Precise Orbit Determination using Satellite Laser Ranging and Inter-satellite Link observations for BDS-3 satellites

Weijing Qu[1], Yong Huang[1], Junyi Xu[2], Shuxian Sun[2], Shanshi Zhou[1],Yufei Yang[2], Bing He[3], Xiaogong Hu[1]

1. Shanghai Astronomical Observation, Shanghai, China
2. Beijing Satellite Navigation Center, Beijing, China
3. Zhejiang University of Water Resources and Electric Power, Zhejiang, China

1. Introduction

Since July 31, 2020, Beidou Satellite Navigation System (BDS) provides various services worldwide. The BDS satellites are equipped with the inter-satellite link (ISL) equipment, which can observe other satellites and ground monitoring stations with Ka-band measurements. The relative satellite clock and geometric distance can be separated to decouple the satellite orbit and clock difference using the dual one-way ISL ranging measurements of BDS satellites. The geometric distance is taken as the observation and is combined with the ground-based measurements to determine the precision orbit of BDS satellites. However, orbit determination using ISL measurements results in uncertainty in the right ascension of the ascending node, inclination of the orbital plane and inaccuracy of the space position of the satellite constellation in the Earth-centred inertial (ECI) frame. This problem can be solved by adding ranging data between the ground anchor station and the constellation.

All BDS satellites are equipped with Laser Retro-reflector Arrays (LRAs) that enable Satellite Laser Ranging (SLR) measurements. SLR has no carrier phase ambiguity and clock difference and is not affected by the ionosphere, which can be used as a measurement technology independent of GNSS. SLR is mainly used for the study of satellite orbit validation and geodesy et al.

In this poster, we focuses on the precision orbit determination for 11 BDS-3 satellites (MEO/IGSO/GEO) based on SLR and inter-satellite link (ISL) measurements from December 29,2019 to January 23, 2020. The results can provide technical support for satellite precision orbit determination(POD), the realization of reference frame and the estimation of geodetic parameters et al.

2. Satellites and Data

Table 1 shows the details information about 11 BDS-3 satellites.

Tab.1 Introduction of BDS 3satellites

	PRN	SLR observation	Orbit surface
MEO	C20	YES	Same orbit surface
	C21	YES	
	C22	NO	
	C28	NO	Same orbit surface
	C29	YES	
	C30	YES	
	C45	NO	Same orbit surface
	C46	NO	
IGSO	C39	NO	/
	C40	NO	/
GEO	C59	NO	/

The center of mass correction for BDS satellites(C29,C21,C20,C30) are from the BDS official website (http://www.beidou.gov.cn/yw/gfgg/201912/ t20191209_19613.html) .

Tab 2 shows the number of SLR normal points(Nps) and stations in 3-day orbit arc.

	Orbit arc	SLR Nps	SLR stations
1	2019/12/29 12:00 - 2020/01/01 12:00	123	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

3.Methodology

Data and models	
Data	SLR data of BDS-3 satellites from global stations ISL data
Arc length	3 days
Observables	The geometric distances between two satellites The distances between SLR station and BDS-3satellites
Elevation angle cut-off	10^0 for SLR station
N-body	DE405
Solar radiation pressure model	ECOM5
Ocean tide model	FES2004 model
Solid Earth tide	IERS2010
Pole tide model	IERS2010
Reference frame	SLRF2014
Troposphere	Marini model for SLR
General relativity effect	IERS2010
Estimated parameters	Satellite positions and velocities, solar pressure model parameters,ISL hardware delay and polar motion parameters

4. Orbit accuracy

4.1 Observation residuals

Observation residuals can be used for the validation of orbit accuracy. Tabl 3 shows the RMS of the orbit determination residuals for all ISL measurements of each satellite. The mean RMS of the 11 satellites is 4.8cm. The RMS of MEO, IGSO and GEO satellite are 4.6cm,4.9cm and 5.9cm, respectively.

The orbital accuracy of the three types of satellites is comparable. Fig 1 shows RMS of orbit determination residuals for SLR. The mean RMS is about 1.5cm.

