Shanghai Astronomical Observatory
Chinese Academy of Sciences

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Status on Chinese Space Geodesy Network and its Applications

Xiaoya Wang, Zhongping Zhang, Fengchun Shu, Guangli Wang, Kewei Xi

Astro-Geodynamics Research Center, Shanghai Astronomical Observatory, Chinese Academy of Sciences, 80 Road NanDan, Shanghai 200030, China;

University of Chinese Academy of Sciences, Beijing 100049, China;

Shanghai Key Laboratory of Space Navigation and Positioning Techniques, Shanghai Astronomical Observatory,CAS, Shanghai 200030, China

Email: wxy@shao.ac.cn

GGOS session G2.1

The Global Geodetic Observing System: Improving infrastructure for future science

Tuesday, 5 May 2020, 08:30–10:15

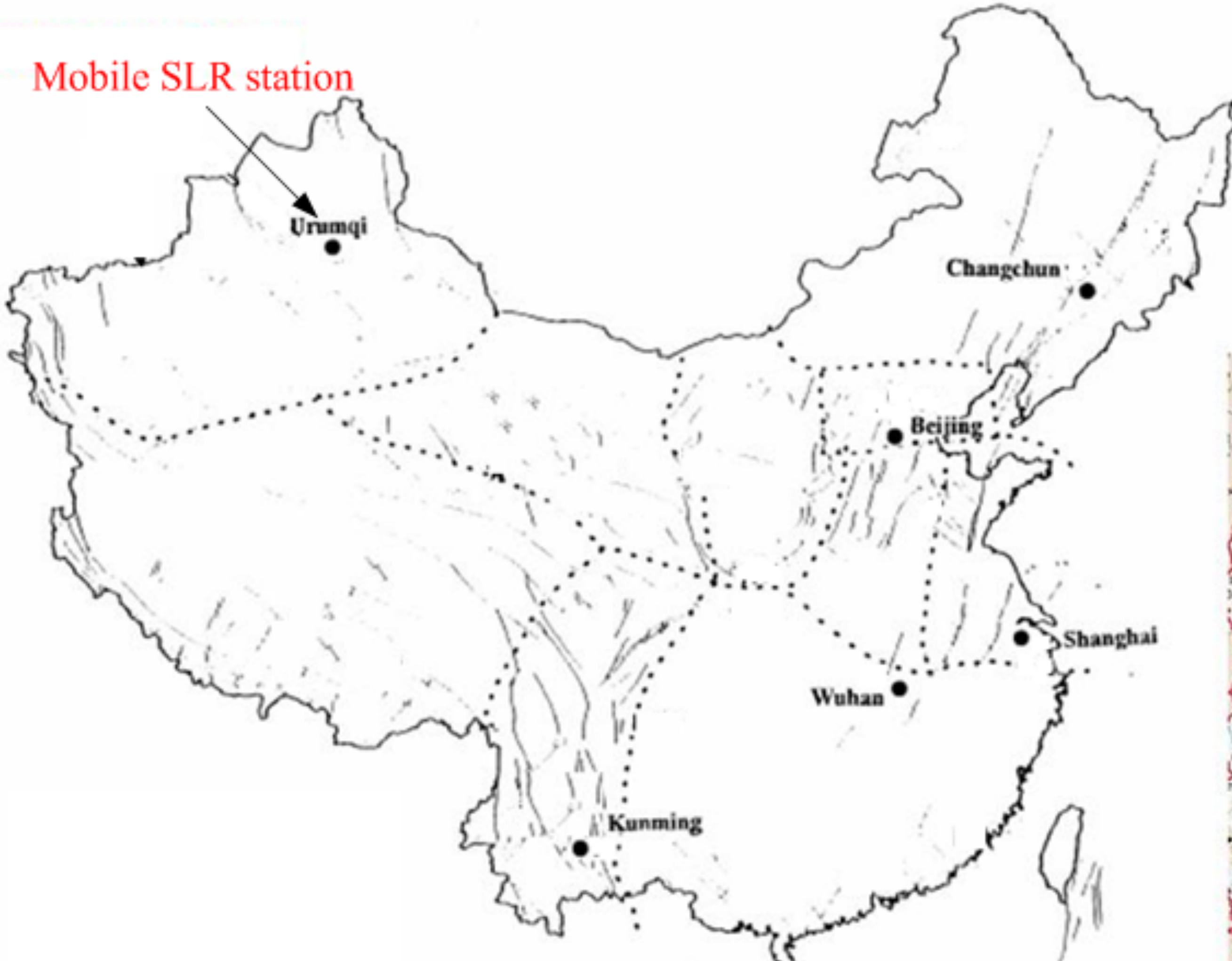
Outline

1. Status of Chinese space geodetic networks
2. Data processing software update
3. CERS，STRF and CERS EOP products
4. Conclusions and future plans

1. Status of Chinese space geodetic networks

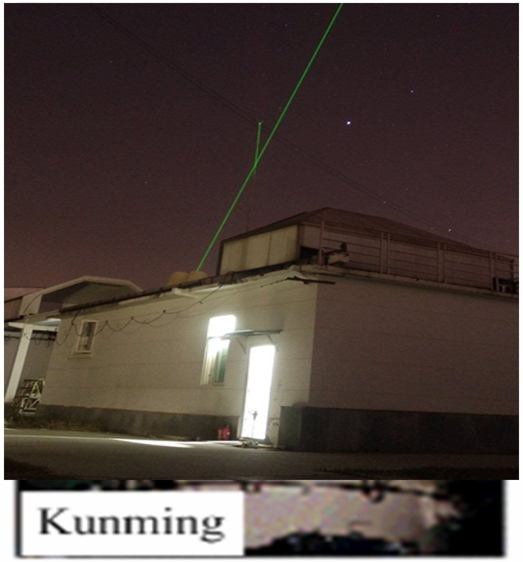
Status of Chinese SLR network

Distribution of Chinese SLR sites



Shanghai, Changchun, Kunming, Beijing, Wuhan sites participate in the global SLR tracking campaign.

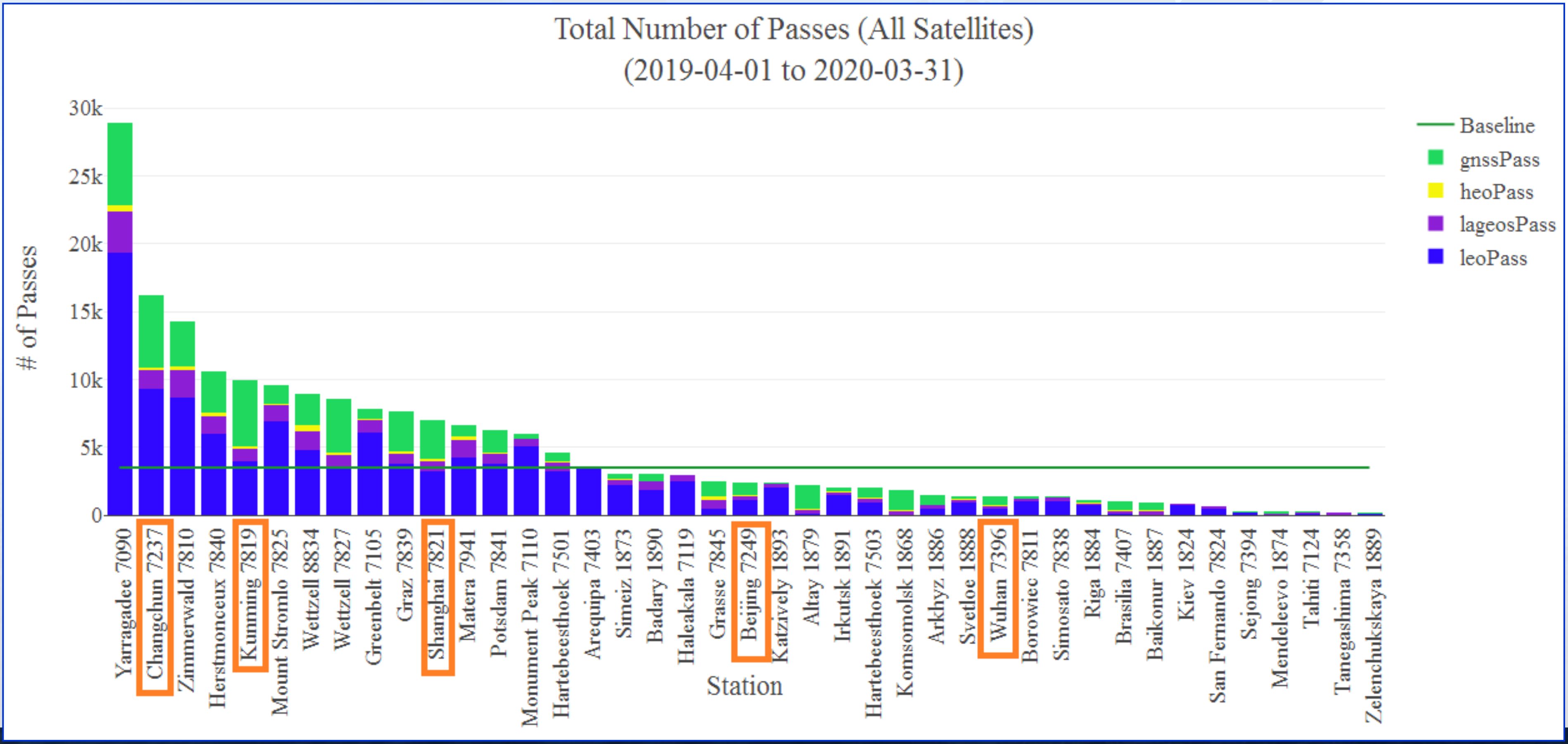
Tracking telescopes of SLR network



The telescopes of the Chinese SLR stations

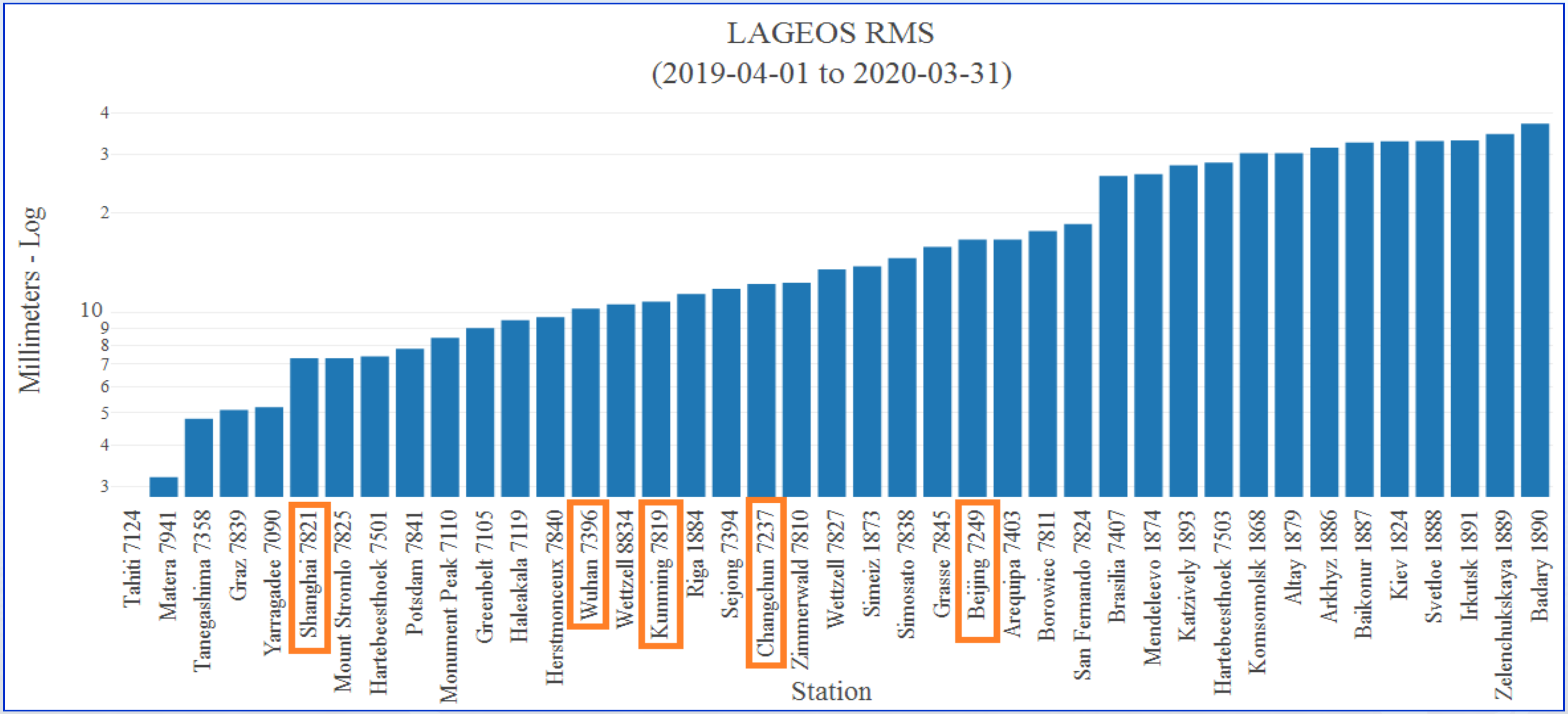
The status of SLR sites

- The routine 1kHz SLR measurements in Shanghai, Changchun, Kunming, Beijing and Wuhan sites and the total passes of laser data per year of over 35k for GEO, GNSS, Lageos, LEO satellites.



The status of SLR sites

- The routine 1kHz SLR measurements with the precision of less than 12mm to Lageos satellites.



- The short and long term stability of laser data are less than 20mm and 10mm respectively.

The status of SLR sites

- The mobile SLR system (TROS) with the aperture of 1 meter has installed in Xinjiang Observatory (Urumqi). The observations to ILRS satellites has been performed since Sep. 19 in 2019.

The mobile SLR system (TROS) in Xinjiang Observatory (Urumqi)

Very significant site in Chinese SLR network

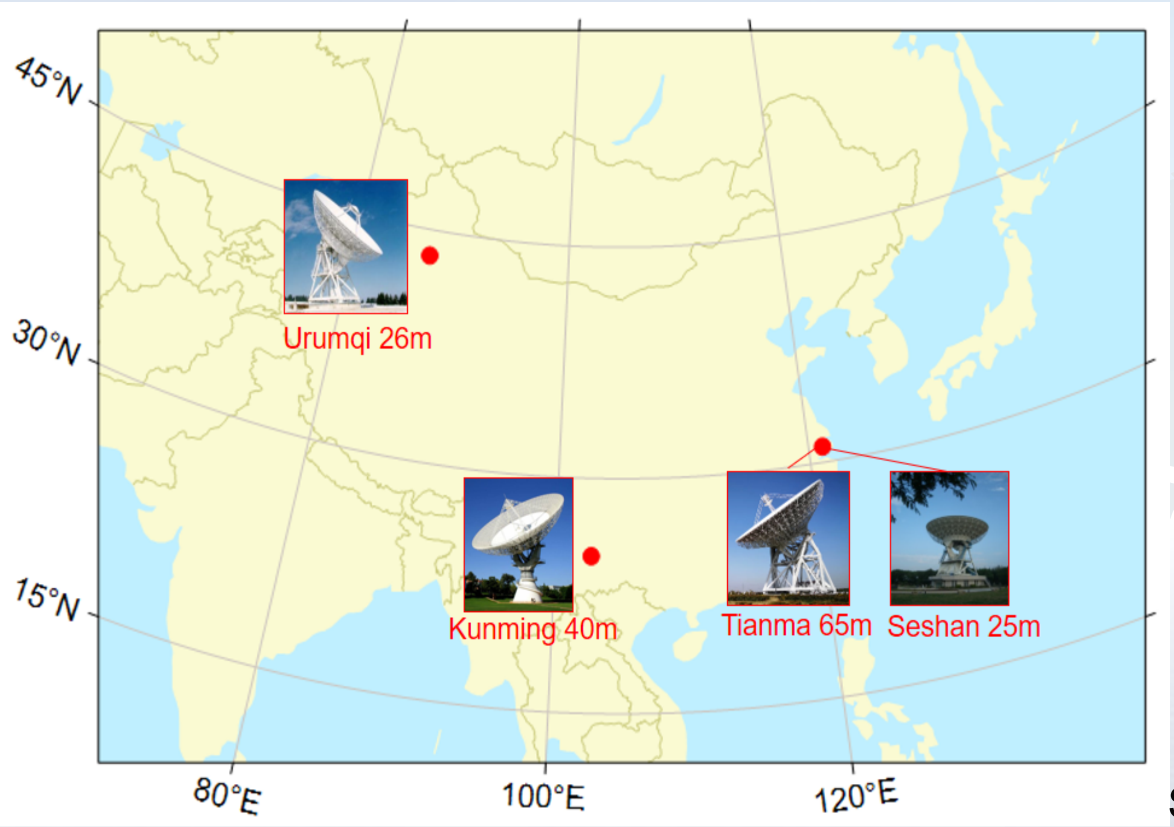
The status of SLR sites

- Shanghai station is developing 10kHz ~ 100kHz rep. rate SLR technology in order to improve the system stability and data quality. Due to high data density, the high rep. rate SLR data are also used to analyse the rotation rate of geodetic satellites.
- Kunming sites has realized the Lunar Laser Ranging with the distance of 380,000km.
- The system updating work in SanJuan station is underway for kHz SLR measurements as one valuable sites in the southern hemisphere.
- The updating 2kHz routine SLR measurements at night and in daylight is also being underway in Chinese network and will be finished in 2022 for geodetic observations.

