Development of BDS and Study of PPP Time Transfer

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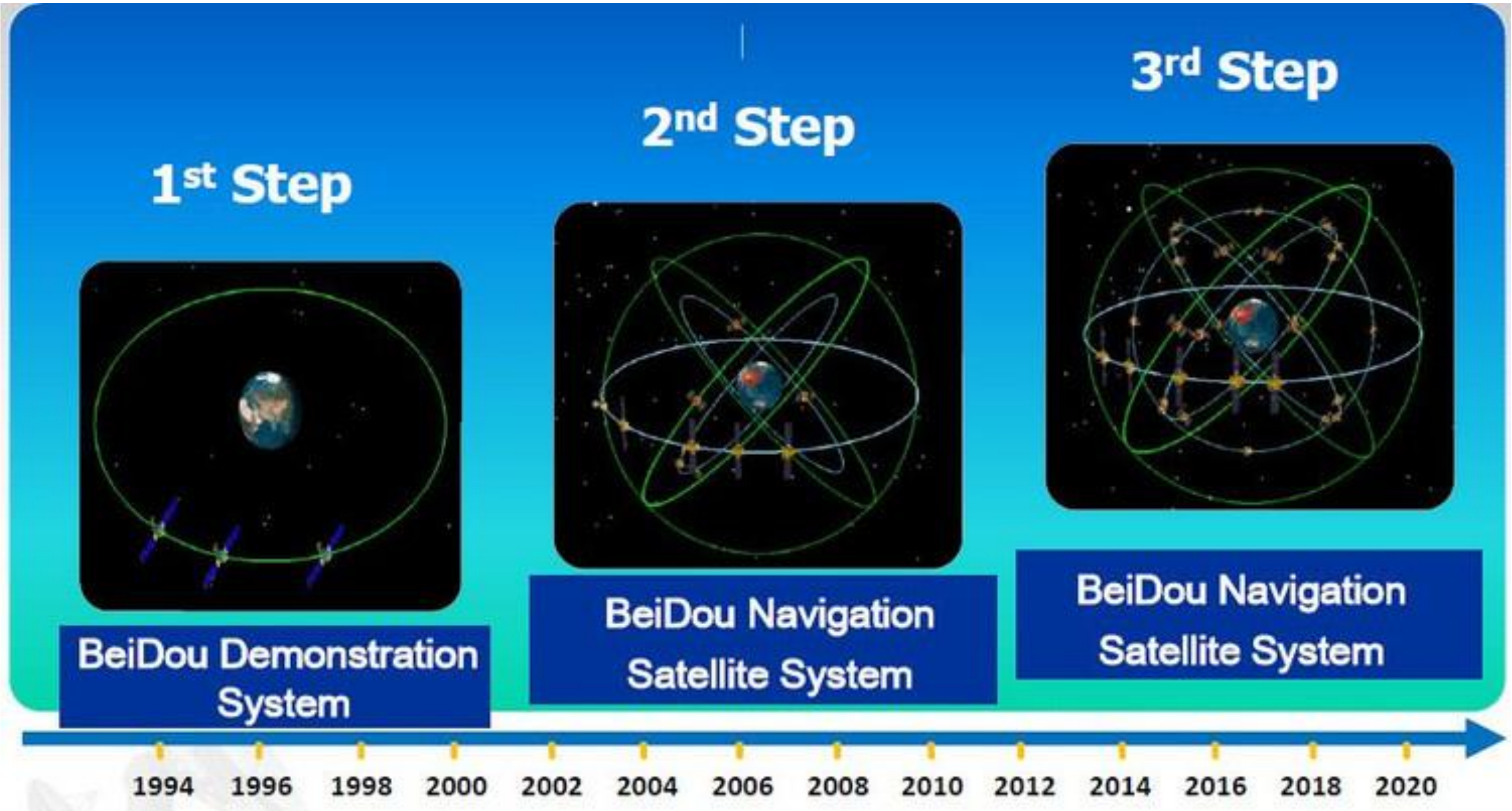
Workshop on the applications of GNSS