Tab.3 RMS of the orbit determination residuals for all ISL measurements of each satellite

PRN	RMS/cm	PRN	RMS/cm
C20	4.1	C39	4.0
C21	4.2	C40	5.8
C22	3.9	C45	4.2
C28	4.6	C46	4.1
C29	4.5	C59	5.9
C30	7.1	mean	4.8

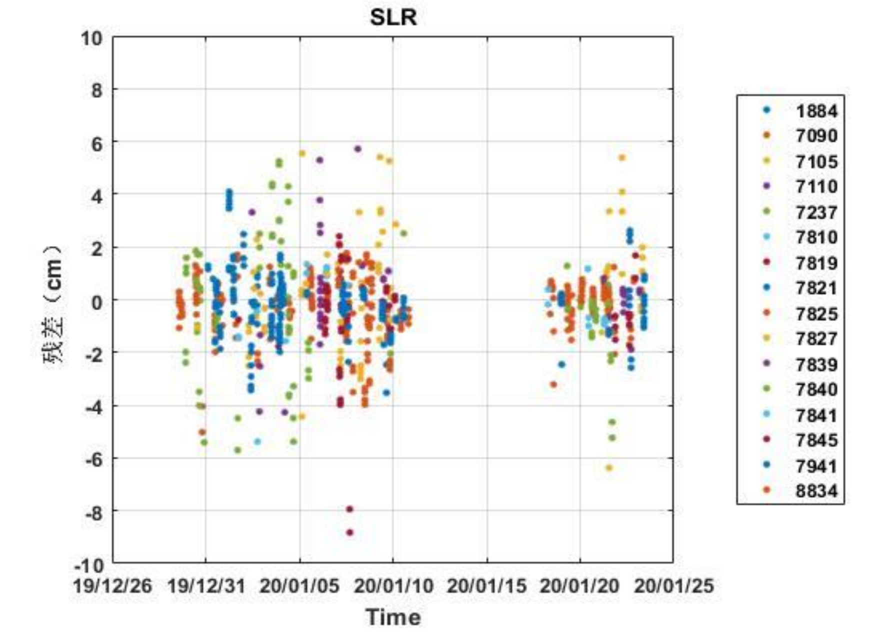

Fig 1. RMS of the orbit determination residuals for SLR measurements

4.2 Orbit overlap comparison

Fig 2 shows RMS of the orbit overlap comparison for 11 BDS-3 satellites. The satellite orbit accuracy of three orbit types is equivalent. The accuracy is 4.2cm,20.4cm and 19.9cm for RTN components and 30.2cm for 3D position.

GEO: the accuracy is 8.2cm,30.5cm and 20.2cmfor RTN components and 39.1cm for 3D position.

IGSO: the accuracy is 4.1cm,25.2cm and 22.0cm for RTN components and 35.4cm for 3D position.

MEO: the accuracy is 3.7cm,17.9cm and 19.4cm for RTN components and 27.8cm for 3D position.