1. Status of Chinese space geodetic networks

Status of Chinese VLBI network

Chinese VLBI facilities operational for the IVS

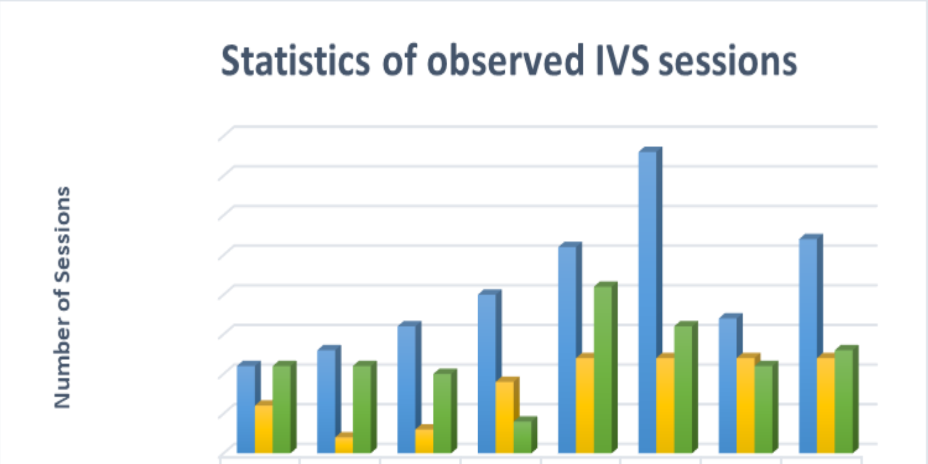


Currently 4 stations regularly participate in the IVS observing program.

Shanghai Correlator
400 CPU cores, 800TB storage,
2Gbps international fiber link

Participation of IVS observing sessions

- Seshan25 and Urumqi are IVS network stations
- Kunming and Tianma65 are cooperative stations of the IVS
- Tianma 65-m antenna supports 3~6 IVS astrometric sessions on annual basis
- Seshan25 also participates in 1-hour IVS intensive session monthly for UT1 measurement



	2012	2013	2014	2015	2016	2017	2018	2019
Seshan25 IVS	11	13	16	20	26	38	17	27
Kunming IVS	6	2	3	9	12	12	12	12
Urumqi IVS	11	11	10	4	21	16	11	13

Each IVS regular observing session spans 24 hours

Mixed-mode geodesy using Chinese VLBI stations

Date	Starting time	Duration	Code	Stations
20150122	9:00	24	cn1501	ShKmUrKsJs
20150122	9:00	24	cdsn02	ShUrKsJs
20150321	0:00	24	cdsn03	ShUrKsJs
20150630	17:30	24	cdsn04	ShKsJs
20150917	10:00	24	cdsn05	ShKmKsJs
20151022	2:00	24	cn1502	ShKmUrBjKsJs
20151113	3:00	24	cn1503	KmUrKsJs
20151210	8:00	24	cn1504	KmUrKsJs
20160506	6:00	24	cn1601	ShKmUrKsJs
20160702	6:00	24	cn1602	ShUrKsJsYgKe
20160928	18:00	24	apsg39	APSG+KsJs
20161130	6:00	24	cn1603	KmUrKeYgKsJs-Ur
20161229	3:00	24	cn1604	KmUrKsJs
20170325	06:00	24	cn1701	ShKmUrKsJs
20170511	06:0	24	cn1702	ShUrKs
20170523	17:30	24	cn1703	ShKmUrKsJs
20170725	17:30	24	APSG40	APSG + KsJsJlSy
20170808	17:30	24	cn1703	T6UrKsJs

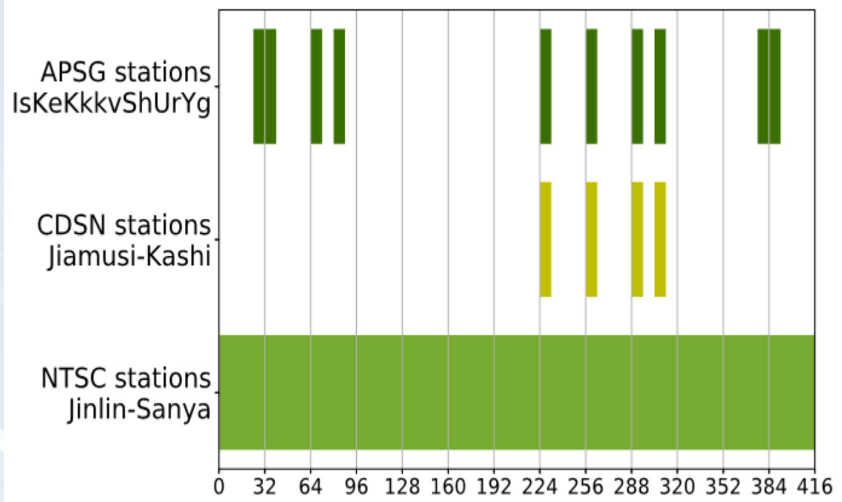


Fig. 2: X-band Frequency sequence wrt 8181MHz.

Table 1: The adjustments and precisions of NTSC and CDSN stations.

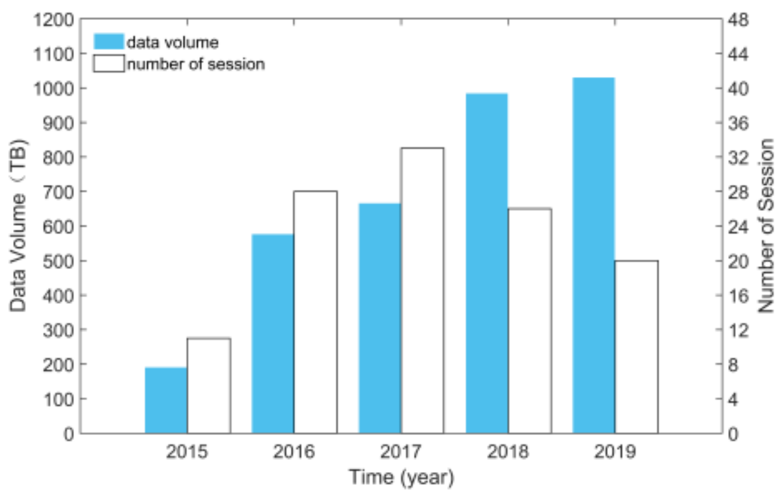
Coordinates	Jilin		Sanya		Jiamusi		Kashi	
	adjustment	σ	adjustment	σ	adjustment	σ	adjustment	σ
U /mm	-49.76	8.91	-58.10	12.58	-53.59	26.56	17.23	26.70
E /mm	24.64	1.87	101.36	2.53	52.94	8.87	35.70	0.44
N /mm	24.98	1.57	-20.60	2.11	-0.73	6.05	106.65	5.93

(He et al. 2019, EVGA)

Shanghai VLBI correlator

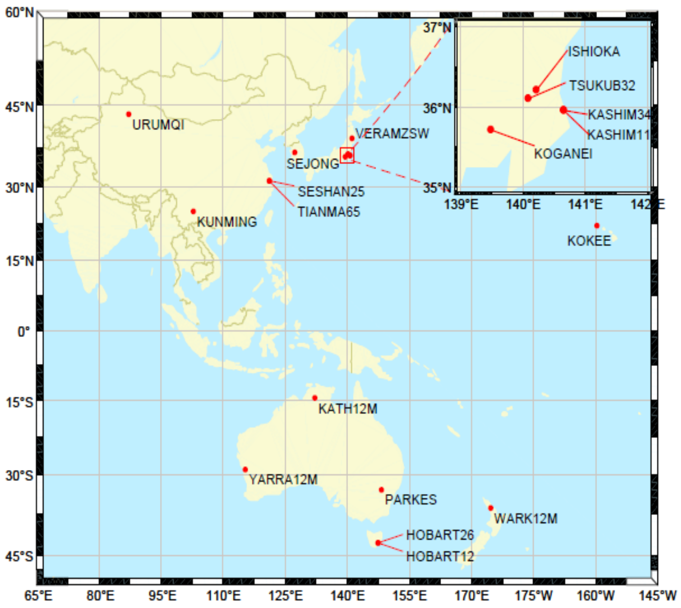
- 118 IVS sessions and 20 CVN sessions have been correlated from 2015 to 2019
  - **AOV**: astrometry of weak ICRF sources
  - **APSG**: regional geodesy around Asian and Pacific area
  - **AUST-AST**: Australian astrometric sessions
  - **CRF/CRD**: monitoring CRF sources, more focused on southern hemisphere
  - **RD**: astrometry of Gaia transfer sources
  - **CVN**: measurement of station positions of Chinese stations

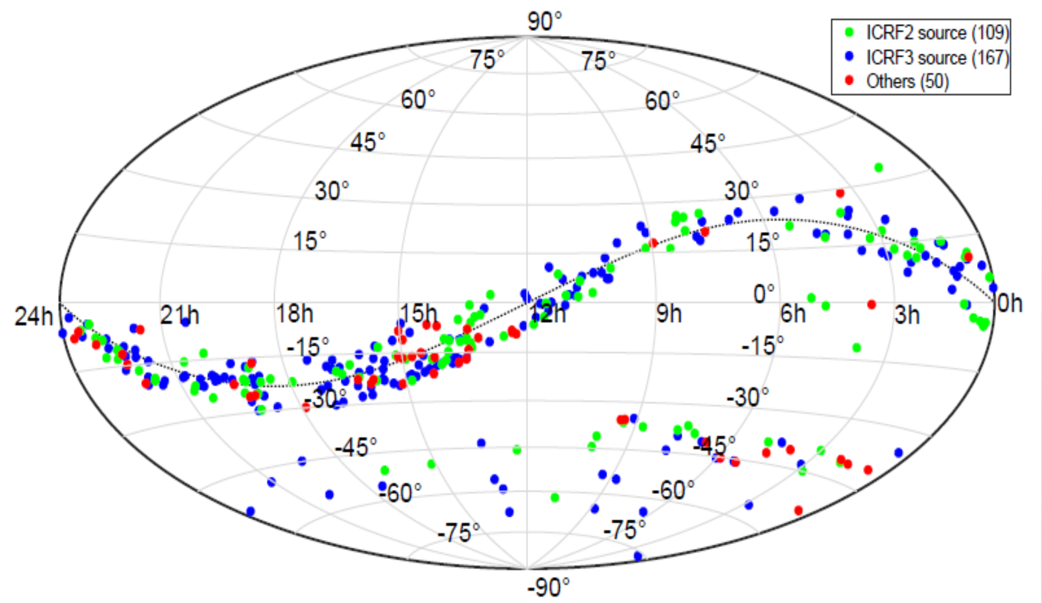
Session Name	2015	2016	2017	2018	2019
AOV	3	3	3	7	6
APSG	2	2	2	2	2
AUS-AST	0	13	14	6	0
IVS-CRF/CRD	6	9	9	6	6
IVS-RD	0	1	5	5	6
IVS Session	11	28	33	26	20
CVN Session	7	5	5	3	0



Astrometry of weak sources with AOV/APSG

- AOV is unique to astrometry of weak sources in the middle southern hemisphere and the ecliptic plane
- SHAO scheduled and correlated part of AOV observing sessions from 2015 onwards



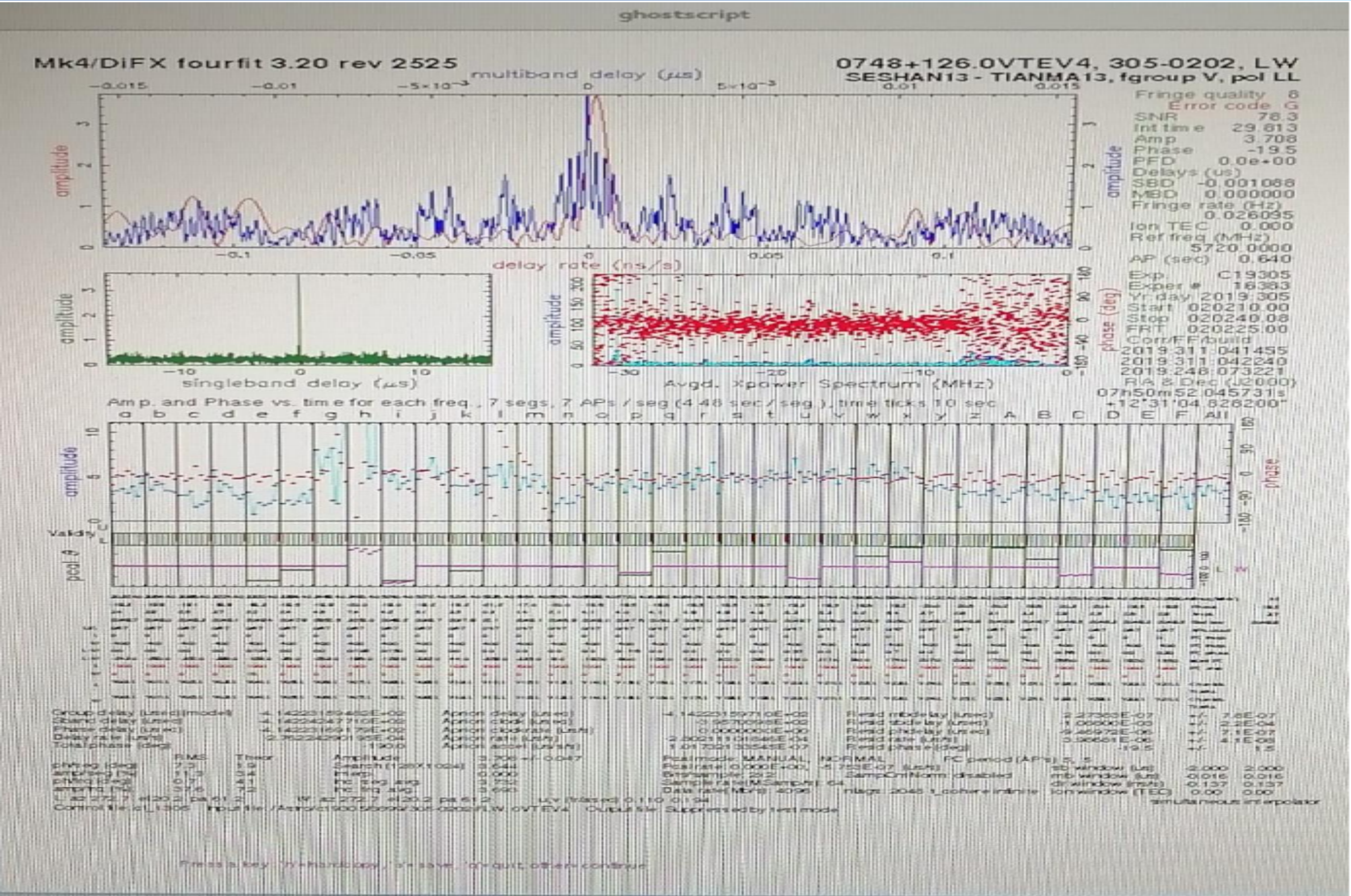


Seshan VGOS – Tianma VGOS Stations

TmVGOS SEFD measured on Sep. 23, 2019

3C144			
F(Ghz)	EL(°)	SEFD-H(Jy)	SEFD-V(Jy)
4	36	2167.7	2058.6
6	35	2387.9	2185.8
8	33	1842.5	1702.3
10	31	2847.2	2377.1
12	29	3103.3	2812.3
14	27	3596.3	2966.3