Content

1.1 BDS overview

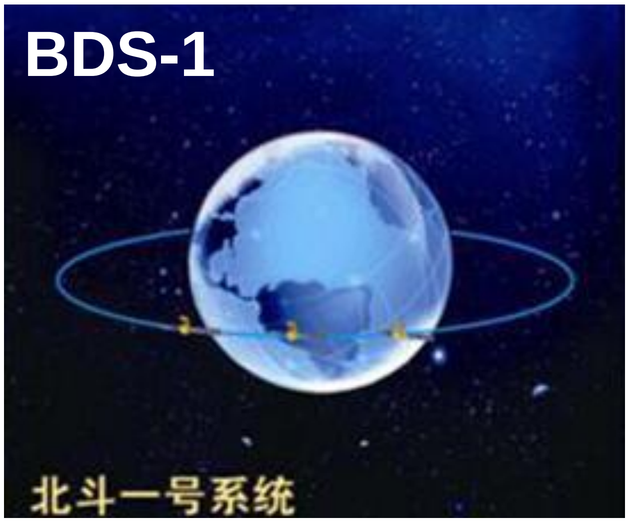
BDS overall construction planning

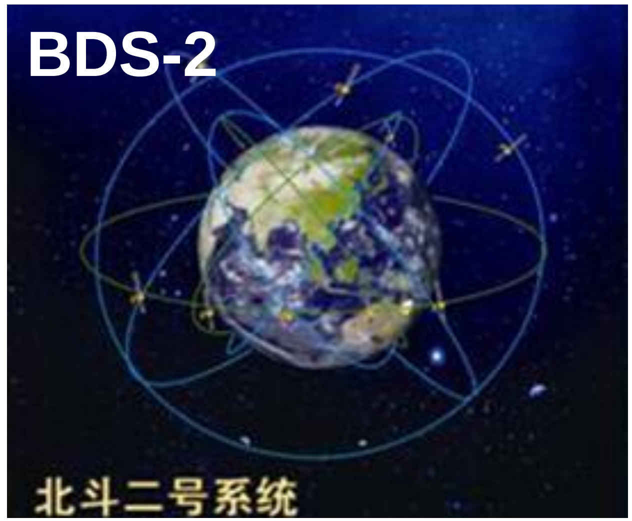


Demonstration system (1994-2000) → **Regional navigation system** (2004-2012) → **Global navigation system** (2009-2020)

1.1 BDS overview

Constellation





3 GEOs

BeiDou 1A 80°E

BeiDou 1B 140°E

BeiDou 1C 110.5°E

5 GEOs(C01-C05)

5+2 IGSOs(C06-C10,C13,C16)

4-1 MEOs(C11,C12,C13,C14)

3 GEOs (**1**)

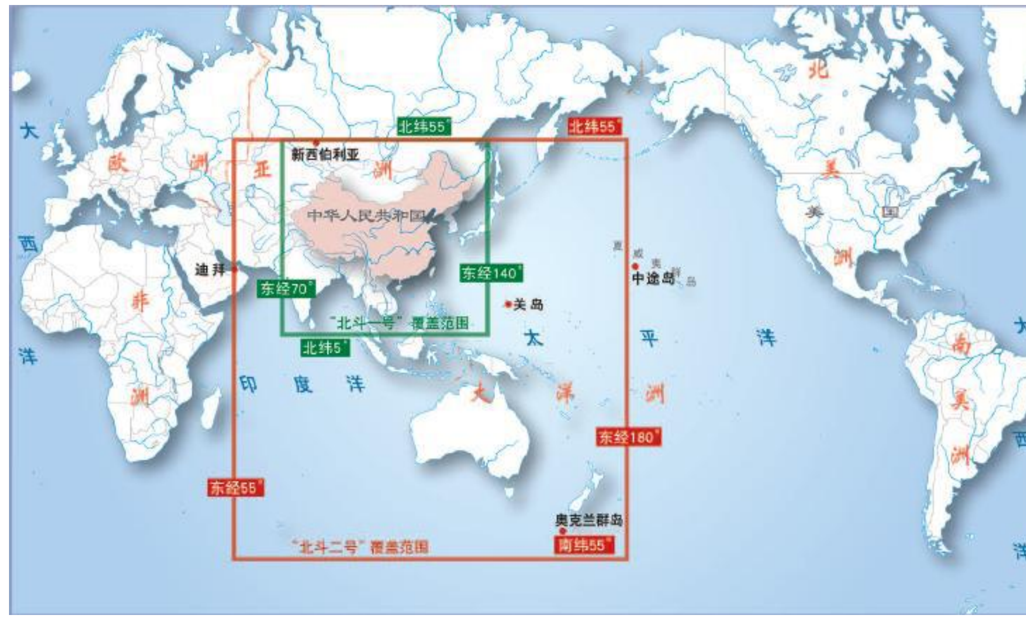
3 IGSOs (**2**)

27 MEOs (**18**)

1.1 BDS overview

Functions and performances of BDS-1 and BDS-2

BDS-1 main functions comprise positioning, short message communication, and timing. The user location can be determined by the master control station using the Radio Determination Satellite System (RDSS) of BDS-1.



BDS-2 comprises three types of orbital satellites. It adopts one-way time passive ranging and realizes passive positioning, which has unlimited for navigation users.

Performance

- **Positioning: 10 m**
- **Speed: 0.2 m/s**
- **Timing 20 ns**

1.1 BDS overview

BDS-3 progress

- Since November 2017, China has completed the launch of 21 BDS-3 satellites.
- In December 2018 , the construction of BDS-3 primary system was completed and the system started to provide RNSS services worldwide.
- Around 2020, the construction of the full BDS-3 system will be completed and it will provide 5 kinds of services.

