iGMAS Update and Preliminary Assessment of Multi-GNSS Performance

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

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iGMAS TEAM

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CONTENT

01

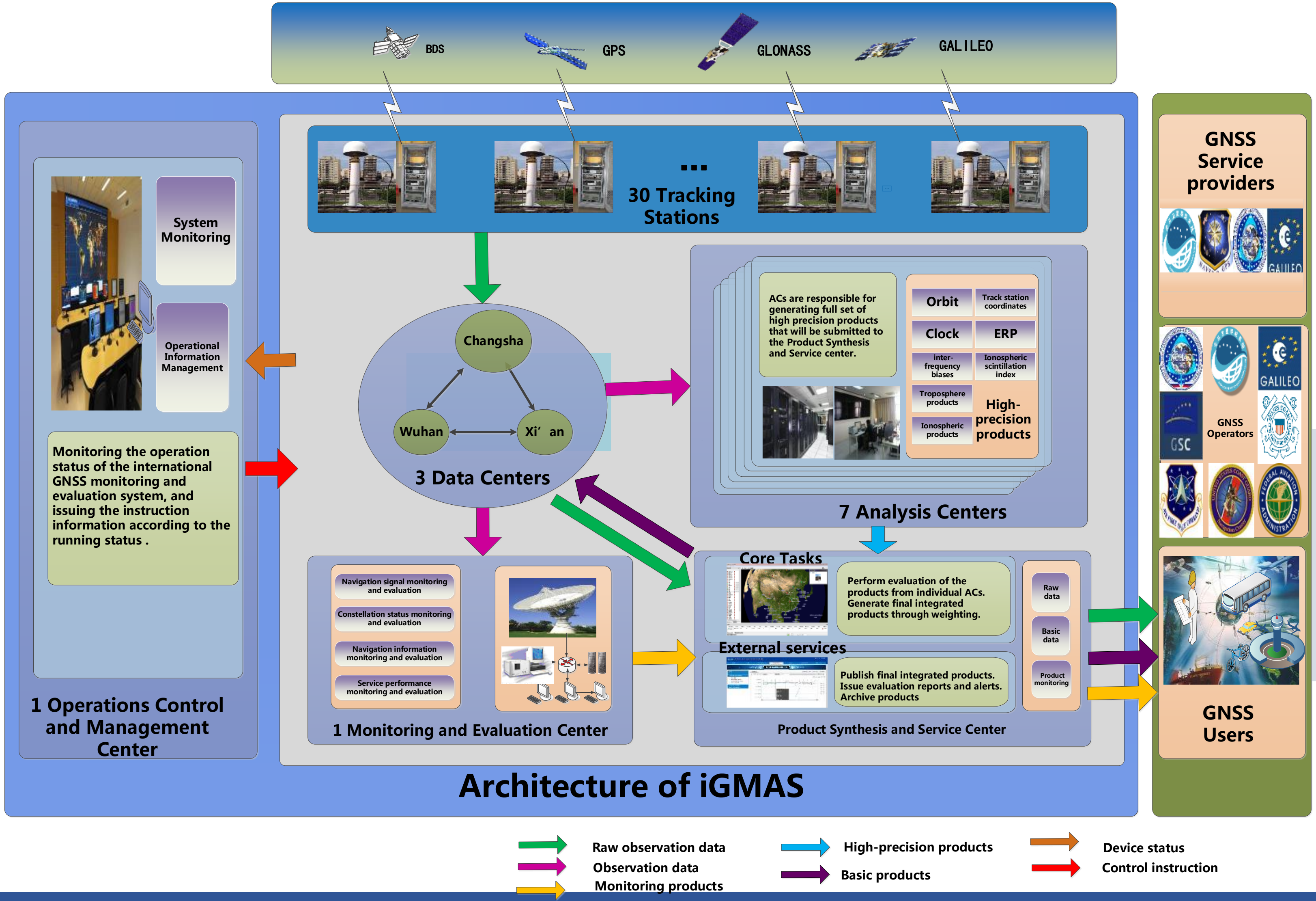
iGMAS Update

1.1 iGMAS Update

The international GNSS Monitoring and Assessment System(iGMAS) has started the service routinely from 2014 (www.igmas.org).With the development of BDS, iGMAS has been improved gradually at:

- **Tracking stations**
- **MAC and AC Centers**
- **Applications**
- **Specifications and Activities**

1.1 iGMAS Infrastructure Update

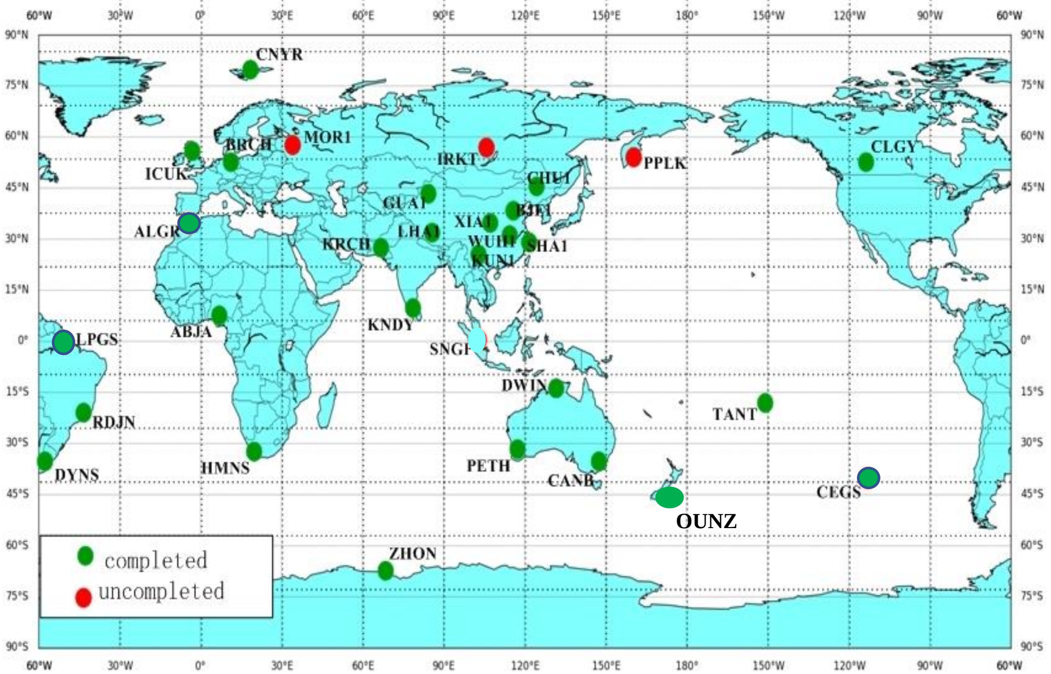


- ◆ **Upgrading tracking stations**
- ◆ **Innovation application for LEO-Augmentation, Meteorology and Railway technology**

1.1 iGMAS Infrastructure Update

30 tracking stations have been built:8 in China,3 in polar regions,19 abroad stations. The new generation of receivers are under upgraded for all stations. The new receivers are capable of tracking all open signals of GNSS.

GPS:L1,L2P,L2C,L5;**BDS**:B1I,B2I,B3I,B1C,B2a;**GLO**:G1,G2;**GAL**:E1,E5A,E5B

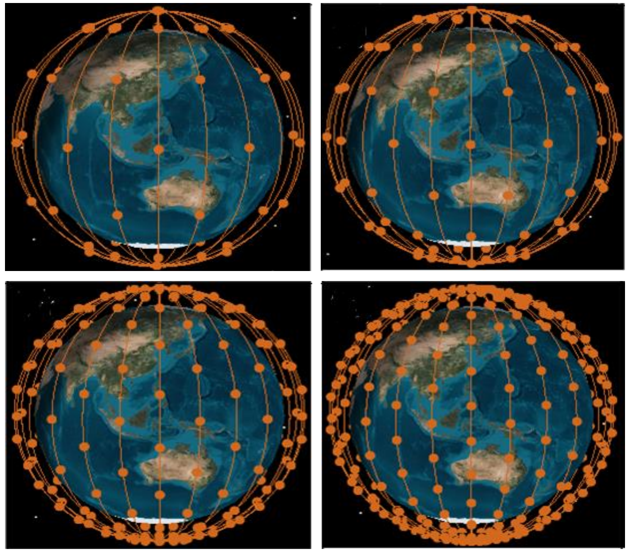


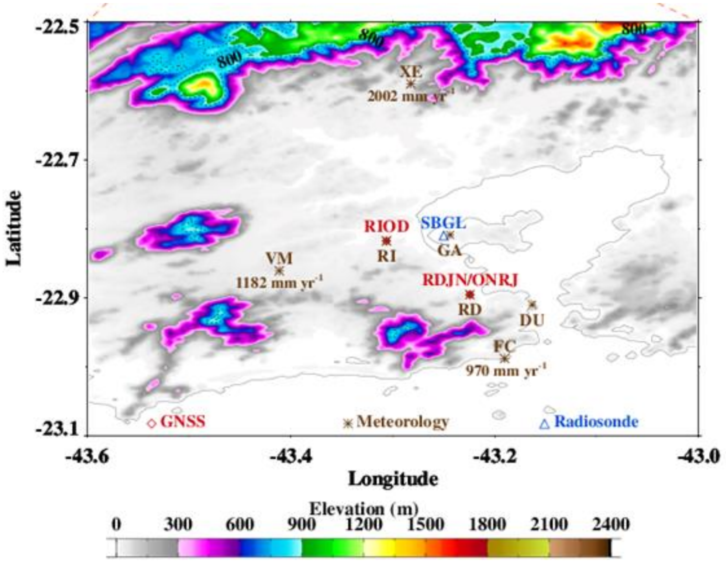
All the Data Centers and Analysis Centers have been upgraded to receive, store, and process all new signals of GNSS, including BDS-3 and provide orbit & clock products for B1IB3I and B1CB2a.

