin: the center of mass for the whole earth, including oceans and atmosphere.

Scale: the unit of length is meter (SI). the scale is consistent with the TCG time coordinate.

Orientation: conform to the recommendation of BIH.

Time evolution: no-net-rotation with regards to horizontal tectonic motions overthe whole earth.

BDCS ellipsoid parameters

Semi-major axis	a = 6378137.0m
Flattening	f = 1:298.257222101
Geocentric gravitational constant	GM= $3986004.418\times10^{8}m^{3}s^{-2}$
Earth's angular velocity	$\omega=7292115.0\times10^{-11}rad\ s^{-1}$

BDCS First Realization

- **Strategy:** four joint campaigns with IGS stations. Coordinates of monitor stations are aligned to ITRF2014 over a set of IGS stations.
  - ✓ 1st: in 2007 ~2009, one station observed after another.
  - ✓ 2nd: in December 2011, the joint campaign , 15 days.
  - ✓ 3rd: in April 2014, the joint campaign, 15 days.
  - ✓ 4th: in 2016, regional joint survey.
- **Result:** The first realization of BDCS is aligned to ITRF2014, and the accuracy of the coordinates is better than 1 cm.

Ref: F. Wu, BeiDou Coordinate System And Its First Realization , ICG-13, 2018

BDCS Update

➢ **Strategy:**

✓ Continuous GNSS tracking measurements are used.

✓ Daily network solutions with loose constraints are obtained by estimating GNSS satellite orbital parameters and stations coordinates.

✓ BDCS is aligned to ITRF once a year by minimum constrain IGS station coordinates in ITRF2014.

➢ **Definition file:**

✓ BDCS(2019v01) definition file had been released.

BDCS Maintenance

➢ **Strategy:**

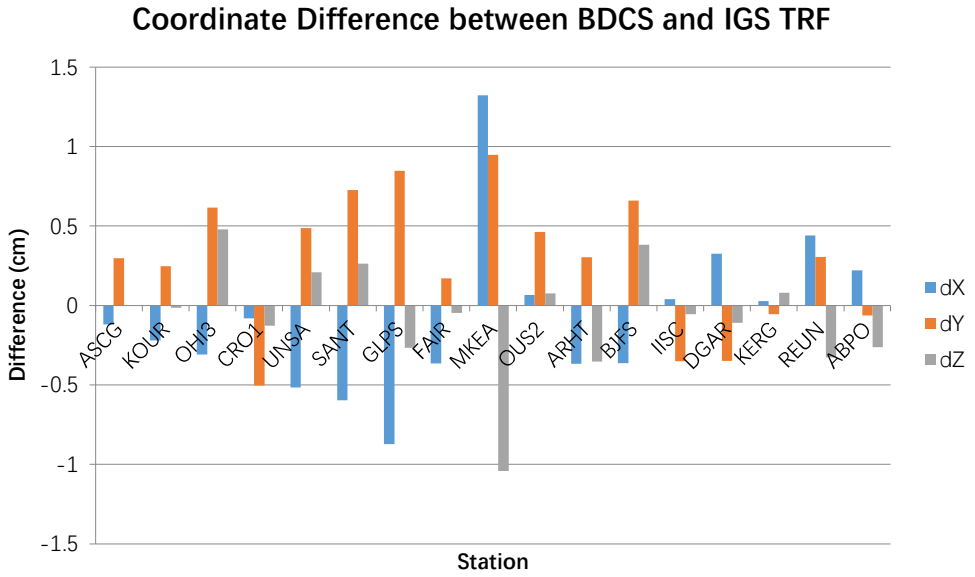
- ✓ Daily network solutions with loose constraints are obtained by estimating GNSS satellite orbital parameters and stations coordinates and then align to ITRF2014.
- ✓ Station coordinates will be updated when the difference between the estimated value and current used value exceeds the threshold (for example 3cm).
- ✓ BDCS accuracy is evaluated using IGS14(2188) products.

BDCS Maintenance

Accuracy Evaluation

Selected stations to evaluate the alignment accuracy

ASCG	KOUR	OHI3
CRO1	UNSA	SANT
FAIR	MKEA	OUS2
ARHT	BJFS	IISC
DGAR	KERG	REUN
ABPO		



Station coordinates difference is about several millimeters

	Trans_X mm	Trans_y mm	Trans_z mm	Rotate_x mas	Rotate_y mas	Rotate_z mas	Scal ppb
estimation	1.45	-2.97	0.23	-0.11	0.00	0.01	0.01
sigma	0.82	0.81	0.82	0.03	0.04	0.03	0.01

The alignment accuracy of BDCS to ITRF2014 is consistent with BDCS(2019V01)