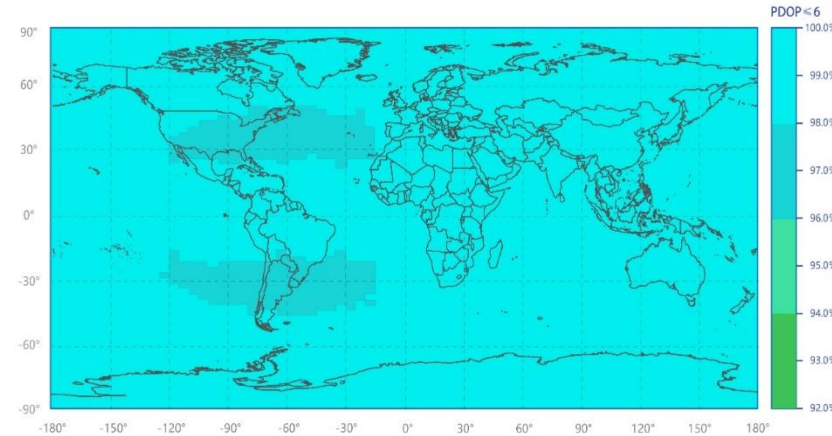
Service Type		Signal Frequency	Satellite
RNSS (Global)		B1I、B3I、B1C、B2a	3IGSO+24MEO
		B1I、B3I	3GEO
SBAS (Regional)		BDSBAS-B1C、BDSBAS-B2a	3GEO
Short Message Communication Service	Regional	L (Uplink) , S (Downlink)	3GEO
	Global	L (Uplink)	14MEO
		B2b (Downlink)	3IGSO+24MEO
International SAR (Global)		UHF (Uplink)	6MEO
		B2b (Downlink)	3IGSO+24MEO
Precisise Point Positioning (Regional)		B2b	3GEO

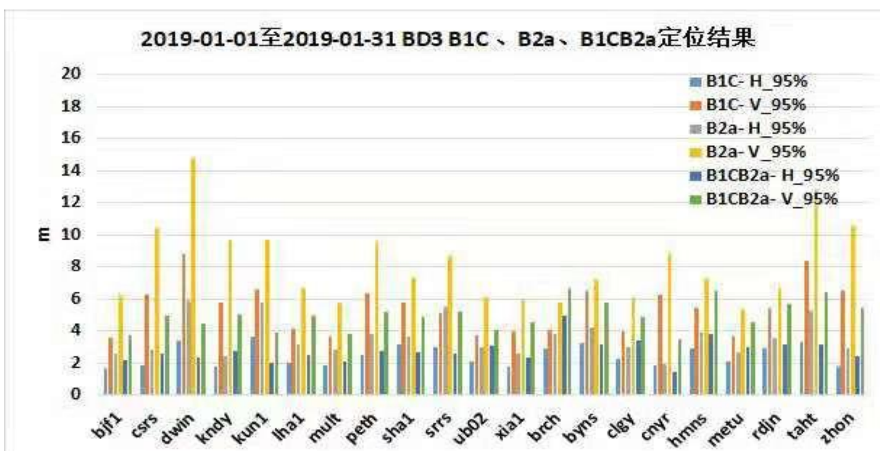
Satellite	Launch Time
First pair MEO	2017.11.05
Second pair MEO	2018.01.12
Third pair MEO	2018.02.11
Fourth pair MEO	2018.03.30
Fifth pair MEO	2018.07.29
Sixth pair MEO	2018.08.25
Seventh pair MEO	2018.09.19
Eighth pair MEO	2018.10.15
First GEO	2018.11.01
Ninth pair MEO	2018.11.19
First IGSO	2019.04.20
Second IGSO	2019.06.25

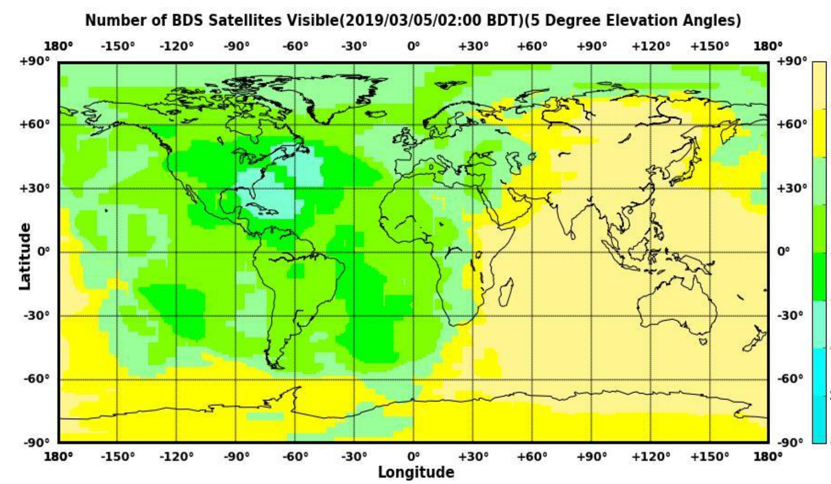
1.1 BDS overview

Performances of BDS-3

- BDS-3 global service availability is over 95%.
- The global positioning accuracy is better than 10m.