1.2 iGMAS Innovation Application

Several innovation application centers have joined iGMAS for more research and applications, such as:

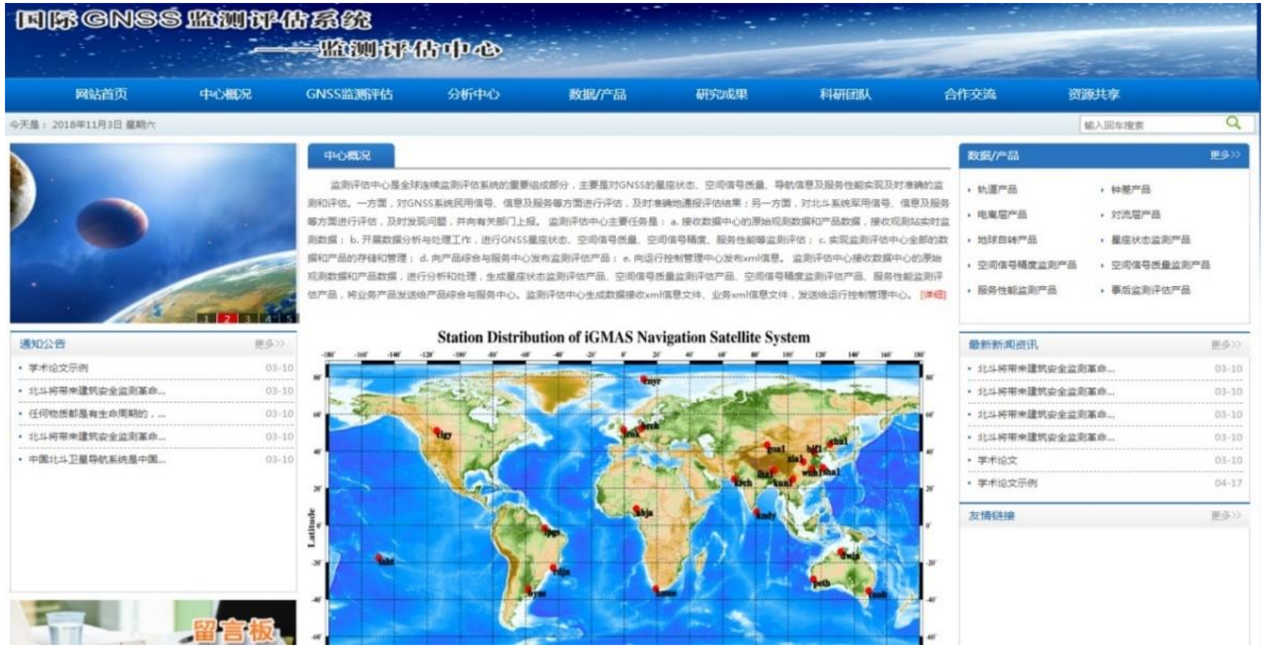
- **Expand and enrich GNSS products such as real-time phase biases and integer recovery clocks.**
- **Enhance current GNSS PNT performances with LEO constellations. Expand the service area of GNSS by providing real-time orbits of LEO satellites, PPP-RTK services, as well as carrier-range GNSS/LEO observations.**
- **Carry out high precision applications at world-wide iGMAS stations with collaborators.**





1.3 iGMAS MACs & ACs Update

- The second Monitoring and Assessment Center was built for iGMAS.
- At MACs, upgrade for near real-time monitoring and capability of processing multi-GNSS new signals. Develop the function of alarming, such as UERE. Working on the improvement of website and APP.
- At ACs, the high precision orbits and clocks for BDS-3 new signals are provided routinely from Step.2019.



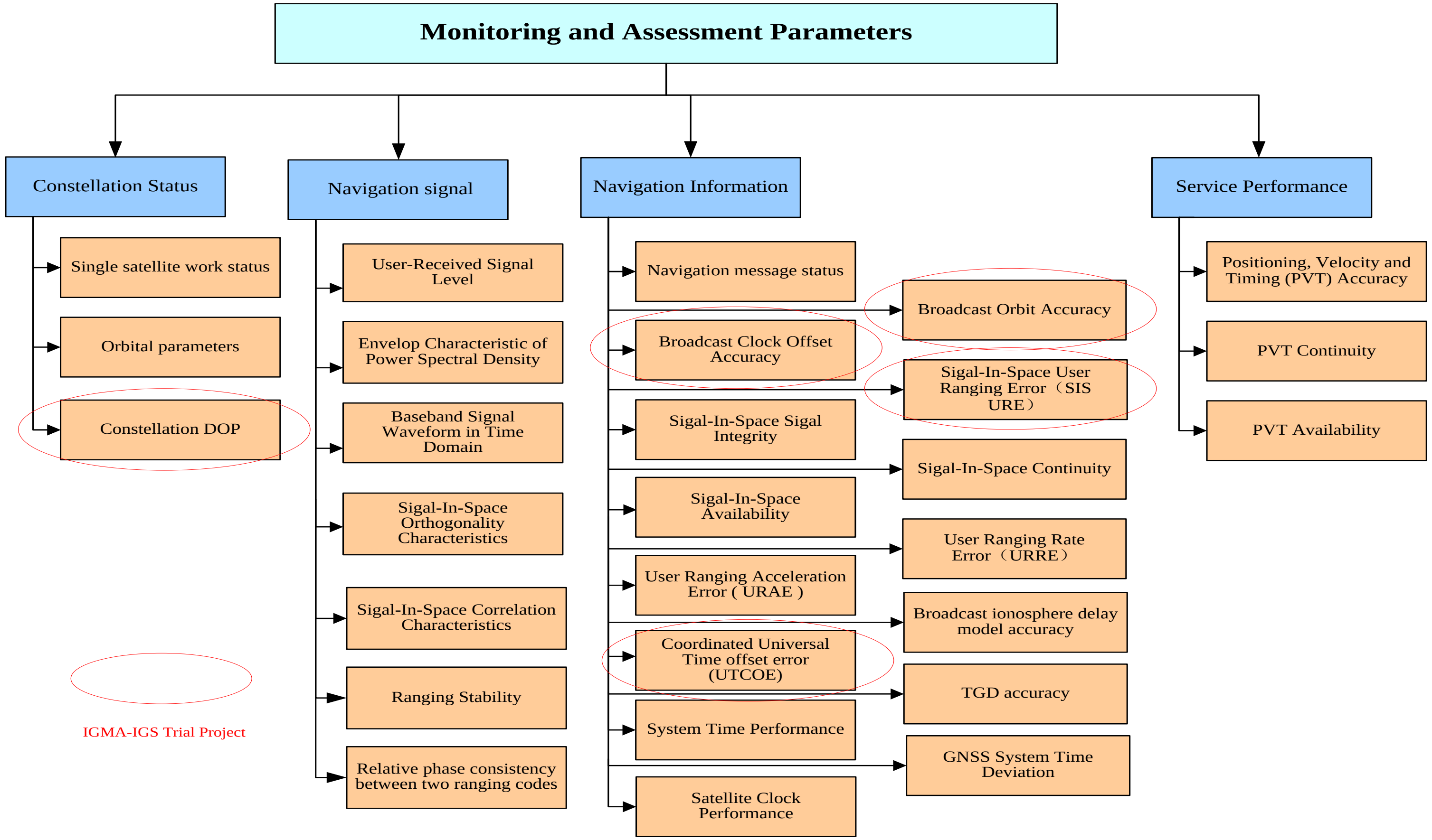
1.4 iGMAS Activities

- A specification has been released for BDS high precision application:《Definitions and descriptions for BDS satellite parameters for high precision application》(http://m.beidou.gov.cn/zt/bdbz/201911/t20191125_19561.html)
- 2019 iGMAS Workshop was held in Aug. in Weihai. There're more than 100 participants from different institutions and universities . The main topic is the improvement of iGMAS and the performance of BDS.

02

Routine Assessment Results

02 iGMAS Monitoring and Assessment Parameters



Four types,29 monitoring and assessment parameters have been defined in iGMAS. Most parameters have been calculated operationally in MACs. The monitoring and assessment reports have been published routinely. Here the results of some parameters discussed in IGMA are presented.