The Role of SLR for BDS/GNSS

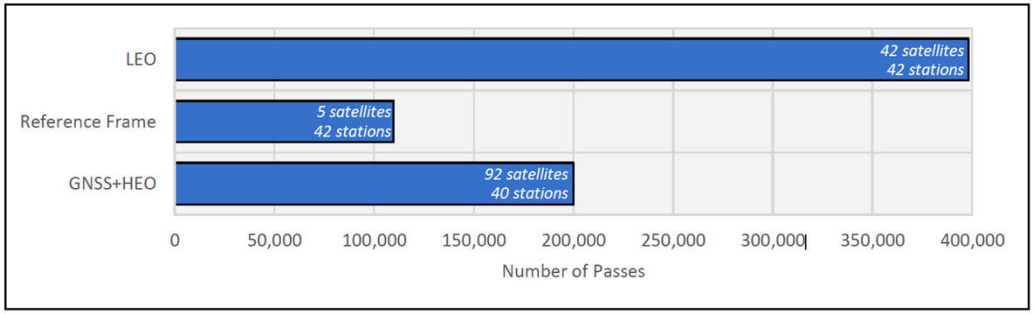
02

ORBITAL AND GEODETIC PARAMETERS ACCURACY IMPROVEMENT

SLR tracking of GNSS by ILRS

Constellation	Satellites
GLONASS	23
Galileo	28
BDS	9 (BDS-3 4)
QZSS	4
IRNSS	7
GPS	2

Satellite support by stations in the ILRS network in 2016-2019



Ref: C. Noll and M. Pearlman, ILRS 2016-2019 report, 2020

ILRS tracking network provides less BDS-3 measurements than other GNSS constellations

The Role of SLR for BDS/GNSS

- Determine and evaluate the accuracy of BDS/GNSS orbit
- Improve GNSS satellite Solar Radiation Pressure (SRP) Models
- Monitor and estimate GNSS satellite antenna offsets (Phase Center offsets (PCOs))
- Improve geodetic products by decreasing the correlation of geocenter coordinates and orbit parameters.

Both GNSS operators and geodetic studies would benefit from SLR tracking data!

SLR used for BDS-3 orbit determination

Initial result of orbit determination using SLR and ISL data

BDS-3 Observations

PRN	Type	SLR data	ISL data
C20	MEO	YES	YES
C29	MEO	YES	YES
C30	MEO	YES	YES
C21	MEO	YES	YES
C22	MEO	NO	YES
C28	MEO	NO	YES
C45	MEO	NO	YES
C46	MEO	NO	YES
C59	GEO	NO	YES
C39	IGSO	NO	YES
C40	IGSO	NO	YES

SLR Normal Points(NPs) quantity in 3-day arc

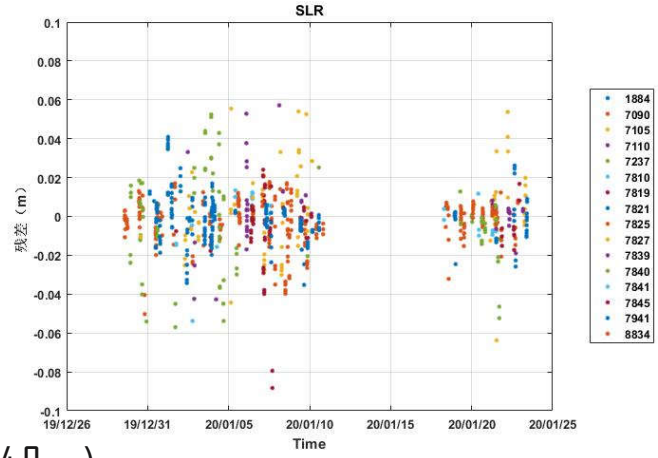
Arc No.	Time period	SLR NPs	SLR stations
1	2019/12/29 12:00 - 2020/01/01 12:00	119	7
2	2020/01/01 00:00 - 2020/01/04 00:00	110	9
3	2020/01/03 12:00 - 2020/01/06 12:00	124	9
4	2020/01/06 00:00 - 2020/01/09 00:00	158	10
5	2020/01/08 12:00 - 2020/01/11 12:00	106	9
6	2020/01/18 00:00 - 2020/01/21 00:00	72	9
7	2020/01/20 12:00 - 2020/01/23 12:00	125	13

Very limited satellite-to-ground measurements are used

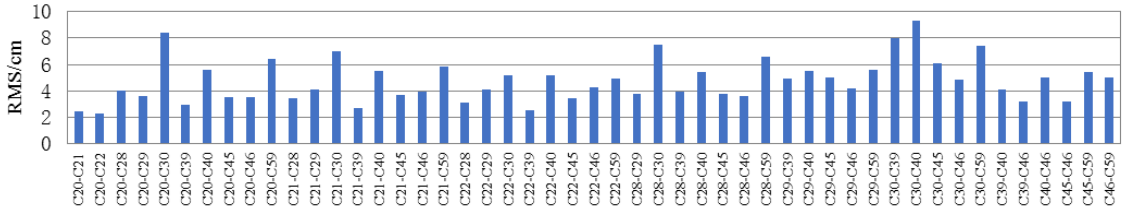
SLR used for BDS-3 orbit determination

Initial result of orbit determination using SLR and ISL data

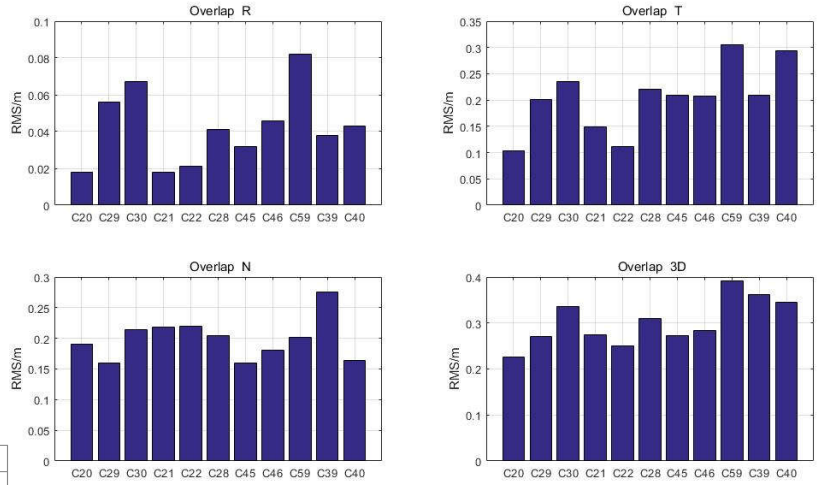
SLR Residuals (RMS=1.3cm)