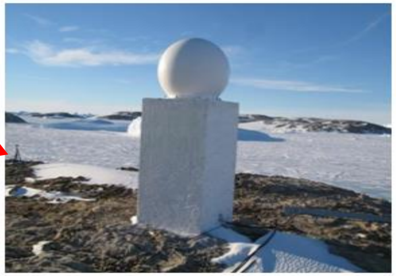
1.2 iGMAS

International GNSS Monitoring and Assessment System(iGMAS)

Monitoring and assessment center (1):
Evaluating system performance

Operation control and management center (1):
Monitoring and managing system operational status

Tracking station (24):
Receiving observation data



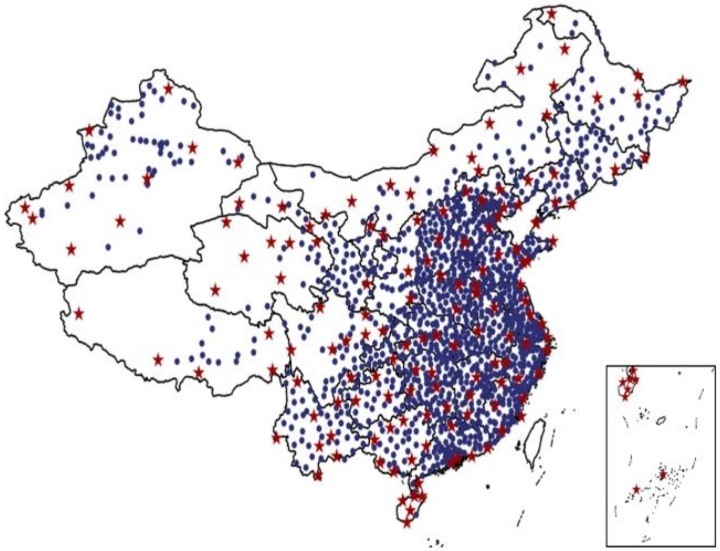
Data center (3):
Integrating observation from various tracking stations

Analysis center (12):
Calculating various core products

Products combination and service center (1):
Integrating various center products

1.3 BDS GBAS

National BDS Ground Augmentation



System composition:

- ◆ Network of reference stations;
- ◆ Data processing system;
- ◆ Operation service platform;
- ◆ Data transmission system;
- ◆ User terminal

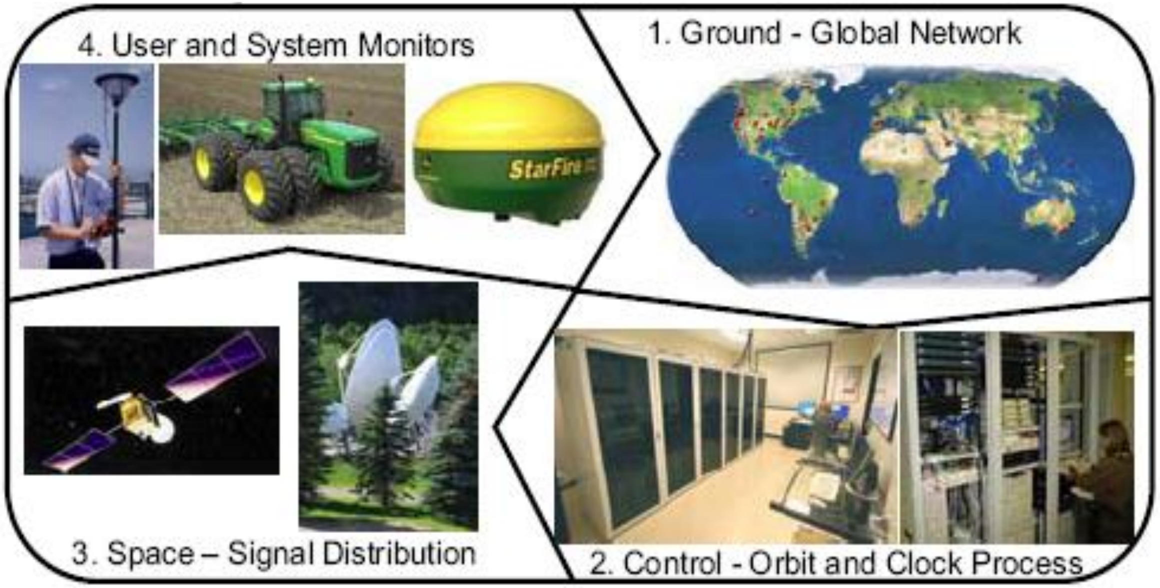
- ◻ More than 2200 reference stations have been built
- ◻ Service area : China
- ◻ Broadcast means: Satellite, Digital and Mobile Communication
- ◻ Positioning accuracy:
  - ➢ wide-area: meter level and decimeter level
  - ➢ Regional: centimeter level
  - ➢ post-processing: millimeter level

1.4 BDS PPP

System Construction PPP service

Service Plan:

