IGS 2026 WORKSHOP
SANTIAGO DE CHILE
33°26' S 70°39' O

1–5 June 2026

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Real-time multi-GNSS orbit and clock combination at SHAO

IGS 2026
WORKSHOP
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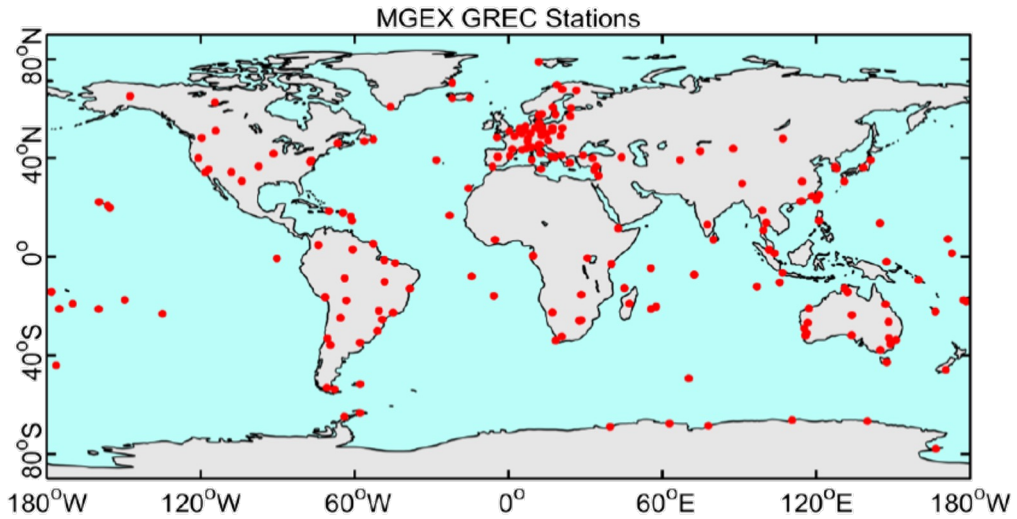
33°26' S 70°39' O

Background

IGS Real-Time service

- IGS Real-Time Working Group (RTWG) established in 2001
- Real-Time Pilot Project (RTPP) proposed in 2007
- IGS Real-Time Service (RTS) officially launched in 2013



Center	Mountpoints*	Description
APM	SSR*00APM#	GPS+GLO+GAL+BDS RT orbits and clocks based on internal APM Ultra Rapid product.
BKG	SSR*00BKG#	GPS+GLO+GAL RT orbits, clocks and code biases based on CODE orbits and biases; yaw angle in addition.
CAS	SSR*00CAS#	GPS+GLO+GAL+BDS RT orbits and clocks based on GFZ orbits. Also includes code biases.
CAS	IONO00CAS#	VTEC from Global Ionospheric Map.
CHC	SSR*00CHC1	GPS+GLO+GAL+BDS RT orbits and clocks. Also includes code and phase biases.
CNES	SSR*00CNE#	GPS+GLO+GAL+BDS RT orbits and clocks based on GFZ orbits. Also includes VTEC from Global Ionospheric Map, yaw angle, code and phase biases.
CNES	IONO00CNE1	VTEC from Global Ionospheric Map.
GFZ	SSR*00GFZ#	GPS+GLO+GAL+BDS orbits and clocks based on internal GFZ orbits every 2 hours. Also includes code biases.
GMV	SSR*00GMV#	GPS+GLO+GAL+BDS RT orbits and clocks based on GMV-generated orbits. Stream in RTCM format delivers code biases.
JPL	SSRA11JPL0	GPS+GAL RT orbits and clocks.
JPL	SSRA12JPL0	GPS+GAL RT orbits and clocks.
JPL	SSRA21JPL0	GPS+GLO RT orbits and clocks.
JPL	SSRA22JPL0	GPS+GLO RT orbits and clocks.
NRCan	SSRA00NRC0	GPS RT orbits and clocks based on hourly orbits from NRCan software. Also includes code biases.
SHAO	SSR*00SHA#	GPS+GLO+GAL+BDS RT orbits and clocks. Also includes code biases.
SHAO	SSR*01SHA#	GPS+GLO+GAL+BDS RT orbits and clocks. Also includes code and phase biases.
UPC	IONO00UPC1	VTEC from Global Ionospheric Map.
WHU	SSR*00WHU#	GPS+GLO+GAL+BDS RT orbits and clocks based on IGU (GPS) and IGS WHU AC orbits.
WHU	OSBC00WHU1	Observable Specific signal Biases (OSB) for GPS: L1/L2/L5, Galileo: E1/E5a/E5b/E6/E5, BDS-2: B1I/B2I/B3I, BDS-3: B1I/B1C/B2a/B2b/B2/B3I. Satellite orbits and clocks are fixed and used from SSRC00WHU0. Moreover, multi-frequency raw ambiguities are all fixed during the data processing of estimating phase OSBs.