ISL Residuals(RMS=4.8cm)



Orbit overlap Accuracy

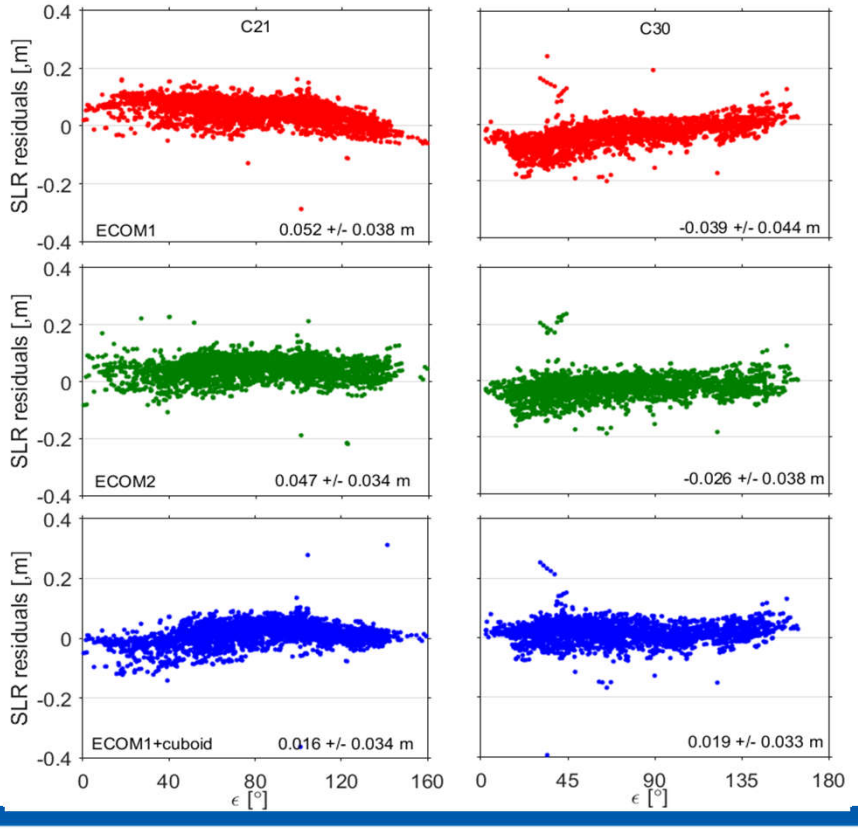


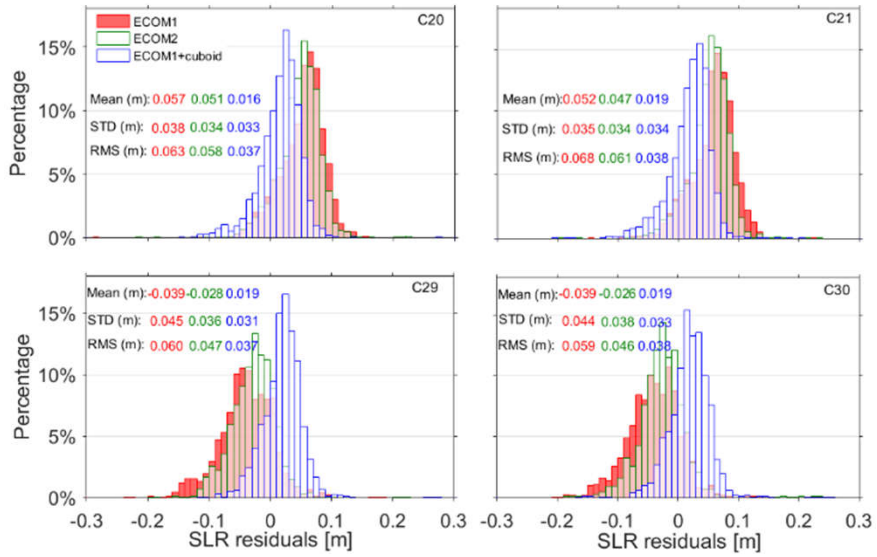
12-hour overlap accuracy is about 4/30cm in R/3D direction

Decimeter level accuracy of satellite orbit can be obtained using very limited SLR data.