Seshan VGOS – Tianma VGOS fringe test on Nov. 7, 2019

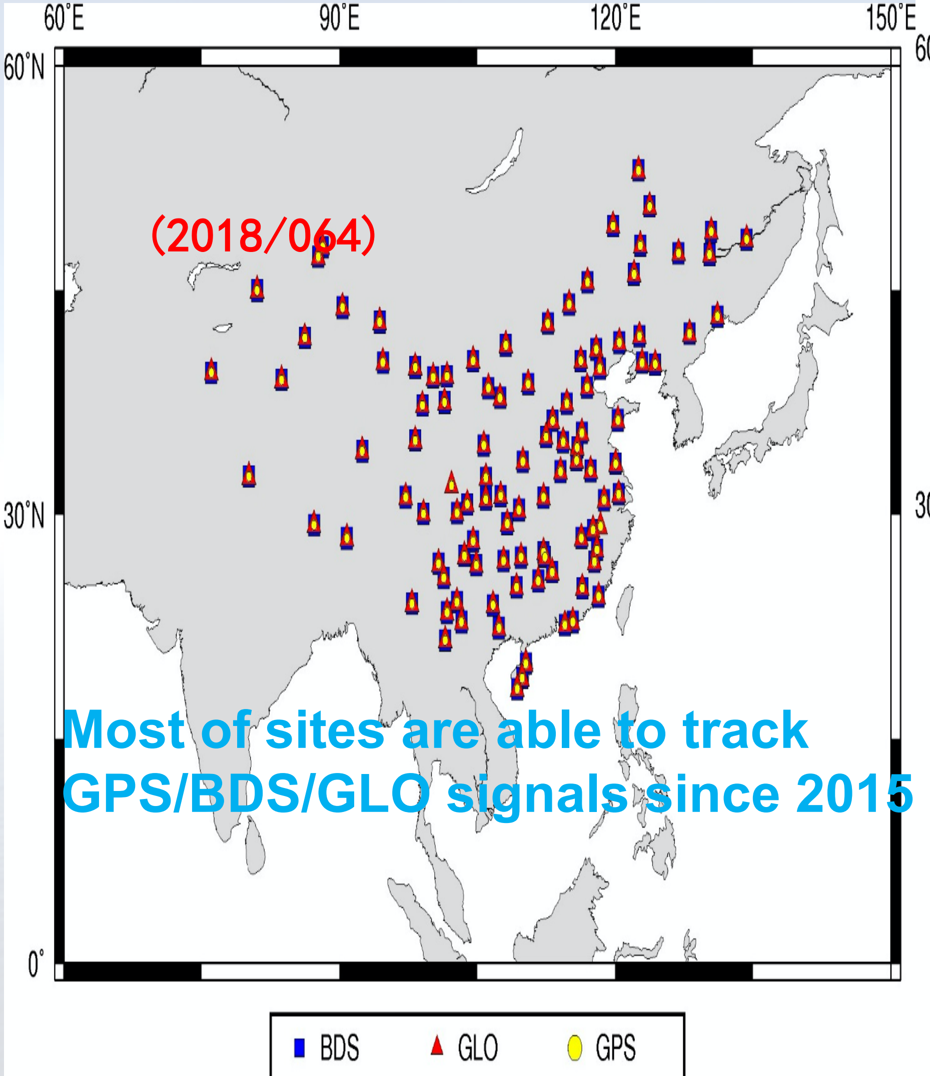


1. Status of Chinese space geodetic networks

Status of Chinese GNSS network

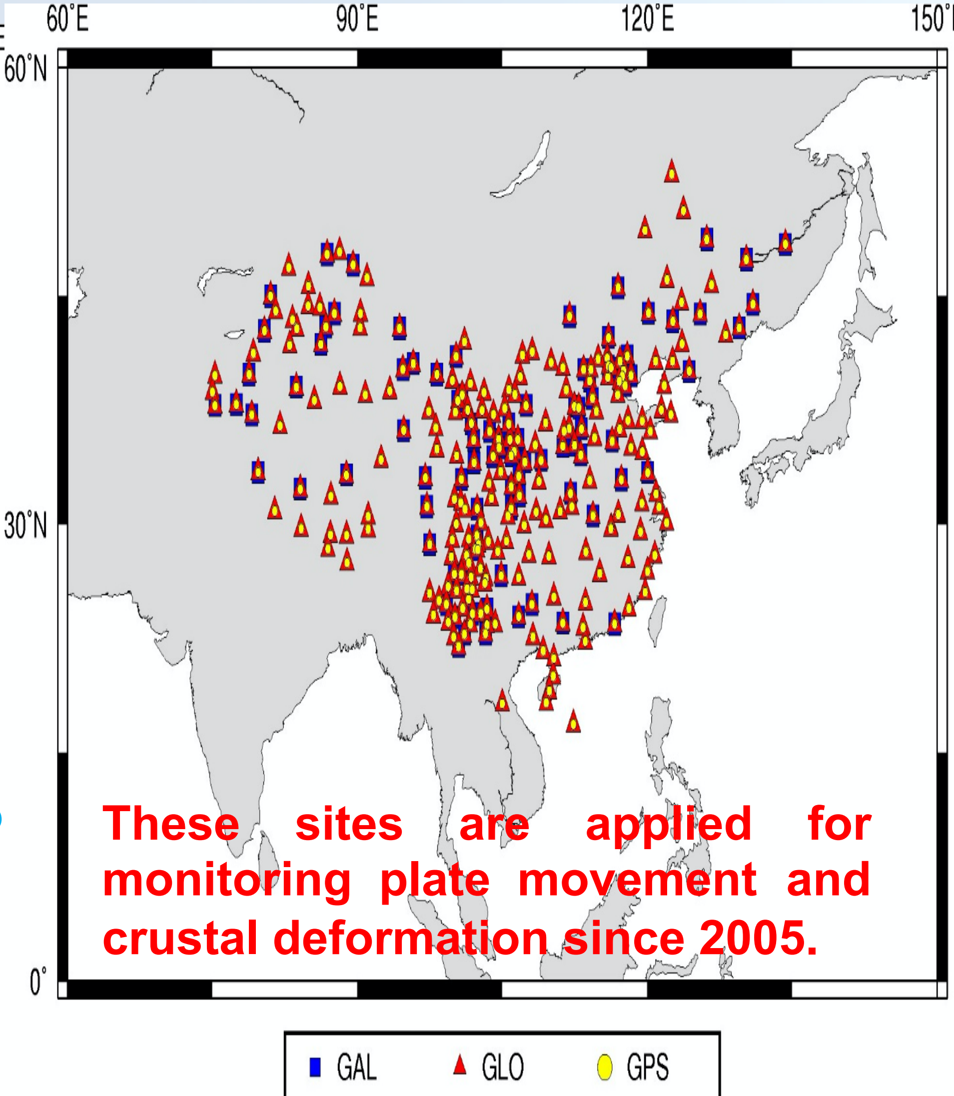
Chinese GNSS network

Sub-net1 distribution of 103 multi-GNSS Stations(150 sites in future)



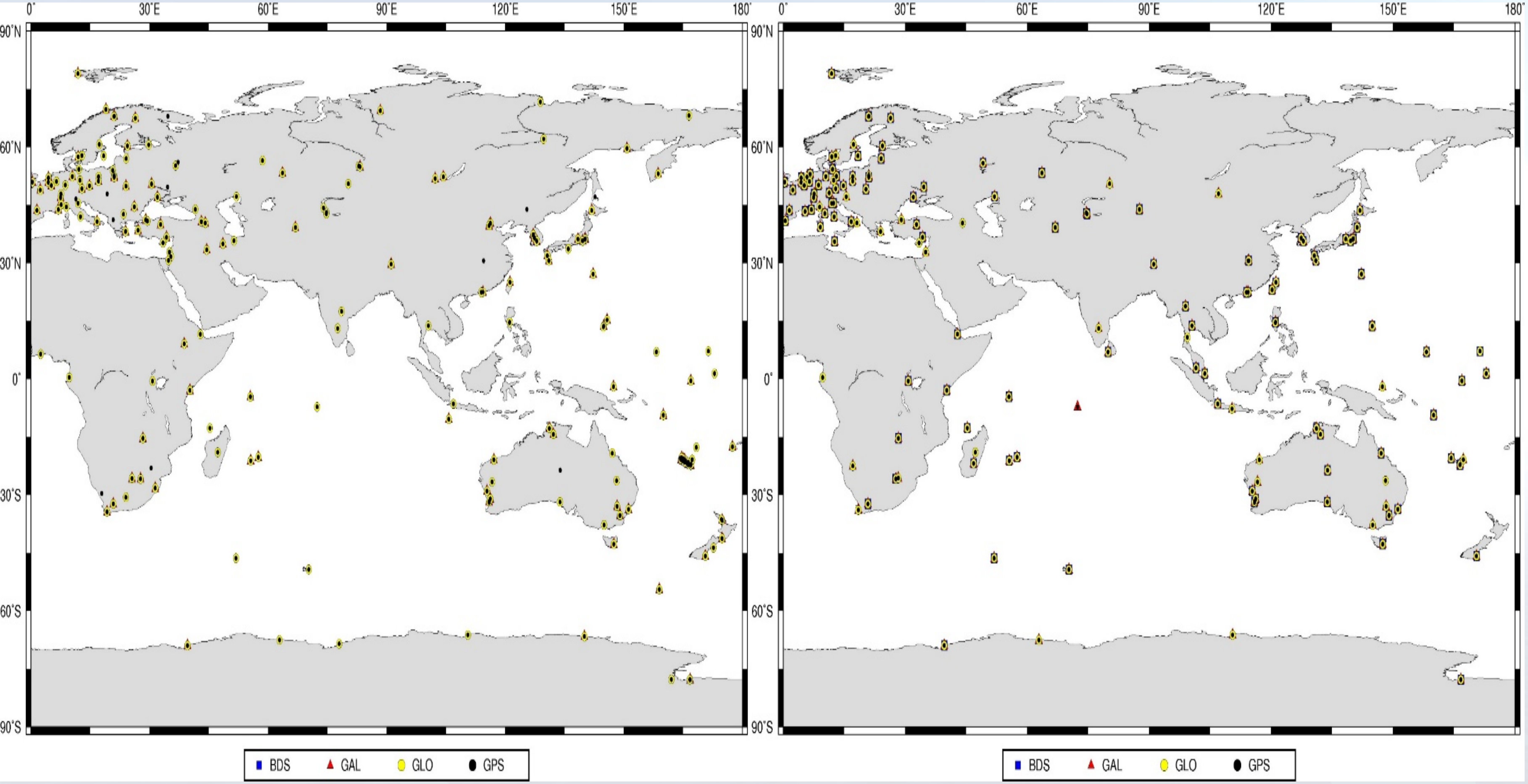
Most of sites are able to track GPS/BDS/GLO signals since 2015

Sub-net2 distribution of 260 Stations (2020/001)



These sites are applied for monitoring plate movement and crustal deformation since 2005.

Global GNSS network from IGS and MGEX used



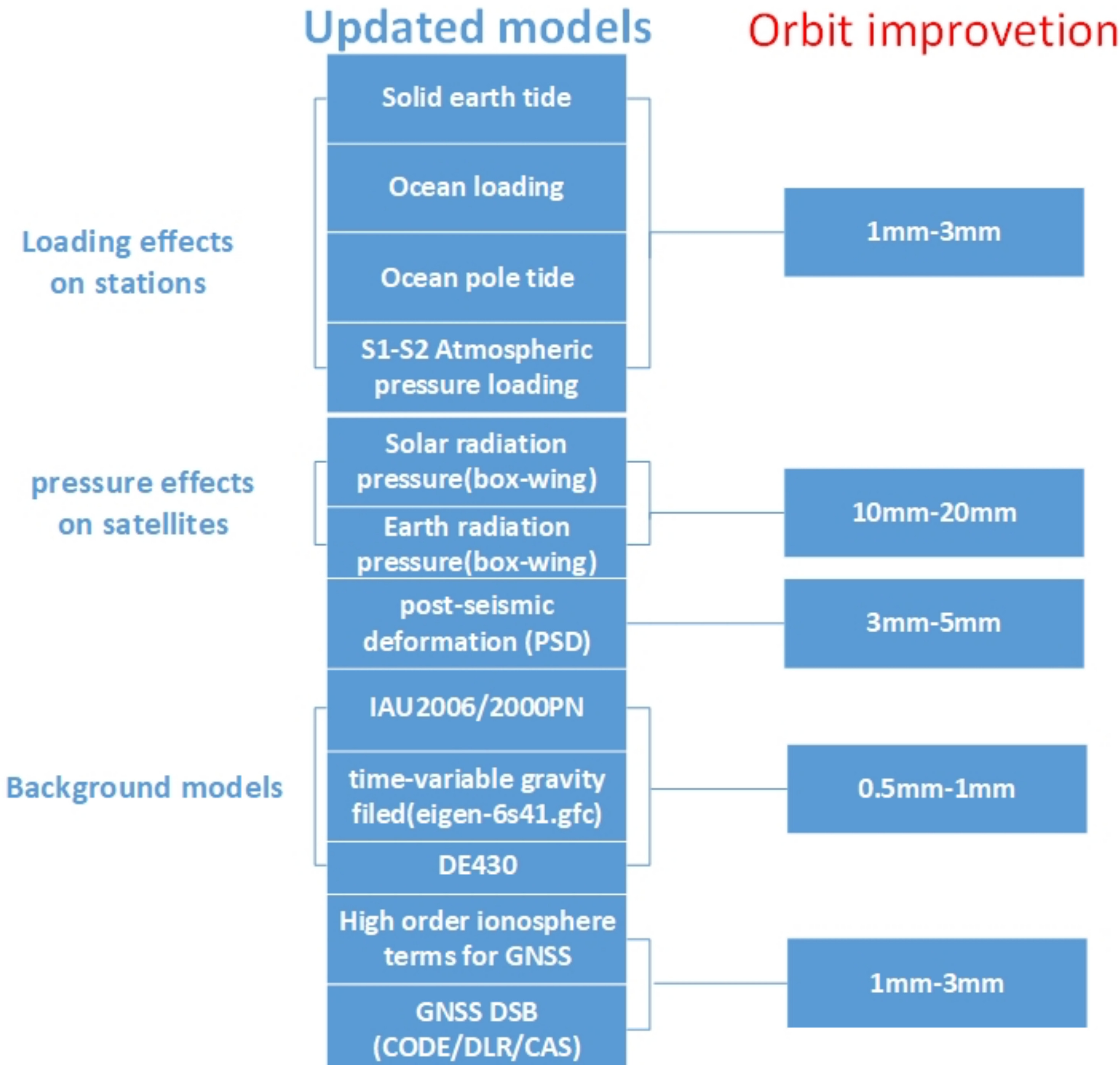
IGS 445 Stations distribution (2020/001)

MGEX 314 multi-GNSS Stations distribution (2020/001)

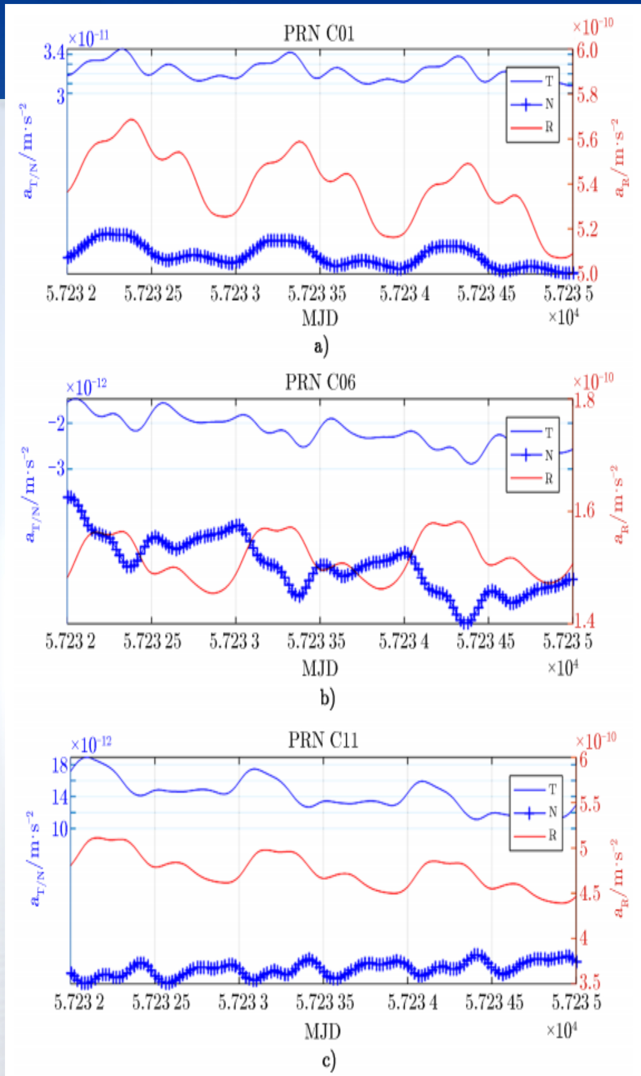
2. Data processing software update

GNSS data processing software update

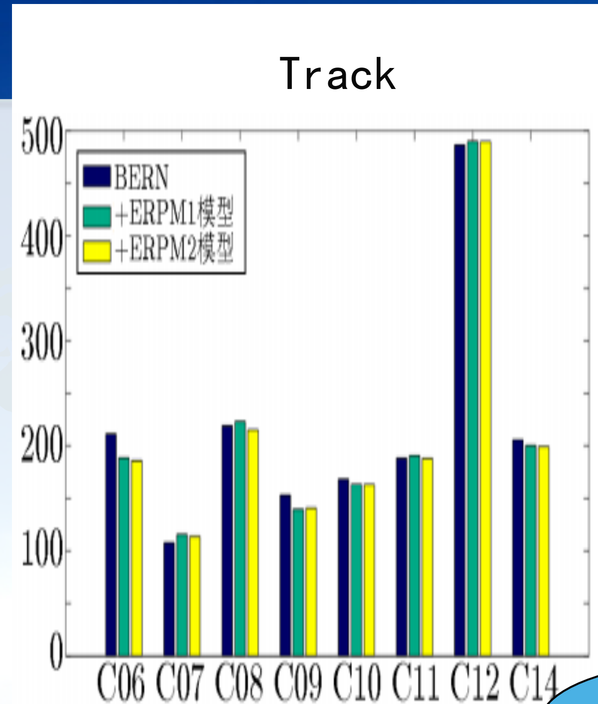
The GNSS data
processing soft
ware has been
updated accord
ing to the reco
mmended mod
els by IERS con
ventions(2010).
Nowadays, GN
SS data proces
sing software h
as realized mult
i-GNSS precise
orbit determina
tion and the SL
R orbit validatio
n.