2.1 Broadcast Ephemeris Accuracy (Orbit&Clock&SISURE)

- **With the reference orbit and clock from iGMAS(http://www.igmas.org),PCO and TGD correction.**
- **The mean clock bias is calculated at each epoch from the average broadcast-minus-precise clock values of all satellites in each constellation to remove the clock reference offset.**
- **The corresponding TGD corrections of the BDS broadcast clocks are applied for the comparison with the precise clock based on ionosphere-free observations.**
- **A "Global Average SISURE" for each navigation system can be calculated as:**

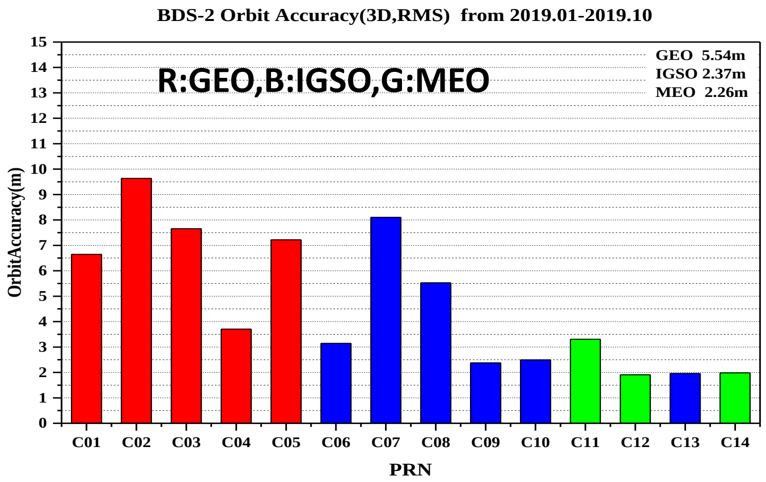
$$SISURE = \sqrt{(w_R \cdot \Delta R - c\Delta dt)^2 + w_{A,C} \cdot (\Delta A^2 + \Delta C^2)}$$

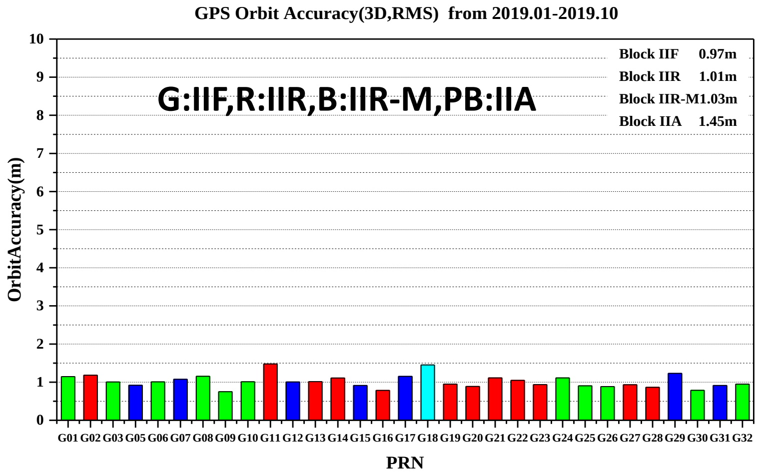
$\Delta R, \Delta A, \Delta C$ **are the radial, along and cross errors of the orbit respectively(unit: m).**

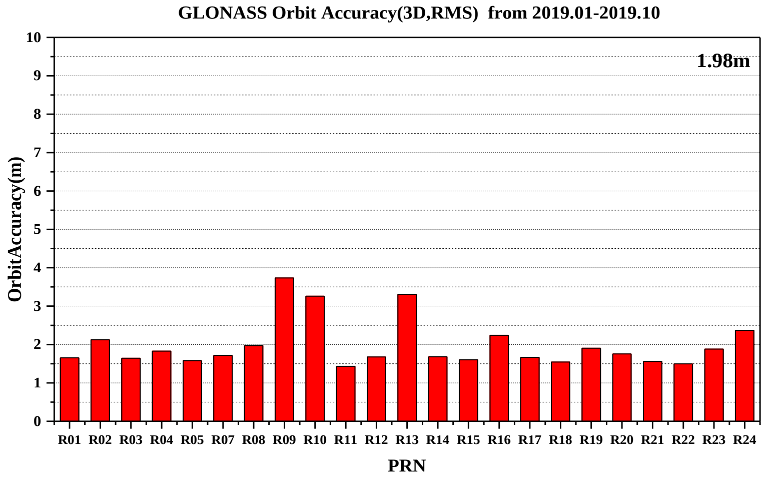
$c, \Delta dt$ **are the speed of light, the broadcast clock error(unit: second).**

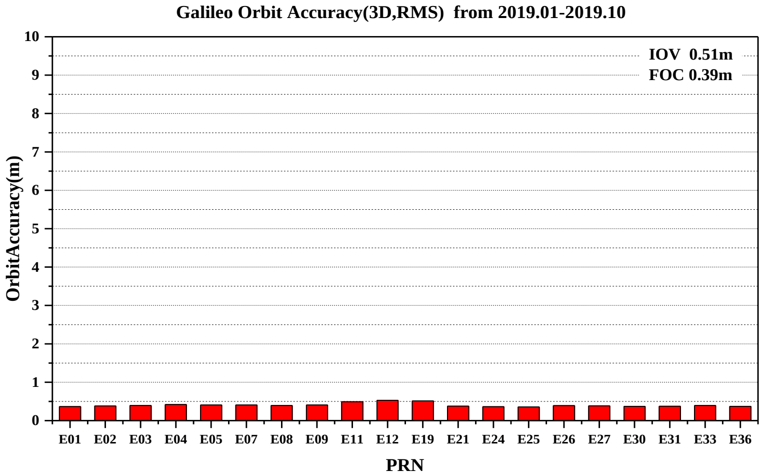
2.1 Broadcast Ephemeris Accuracy (Orbit&Clock&SISURE)

◆ Accuracy of BDS-2, GPS, Galileo and GLONASS broadcast orbit from 2019.01-2019.10



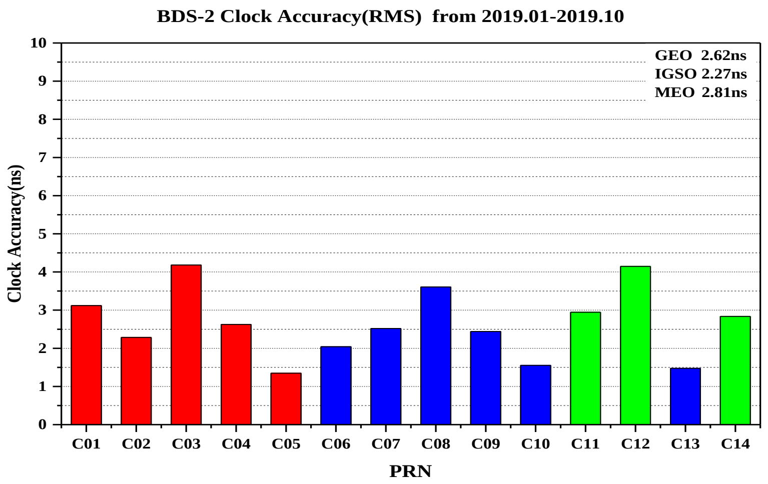


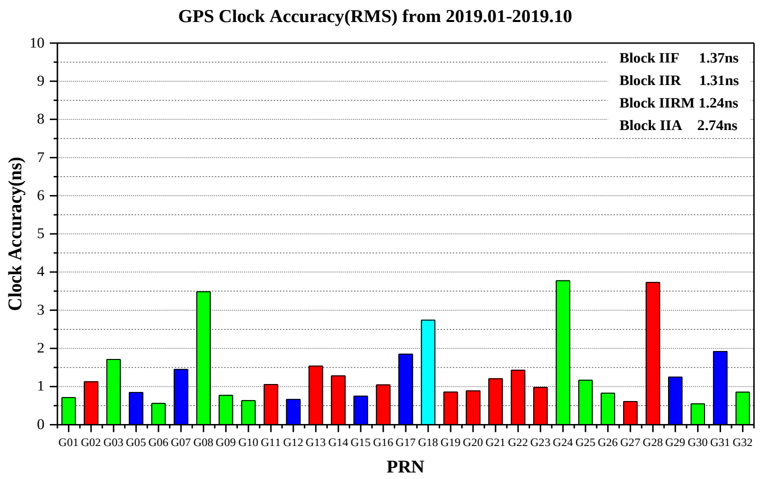


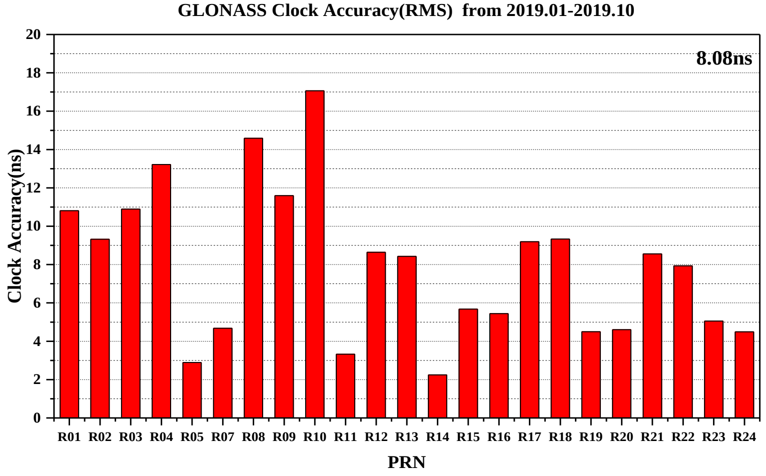


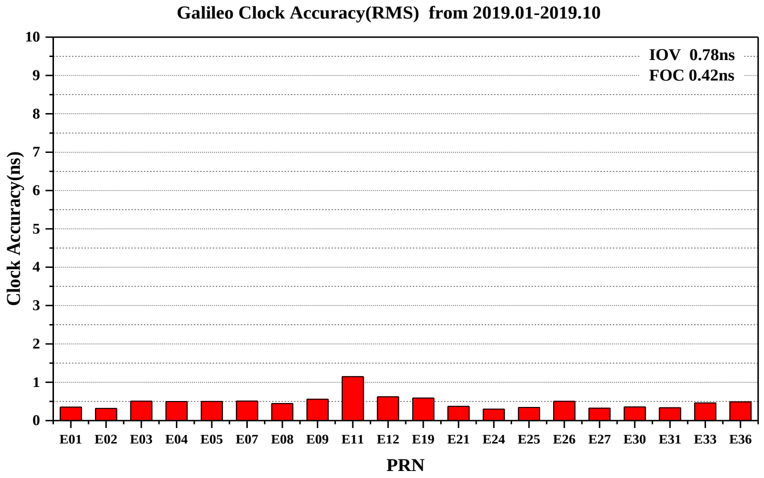
2.1 Broadcast Ephemeris Accuracy (Orbit&Clock)

