Update on the BeiDou Coordinate System(BDCS)

14th Meeting of the International Committee on Global Navigation Satellite Systems

Li Liu[1], Junyi Xu[1], Shanshi Zhou[2], Fumei Wu[3]

1. Beijing Satellite Navigation Center, Beijing, China
2. Shanghai Astronomical Observatory, Academy China, Shanghai, China
3. Xi'an Research Institute of Surveying and Mapping, Xi'an, China

2019-12-10

CONTENT

01

BDCS Definition

I. Definition

- The definition of BDCS is in accordance with the specifications of the International Earth Rotation and Reference System Service (IERS), and it is consistent with the definition of the China Geodetic Coordinate System 2000 (CGCS2000). BDCS and CGCS2000 have the same ellipsoid parameters.

- **The definition of BDCS**:
  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 over the whole earth.

II. Ellipsoid

Defining parameters of the BDCS ellipsoid

Semi-major axis	**a = 6378137.0m**
Flattening	**f = 1:298.257222101**
Geocentric gravitational constant	**GM= 3986004.418×10^8m^{3}s^{-2}**
Earth's angular velocity	**ω=7292115.0×10^{-11}rad s^{-1}**

02

BDCS Realization and Update
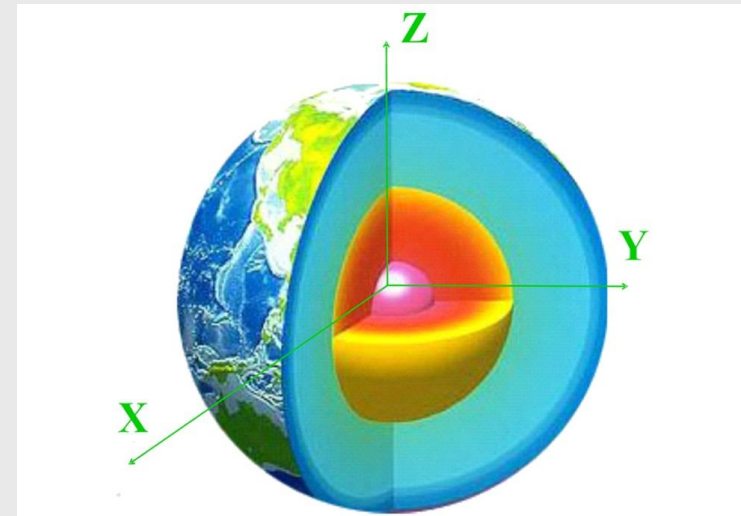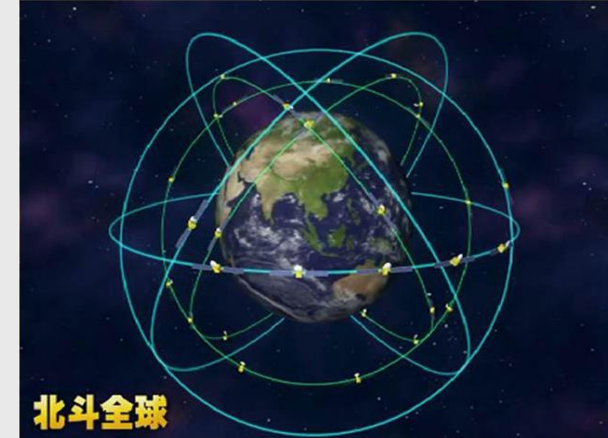
BDCS Realization and Update

I. BDS developments

BDS-1 established in 2003

BDS-2 established in 2012

BDS-3 will provide global service in 2020

II. First Realization of BDCS

- ➤ **Strategy**: four joint campaigns with IGS stations. Coordinates of monitor stations are aligned to ITRF2014 over a set of IGS stations.

  - ✓ The initial observation: in 2007 ~2009, one station after another.

  - ✓ The second observation: in December 2011, the joint campaign , 15 days.

  - ✓ The third observation: in April 2014, the joint campaign, 15 days.

  - ✓ The fourth observation: in 2016, regional joint survey.

- ➤ **Result**: The first realization of BDCS is aligned to ITRF2014, and the accuracy of the coordinates is superior to 1 cm.

III. Stations

➢ BDCS stations

By the end of 2018, BDS stations had been updated to track all BDS signals and other GNSS signals.

➢ IGS/MEGX stations

IGS stations are selected to align BDCS to ITRF2014 and estimate the transformation parameters.

IV. BDCS Update

- **Strategy:**
  - ✓ Continuous GNSS tracking data are used.
  - ✓ Daily network solutions with loose constrained are obtained by estimating GNSS satellite orbital parameters and stations coordinates.
  - ✓ Align to ITRF once a year by minimum constrain IGS station coordinates in ITRF2014.

- **Data:**
  - ✓ 2019.01.01-2019.03.31, more than 120 global stations, including IGS stations and BDS stations, were selected.