SLR used for BDS-3 SRP Models Improvement

Refine the Solar Radiation Pressure(SRP) for BDS-3 satellites





- ✓ Compared with ECOM1 and ECOM2, SLR residuals decreased by 50% using enhanced ECOM1 model.
- ✓ SLR data is used to validate the SRP Models

Geodetic Parameters Estimation using BDS-3

TRF scale using BDS-3

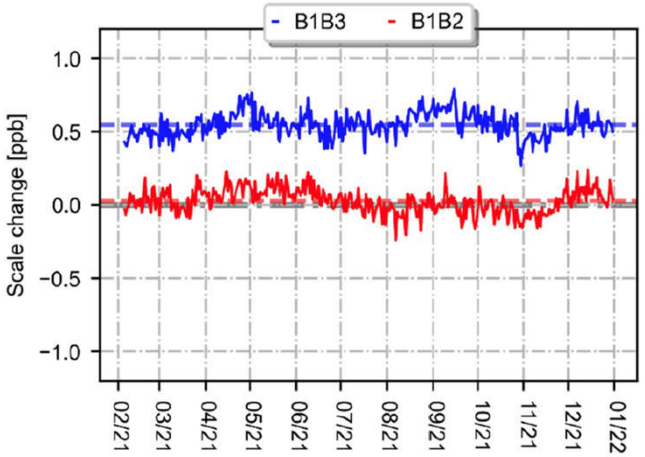
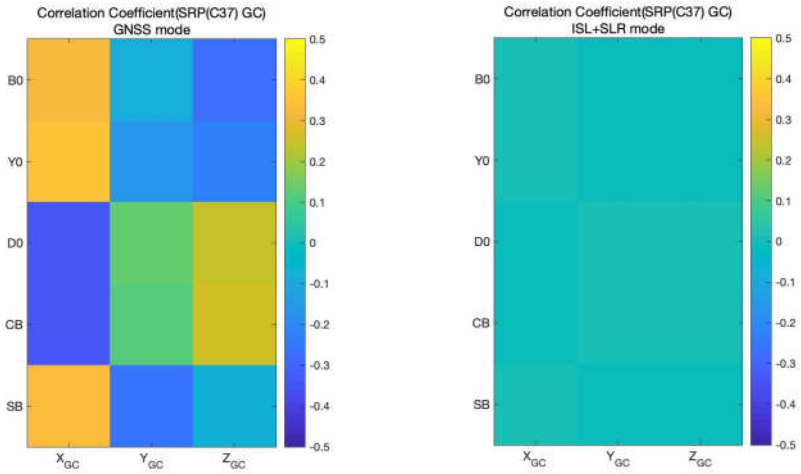


Fig. 10 Time series of the TRF scale change between the solutions with the scale defined by the IGS14-based GPS PCO and the BDS-3 PCO scale based on the CSNO calibration

Ref:R. Zajdel, P. Steigenberger, O. Montenbruck, On the potential contribution of BeiDou-3 to the realization of the terrestrial reference frame scale, GPS Solutions (2022)26:109

Geocenter motion estimate using BDS-3



Advantages of BDS-3:

- Due to the high-accuracy of satellite pre-launch PCO calibration, BDS -3 has great potential contribution to the realization of the ITRF scale and determine scale-independent other GNSS satellite PCOs.
- ISL+SLR technology co-location onboard BDS-3 realize a 'no satellite clock offset' space geodetic system, which will undoubtedly significantly improve the accuracy of geocenter estimation.

SLR Tracking Applications

From: 张海峰 <hfzhang@shao.ac.cn>
Date: Wednesday, September 21, 2022 at 5:25 AM
To: Claudia Carabajal <claudia.c.carabajal@nasa.gov>
Cc: "lujun@beidou.gov.cn" <lujun@beidou.gov.cn>, zzp <zzp@shao.ac.cn>
Subject: [EXTERNAL] MRS of BDS-3 MEO satellites tracked by ILRS

Dear Claudia,

According to the experiences and applications from the existed 9 Beidou satellites tracked by ILRS stations and in order to further enhance the international cooperation of BDS-3, China Satellite Navigation Engineering Center (CSNEC) has decided to the application of BDS-3 remaining 20 MEO satellites to ILRS. Meanwhile the chair of the IGS Muti-GNSS project (MGEX), Oliver Montenbruck, also hopes to perform the laser tracking to BDS-3 MEO satellites by ILRS network. When BDS-3 satellites are added to ILRS track campaign, the investigations of international GNSS systems will be abundantly actualized and helpful for improving the orbit model of navigation satellites, performances of GNSS systems and so on.

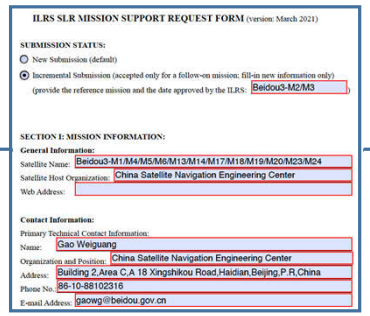
CSNEC has authorized Shanghai Astronomical of Observatory (SHAO) to apply for BDS-3 MEO satellites to ILRS. According to the types and manufacturers of LRAs on the satellites, two kinds of BDS-3 MEO satellites are separated and two MSRs are also provided with the attachments ("ilrsmsr_202103_Beidou3-M1M4M5M6M13M14M17M18M19M20M23M24.pdf" and "ilrsmsr_202103_Beidou3-M7M8M11M12M15M16M21M22.pdf"). The CPF files are also provided by SHAO.

Please deliver this MSR to MSC and ILRS GB and discuss about this application.

Thank you.