- Accuracy of BDS-2, GPS, Galileo and GLONASS **broadcast clock** from 2019.01-2019.10



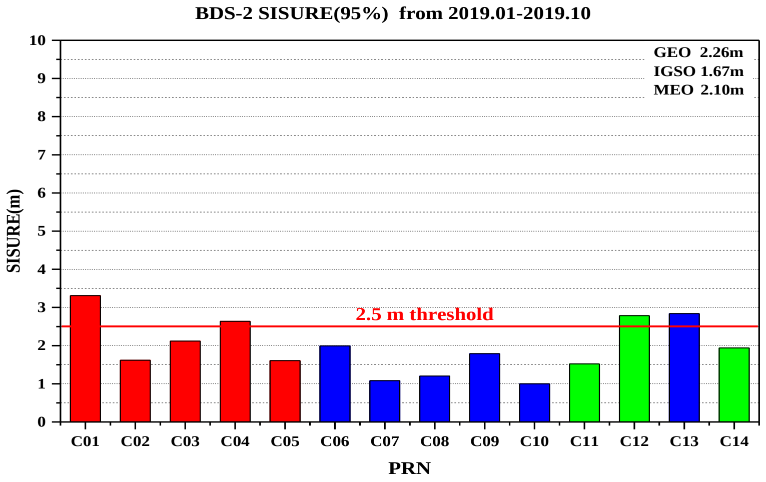


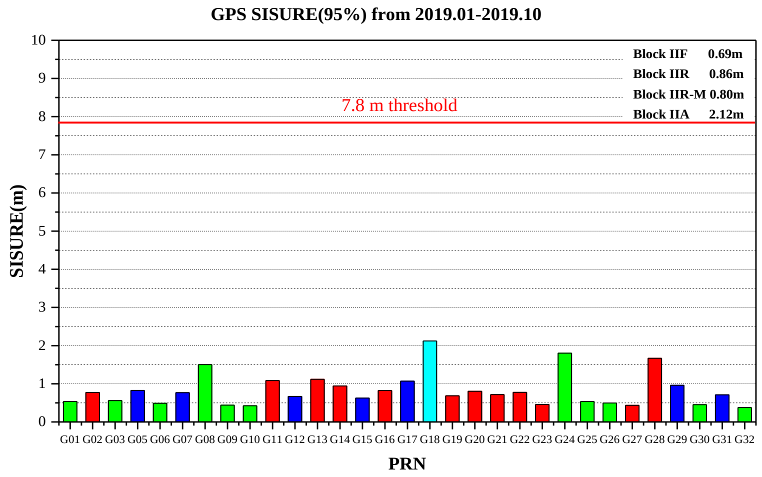


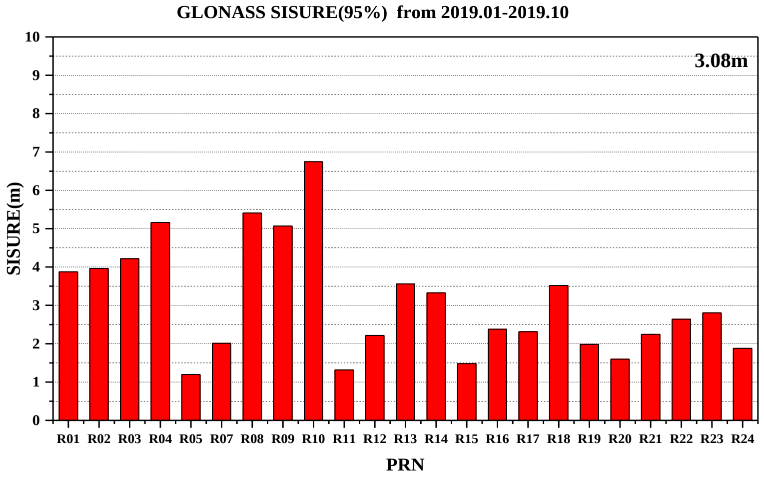


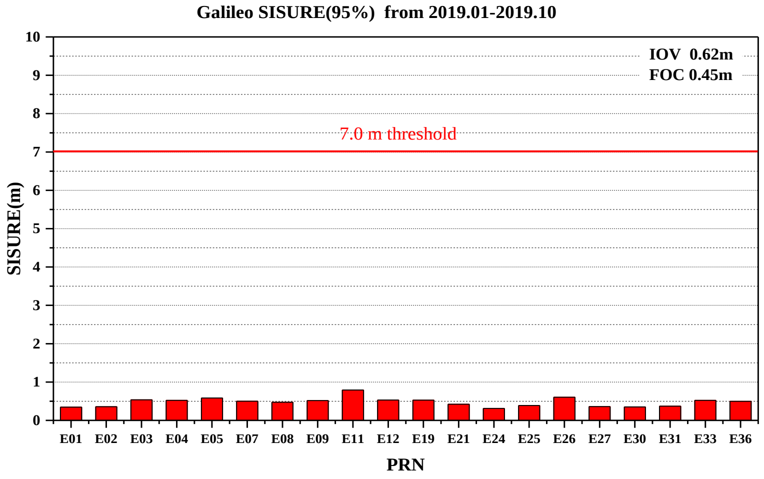
SIS User Range Error(SISURE)

- **SISURE of BDS-2, GPS, Galileo and GLONASS broadcast ephemeris from 2019.01-2019.10**

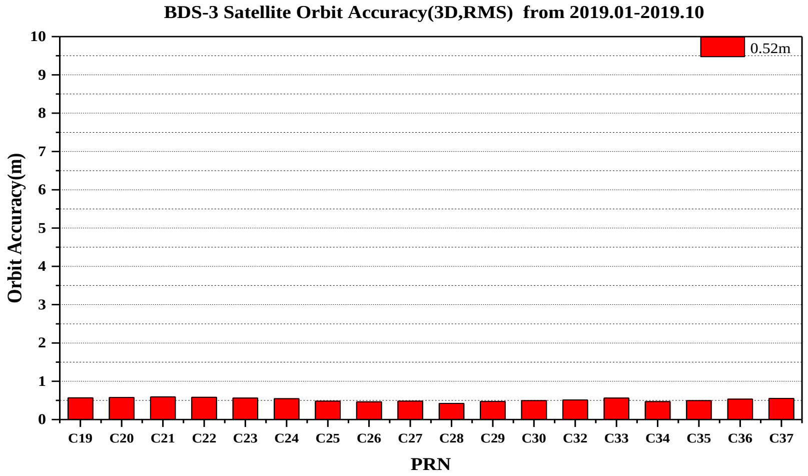


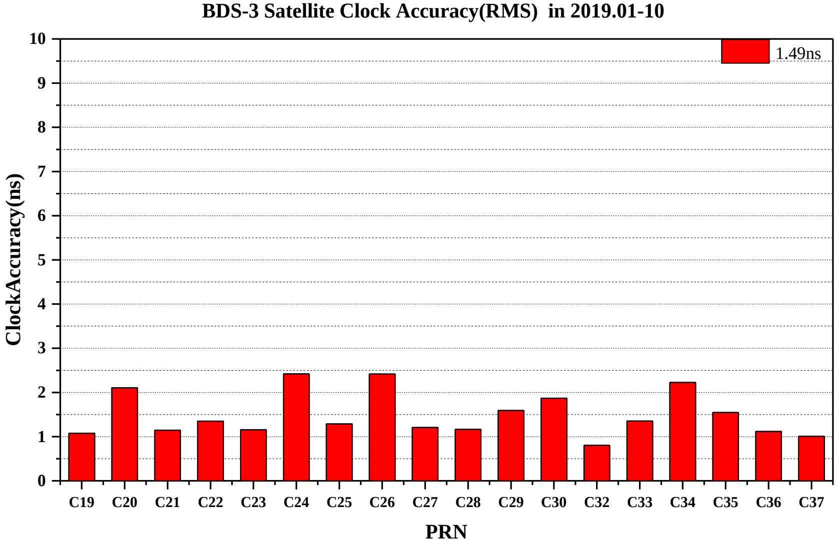


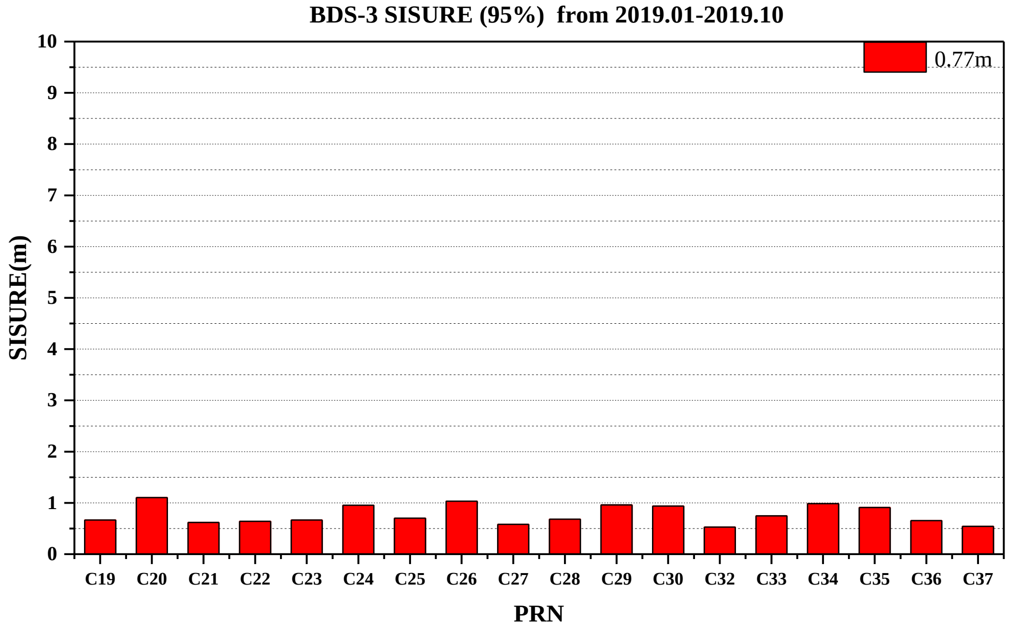




2.2 Broadcast Ephemeris Accuracy (Orbit &Clock&SISURE)-BDS-3







SISURE of each satellite in ten months

The accuracy of BDS-3 orbit and clock have been improved obviously. The SISURE of BDS-3 is much better than BDS-2 which satisfies the promise in ICD.