- **Definition file:**
  - ✓ A BDCS(2019v01) definition file had been released on BDS official website, and submitted to ICG-14

http://en.beidou.gov.cn/SYSTEMS/Officialdocument/

BeiDou Coordinate System

Responsible Organization:	China Satellite Navigation Office (CSNO)
Abbreviated Name:	BDCS
Associated TRS:	ITRS
Coverage of Frame:	Global
Type of Frame:	3-Dimensional
Latest Version:	2019V01

Brief Description

BDCS is an Earth-centered, Earth-fixed terrestrial reference system. The definition of BDCS is in accordance with the specifications of the International Earth Rotation and Reference System Service (IERS), and its realization is aligned to the latest International Terrestrial Reference System (ITRF). The BDCS (2019V01) is the current solution obtained by adopting more than 100 stations.

Definition of Frame

Origin: Earth's center of mass.

Axes:

Z-Axis: The direction of the IERS Reference Pole (IRP).

X-Axis: the intersection of the IERS Reference Meridian (IRM) and the plane passing through the origin and normal to the Z-Axis.

Y-Axis: together with Z-Axis and X-Axis, constitutes a right-handed orthogonal coordinate system.

Scale: The length unit is the international system of units (SI) meter.

Orientation: Given by the Bureau International de l'Heure (BIH) orientation of 1984.0.

Time Evolution: Its time evolution in orientation will create no residual global rotation with regards to the crust.

Coordinate System: Cartesian Coordinates (X, Y, Z).

Defining Parameters: The geometric center of the BDCS Ellipsoid coincides with the Earth's center of mass, and the rotation axis of the BDCS Ellipsoid is the Z-Axis. The parameters of the BDCS Ellipsoid are shown as follows:

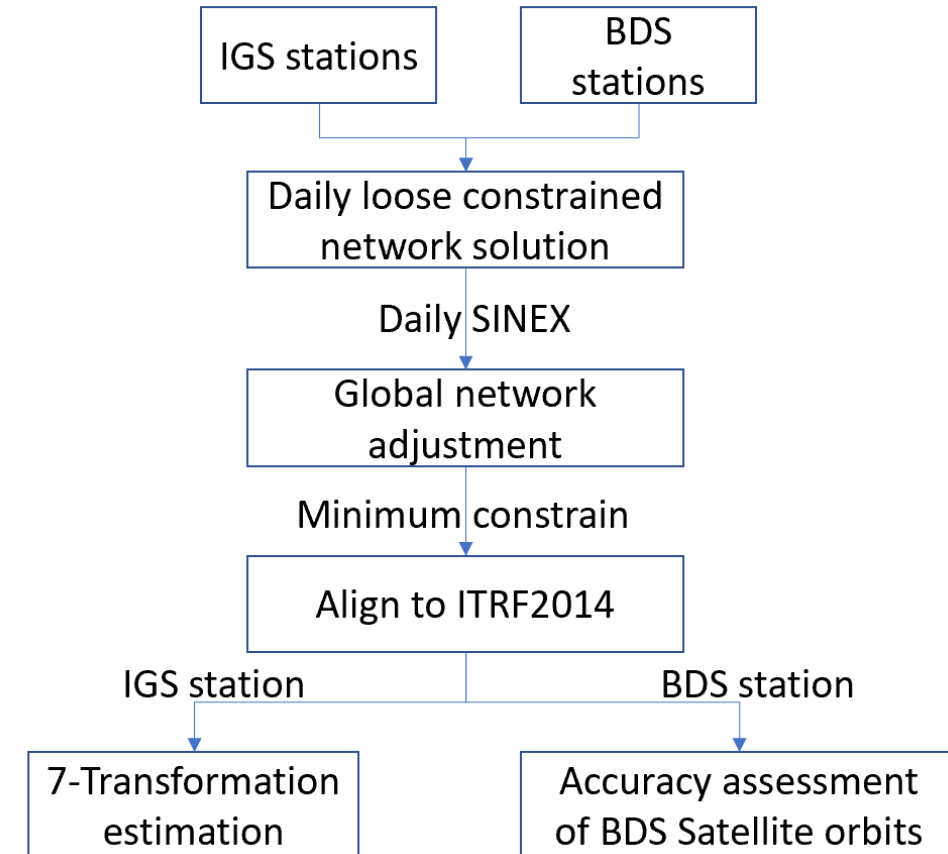| Semi-major axis	a= 6378137.0 m
Geocentric gravitational constant(including the atmosphere)	$\mu=3.986004418\times10^{14}\,m^3/s^2$
Flattening	f=1/298.257222101
Earth's rotation rate	$\dot{\Omega}_e = 7.2921150 \times 10^{-5}$ rad/s

Transformation Parameters:

Transformation parameters from BDCS(2019V01) to ITRF2014.