Best regards

Zhang Haifeng

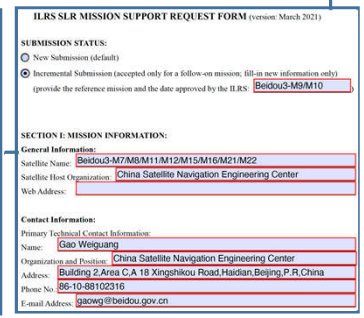


ILRS SLR MISSION SUPPORT REQUEST FORM (version: March 2021)

SUBMISSION STATUS:
New Submission (default)
Incremental Submission (accepted only for a follow-on mission; fill-in new information only)
(provide the reference mission and the date approved by the ILRS: Beidou3-M2/M3)

SECTION I: MISSION INFORMATION:
General Information:
Satellite Name: Beidou3-M1/M4/M5/M6/M13/M14/M17/M18/M19/M20/M23/M24
Satellite Host Organization: China Satellite Navigation Engineering Center
Web Address:

Contact Information:
Primary Technical Contact Information:
Name: Gao Weiguang
Organization and Position: China Satellite Navigation Engineering Center
Address: Building 2,Area C,A 18 Xingshikou Road,Haidian,Beijing,P.R,China
Phone No: 86-10-88102316
E-mail Address: gaowg@beidou.gov.cn



ILRS SLR MISSION SUPPORT REQUEST FORM (version: March 2021)

SUBMISSION STATUS:
New Submission (default)
Incremental Submission (accepted only for a follow-on mission; fill-in new information only)
(provide the reference mission and the date approved by the ILRS: Beidou3-M9/M10)

SECTION I: MISSION INFORMATION:
General Information:
Satellite Name: Beidou3-M7/M8/M11/M12/M15/M16/M21/M22
Satellite Host Organization: China Satellite Navigation Engineering Center
Web Address:

Contact Information:
Primary Technical Contact Information:
Name: Gao Weiguang
Organization and Position: China Satellite Navigation Engineering Center
Address: Building 2,Area C,A 18 Xingshikou Road,Haidian,Beijing,P.R,China
Phone No: 86-10-88102316
E-mail Address: gaowg@beidou.gov.cn

- The SLR MISSION SUPPORT REQUEST (MSRs) for all BDS-3 MEOs have been submitted to ILRS Governing Board(GB) by SHAO on behalf of China Satellite Navigation Engineering Center(CSNEC).
- These applications had been received by GB.
- BDS-3 MEOs orbit predictions for SLR tracking will be provided regularly on website.

SLR Retroreflector Information

关于发布北斗卫星有关参数的公告

来源：北斗网　　发布时间：2019-12-30

为促进北斗系统的高精度应用，现将批准的北斗卫星有关参数予以发布（内容附后）。

文件中所有参数由北斗卫星制造厂家提供，参数的具体定义、描述和文件格式说明可参考北斗专项标准《北斗/全球卫星导航系统（GNSS）卫星高精度应用参数定义及描述》。

特此公告。

中国卫星导航系统管理办公室

二〇一九年十二月三十日

附件：

1、北斗卫星天线相位中心文件

2、北斗卫星参数文件

表 B. 3　卫星信息文件数据部分格式

卫星信息文件数据部分格式		
字段名称	描述	格式（FORTRAN）（默认：右对齐）
+SATEINFO	-卫星信息数据记录部分开始	9X
SYSTEM	-系统标识	A1,1X
SVN	-SVN 号	I4,1X
COSPAR-ID	-COSPAR-ID	I4,A1,I3,A1,1X
PRN	-PRN 号	A1,I2,1X
LAUNCHED	-PRN 号启用时间	I7,A1,I5,1X
DECOMMISSIONED	-PRN 号结束时间	I7,A1,I5,1X
SAT MASS	-卫星质量	F6.2,1X
SAT TYPE	-卫星类型	A15,1X
SAT RETROREFLECTOR	-卫星角反射器位置参数(星体坐标系)	
	X	F11.6,1X
	Y	F11.6,1X
	Z	F11.6,1X
-SATEINFO	-卫星信息数据记录部分结束	9X