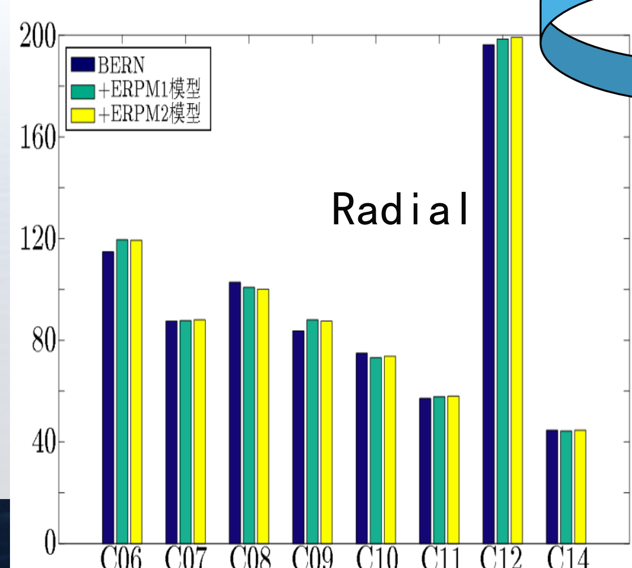


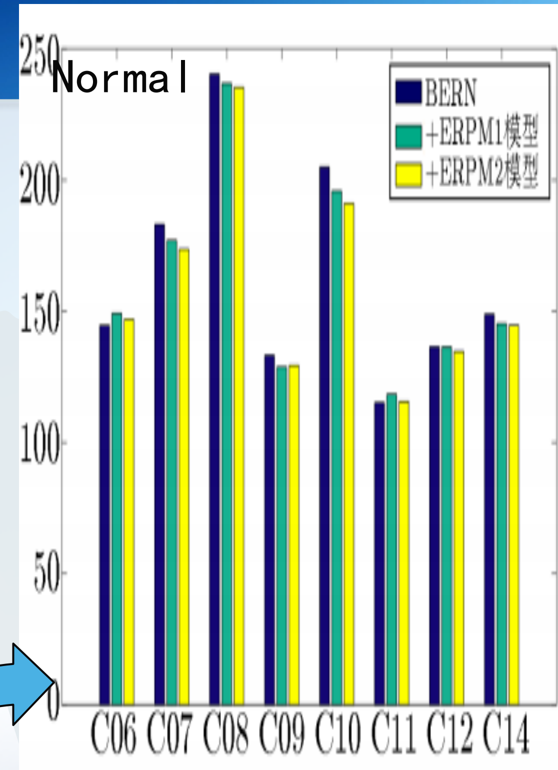
Earth Radiation Pressure for BDS



The acceleration change of earth radiation pressure of BDS GEO (a) / IGSO (b) / MEO (c) satellite in R / T / N.

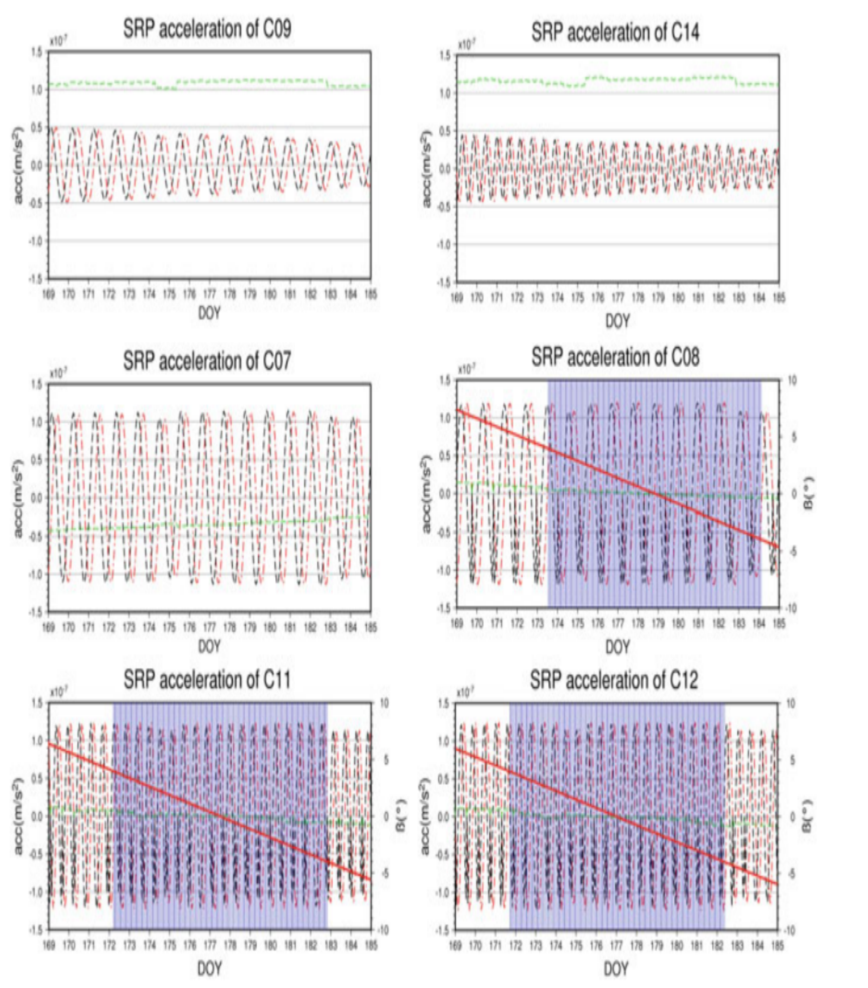




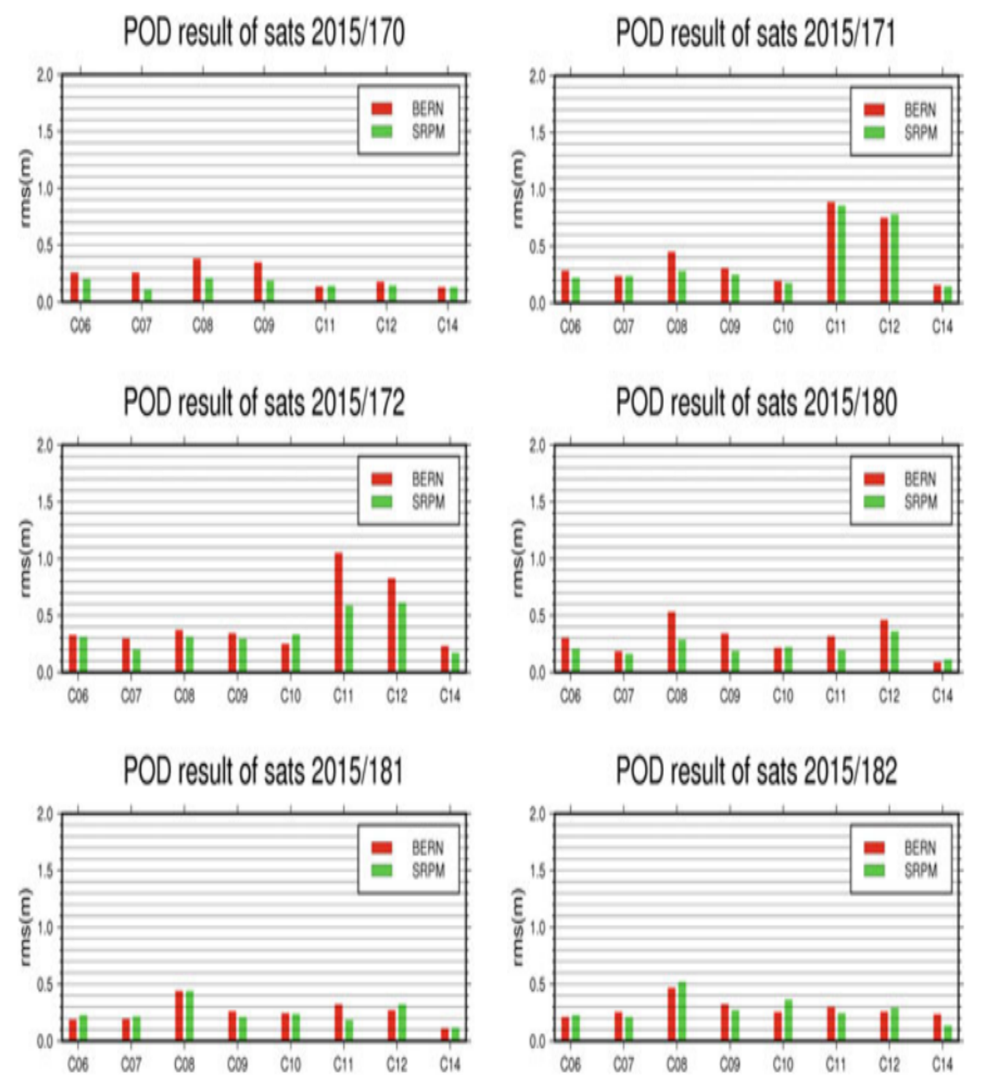


Orbit accuracy comparisons of 3 status: without the earth radiation pressure model（BERN）, considering point source ERP model(ERPM1) and numerical grid ERP model(ERPM2) (w.r.t GFZ precision orbit)

Solar Radiation Pressure model considering attitude switching

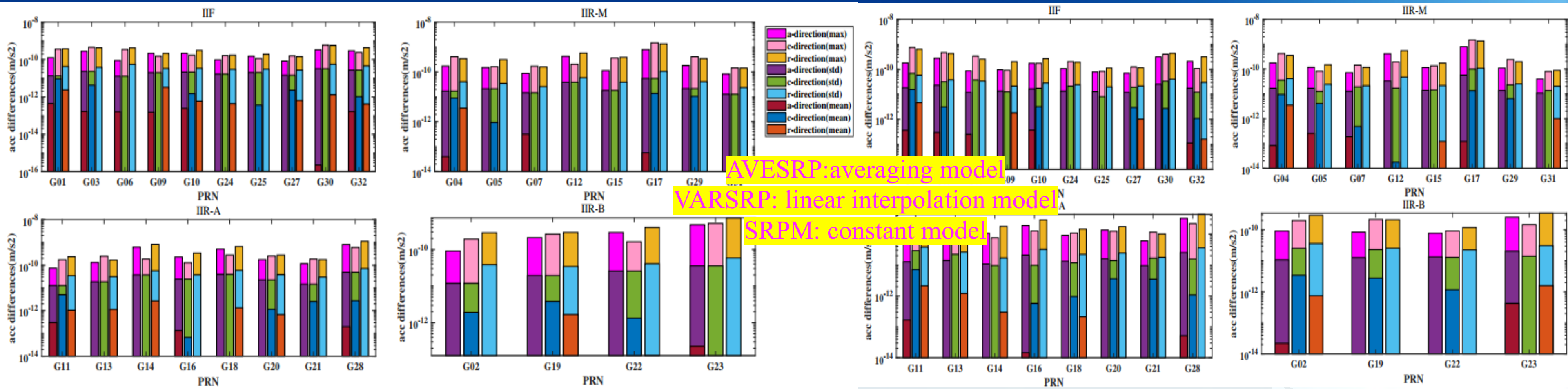


Acceleration change during attitude switching period (The R/T/N was plotted in black/red/green. The blue shadow is satellite orbit-normal and the sun elevation is drawn with red .)



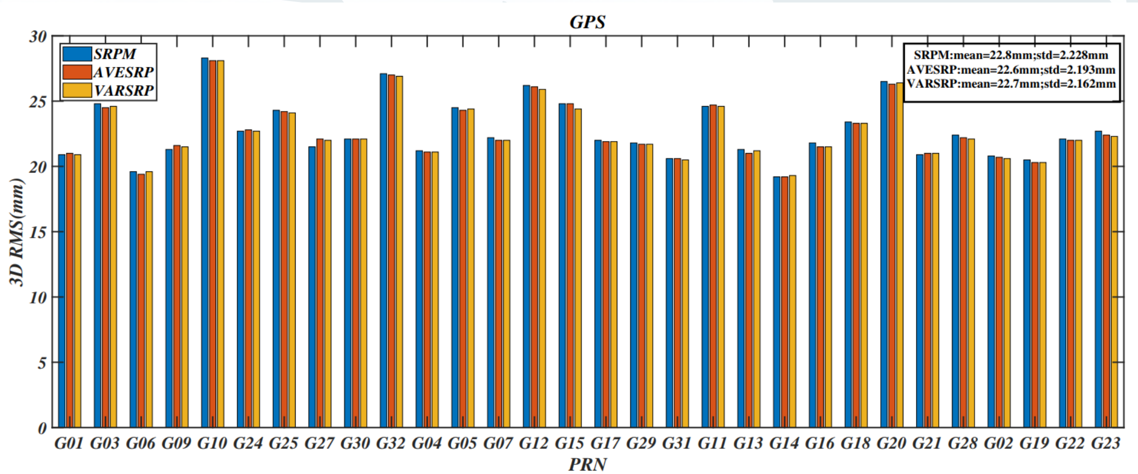
The orbit comparison between the BERN and SRPM model during attitude switching (w.r.t GFZ precision orbit) in period.

SRP model with considering Solar Irradiance Change(GPS test)



SRP acceleration difference of AVESRP and SRPM(Right), VARSRP and SRPM(Left)

The VARSRP and AVESRP models are more consistent and show common features. The acceleration difference of most GPS satellites is up to $10^{-10} m/s^2$, some even reach to $10^{-9} m/s^2$, the mean value is around $10^{-13} m/s^2$, and the mean square error is about $10^{-11} m/s^2$.