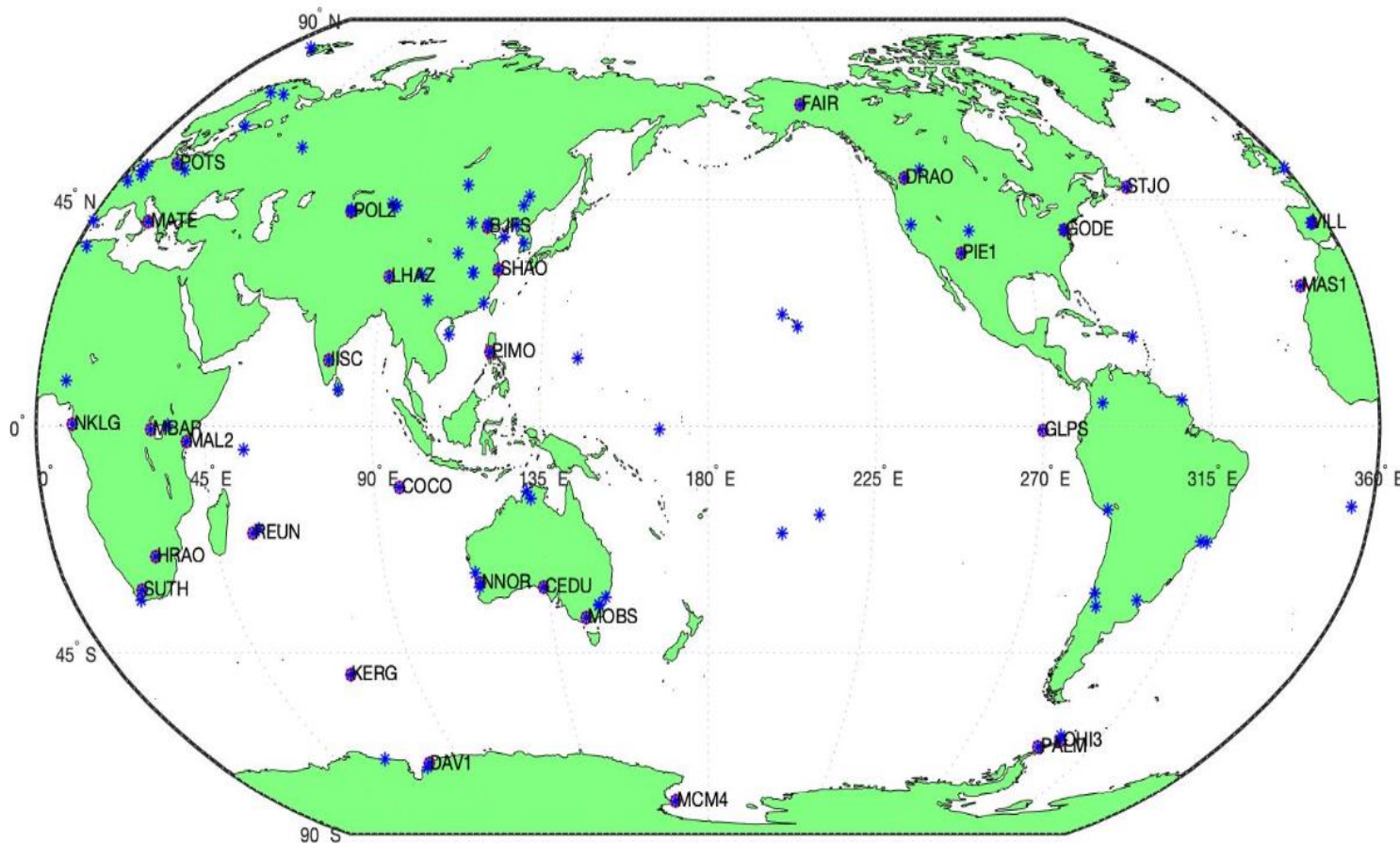|	Tx (mm)	Ty (mm)	Tz (mm)	Rx (mas)	Ry (mas)	Rz (mas)	Scal (ppb)
Estimation	-0.37	1.12	-0.55	0.01	-0.02	0.05	0.011
STD	0.74	0.74	0.74	0.03	0.03	0.04	0.012

➢ Obs.: pseudo-range and carrier phase ionospheric-free combinations

➢ Estimations:
  ➢ satellite orbital parameters
  ➢ ECOM-9 solar radiation pressure
  ➢ station coordinates
  ➢ zenith time delay
  ➢ phase ambiguity
  ➢ satellite and station clock offsets