INFO-BDSsatellite-20200311更新.info.txt

```
     1.0           C                                   CSNO VERSION / TYPE / AGENCY
BDS SateInfo      BDST              2019-11-06        PGM / TIME SYSTEM /DATE
The satellite information file contains satellite mass,type,COMMENT
position of retroreflector, satellite effective surface     COMMENT
area, satellite structual material, absorption coefficient, COMMENT
specular reflection coefficient, diffuse reflection         COMMENT
coefficient,etc.                                            COMMENT
The satellite information are provided by satellite         COMMENT
manufacturers.                                              COMMENT
                                                            END OF HEADER

+SATEINFO
C C003 2010-001A C01 2010016:00000 0000000:00000 1382.00  BEIDOU-2G-CAST  -0.624100   -0.570500    1.100000
C C016 2012-059A C02 2012299:00000 0000000:00000 1551.00  BEIDOU-2G-CAST  -0.606500   -0.570200    1.100000
C C018 2016-037A C03 2016164:00000 0000000:00000 1486.00  BEIDOU-2G-CAST  -0.614600   -0.570100    1.100100
C C006 2010-057A C04 2010304:00000 0000000:00000 1536.00  BEIDOU-2G-CAST  -0.606900   -0.570200    1.100000
C C011 2012-008A C05 2012055:00000 0000000:00000 1502.00  BEIDOU-2G-CAST  -0.605800   -0.570300    1.100100
C C005 2010-036A C06 2010212:00000 0000000:00000 1284.00  BEIDOU-2I-CAST  -0.417300   -0.572900    1.100100
C C007 2010-068A C07 2010352:00000 0000000:00000 1284.00  BEIDOU-2I-CAST  -0.418500   -0.573000    1.100000
C C008 2011-013A C08 2011100:00000 0000000:00000 1284.00  BEIDOU-2I-CAST  -0.420300   -0.573500    1.100000
C C009 2011-038A C09 2011208:00000 0000000:00000 1284.00  BEIDOU-2I-CAST  -0.425800   -0.573500    1.099700
C C010 2011-073A C10 2011336:00000 0000000:00000 1278.00  BEIDOU-2I-CAST  -0.426700   -0.573200    1.099500
C C012 2012-018A C11 2012122:00000 0000000:00000 1193.00  BEIDOU-2M-CAST  -0.426400   -0.537900    1.100000
C C013 2012-018B C12 2012122:00000 0000000:00000 1176.00  BEIDOU-2M-CAST  -0.427100   -0.537900    1.100100
C C015 2012-050B C14 2012262:00000 0000000:00000 1184.00  BEIDOU-2M-CAST  -0.430200   -0.538200    1.099800
C C017 2016-021A C13 2016089:00000 0000000:00000 1283.00  BEIDOU-2I-CAST  -0.421500   -0.572600    1.100000
C C019 2018-057A C16 2018191:00000 0000000:00000 1272.00  BEIDOU-2I-CAST  -0.405600   -0.573500    1.100000
C C020 2019-027A C18 2019137:00000 0000000:00000 1500.00  BEIDOU-2G-CAST  -0.629400   -0.570200    1.099900
C C201 2017-069A C19 2017309:00000 0000000:00000 0943.00  BEIDOU-3M-CAST   0.593300   -0.086960    1.260040
C C202 2017-069B C20 2017309:00000 0000000:00000 0942.00  BEIDOU-3M-CAST   0.594700   -0.084560    1.264440
C C206 2018-018B C21 2018043:00000 0000000:00000 0942.00  BEIDOU-3M-CAST   0.598600   -0.086560    1.265040
C C205 2018-018A C22 2018043:00000 0000000:00000 0941.00  BEIDOU-3M-CAST   0.596700   -0.087560    1.267340
C C209 2018-062A C23 2018210:00000 0000000:00000 0945.00  BEIDOU-3M-CAST   0.604500   -0.080860    1.271840
C C210 2018-062B C24 2018210:00000 0000000:00000 0946.00  BEIDOU-3M-CAST   0.605400   -0.082460    1.262840
C C212 2018-067B C25 2018236:00000 0000000:00000 1043.30  BEIDOU-3M-SECM   0.656600    0.428700    0.610000
C C211 2018-067A C26 2018236:00000 0000000:00000 1041.80  BEIDOU-3M-SECM   0.655900    0.427900    0.609200
C C203 2018-003A C27 2018012:00000 0000000:00000 1018.00  BEIDOU-3M-SECM   0.609600    0.431570    0.620390
C C204 2018-003B C28 2018012:00000 0000000:00000 1014.40  BEIDOU-3M-SECM   0.608000    0.431120    0.608010
C C207 2018-029A C29 2018089:00000 0000000:00000 1010.40  BEIDOU-3M-SECM   0.609500    0.426000    0.614200
C C208 2018-029B C30 2018088:00000 0000000:00000 1008.60  BEIDOU-3M-SECM   0.609700    0.427300    0.615300
C C213 2018-072A C32 2018262:00000 0000000:00000 1007.00  BEIDOU-3M-CAST   0.628300   -0.086760    1.236740
C C214 2018-072B C33 2018262:00000 0000000:00000 1007.00  BEIDOU-3M-CAST   0.627600   -0.088160    1.229340
C C216 2018-078B C34 2018288:00000 0000000:00000 1046.60  BEIDOU-3M-SECM   0.672800    0.428200    0.611400
C C215 2018-078A C35 2018288:00000 0000000:00000 1045.00  BEIDOU-3M-SECM   0.672400    0.429100    0.609500
C C218 2018-093A C36 2018322:00000 0000000:00000 1061.00  BEIDOU-3M-CAST   0.613300   -0.089160    1.097740
C C219 2018-093B C37 2018322:00000 0000000:00000 1061.00  BEIDOU-3M-CAST   0.608200   -0.089860    1.093540
C C220 2019-023A C38 2019110:00000 0000000:00000 2952.00  BEIDOU-3I-CAST  -0.989260   -0.711820    1.972390
C C221 2019-035A C39 2019175:00000 0000000:00000 2949.00  BEIDOU-3I-CAST  -0.982410   -0.712660    1.927750
C C224 2019-073A C40 2019309:00000 0000000:00000 2870.00  BEIDOU-3I-CAST  -0.983400   -0.711500    1.952000
C C227 2019-090A C41 2019350:00000 0000000:00000 1059.00  BEIDOU-3M-CAST   0.610400   -0.090060    1.092440
C C228 2019-090B C42 2019350:00000 0000000:00000 1059.00  BEIDOU-3M-CAST   0.608400   -0.089260    1.092040
C C225 2019-078A C43 2019327:00000 0000000:00000 1078.80  BEIDOU-3M-SECM   0.633900    0.425000    0.609400
C C226 2019-078B C44 2019327:00000 0000000:00000 1075.40  BEIDOU-3M-SECM   0.634700    0.424800    0.608900
C C222 2019-061A C45 2019265:00000 0000000:00000 1059.00  BEIDOU-3M-CAST   0.529300   -0.086660    1.170740
C C223 2019-061B C46 2019265:00000 0000000:00000 1058.00  BEIDOU-3M-CAST   0.529500   -0.088160    1.163440
C C217 2018-085A C59 2018305:00000 0000000:00000 2968.00  BEIDOU-3G-CAST   0.589600   -0.084460    0.763740
-SATEINFO
```