- ✓ **3 GEO satellite**
- ✓ **Serve China and surrounding areas**
- ✓ **Accuracy: Dynamic dm, Static cm**

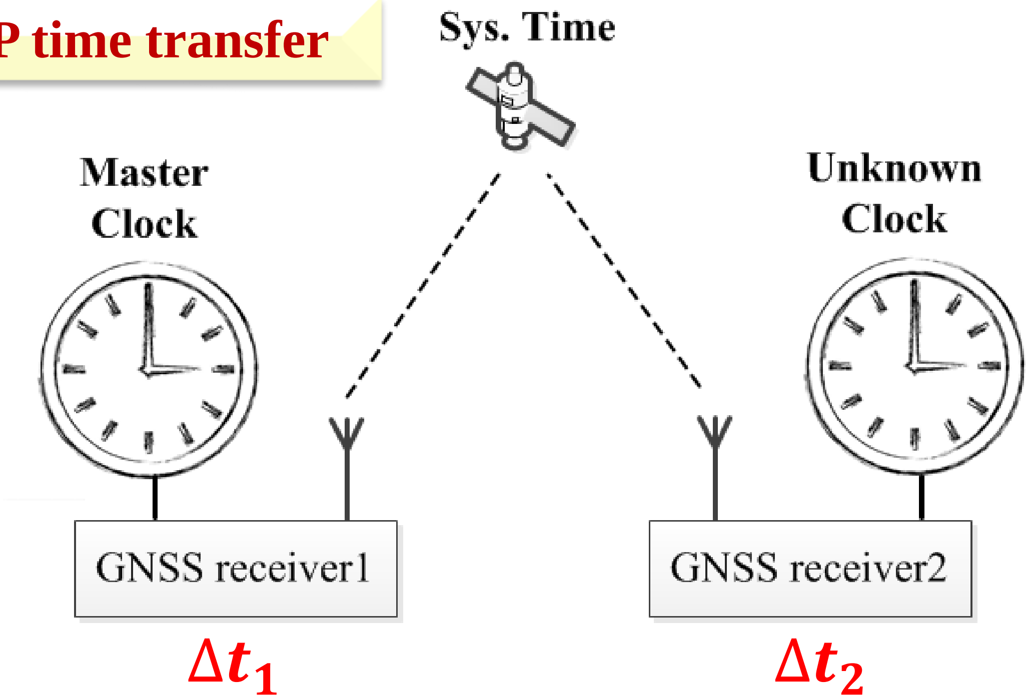


Construction Plan:

Launched one GEO, and in orbit testing

2.1 Overview of PPP time transfer

Principle of PPP time transfer



Δt_1=Master- Sys.Time

Δt_2=Unknown- Sys.Time

$$\Delta t_1 - \Delta t_2 = (\text{Master} - \text{Sys.Time}) - (\text{Unknown} - \text{Sys.Time})$$
$$= \text{Master-Unknown}$$