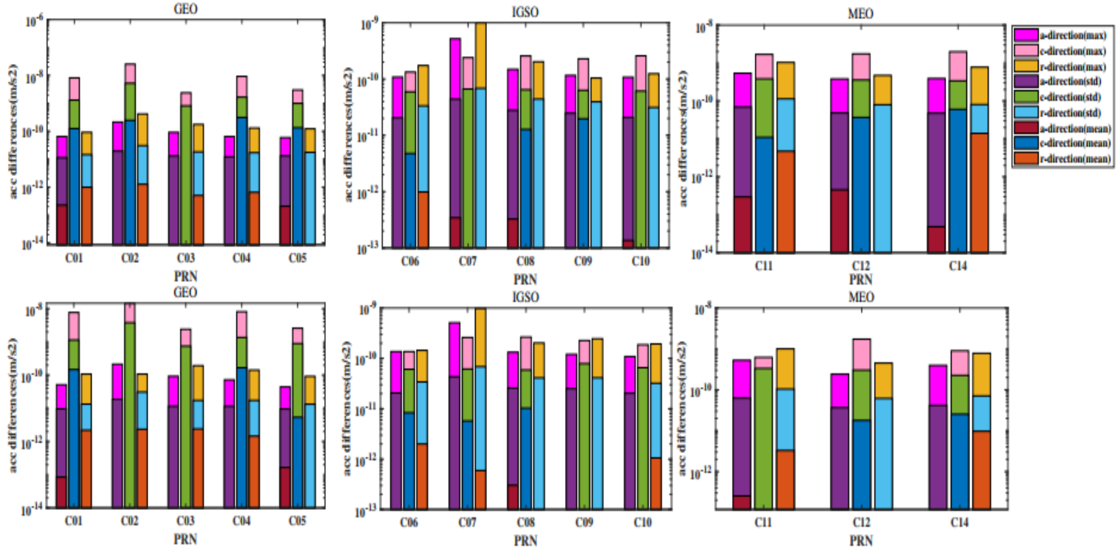


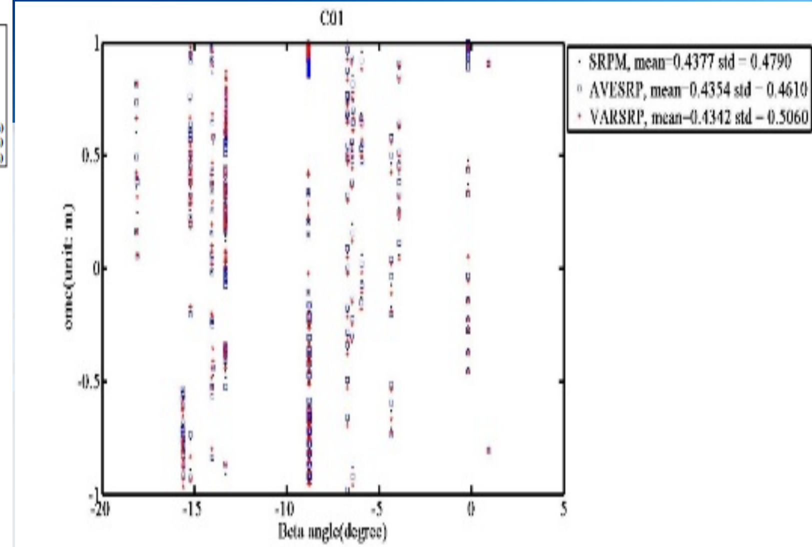
3D-RMS of GPS orbit for SRPM, AVESRP and VARSRP

Conclusion

1.The three models have little difference in the orbit determination accuracy of GPS satellites.
2.AVESRP: 10% (3 satellites) unchanged; 70%(21 satellites) improved;
3.VARSRP: 17% (5 satellites) unchanged; 73%(22 satellites）improved
4.The improvement is about 0.1—0.5 mm.

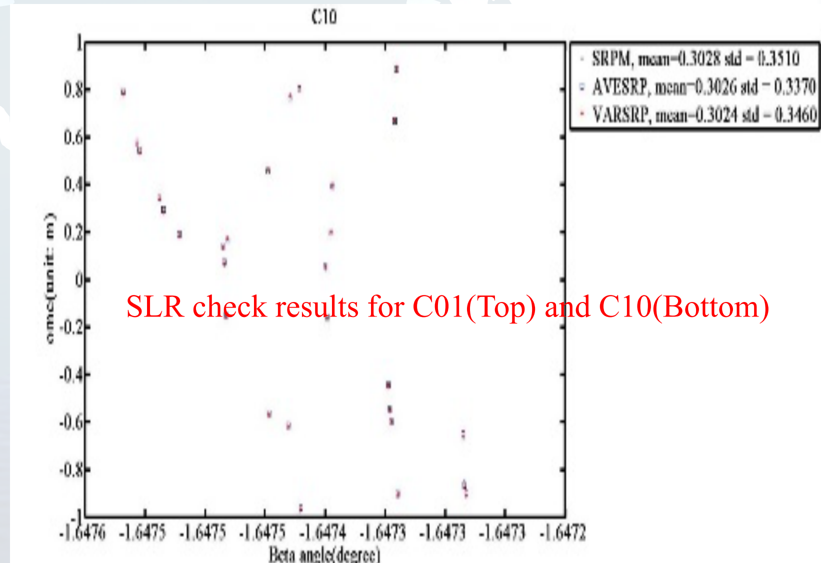
SRP model with considering Solar Irradiance Change(BDS test)



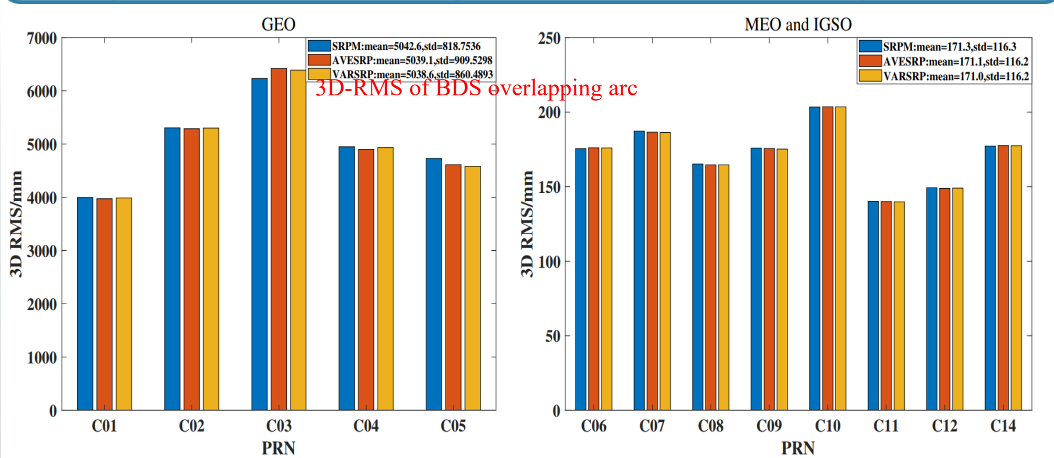


SRP acceleration difference of AVESRP and SRPM(Top), VARSRP and SRPM(Bottom)

The acceleration difference of BDS can reach to $10^{-10}m/s^2$, and some even reach to $10^{-9}-10^{-8}m/s^2$, the average is about $10^{-11}m/s^2$ magnitude, and the mean square error is around $10^{-11}m/s^2$



SLR check results for C01(Top) and C10(Bottom)

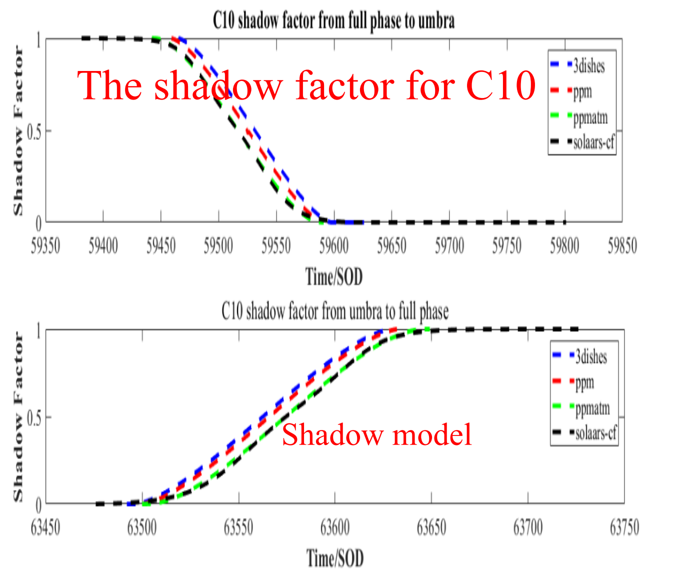


3D-RMS of BDS overlapping arc

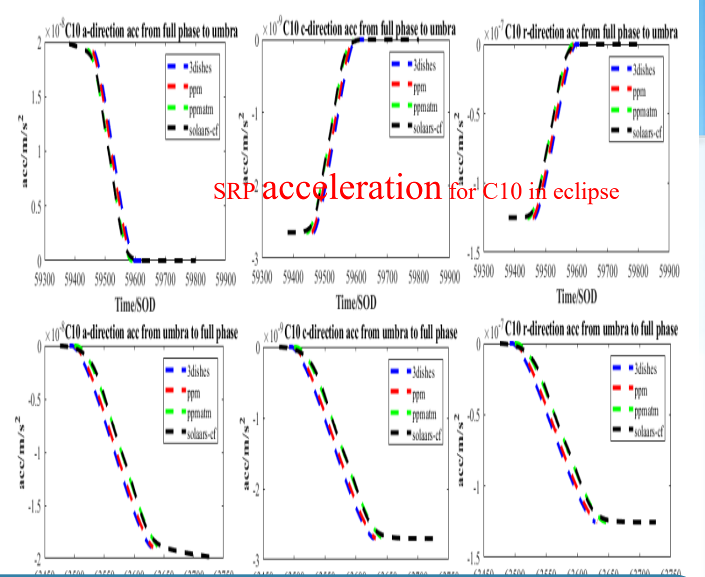
GEO: AVESRP(3.5mm) Improved; VARSRP(4.0mm)Improved
MEO and IGSO: 0.1-0.5mm (Slightly Improved)

C01: AVESRP(2.3mm) Improved; VARSRP(3.5mm)Improvement
C10: AVESRP(0.2mm) Improved; VARSRP(0.4mm)Improvement

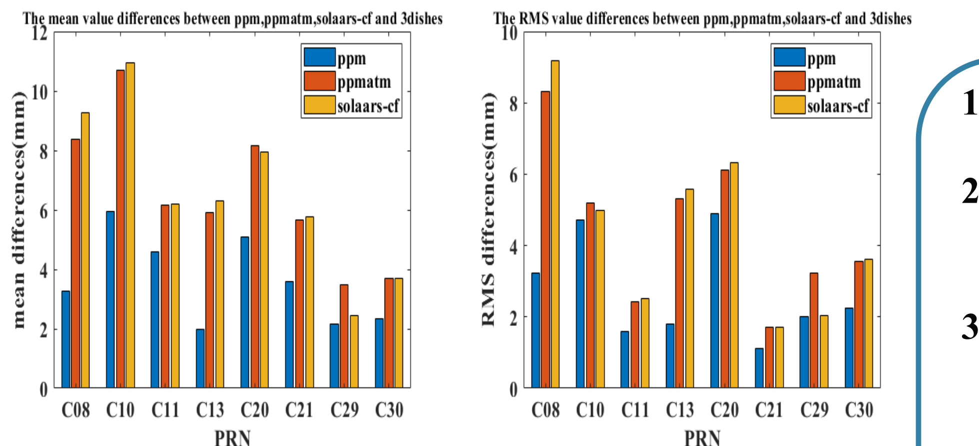
The Refinement of Shadow Model for Beidou Satellites



1. Shadow models(PPM, PPMatm, SOLAARS-CF) with earth oblateness and atmosphere effect enter shadow earlier and come out later than 3dishes
2. The SRP acceleration of PPMatm and SOLAARS-CF have significant difference with PPM and 3dishes
3. PPMatm is highly consistent with SOLAARS-CF



3dishes: conical spherical model considering earth shadow and moon shadow
PPM: prospective projection model considering earth oblateness(from Li(2018))
PPMatm: linear function describing atmosphere effect based on PPM model(from Li(2018))
SOLAARS-CF: semi-empirical model considering earth oblateness and atmosphere effect(from Robertson(2015))



SLR check result for Beidou satellites(mean and RMS of three models regard to 3dishes)

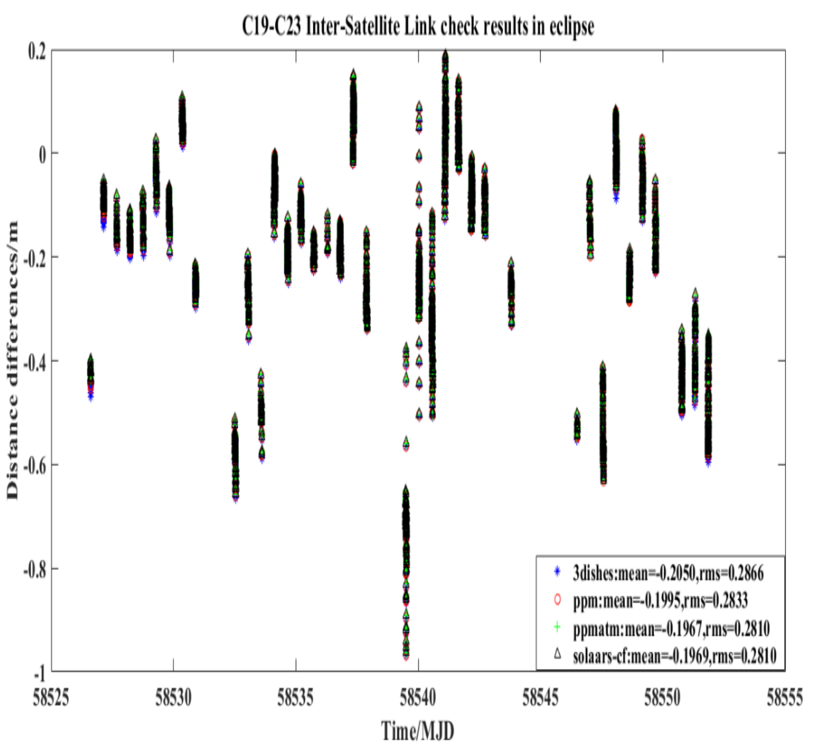
Conclusion

1. **PPMatm and SOLAARS-CF's performance is better than other two models**
2. **Mean: The maximum improvement of PPMatm and SOLAARS-CF can reach to 10mm, it is generally 2-8mm**
3. **RMS: The maximum improvement of PPMatm and SOLAARS-CF can reach to 8mm, it is generally 2-6mm**
4. **The performance of PPMatm and SOLAARS-CF is comparable**

The Refinement of Shadow Model for Beidou Satellites

The information of Inter-satellite link

Time period (DOY)	Launch	Eclipse (Yes or No)	Reception	Eclipse (Yes or No)
043-070	C19	Yes	C23	No
043-070	C21	Yes	C23	No
102-118	C27	Yes	C22	No
102-118	C30	Yes	C23	No



Regard C19-C23 Inter-satellite link check as an example

The statistics result of Inter-satellite link check

sat-link	Shadow model	Mean(m)	RMS(m)	dif_{mean}(m)	dif_{RMS}(m)
C19-C23	3dishes	-0.2050	0.2866	0	0
	PPM	-0.1995	0.2833	0.0055	0.0033
	PPMatm	-0.1967	0.2810	0.0083	0.0056
	SOLAARS-CF	-0.1969	0.2810	0.0081	0.0056
C21-C23	3dishes	-0.2393	0.2981	0	0
	PPM	-0.2375	0.2965	0.0018	0.0016
	PPMatm	-0.2357	0.2946	0.0036	0.0035
	SOLAARS-CF	-0.2360	0.2947	0.0033	0.0034
C27-C22	3dishes	-0.2412	0.3896	0	0
	PPM	-0.2358	0.3859	0.0054	0.0037
	PPMatm	-0.2331	0.3829	0.0081	0.0067
	SOLAARS-CF	-0.2329	0.3834	0.0083	0.0062
C30-C22	3dishes	-0.1419	0.3532	0	0
	PPM	-0.1385	0.3515	0.0034	0.0017
	PPMatm	-0.1375	0.3509	0.0044	0.0023
	SOLAARS-CF	-0.1384	0.3511	0.0035	0.0021