http://www.beidou.gov.cn/yw/gfgg/201912/t20191209_19613.html

BDCS Precise Transfer

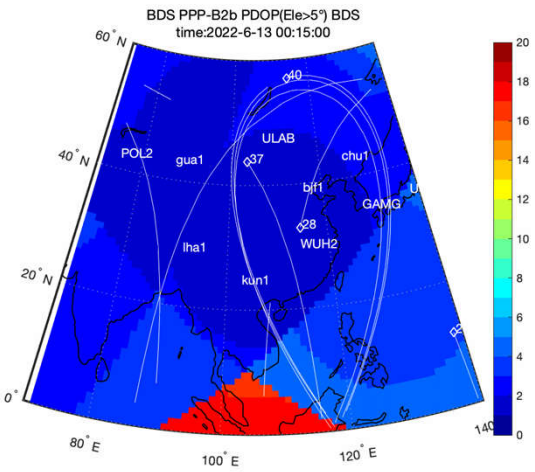
BDS PPP-B2b SERVICE AND SPATIAL TRANSFER ACCURACY

03

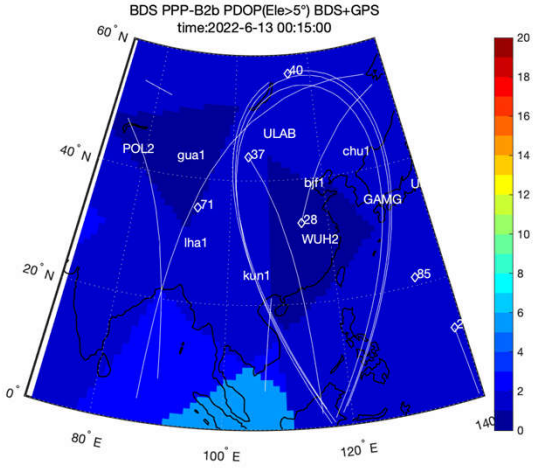
BDCS transferred by BDS PPP-B2b service

- BDCS provides spatial datum for BDS PPP-B2b service
- BDS PPP-B2b service transfers spatial datum precisely

PDOP(BDS Only)



PDOP (BDS+GPS)

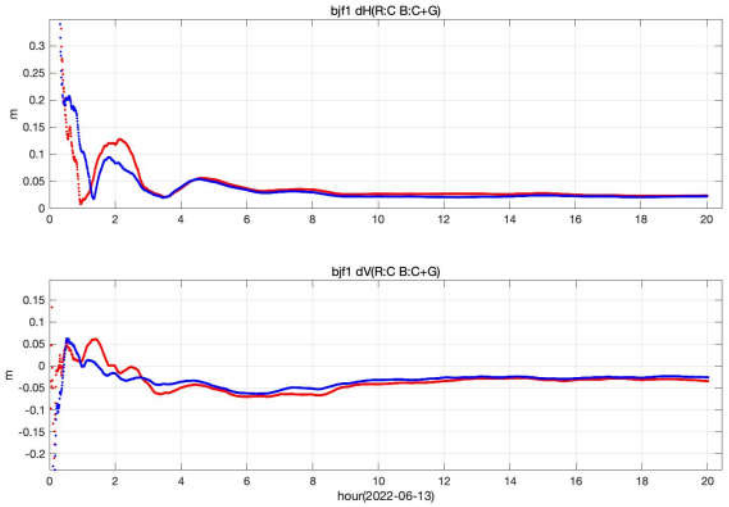


PPP-B2b PDOP is improved using dual-GNSS mode

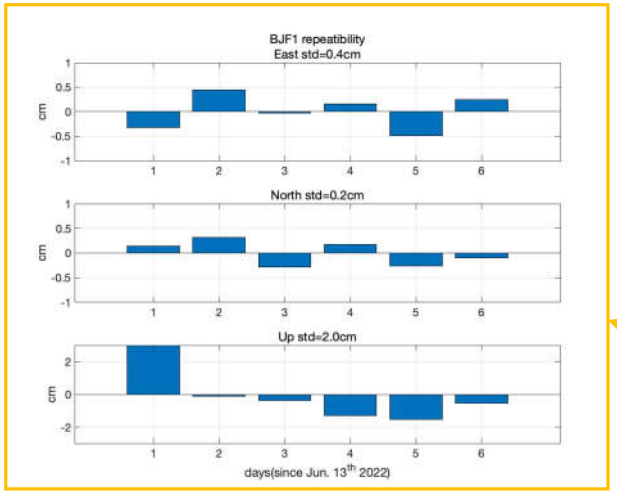
- **PPP Strategy :**
- Broadcast ephemeris: GPS+BDS
- BDS PPP-B2b messages(GPS+BDS orbit/clock/DCB corrections)
- BDS broadcast EOPs
- Receiver antenna PCO: IGS14.atx
- Dual-frequency ionospheric free combinations
- Estimations: coordinates, ZTD, phase ambiguities, receiver clock offsets