➢ Alignment: minimum constrain 31 IGS station coordinates in ITRF2014

IGS stations

BDS stations

Daily loose constrained network solution

Daily SINEX

Global network adjustment

Minimum constrain

Align to ITRF2014

IGS station

BDS station

7-Transformation estimation

Accuracy assessment of BDS Satellite orbits

BDCS Realization and Update

BDS and IGS stations

net solution stations

Stations with minimum constraints

VILL	MOBS	POL2
MAS1	CEDU	KERG
STJO	SHAO	REUN
OHI3	PIMO	MAL2
PALM	NNOR	MBAR
GODE	BJFS	HRAO
GLPS	COCO	SUTH
PIE1	LHAZ	MATE
DRAO	DAV1	POTS
FAIR	IISC	NKLG
MCM4		

03

Accuracy Evaluation

➢ **Transformation parameters:**

1. Precise coordinate method: Comparing IGS station coordinates estimated in BDCS with that of ITRF2014.
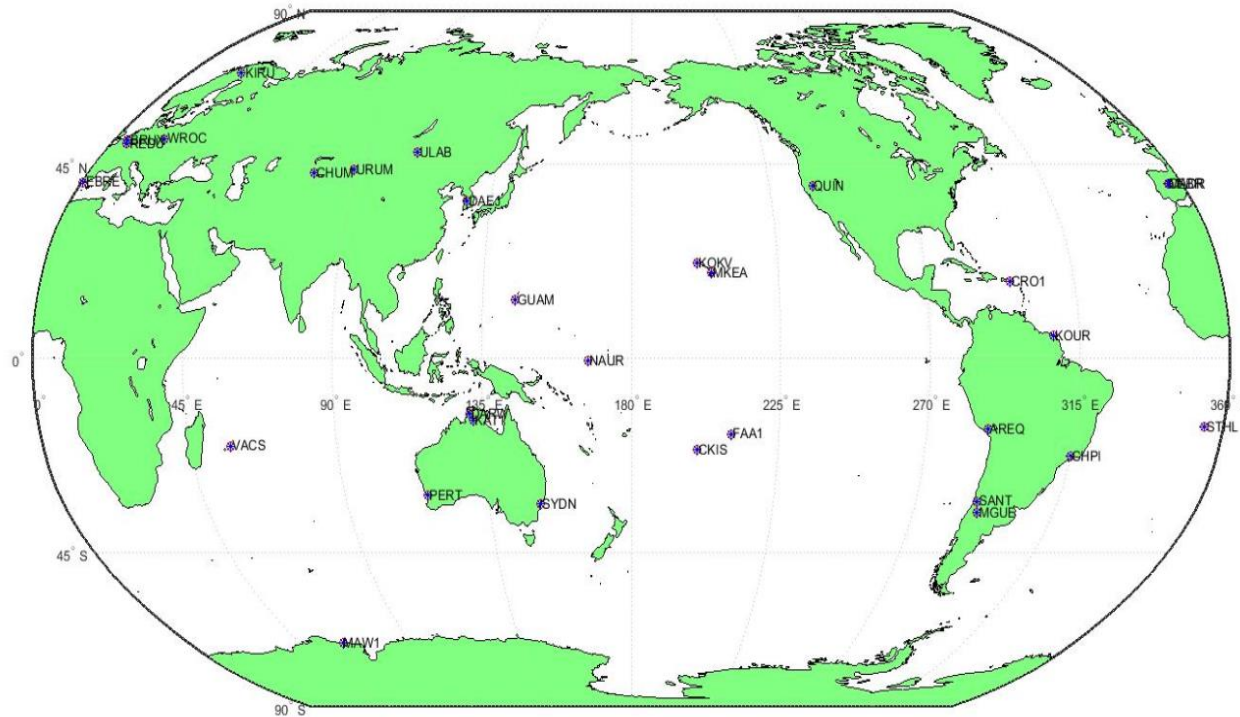
2. SLR method: Comparing SLR station coordinates obtained by using SLR data and BDS broadcast ephemeris with that of ITRF2014

3. BDS observation method: Comparing IGS station coordinates obtained by using BDS observations and broadcast ephemeris with that of ITRF2014.