2.3 UTCOE

➢ Methodology

- Using absolutely calibrated receiver connected to UTC(NTSC) which is bridged to UTC or UTC(k) with BIPM rapid UTC product, i.e. UTCr-UTC(k)

➢ Time Reference

- BDS time connects with UTC via UTC(NTSC). UTC is taken as BDS time reference.
- GPS time reference is UTC(USNO).
- UTC（SU）is taken as GLONASS time reference.

➢ Statistic Method and Step

- Yearly RMS&95% statistic of daily UTC offset with one year moving window for BDS,GPS and GLONASS.

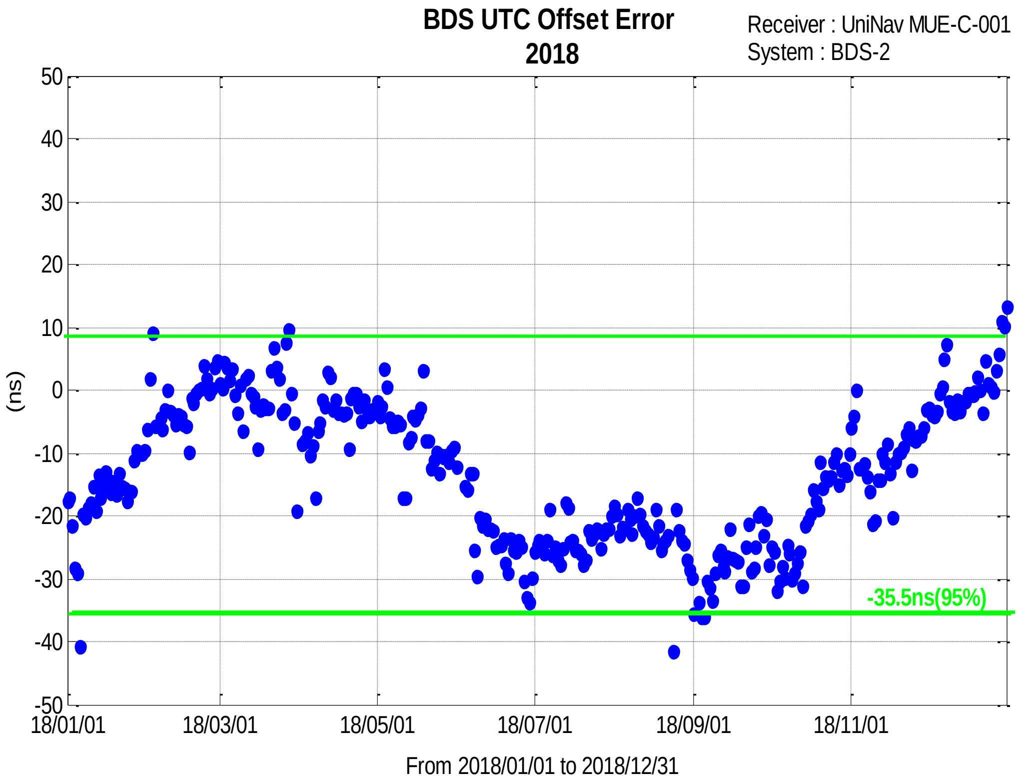
UTCO_ref :

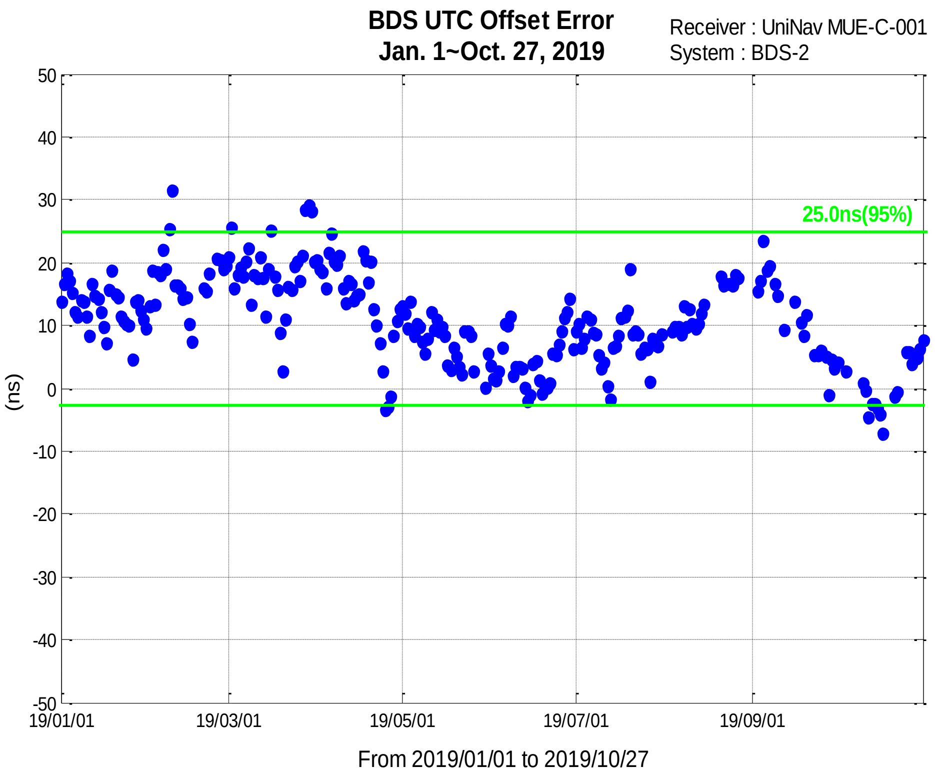
$BDT_{SIS}-UTCr = -[UTC(NTSC)-BDT_{SIS}] - [UTCr-UTC(NTSC)]$

$GPST_{SIS} - UTC(USNO) = [UTCr - UTC(USNO)] - [UTC(NTSC)-GPST_{SIS}] - [UTCr-UTC(NTSC)]$

$UTC(SU) - GLONASST_{SIS} = [UTC(NTSC)-GLONASST_{SIS}] + [UTCr-UTC(NTSC)] - [UTCr - UTC(SU)]$

2.3 UTCOE





365samples 35.5ns(95%) 17.3ns(RMS)
-13.2ns(AVG) 11.2ns(STD)
-41.4ns(MAX)

304samples 25.0ns(95%) 13.1ns(RMS)
11.0ns(AVG) 7.1ns(STD)
31.6ns(MAX)

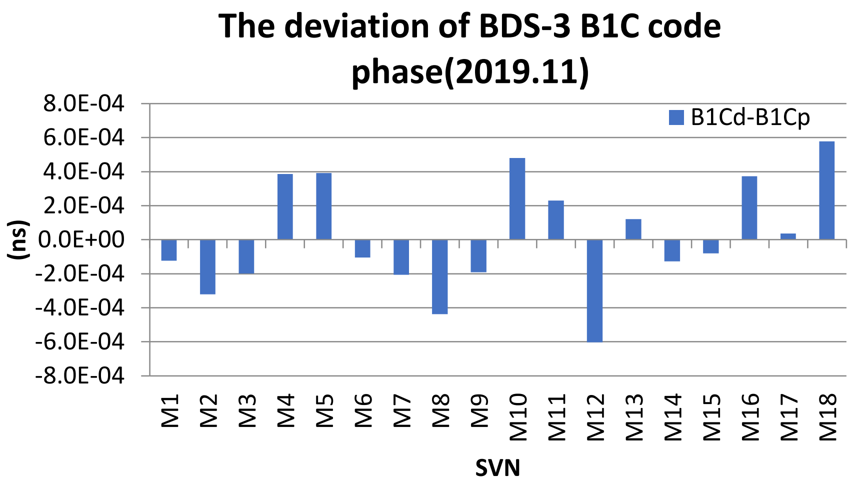
BDS UTC Offset Error (RMS) in 2018 is 17.3ns

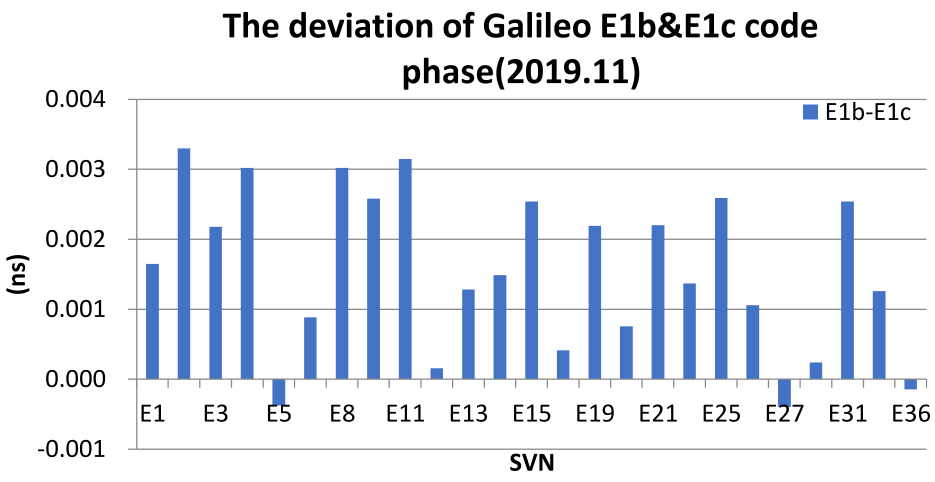
BDS UTC Offset Error (RMS) in 2019 is 13.1ns