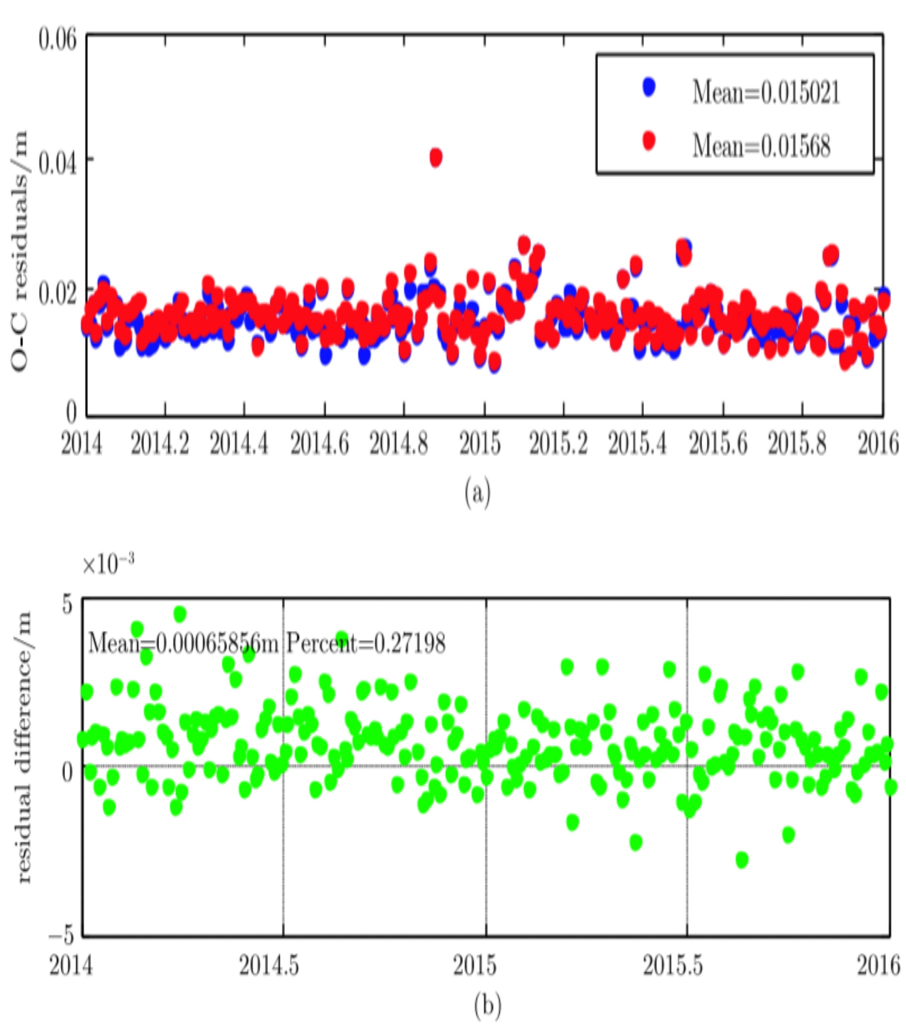
Conclusion

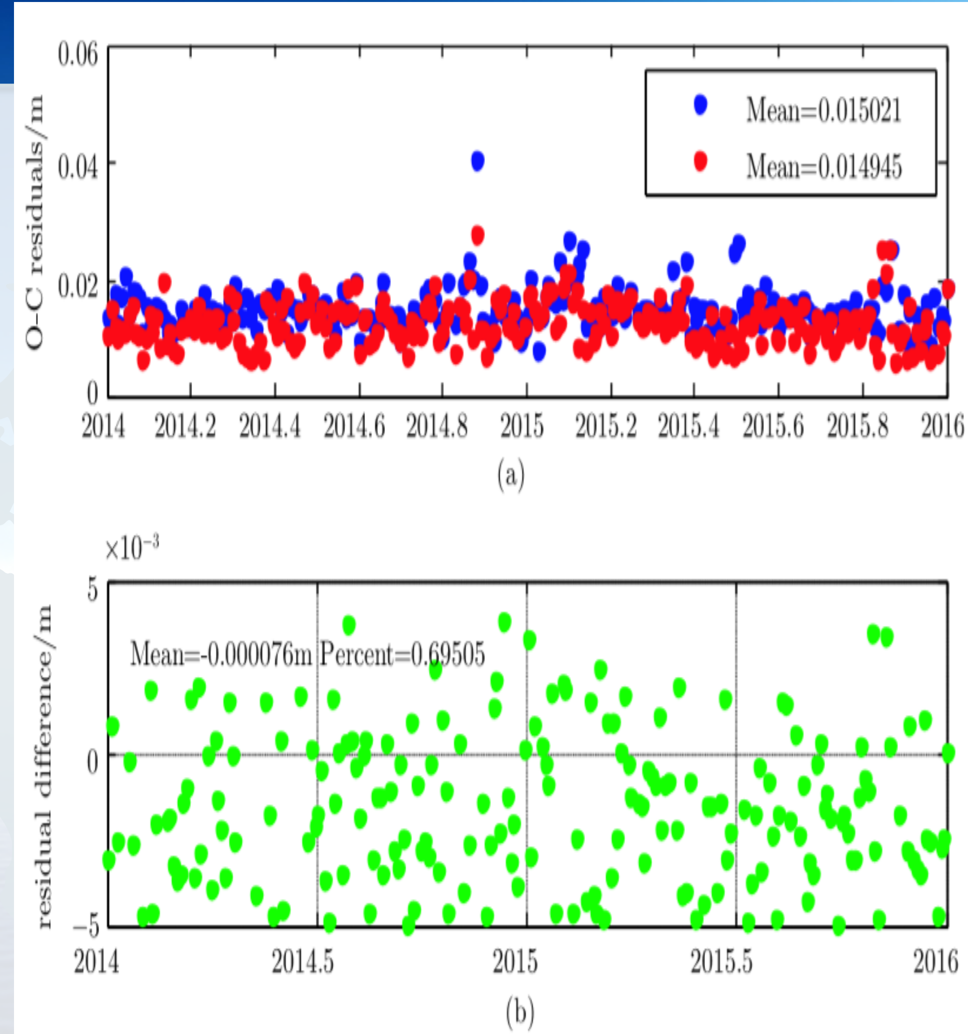
1. **Mean: The maximum improvement of PPMatm and SOLAARS-CF can reach to 8mm, it is generally 2-6mm**
2. **RMS: The improvement of PPMatm and SOLAARS-CF is generally 2-6mm**
3. **The performance of PPMatm and SOLAARS-CF is comparable**

2. Data processing software update

SLR data processing software update

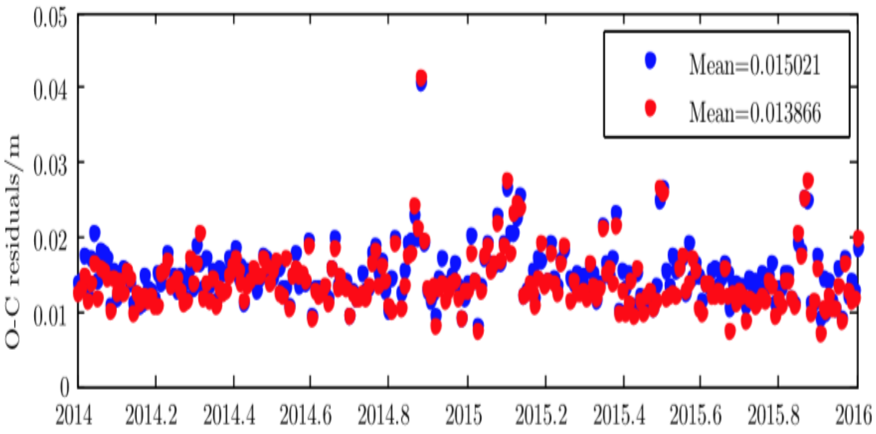
Ocean Tide Model Update



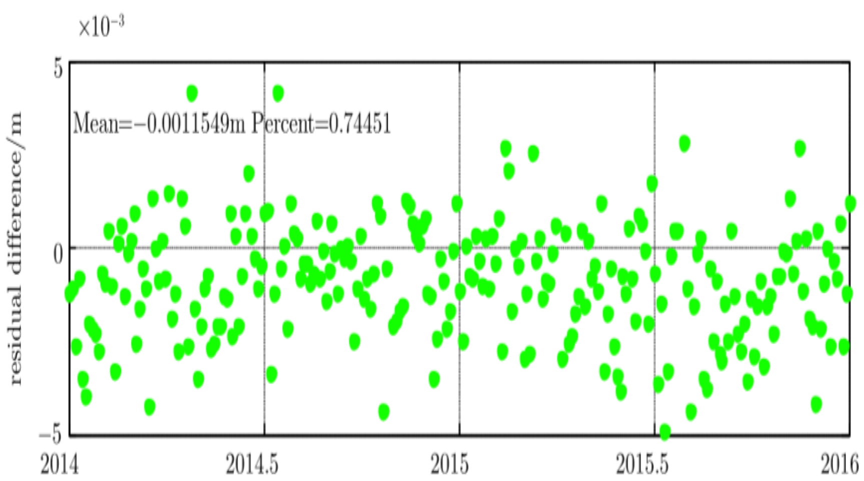


Lageos1(left) and Lageos2(right)'s residual WRMS with CSR3.0(blue) model and FES2004(red) model, and differences between 2 models(down). FES2004 shows better.

Reference Frame Update



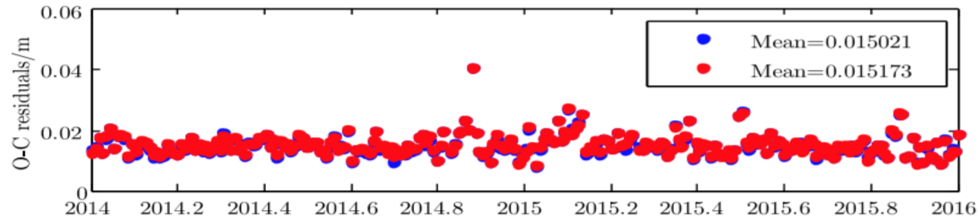
(a)



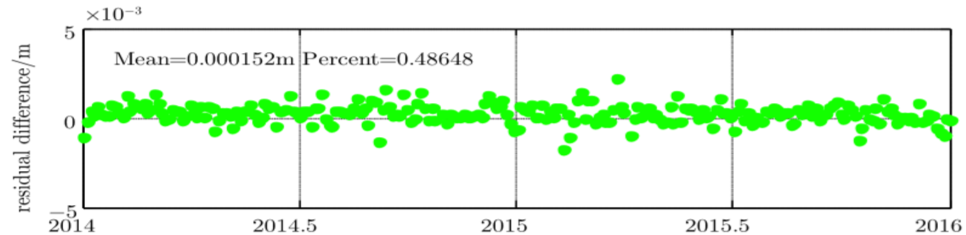
(b)

Lageos1's residual WRMS with SLRF2008(blue) and SLRF2014(red), and the difference between 2 models(down). SLRF2014 shows better.

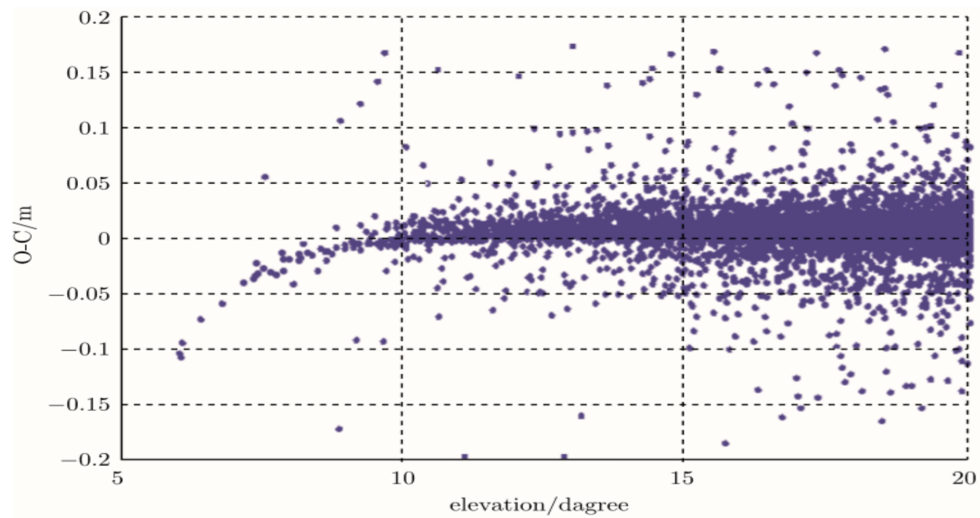
Troposphere Model Update



(a)



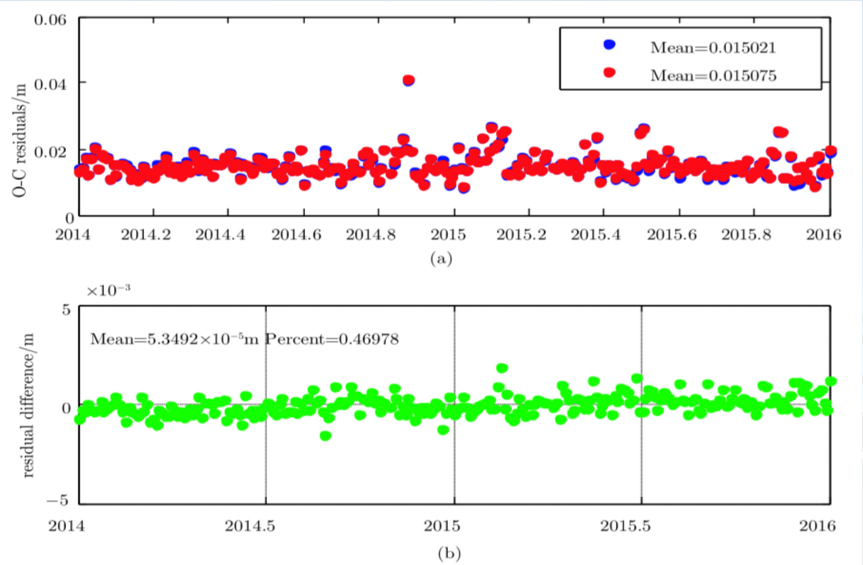
(b)



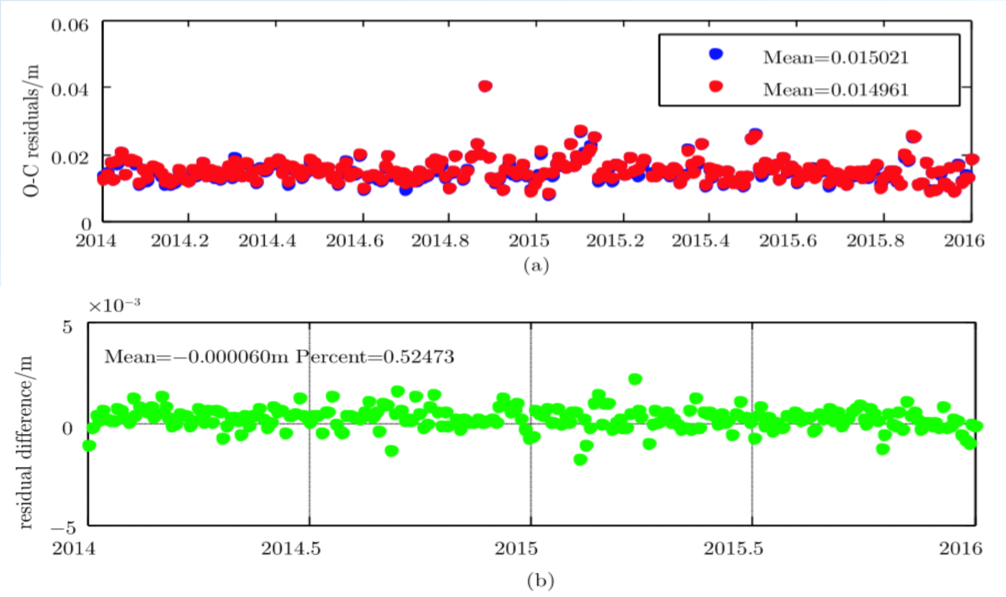
Lageos1's residual WRMS with Marini-Murray model(blue) and Mendes-Pavlis(red) model, and the difference between 2 models. Mendes-Pavlis model performs better in low elevation.