(1). Precise coordinate method

Selected stations to evaluate the alignment accuracy

Selected Stations

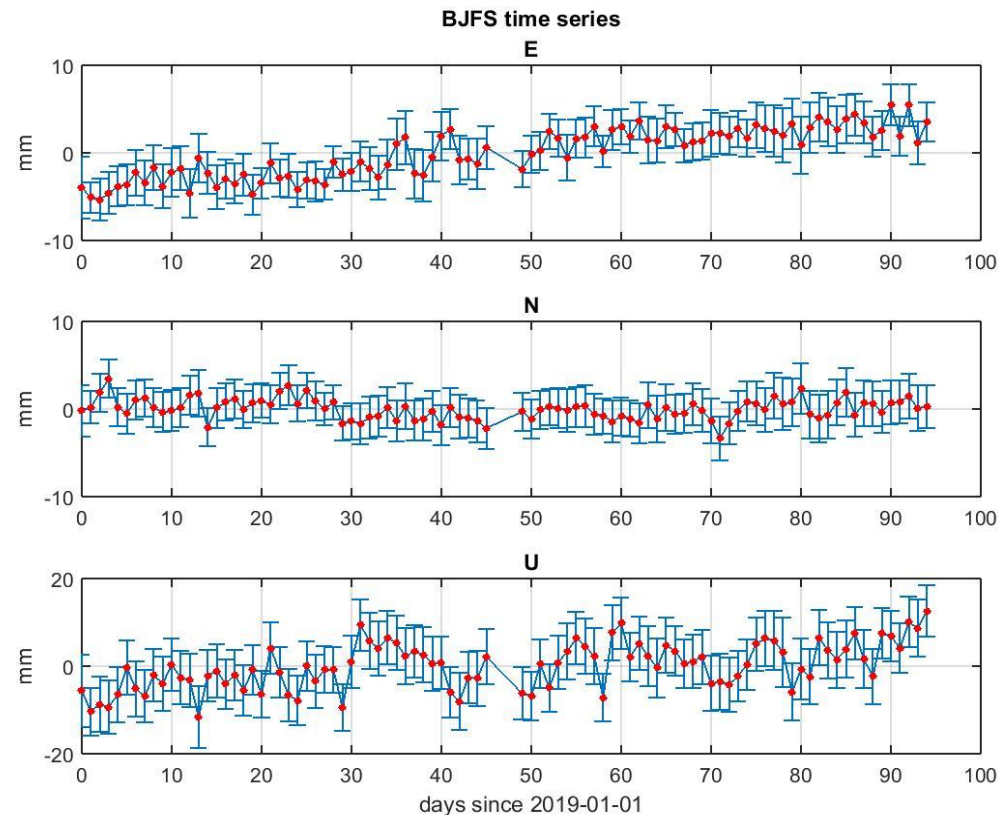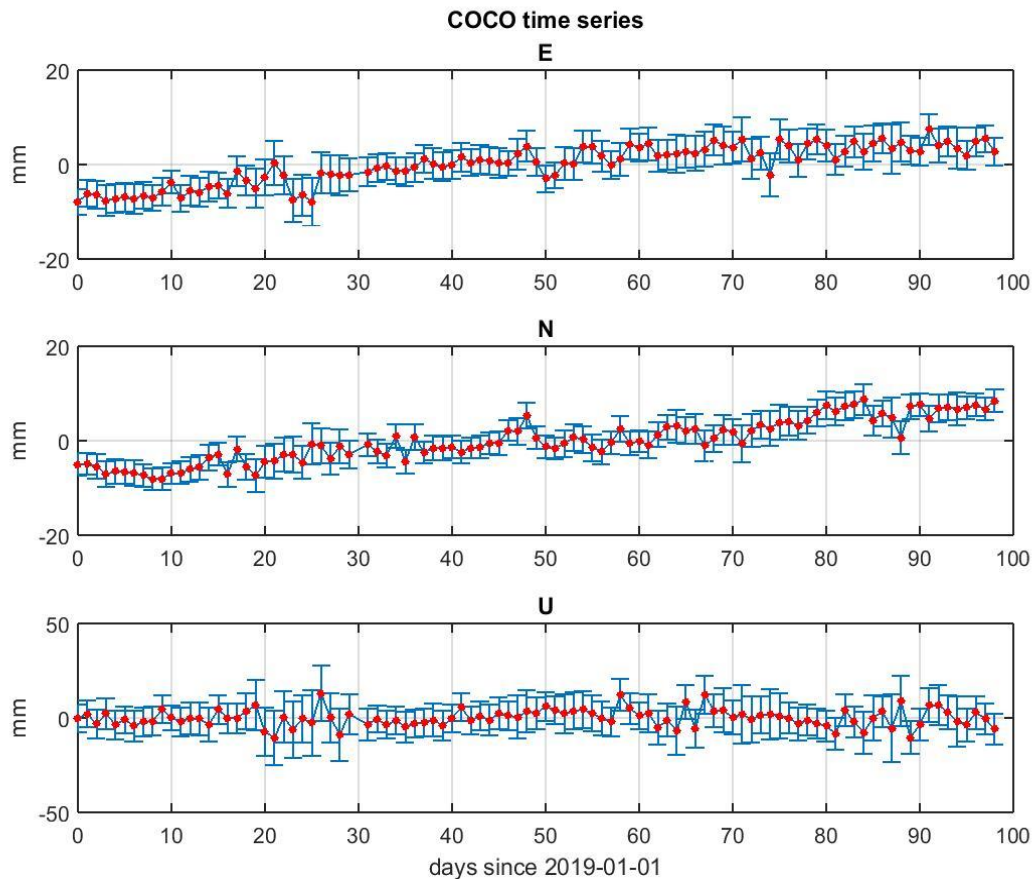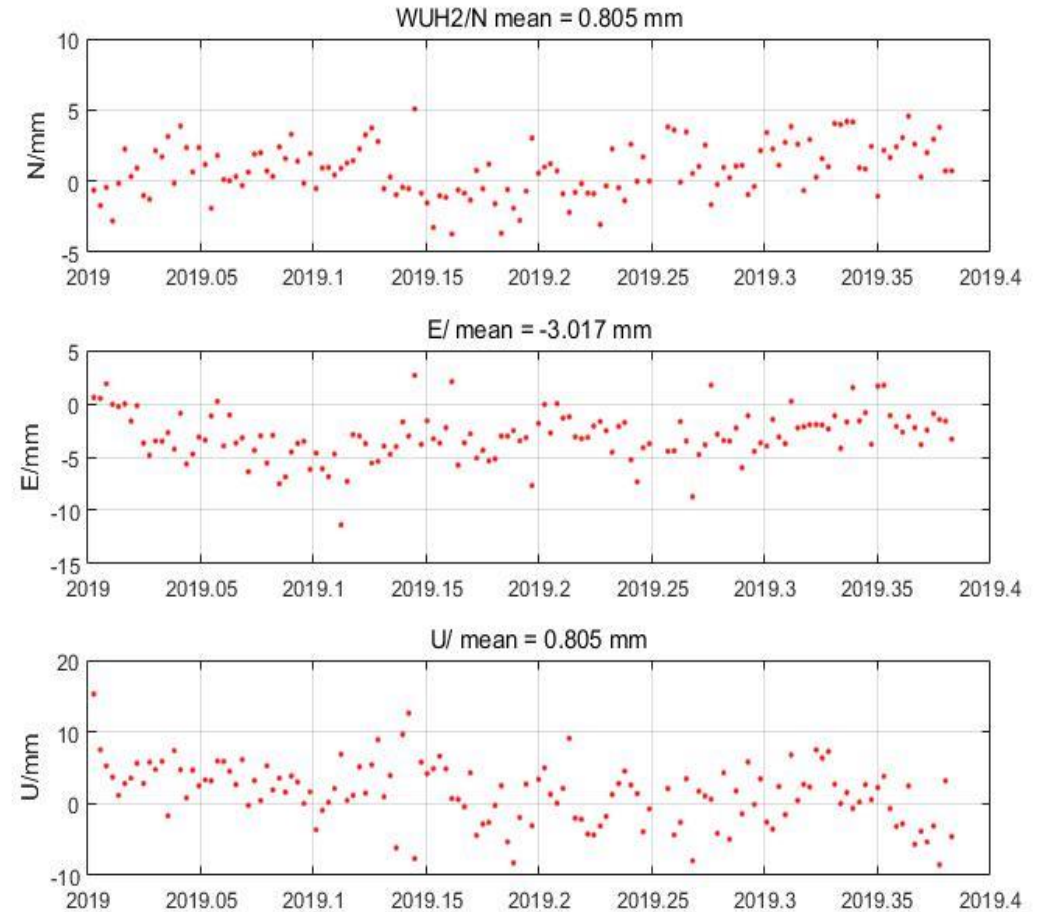