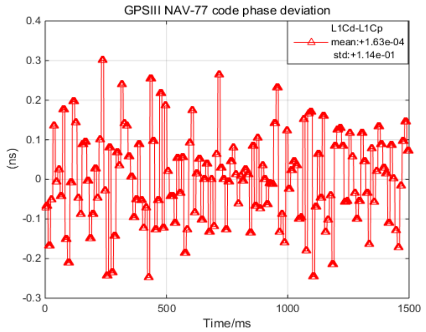
Tolerance:20ns(RMS)

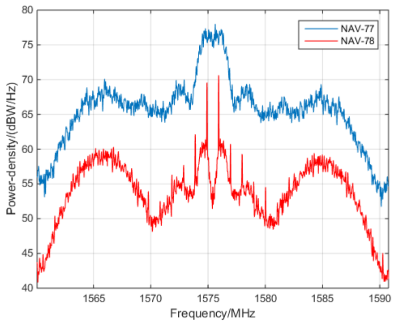
2.4 Signal Quality

◆ Deviation of code phase







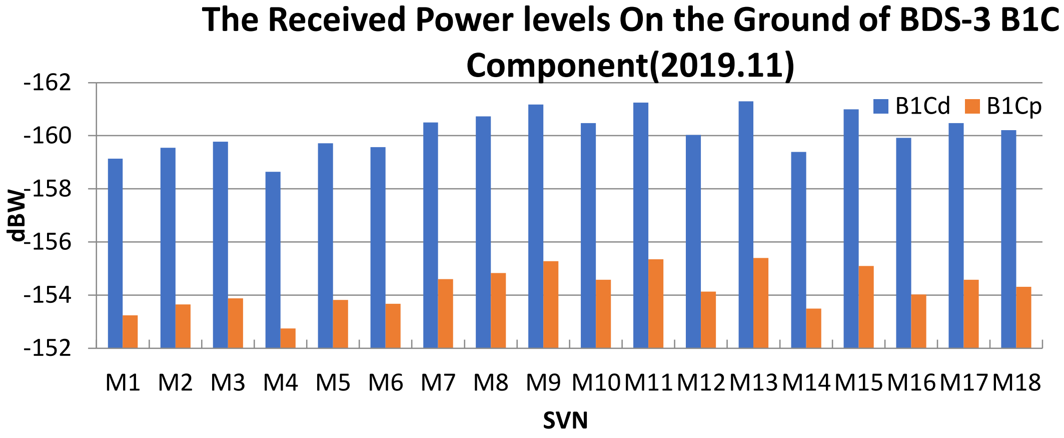


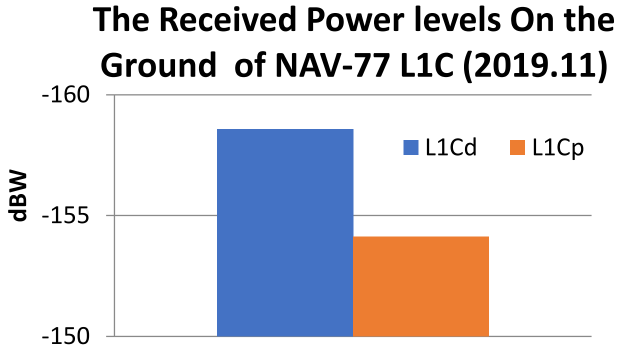
GNSS	B1Cd-B1Cp	L1Cd-L1Cp	E1b-E1c
max	5.78E-04	1.63e-4	3.30E-03
mean	1.10e-05	1.63e-4	1.56E-03

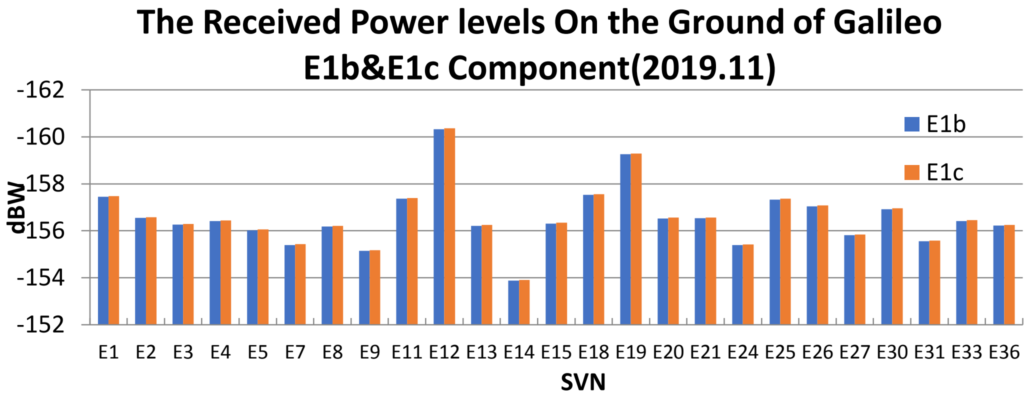
The deviation of signal code phase of all navigation systems' components meet the ICD stipulation.

2.4 Signal Quality

◆ Power levels received on the ground







GNSS	B1Cd-B1Cp		L1Cd-L1Cp		E1b-E1c
max	-158.63	-154.06	-158.57	-154.13	-153.87
mean	-160.41	-155.83	-158.57	-154.13	-156.56

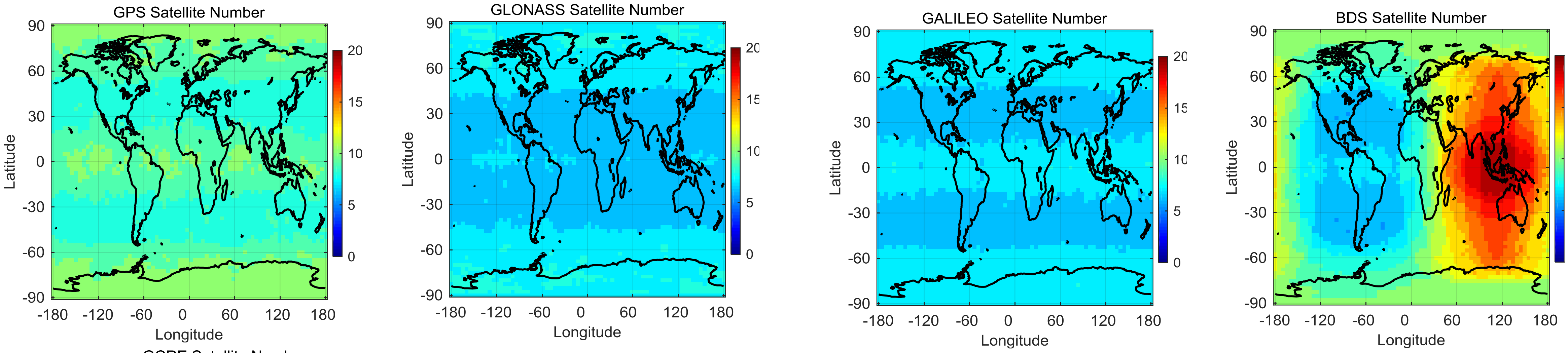
The power levels received on the ground of all navigation systems' components meet the ICD stipulation.

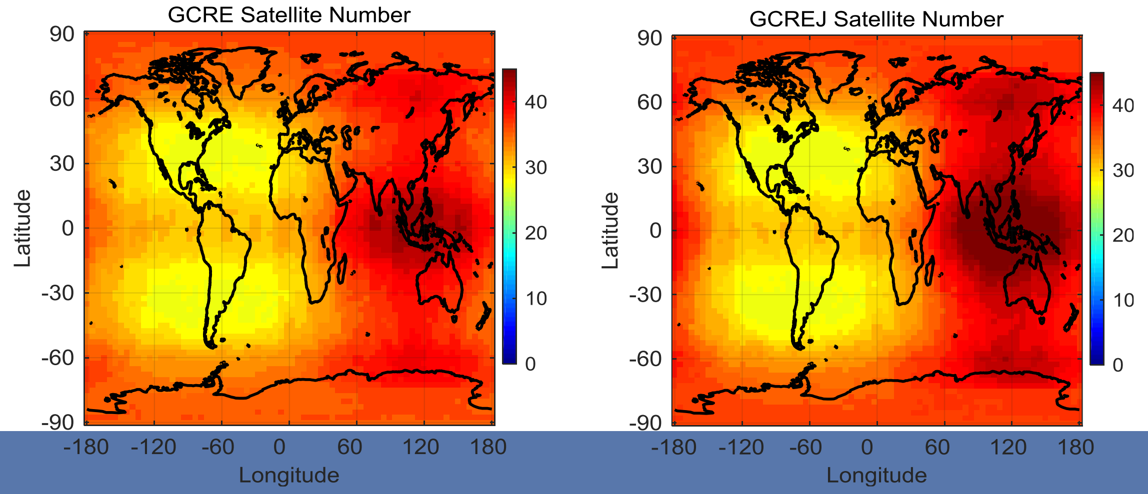
03

Preliminary Performance of Joint Multi-GNSS

3.1 Multi-GNSS Performance-Number of Visible Satellites

The number of visible satellites at each grid (5◦ *5◦) are calculated with the broadcast ephemeris during the day 288 to 294 of 2019.