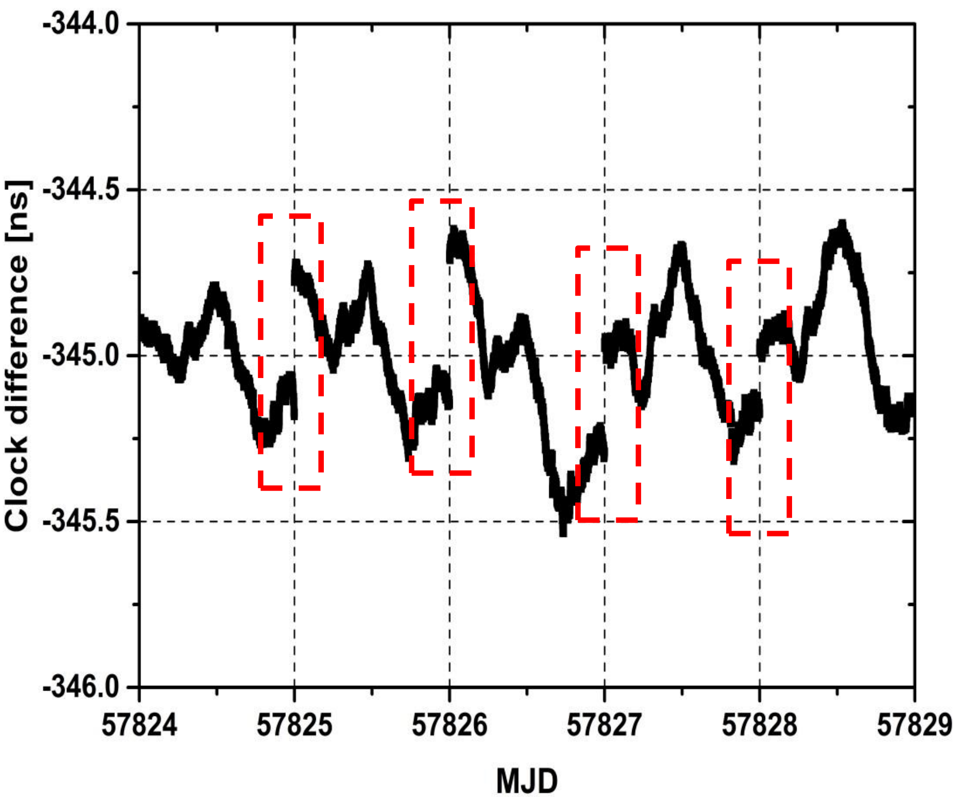
2.1 Overview of PPP time transfer

Challenges in PPP time transfer

- ☐ **Day-boundary discontinuity effects its continuity**
- ☐ **Consistence of Multi-GNSS PPP time transfer**
- ☐ **How to use the prior constraint information to improve the PPP time transfer performance**
  - Station coordinate
  - Tropospheric delay
  - Clock model

2.2 Continuity of PPP time transfer

Day-boundary jump in traditional PPP time transfer



About 80ps-1000ps

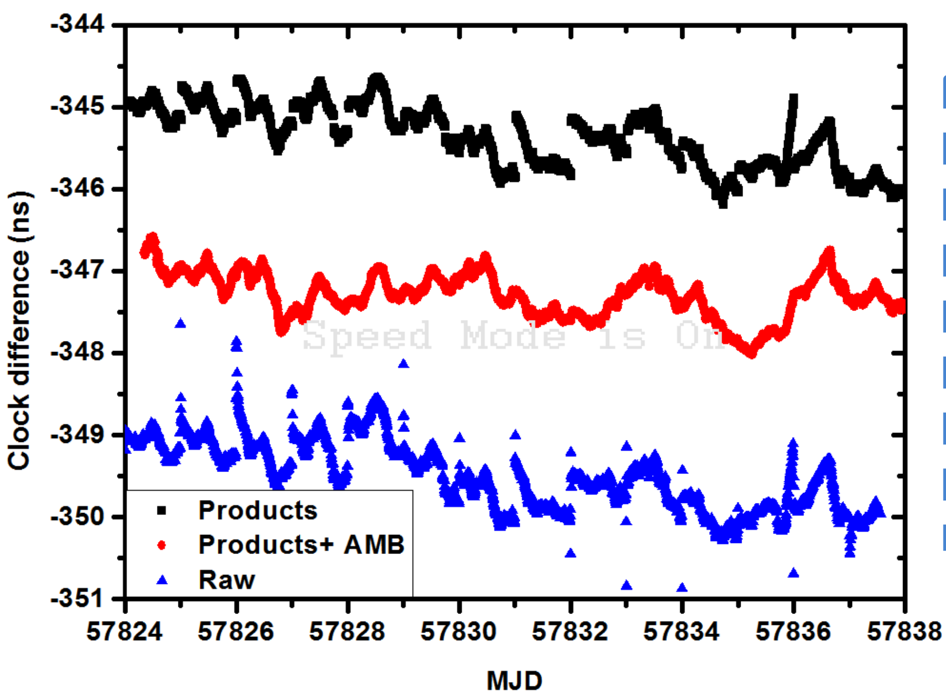
Main influence factors

- Daily temperature
- Cable corrosion
- Noise of pseudo-range observation
- Continuity of GNSS satellite products
- Geodetic data solution strategy
- … …

2.2 Continuity of PPP time transfer

Our solution for Day-boundary discontinuity

- Edge effect strategy → Continuous satellite products
- Continuity strategy → Continuous carrier phase ambiguity



Continuous satellites products improved the big jumps, still with small jumps (<500ps).

Continuous satellites products+ AMB further improved the jumps, and the jumps is smaller than 55ps.

2.3 Consistency of PPP time transfer

Present situation

- Only used single GNSS for timing (GPS or GLONASS)
- Available satellite number is small (about 8-10 for one station)
- The security and robust is insufficient
- Newly GNSS (Galileo and BDS) should be applied in time transfer
- Un-consistency for different GNSSs based PPP time transfer

Combining GPS, BDS, and Galileo Satellite Systems for PPP timing was developed

2.3 Consistency of PPP time transfer

Our solution for un-consistency in multi-GNSSs

$$L_i^G = \rho_i^G + c\left(dt_r^G - dt_{i,s}^G\right) + T_{trop} + N^G + \varepsilon_{i,L}^G$$

$$P_i^G = \rho_i^G + c\left(dt_r^G - dt_{i,s}^G\right) + T_{trop} + \varepsilon_{i,P}^G$$