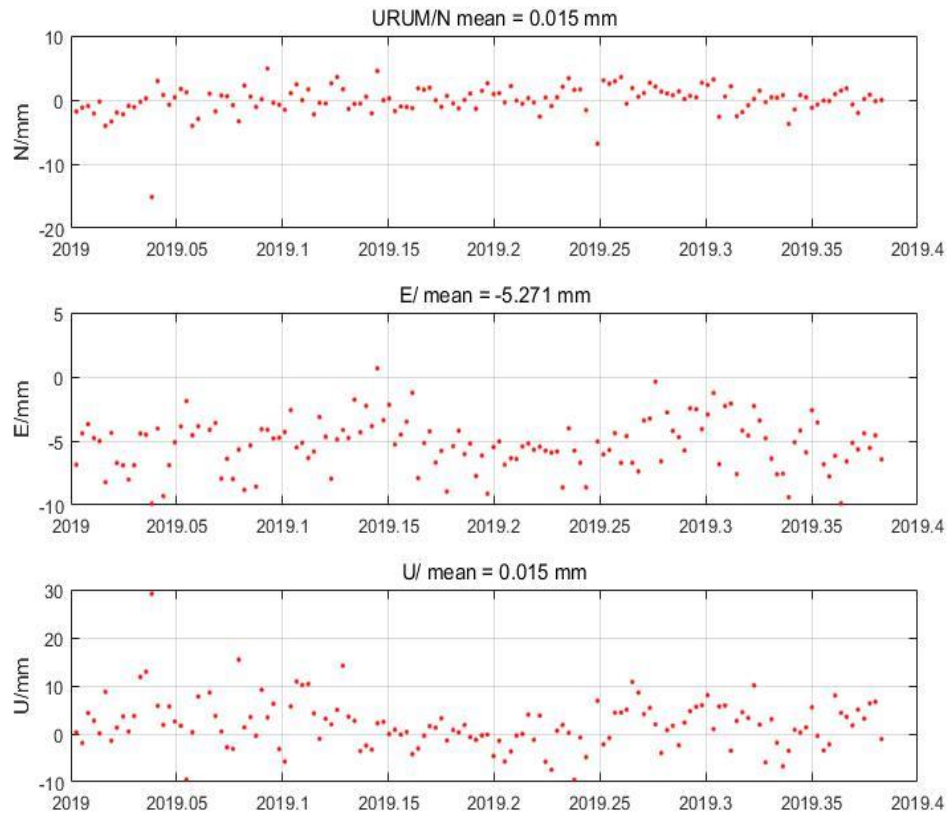| CHPI	VACS	DAEJ
MAW1	REDU	CHUM
KOUR	BRUX	ULAB
GUAM	MKEA	URUM
CRO1	KIRU	CKIS
STHL	NAUR	SYDN
KOKV	WROC	DARW
MADR	MGUE	KAT1
CEBR	QUIN	FAA1
EBRE	SANT	PERT
AREQ		