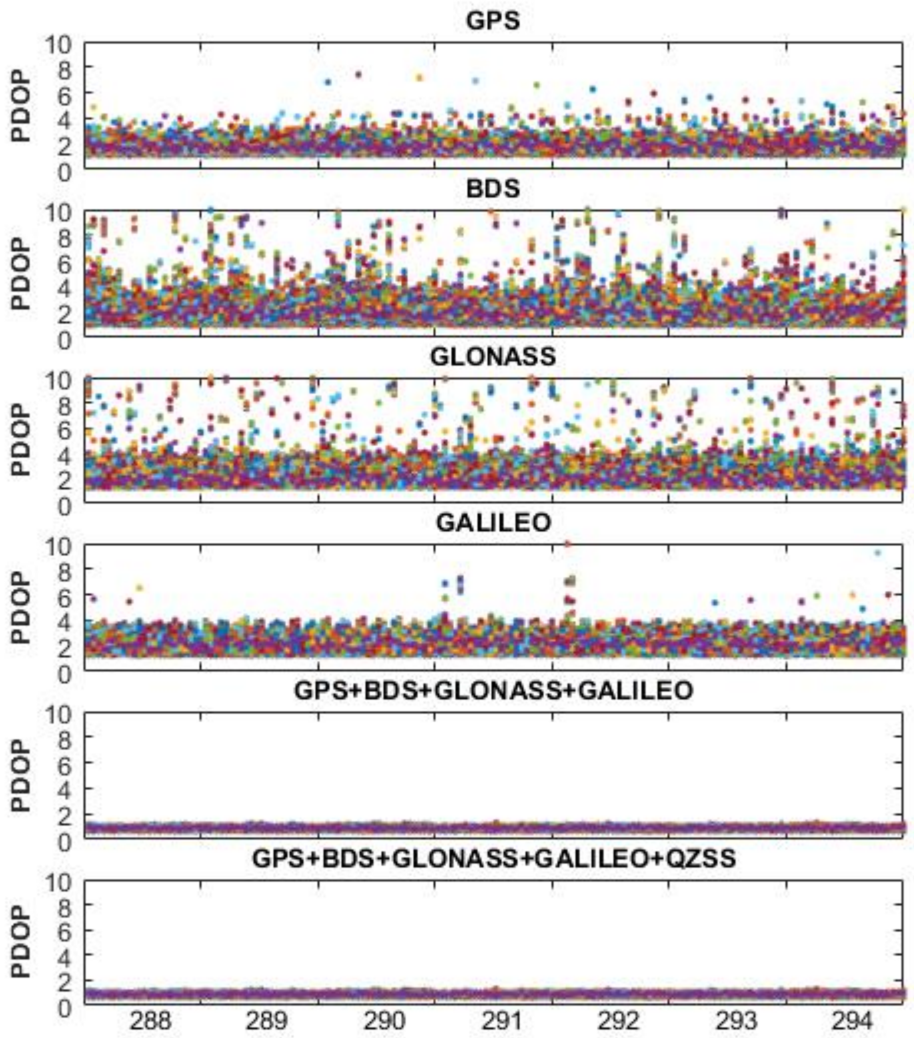


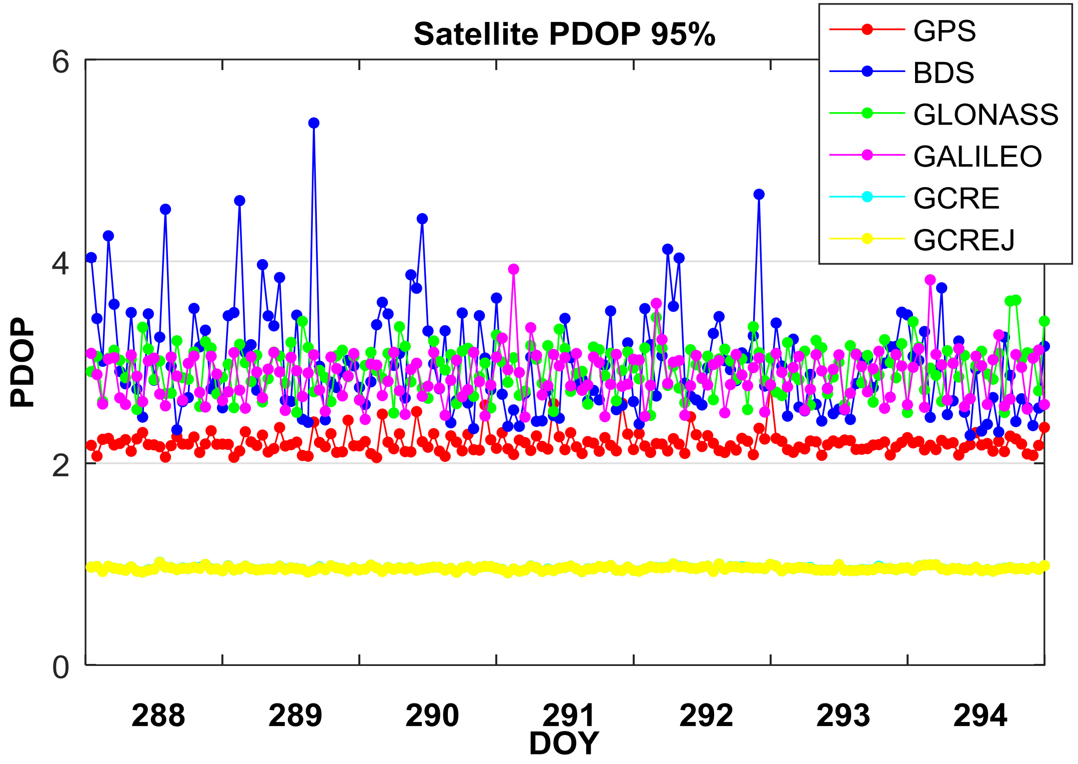


The average maps of GCREJ multi-GNSS show that more than 27 satellites are visible at least at each global grid.

3.2 Multi-GNSS Performance-PDOP

The PDOP at each grid (5deg) and the 95% statistics are also calculated with the broadcast ephemeris during the day 288 to 294 of 2019.The PDOP of joint multi-GNSS is much smaller than that of each GNSS constellation.





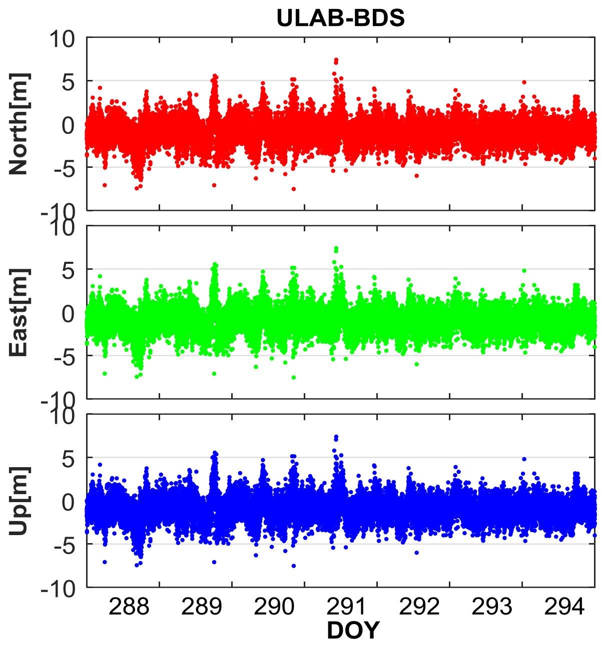
Multi-GNSS Performance-SPP&PPP

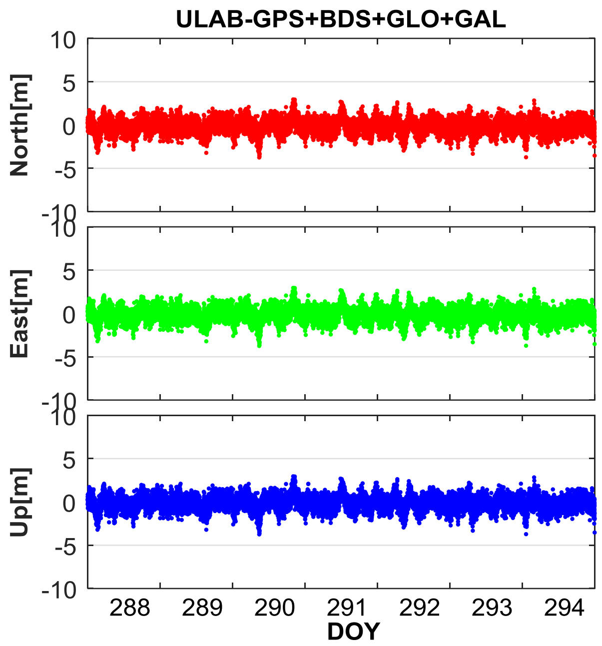
At several IGS and iGMAS stations in Asian area, we used L1/L2 (GPS), B1/B3 (BDS), G1/G2 (GLONASS), E1/E5a (Galileo) and L1/L2 (QZSS) to perform double-frequency multi-SPP(pseudo-range) with the broadcast ephemeris and multi-PPP(pseudo-range and phase) with precise orbit&clock. The station coordinates in ITRF2014 provided by iGMAS are used as the reference.