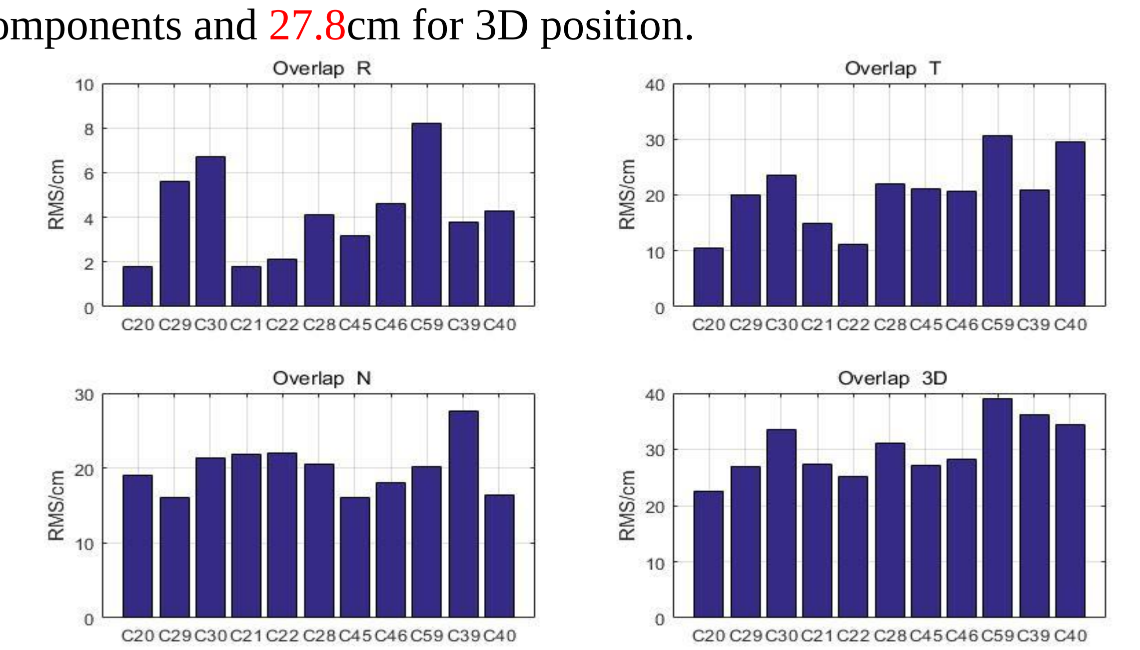

Fig.2 RMS values of the orbit overlap comparison for 11 satellites

Tab 4 shows that the BDS-3 observations using SLR is very limit for 3-d arcs. If the SLR observations can increase, it will help to improve the orbital accuracy.

Tab.4 Number of SLR Observations and stations for four BDS satellites each arc

PRN	Orbit arc No.（Valid station / Valid SLR data）						
	1	2	3	4	5	6	7
C20	5/29	5/53	5/35	6/83	7/55	2/22	7/49
C29	3/19	4/13	4/24	7/32	7/23	5/14	8/32
C30	4/26	6/29	2/7	4/22	4/14	/	/
C21	4/45	3/15	5/58	4/21	3/14	4/36	11/4 4

4.3 Orbit prediction

Tab 5 shows that the accuracy of 12h and 24h predicted orbit is less than 7.0cm for R component and about 40.0cm for the 3D position for MEO satellites. For GEO satellite, the accuracy and about 1m for 3D position. For IGSO satellite, the accuracy is about 10.0cm for R component and 60.0cm for 3D position.