Coordinate time series of IGS stations in BDCS

Coordinate residuals of IGS stations

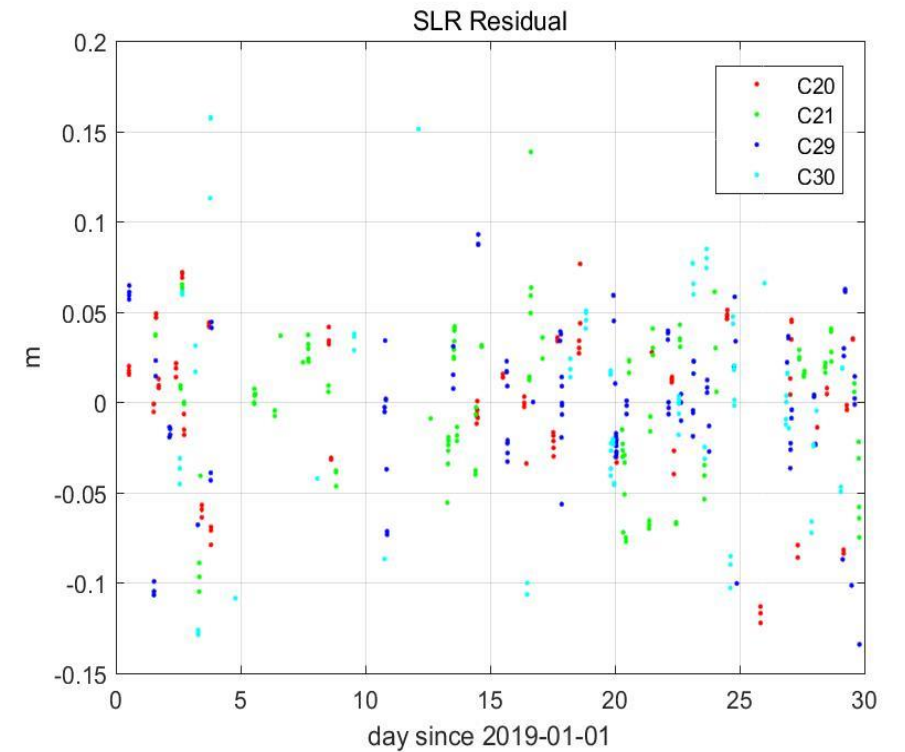**The accuracy is in milli-meter level**

(2). SLR method

4 BDS-3 satellites SLR data are used from global SLR tracking network.
Coordinates are estimated using BDS broadcast ephemeris.

Station ID	X /cm		Y /cm		Z /cm		Obs. Num
	adj	std	adj	std	adj	std	
70900513	3.81	1.32	1.21	2.92	-5.53	2.40	123
78457801	12.73	2.30	-2.32	1.29	2.23	1.85	75
78393402	19.48	4.10	-1.49	3.28	18.36	4.73	33
78403501	1.08	2.93	-8.50	1.17	-7.66	3.07	80
88341001	-0.15	4.67	-6.14	2.01	6.58	4.64	49
71100412	-8.80	3.31	5.18	5.31	0.68	5.57	29
72496102	12.67	6.66	17.38	13.80	13.45	15.03	26