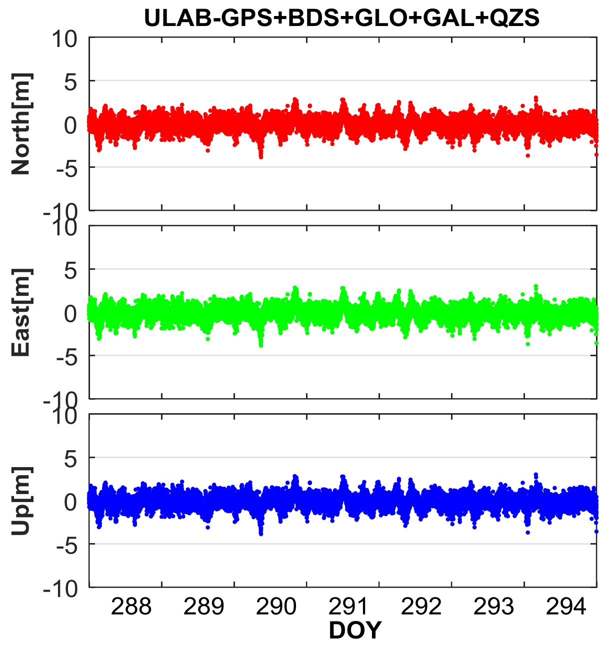
$$
\begin{cases}
P_{IF} = u_r^s \cdot X + c \cdot \left(\delta t_r + l_{b_P}\right) - c \cdot \left(\delta t_{IF}^s - dD\right) + M_W \cdot Z_W + \varepsilon_P \\
\Phi_{IF} = u_r^s \cdot X + c \cdot \left(\delta t_r + l_{b_P}\right) - c \cdot \left(\delta t_{IF}^s - dD\right) + M_W \cdot Z_W \\
\qquad + \left(l_{b_\varphi} - l_{B_\varphi}\right) - \left(l_{b_P} - l_{B_P}\right) + \alpha_{1,2} \cdot \lambda_1 \cdot N_1 + \beta_{1,2} \cdot \lambda_2 \cdot N_2 + \varepsilon_\Phi
\end{cases}
$$

$$
\begin{cases}
\alpha_{1,2} = \dfrac{f_1^2}{f_1^2 - f_2^2}, \qquad \beta_{1,2} = \dfrac{-f_2^2}{f_1^2 - f_2^2} \\
l_{B_P} = \alpha_{1,2} \cdot B_{P_1} + \beta_{1,2} \cdot B_{P_2}, l_{b_P} = \alpha_{1,2} \cdot b_{P_1} + \beta_{1,2} \cdot b_{P_2} \\
l_{B_\varphi} = \alpha_{1,2} \cdot B_{\varphi_1} + \beta_{1,2} \cdot B_{\varphi_2}, l_{b_\varphi} = \alpha_{1,2} \cdot b_{\varphi_1} + \beta_{1,2} \cdot b_{\varphi_2}
\end{cases}
$$

3.3 Multi-GNSS Performance-SPP



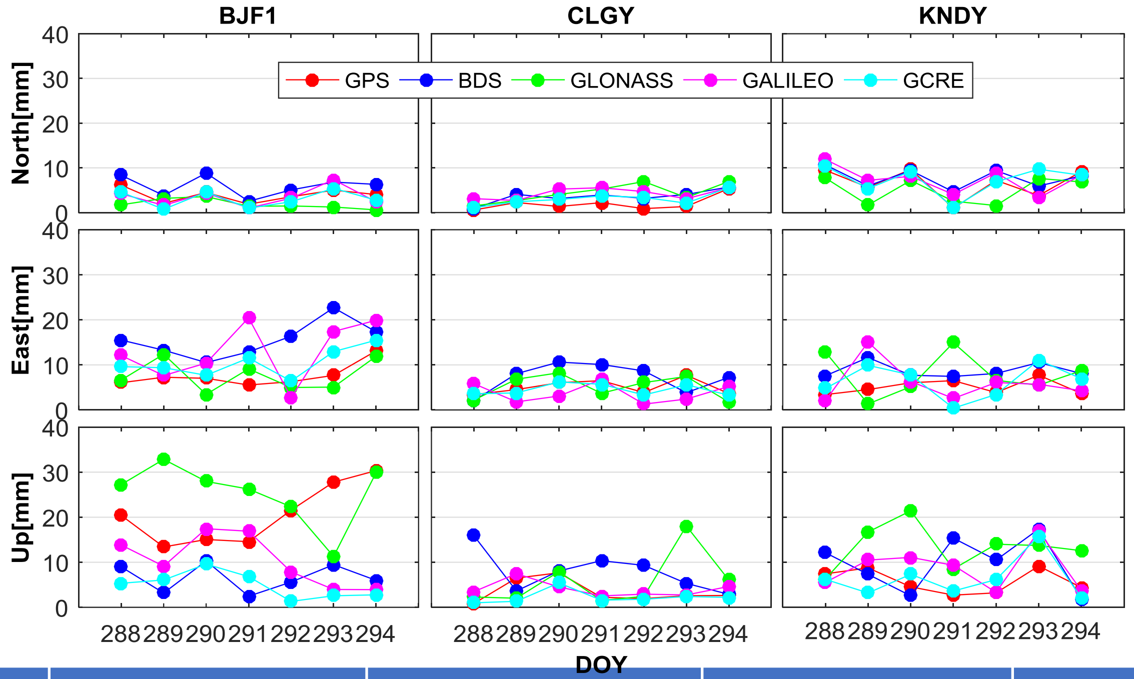




	G	C	R	E	G+C+R+E	G+C+R+E+J
RMS-N[m]	1.5013	1.3174	3.3669	0.7869	0.6964	0.6688
RMS-E[m]	1.1589	1.3182	3.6352	0.7190	0.7137	0.7087
RMS-U[m]	3.0924	2.4364	7.5947	1.7530	1.4947	1.4408

3.3 Multi-GNSS Performance-PPP

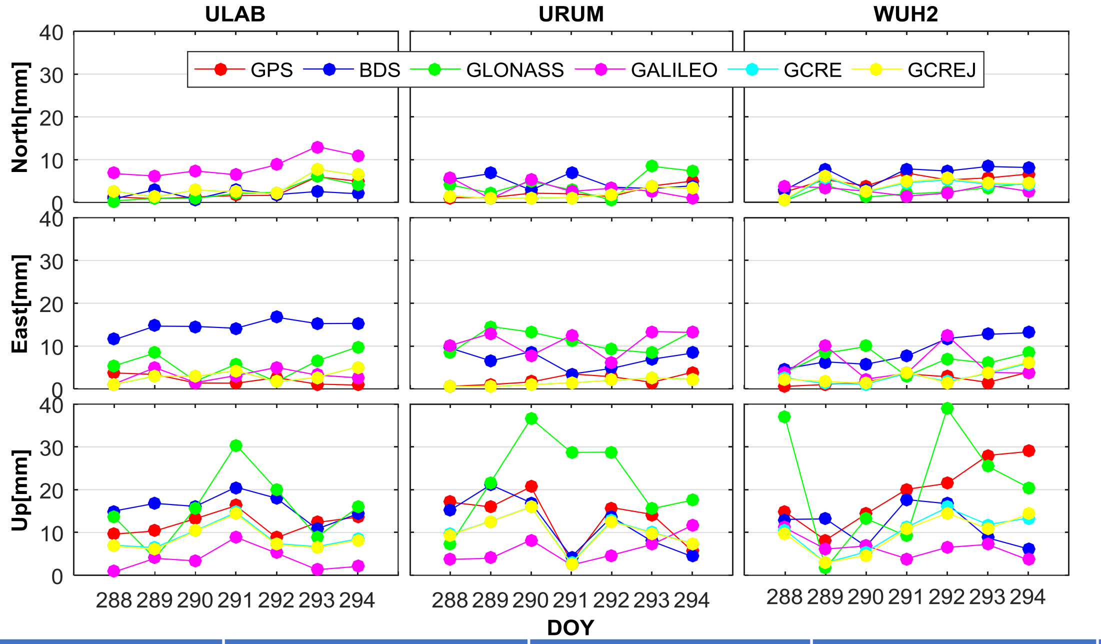
- iGMAS tracking stations



	G	C	R	E	G+C+R+E
RMS N[mm]	6.10	7.40	6.20	7.50	6.00
RMS E[mm]	6.30	8.70	7.50	8.60	6.60
RMS U[mm]	8.50	10.20	16.3	9.70	7.50
Convergence time N[min]	11.60	17.20	13.96	17.92	6.39
Convergence time E[min]	23.51	25.00	24.57	30.57	14.06
Convergence time U[min]	28.94	36.33	31.76	40.84	26.12

3.3 Multi-GNSS performance-PPP

- **IGS tracking stations**



	G	C	R	E	G+C+R+E	G+C+R+E+J
RMS N[mm]	3.40	4.40	3.10	4.80	3.40	3.20
RMS E[mm]	5.00	9.00	7.80	6.50	2.40	2.50
RMS U[mm]	11.90	13.20	17.80	9.40	9.70	9.40
Convergence time N[min]	12.90	19.761	16.6667	14.28	6.38	6.19
Convergence time E[min]	26.85	23.80	30.4762	26.23	10.95	10.14
Convergence time U[min]	30.66	38.19	35.2381	32.57	20.57	19.61

4 Summary

- **iGMAS is developing progressively. The infrastructure, MACs and ACs have been improved gradually.**
- **The performance of BDS-3 is better than BDS-2 significantly.**
- **Joint Multi-GNSS has obvious advantages at PDOP and convergence time then any single constellation.**