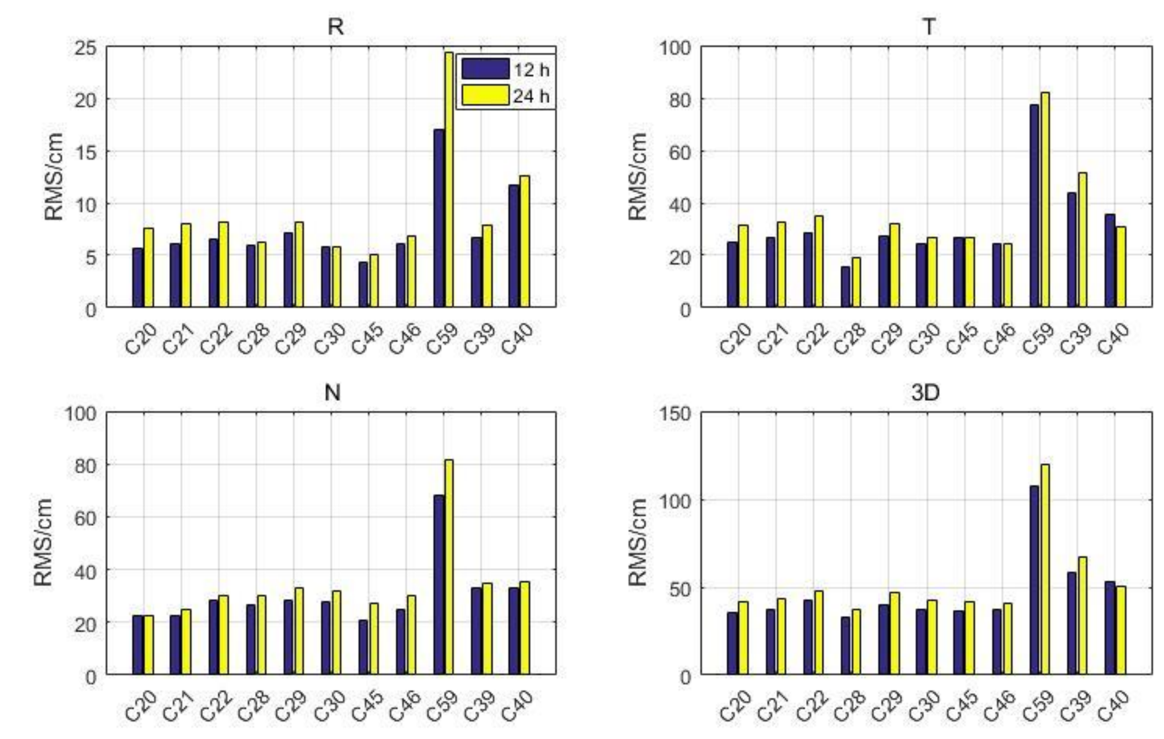

Fig 3. RMS of 12 h and 24 h predicted orbit errors for 11 satellites

Tab 5. Accuracy of Predicted orbit for 11 satellites

	12h				24h			
	R/cm	T/cm	N/cm	3D/cm	R/cm	T/cm	N/cm	3D/cm
MEO	6.0	24.9	25.2	37.5	7.0	28.6	28.8	42.8
IGSO	9.2	39.7	32.9	55.5	10.2	41.1	35.1	58.5
GEO	17.0	77.4	68.4	107.6	24.3	82.2	81.8	120.0

5. Polar motion parameters

The earth rotation parameters are estimated simultaneously with the satellite orbit. Fig 4 shows the different between IERS C04 and the estimate polar motion parameters(Xp and Yp). Although the accuracy of the pole motion is about 3.0mas due to the small amount of SLR observation data, the method is feasible to calculate the earth rotation parameters.

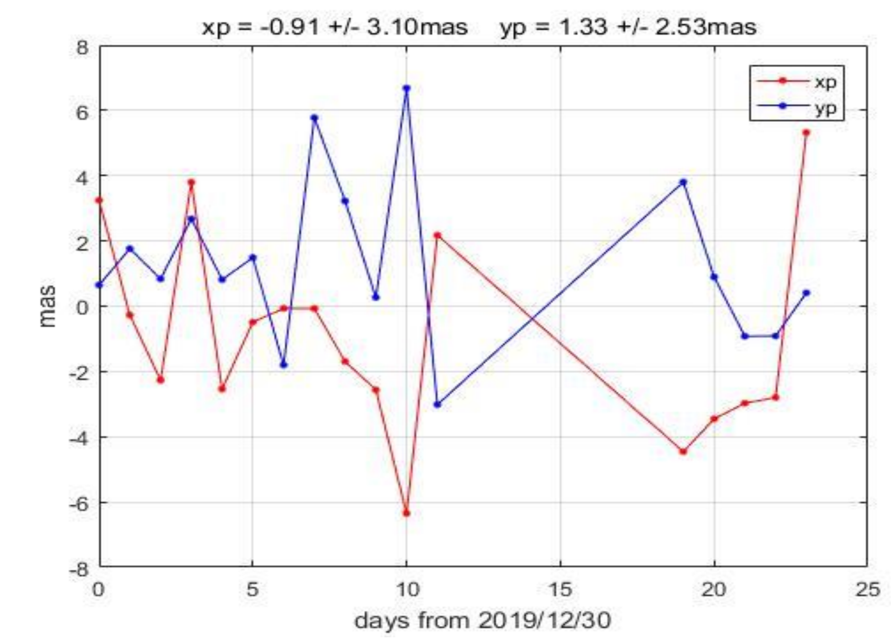

Fig 4 Time series of pole motion parameters(Xp and Yp)

6. Conclusions

We estimate the precision orbit of BDS-3 satellites (MEO/IGSO/GEO) and polar motion parameters using combined SLR and ISL measurements. The accuracy of BDS-3 satellite orbit determination based on the SLR and ISL is greatly improved compared with the SLR data only, especially for GEO and IGSO satellites. The satellite orbit accuracy of three orbit types is equivalent. The accuracy is 4.2cm for radial components and 30.2cm for 3D position. The accuracy of 12h and 24h predicted orbit is about 40.0cm for the 3D position for MEO satellites, less than 60.0cm for IGSO satellites and about 1m for GEO satellites. The accuracy of the pole motion is about 3.0mas due to the small amount of SLR observation data. This means that the method is feasible to calculate the earth rotation parameters. The results show that the high precision orbit of the navigation satellites can be achieved using ISL measurement and very limit SLR data. If BDS constellation can be intensively tracked, it will help to improve the orbital accuracy. Meanwhile, it will benefit to scientific researches (reference frame, geocenter and scale et al.)