Earth Gravity Model update

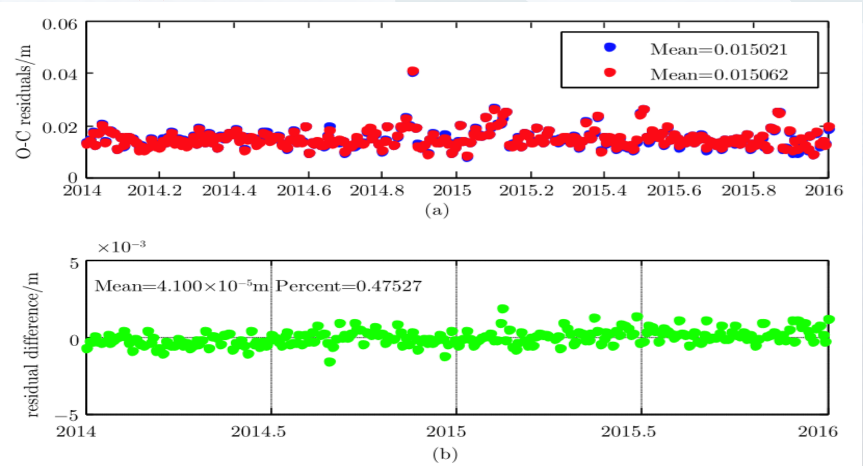
Influence of Different gravity models on Lageos1 orbit(4 models:EGM2008, GGM05C, GOCO05C, G0CO05S, in blue point) with CM01C model(in red). EGM2008, GGM05C and G0C005S perform better than GM01C. GGM05C shows better.



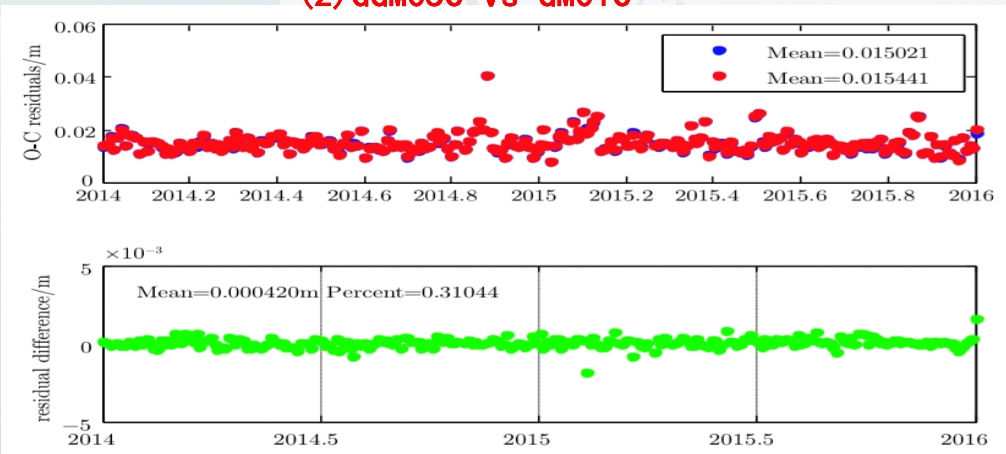
(1) EGM2008 vs GM01C



(2) GGM05C vs GM01C

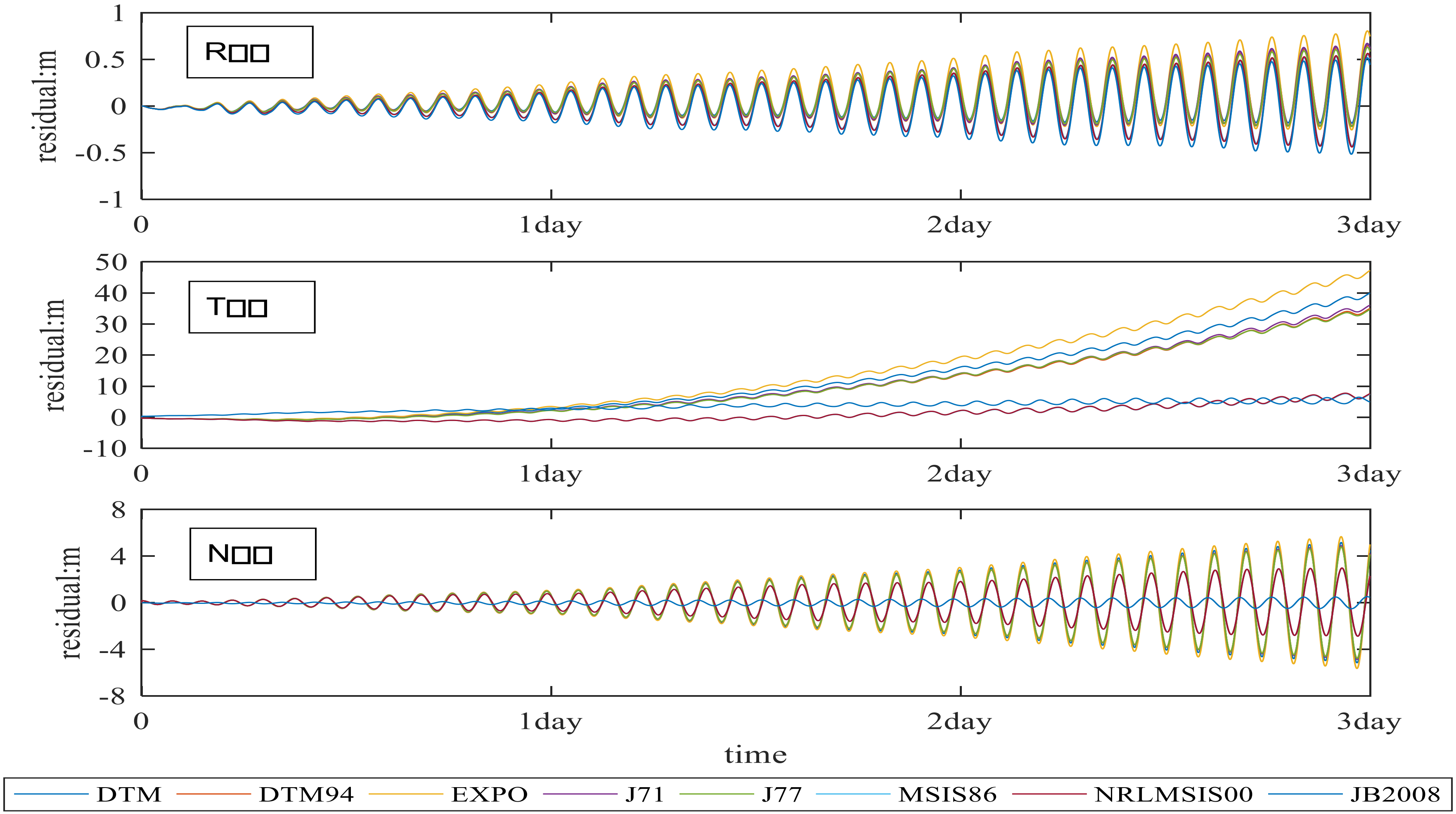


(3) GOCO05C vs GM01C



(4) GOCO05S vs GM01C

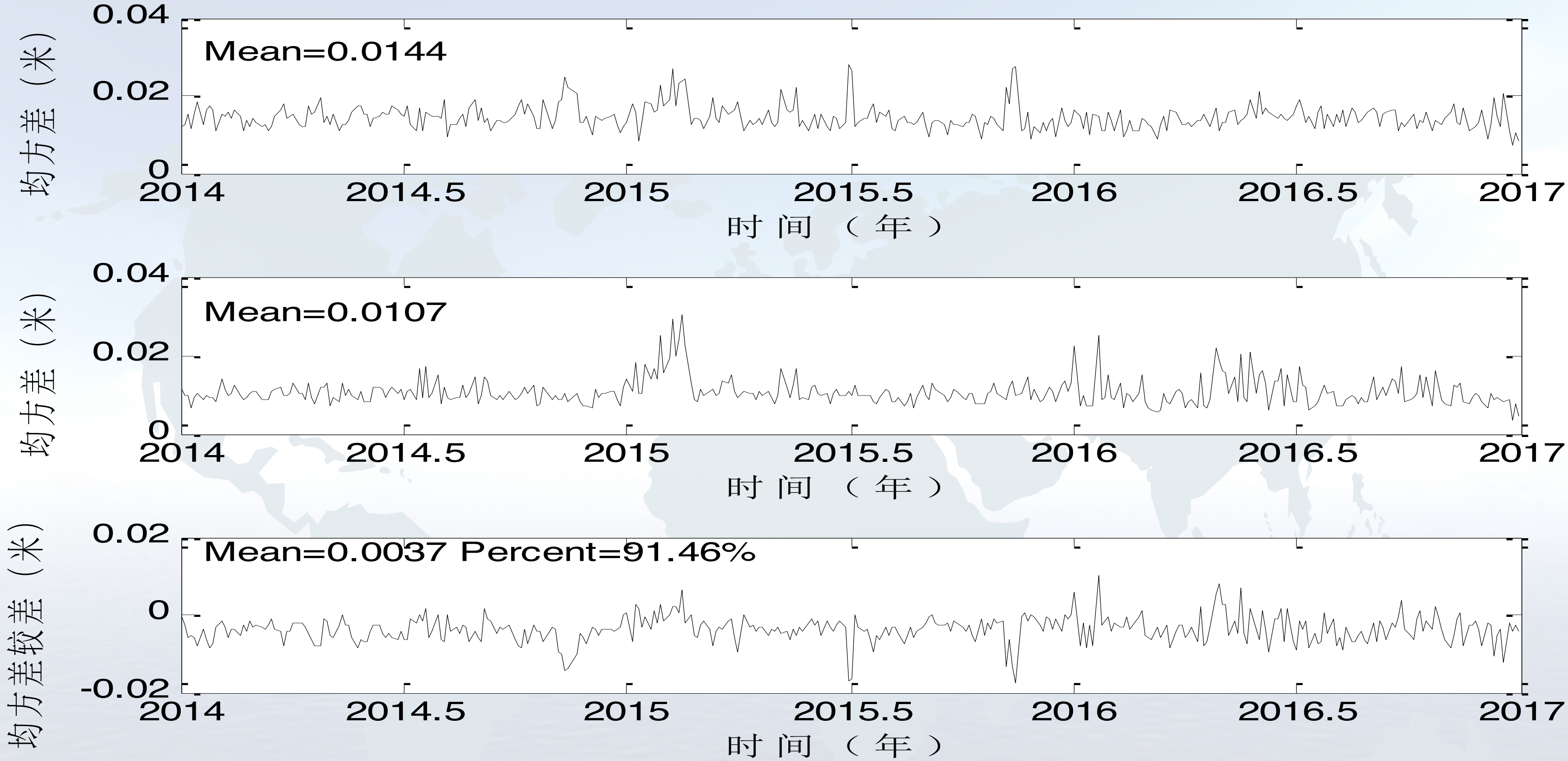
Atmosphere Drag Model Update



We add 2 new drag models: NRLMSISE00 and JB2008. The RTN difference of JASON2 predicted orbit and precise orbit with 8 atmosphere drag model(exponential model, DTM, DTM94, J71, J77, JB2008, MSIS86, NRLMSIS00). NRLMSISE00/MSIS86 drag models show better.

Weighting strategy Update

LAGEOS 1 orbit precision rms by old experience weighting strategy (up)， by modified FCM weighting strategy with SLR seasonal quick report information （middle）， the difference of above two and the improved arc ratio.（bottom）



The observed residual rms was improved by 3.7mm on average and 91.46% of the arc segment was improved. The residual RMS of all the stations involved in the calculation was reduced.

Weighting strategy Update

SLR core sites residual RMS and NPT number with different weighting strategy

SLR site	Old experience weighting strategy		Modified FCM weighting strategy	
	NPT Number	Residual RMS(m)	NPT Number	Residual RMS
7080	1497	0.0189	1500	0.0176
7090	34835	0.0176	34919	0.0172
7105	14973	0.0235	15116	0.0158
7110	10258	0.0204	9739	0.0140
7501	9066	0.0195	8862	0.0178
7810	14999	0.0108	15016	0.0090
7825	13491	0.0169	13983	0.0128
7839	6466	0.0125	6417	0.0107
7840	12991	0.0102	13067	0.0098
7941	13970	0.0154	14210	0.0095
8834	4227	0.0208	4289	0.0201

The residual RMS of all SLR sites are reduced and the NPT number is improved.

3. CERS，STRF and CERS EOP products

http://cers.shao.ac.cn

CERS
Chinese Earth Rotation and Reference Systems Service
Shanghai Astronomical Observatory

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CERS Introduction

The Chinese Earth Rotation and Reference Systems Service (CERS), formerly the Chinese Earth Rotation Service, is the body responsible for maintaining global time and reference frame standards, notably through its Earth Orientation Parameter (EOP) and Global Celestial Reference System (CRS) groups.

more...

Data and Products

The CERS mainly contains the Earth Orientation Parameters(EOPs), Global Celestial Reference Frame(CRF), Terrestrial Reference Frame(TRF), VLBI/SLR/GNSS/DORIS sub-center, IGMAS(International GNSS Monitoring and Assessment System) and Geophysical Fluids Data, Gravity research.

more...

Publications

Here gives annual reports, technical notes and publications about the CERS.

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View news ordered by date or with respect to publications or general topics of the CERS. Calendars of meetings

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Data / Products
- SHAO TRF/TRS
- EOPs
- VLBI AC
- SLR AC
- GNSS AC
- DORIS AC
- iGMAS AC
- Geophysical Fluids Data
- Gravity

SHAO Terrestrial Reference Frame

SHAO Terrestrial Reference Frame（STRF）is the basis for positioning and navigation at the Earth and its near environment and for scientific applications. Celestial Reference Frame（CRF）is a quasi-inertial reference frame defined based on the radio positions of extragalactic sources distributed over the entire sky (Gérard, 2010). Earth Orientation Parameters（EOP）are fundamental parameters connecting the high-precision TRF and CRF. They include precession, nutation and ERP. Precession and nutation show the motion of the earth rotation axis in space that can be obtained by models such as IAU2006 precession model and IAU2002 nutation model. ERP include Px, Py, UT1-UTC and LOD.

SHAO TRF products：

- STRF2013-TRF-GPS.SNX
- STRF2013-TRF-VLBI.SNX
- STRF2013-TRF-SLR.SNX
- STRF2013-TRF-DORIS.SNX

- Leader: WANG Xiaoya (wxy@shao.ac.cn)
- Member: HE Bing, WU Bing, HU Xiaogong, WANG Guangli, ZHAO Qunhe

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Earth orientation Parameter and data

Missions of the EOP Product Centre of Chinese International Earth Rotation Service and Reference Systems :
Collect through the world the time series of the Earth Orientation Parameters (EOP):
polar motion (x,y)
universal time (UT1-UTC, UT1-TAI)
Celestial pole offsets (Dpsi, Deps)

These time series are derived from the various astro-geodetic techniques (SLR, GNSS, VLBI and DORIS).
Archive EOP and make them avaible through WEB(no FTP)(EOPs products introduction)
Analyse EOP and in particular monitor their consistencies with respect to the international terrestrial and celestial referene frames.
Compute a combined standard solution for EOP (Chinese Bulletin A) and C04 solution (eop_daily.txt).