SLR Residual

The accuracy is in centi-meter level

(3). BDS observations at IGS stations

Station	E /cm		N /cm		U /cm	
	adj	std	adj	std	adj	std
MET3	5.56	2.47	-18.63	2.34	-9.42	5.37
GANP	6.40	4.12	-4.12	2.22	-31.05	7.18
BOR1	6.51	5.35	-6.69	3.06	-35.48	6.02
ZIM2	6.33	6.15	-5.16	2.86	-39.09	7.26
POTS	1.99	3.02	1.25	1.56	-26.23	3.99
WUH2	12.09	2.76	2.01	0.52	-17.54	7.04
URUM	6.90	5.75	1.91	0.90	10.35	6.31
SGOC	-2.36	7.87	6.49	0.69	8.18	7.97
ULAB	1.32	5.04	1.03	0.60	0.91	11.41
STHL	-0.71	3.78	-4.61	1.92	8.53	6.59
MOIU	0.64	3.54	5.85	0.33	4.11	4.30
TUVA	3.27	18.83	-17.80	3.48	-16.06	11.08
ARHT	1.44	1.46	-5.90	1.13	6.28	1.38
SAVO	-2.37	4.25	-3.83	1.52	-22.73	3.35
POVE	-4.76	8.57	-3.35	0.83	-10.90	8.85

BDS-3 satellites observations are used from IGS stations. Coordinates are estimated using BDS broadcast ephemeris.
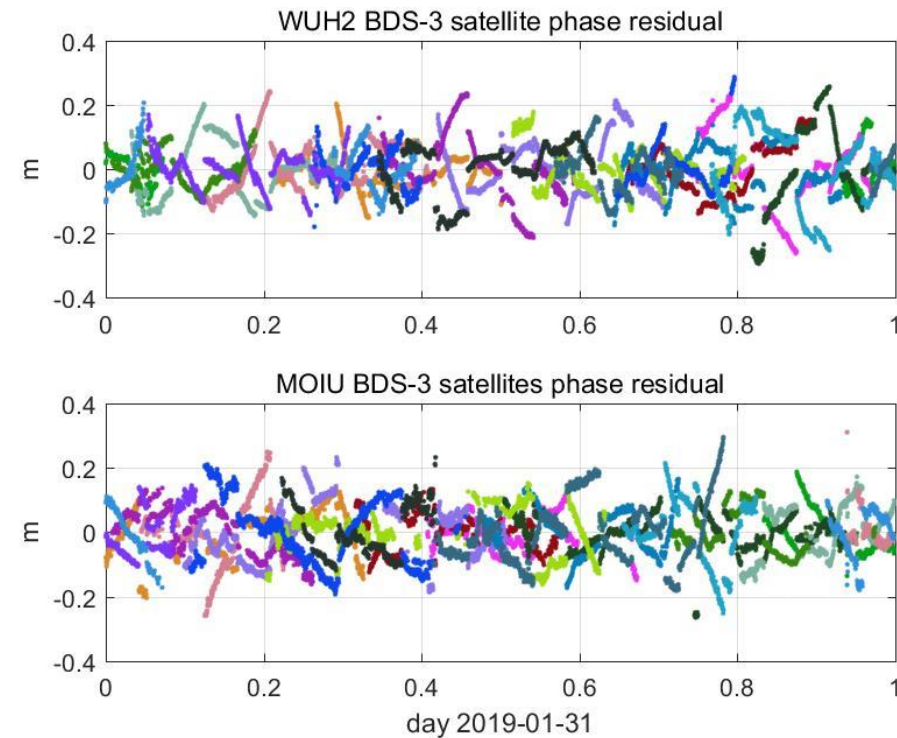
The accuracy is in centi-meter level

Accuracy Evaluation

7-parameters estimations:

Method	Trans_x cm/(sig.)	Trans_y cm/(sig.)	Trans_z cm/(sig.)	Rotate_x mas/(sig.)	Rotate_x mas/(sig.)	Rotate_x mas/(sig.)	Scal ppb/(sig.)
Precise coordinate	-0.04	0.11	-0.06	0.01	-0.02	0.05	0.011
	0.07	0.07	0.07	0.03	0.03	0.04	0.012
SLR	1.0	1.7	1.6	3.93	-0.86	0.45	0.991
	4.2	4.0	3.9	1.54	1.56	1.67	0.59
BDS obs.	4.5	-2.8	7.8	1.03	-0.78	0.70	1.199
	1.1	2.7	1.1	1.68	1.21	0.49	0.272

Precise coordinate method is the most accurate, and is used to estimate transformation parameters from BDCS(2019v01) to ITRF2014, but it can't be used by navigation users to monitor BDCS accuracy.
SLR and BDS obs. methods are less accurate, while it can be adopted to monitor BDCS accuracy by users.

Conclusions

➤ BDCS(2019v01) is aligned to ITRF2014 by using of IGS stations, and the accuracy is in milli-meters level.

➤ The accuracy of BDCS(2019v01) is evaluated by broadcast ephemeris, and the accuracy is in centi-meters level.

➤ With the construction of BDS, BDCS will be continuously updated.