One common clock Bias + ISB

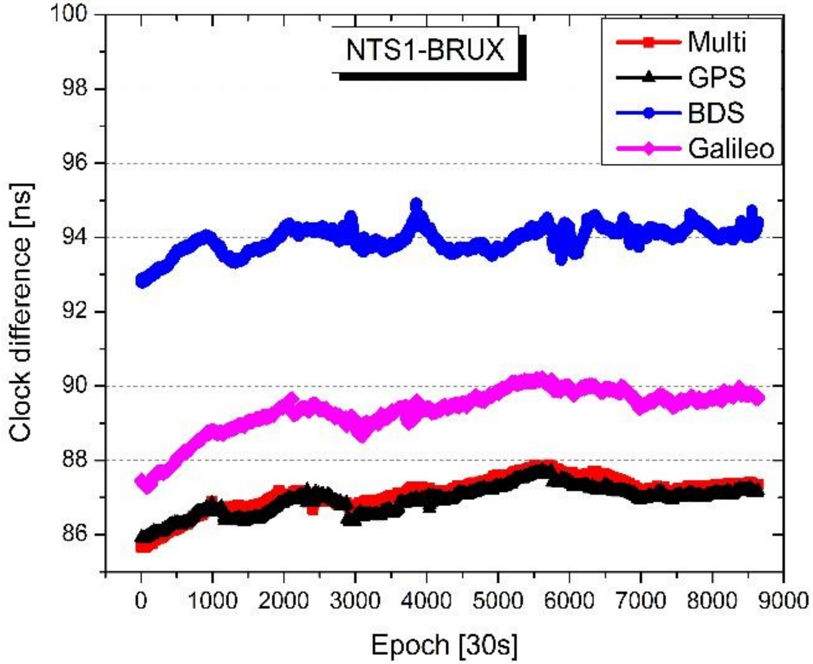
ISB: daily constant

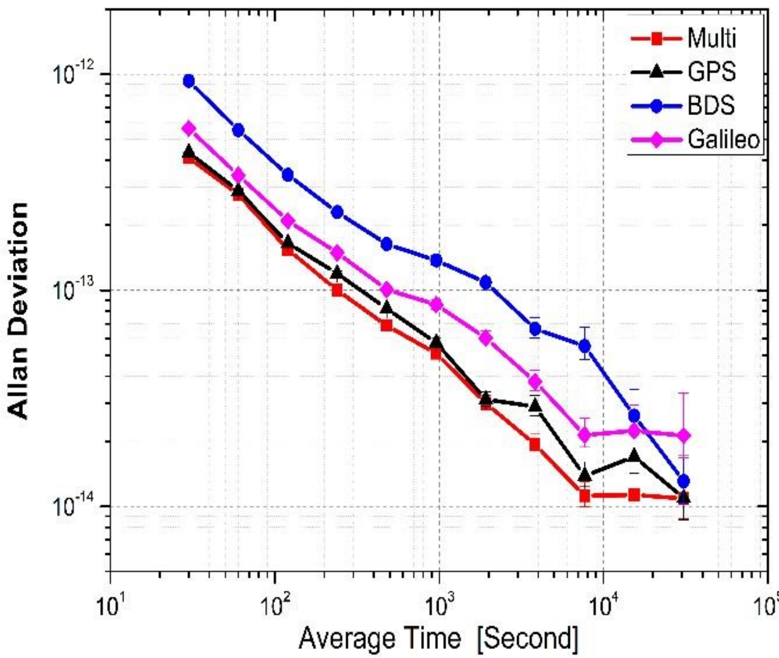
$dt_r^G = t - t_{sys}^G$ (**GPS**) $dt_r^C = t - t_{sys}^C$ (**BDS**) $dt_r^E = t - t_{sys}^E$ (**Galileo**)

Principle of unified Mathematic model

$$\begin{cases} P_i^G = \rho_i^G + c\left(dt_r^G - dt_{i,s}^G\right) + T_{trop} + \varepsilon_{i,P}^G \\ L_i^G = \rho_i^G + c\left(dt_r^G - dt_{i,s}^G\right) + T_{trop} + N^G + \varepsilon_{i,L}^G \\ P_i^C = \rho_i^C + c\left(dt_r^G + ISB_{sys}^{GC} - dt_{i,s}^C\right) + T_{trop} + \varepsilon_{i,P}^C \\ L_i^C = \rho_i^C + c\left(dt_r^G + ISB_{sys}^{GC} - dt_{i,s}^C\right) + T_{trop} + N^C + \varepsilon_{i,L}^C \\ P_i^E = \rho_i^E + c\left(dt_r^G + ISB_{sys}^{GE} - dt_{i,s}^E\right) + T_{trop} + \varepsilon_{i,P}^E \\ L_i^E = \rho_i^E + c\left(dt_r^G + ISB_{sys}^{GE} - dt_{i,s}^E\right) + T_{trop} + N^E + \varepsilon_{i,\Phi}^E \end{cases}$$

2.3 Consistency of PPP time transfer





◆Multi-system solution shows improvement over the GPS-only solution in noise level and frequency stability

◆Multi-system solution overcomes the un-consistency of different GNSSs

2.4 Other analysis of PPP time transfer

Traditional PPP time transfer

$$\begin{cases} P = \rho + c\left(dt_r - dt_s\right) + T_{trop} + \varepsilon_P \\ L = \rho + c\left(dt_r - dt_{i,s}\right) + T_{trop} + N + \varepsilon_L \end{cases}$$