Applications
astrometry, geophysics, space geodesy, orbit determination, timing, positionning

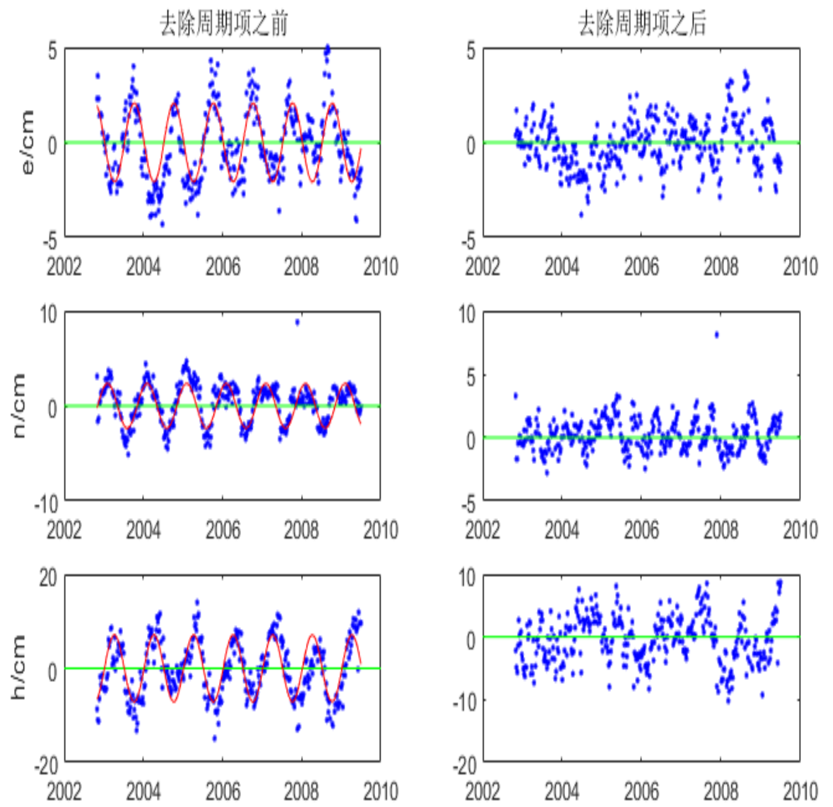
Leader：WANG Xiaoya (wxy@shao.ac.cn)

Member：ZHOU Yonghong, HU Xiaogong, WANG Guangli, WU Bing, HE Bing, XU Xueqing, XU Minghui, ZHAO Qunhe

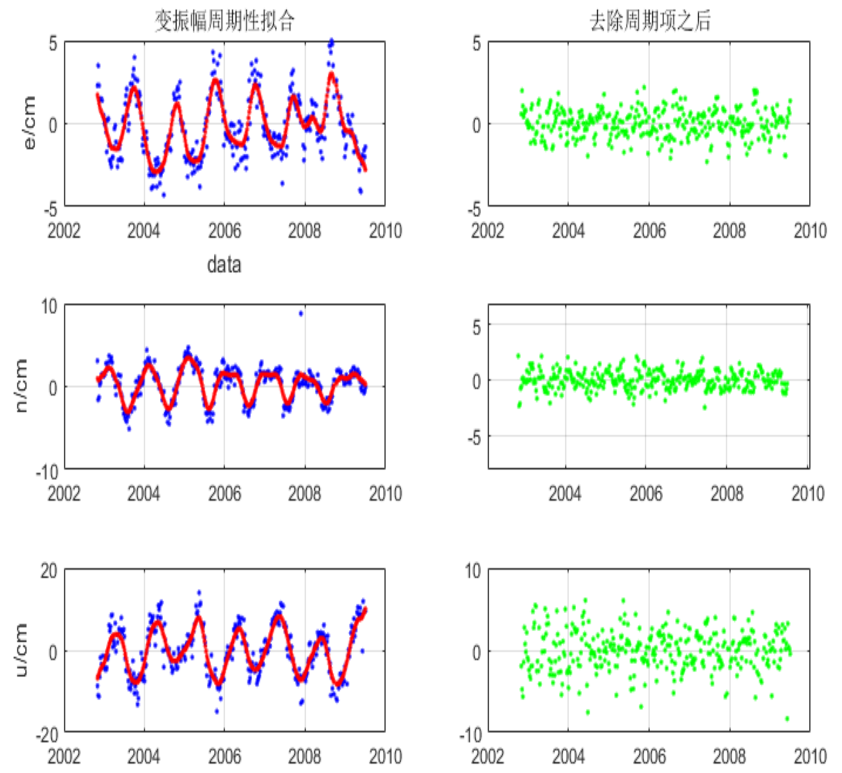
XU Tianhe, SUN Zhangzhen(Xi'an Research Institute of Surveying and Mapping)

Nonline TRF establishment

$$X_{PSD}(t) = X(t_0) + \dot{X}(t - t_0) + \sum_{i=1}^{2}\left(a_i \cos\left(\frac{wt}{i} - \emptyset_i\right) + b_i \sin\left(\frac{wt}{i} - \emptyset_i\right)\right) + \delta X_{PSD}(t)$$

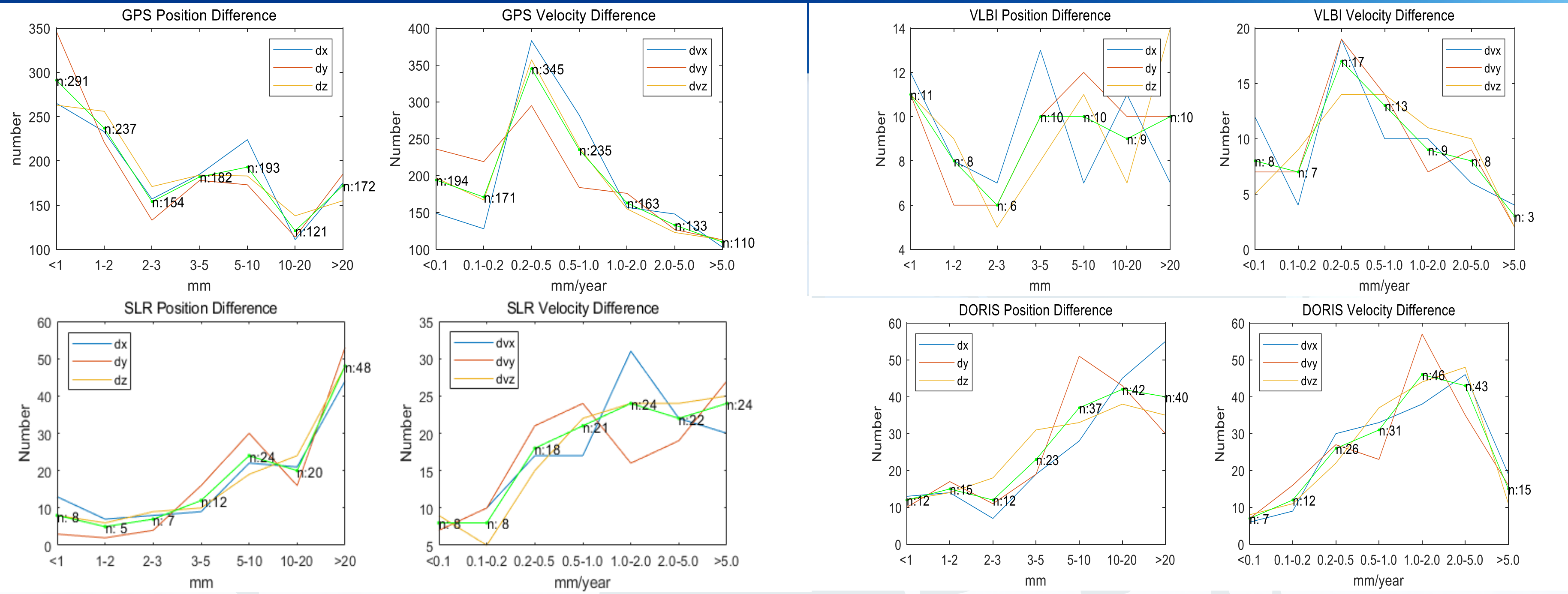


Period fitting based on least square



SSA fitting

STRF Products accuracy evaluation

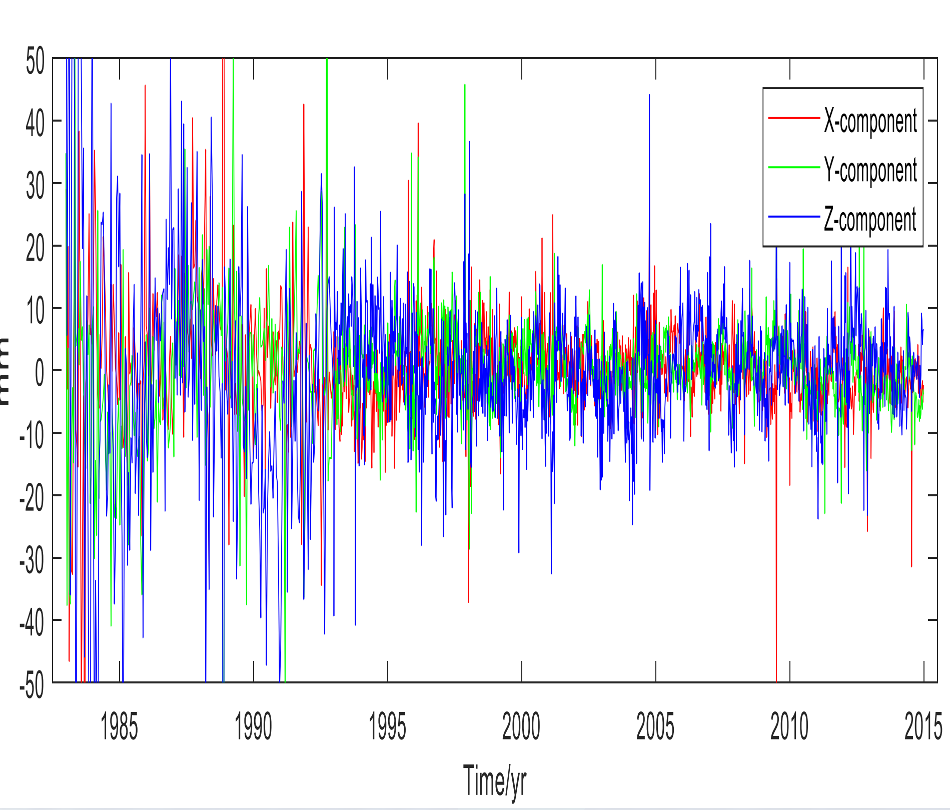


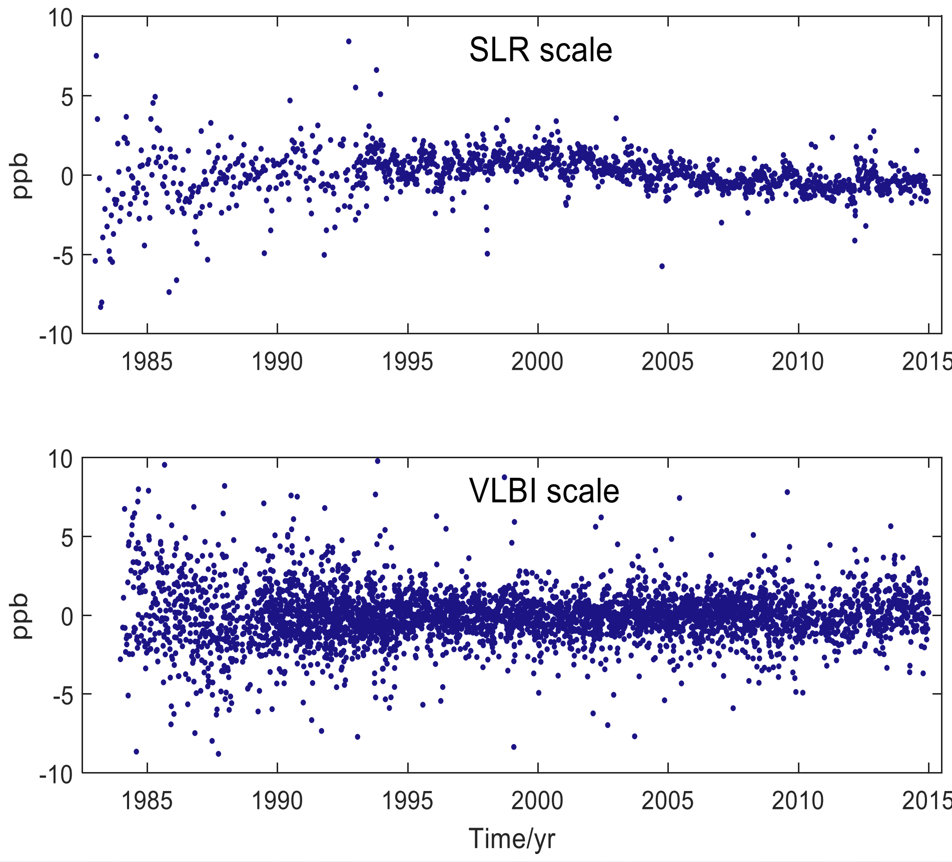
Site number statistics with different accuracy range of STRF2014 (SHAO nonlinear Terrestrial Reference Frame) for GPS/VLBI/SLR/DORIS w.r.t ITRF2014.

Comparison result statistics of the coordinates and velocities for four techniques between SHAO nonlinear Terrestrial reference frame (STRF) and ITRF2014

Technique	Coordinate accuracy statistics (mm)		Velocity accuracy statistics (mm/yr)	
accuracy range	<1	(1,2)	<0.1	(0.1,0.2)
GNSS	21.6%	17.6%	14.4%	12.7%
VLBI	17.2%	12.5%	12.5%	10.9%
SLR	6.5%	4.0%	6.5%	6.5%
DORIS	6.6%	8.3%	3.7%	6.6%

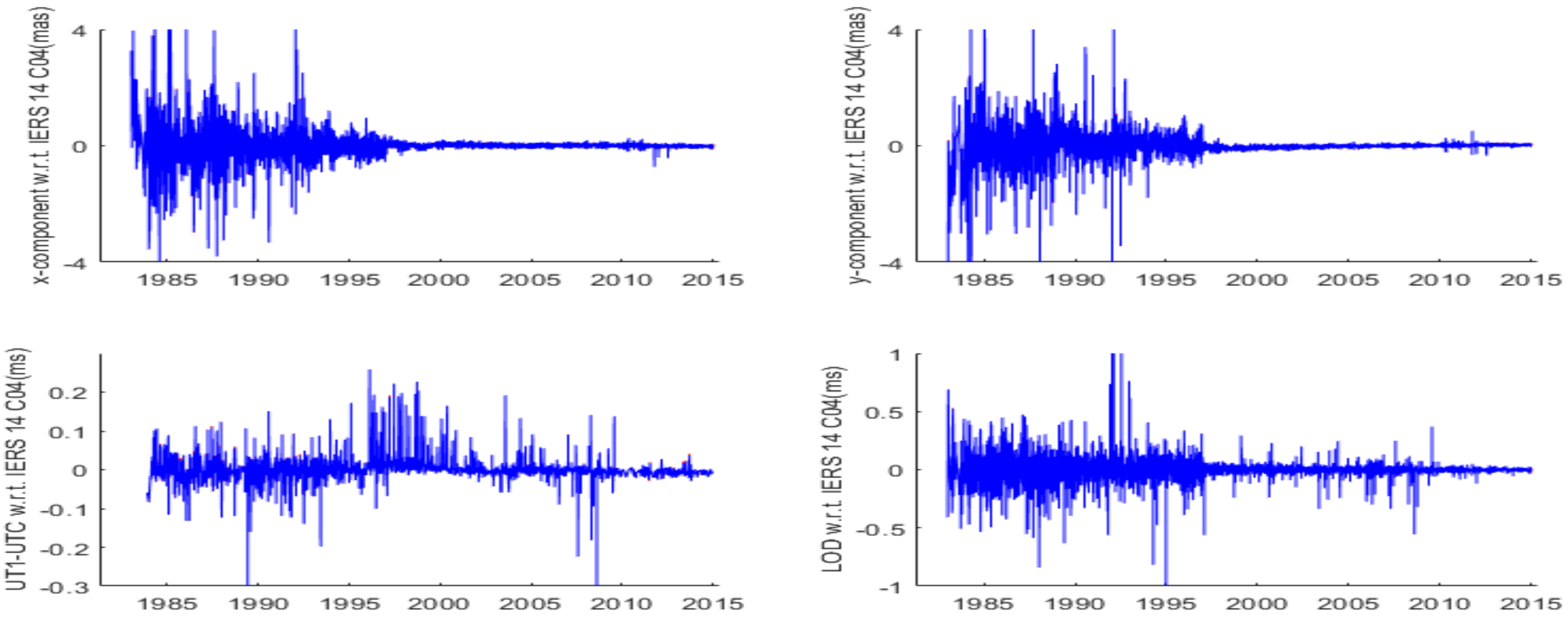
STRF Products accuracy evaluation





Translation parameters and Scale factors of STRF2014.

CERS C04 EOP Products accuracy evaluation



CERS C04 EOP products comparison with IERS 14 C04

EOP Parameters	WRMS w.r.t. IERS C04
x-component of Polar Motion (mas)	0.0564
y-component of Polar Motion (mas)	0.0576
UT1-UTC (ms)	0.0103
LOD (ms)	0.0109

4. Conclusions and future plans

① Chinese space geodetic network has contributed to global space geodesy and GGOS. They will be developed with SLR equipment modification, more GNSS sites and more VGOS sites in future.

② The accuracy and stability of TRF will be improved with multiple efforts from different countries. The observation model and dynamics model of each technology still need to be improved. At present, basic tests of SLR and GNSS have been completed, and VLBI and DORIS also need to be improved.

③ There is a space for improvement in the solution strategy. SLR has been successfully tested, and similar tests are needed for other technologies.

④ The results of the international combination centres for various technologies also need to be compared and tested. The third combination centre is necessary.

⑤ STRF2020 is under considered with dense Chinese GNSS network and multi-GNSS data analysis.

Acknowledgements

This work has been funded by the National Key Research and Development Program of China (2016YFB0501405), the National Natural Science Foundation of China (11973073), the Basic project of Ministry of Science and Technology of China (2015FY310200) and the Shanghai Key Laboratory of Space Navigation and Position Techniques (No.06DZ22101). We really express appreciation all

Thank you for your attention！