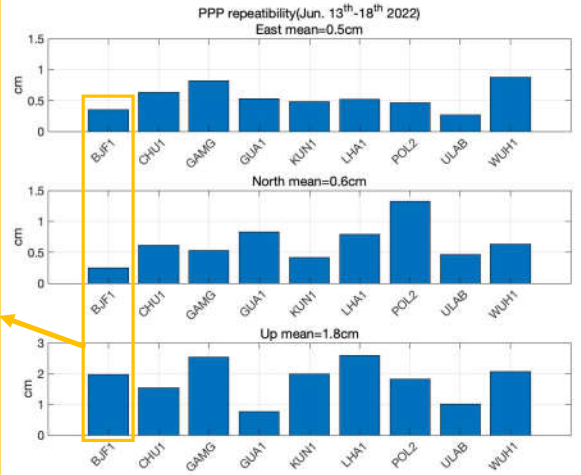
PPP-B2b Convergency and accuracy

Positioning time series using PPP-B2b
(Red: BDS only, Blue: BDS+GPS)



Repeatability(6-day) for static stations



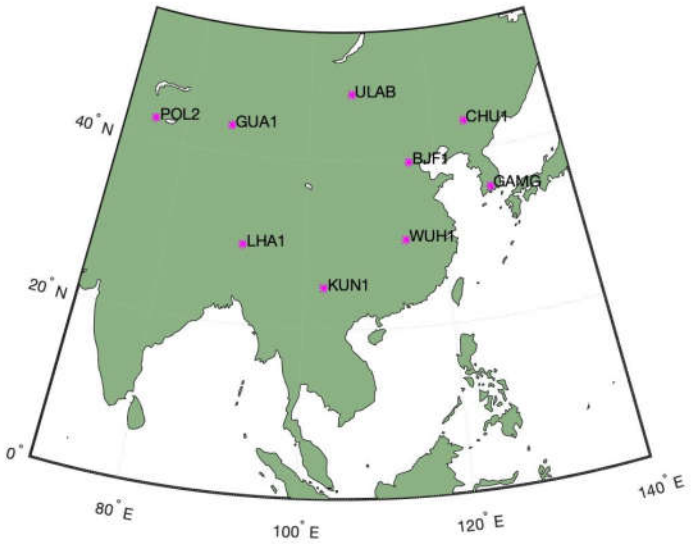


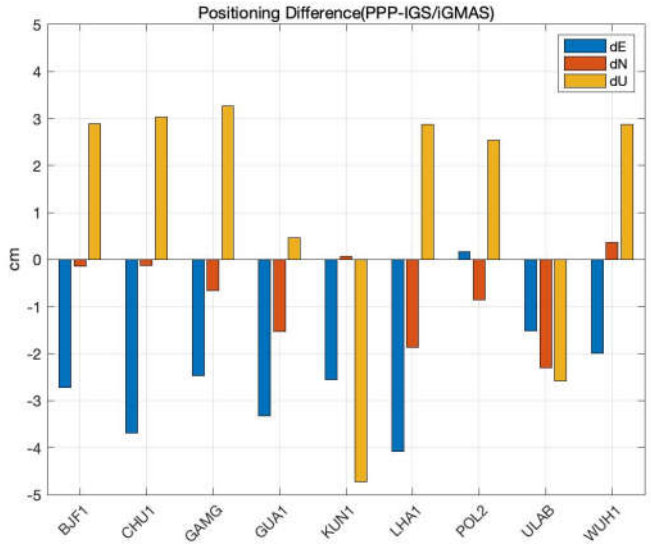
Dual-GNSS processing shortens positioning convergency time

For static stations, coordinates repeatability is better than 1/3cm in horizontal/vertical directions

PPP-B2b Spatial datum transfer

Coordinates comparison between PPP-B2b and IGS/iGMAS week solutions





	Trans_X cm	Trans_Y cm	Trans_Z cm	Rotate_X mas	Rotate_Y mas	Rotate_Z mas	Scal ppb
estimation	-1.7	-2.6	4.5	1.3	-0.4	2.1	-0.0
sigma	2.9	3.5	4.0	0.9	0.7	1.6	0.4

BDCS spatial datum is transferred to China and surrounding areas by PPP-B2b service at centimeter level

Summary

BDCS, SLR FOR GNSS, PPP-B2b SPATIAL TRANSFER

04

Summary

- BDCS is aligned to ITRF regularly. The accuracy is 1.45/-2.97/0.23mm for transition, -0.11/0.00/0.01mas for rotation, and 0.01ppb for scale parameters, which indicate that BDCS is aligned and maintained precisely.

- SLR tracking network provides data for GNSS system services and scientific research. Increasing the global SLR tracking for BDS-3 satellites will be helpful to identify and overcome the satellite orbit model defects, and ameliorate BDS service performance and the geodesy application.

- The BDCS provides BDS PPP-B2b service spatial datum with millimeter level, and the BDS PPP-B2b service transfers the BDCS spatial datum to China and surrounding areas users with centimeter level accuracy.

Thanks For Your Attention