Station coordinate (ρ) — Receiver clock (dt_r) — Tropospheric delay (T_{trop})

Priori constraint information should be used to improve the performance of traditional PPP time transfer

2.4 Other analysis of PPP time transfer

Station coordinate ⟺ Station always static in PPP time transfer

Tropospheric delay ⟺ Constrain with former estimation

Receiver clock ⟺ High performance atomic clock modeling

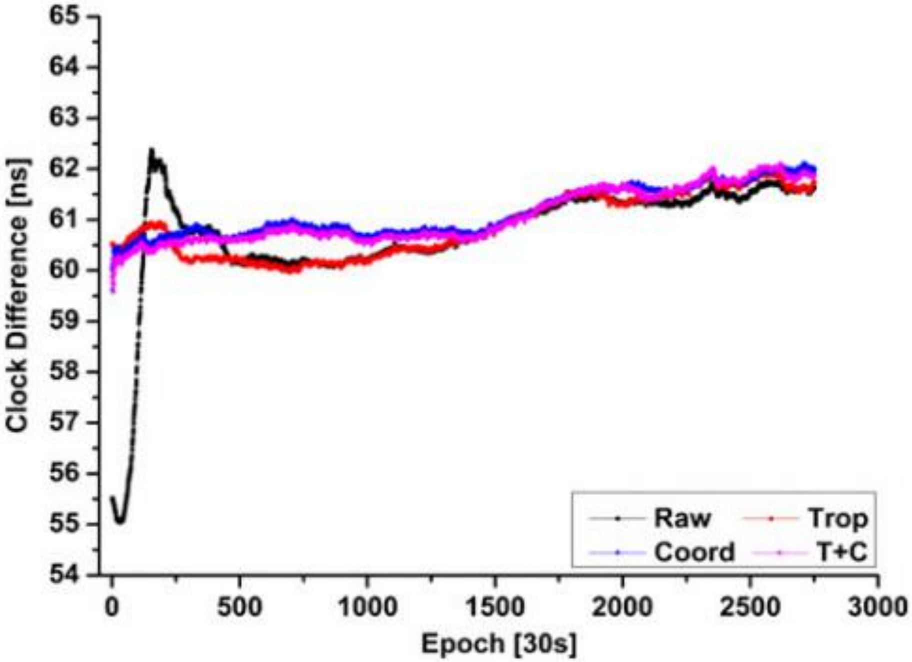
Principle of mathematic model with constraint information

Observed

$$\begin{bmatrix} L_k \\ L_i \end{bmatrix} = \begin{bmatrix} H_k \\ H_i \end{bmatrix} X + \begin{bmatrix} e_k \\ e_i \end{bmatrix}$$

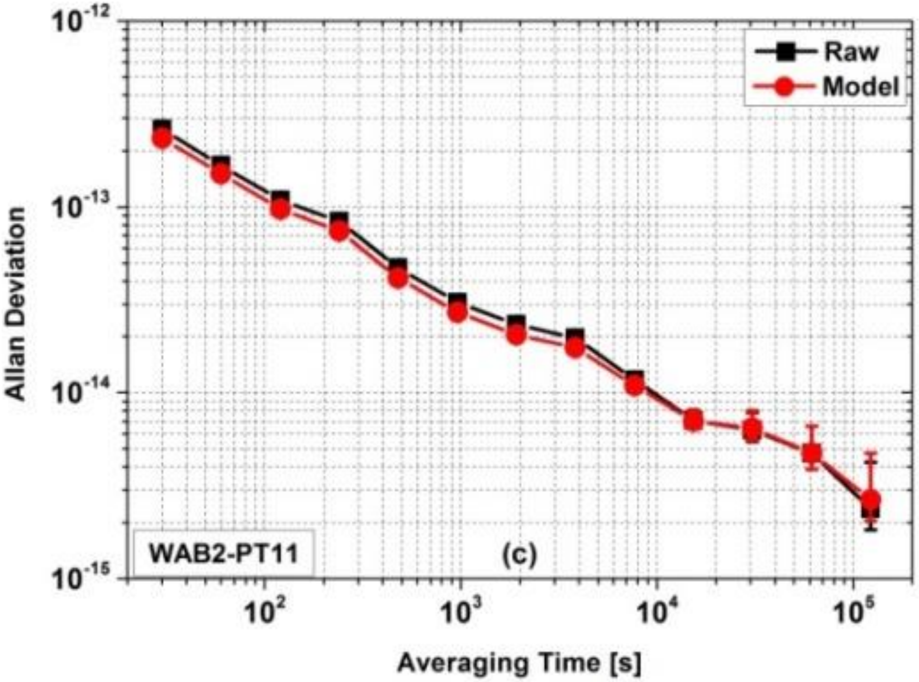
Constraint information

2.4 Other analysis of PPP time transfer



Coordinate and tropospheric constraint PPP time transfer

Atomic clock modeling augment PPP time transfer



Using prior constraint information can improve the performance (noise level and frequency stability) of PPP time transfer

Thank You