* The mountpoints prefix SSR**C** and SSR**A** indicate CoM and APC orbits, respectively.

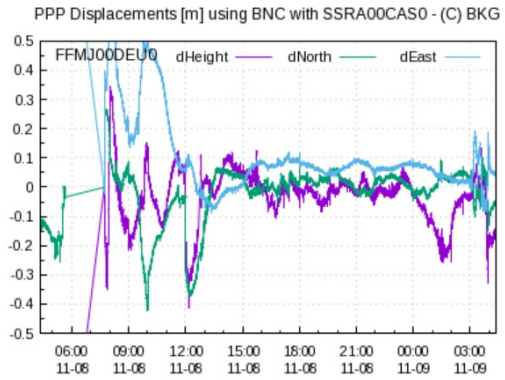
- More than 300 global stations currently provide real-time RTCM observations.

IGS Real-Time service

AC	Solution	RT-Orbits	RT-Clocks	Code-Biases	Phase-Biases	VTEC-Maps	GPS	GLO	GAL	BDS
APM	0	x	x				x	x	x	x
BKG	0	x	x	x			x	x	x	
CAS	0 1	x x	x x	x x	x (G,E,C)	x (+RMS)	x x	x	x x	x x
CHC	0	x	x	x	x (G,E,C)		x	x	x	x
CNES	0	x	x	x	x (G,E,C)	x	x	x	x	x
GFZ	0 1	x x	x x	x x			x x	x x	x x	
GMV	0	x	x				x		x	x
JPL	11 12 21 22	x x	x x				x x	x		
NRCan	0	x	x	x	x (G)		x			
SHAO	0 1	x x	x x	x x			x x	x	x x	x
UPC	0					x				
WHU	0	x	x	x	x (G,E,C)		x	x	x	x

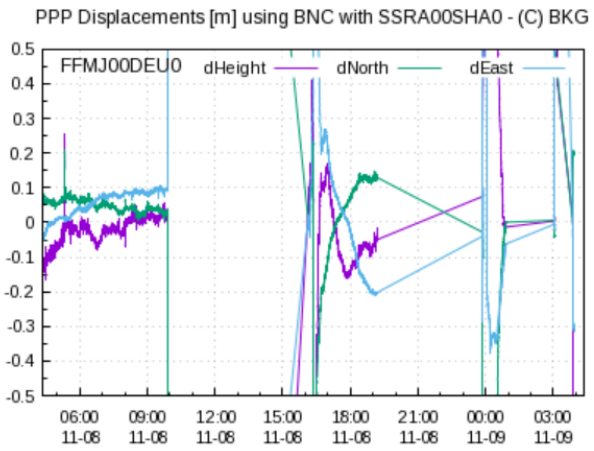
Current Status of IGS RTS Products

- Many ACs provide real-time SSR orbit and clock products
- Product performance varies among ACs (https://igs.bkg.bund.de/ntrip/ppp)
- Only a few ACs provide real-time phase bias products
- Some product standards are still under discussion
- It is necessary to provide combined real-time products (IGS02/IGS03)



Chinese Academy of Sciences solution SSRA00CAS0

- PPP client software: BKG Ntrip Client (BNC)
- Location: IGS reference station FFMJ00DEU, Frankfurt
- Observations: 1Hz, dual frequency, GPS and GLONASS
- Orbit/clock corrections software: **GPSNet** by CAS
- Orbits: ?
- Orbit/clock corrections stream: **SSRA00CAS0** on products.igs-ip.net by CAS
- Orbit/clock corrections encoding: BKG Ntrip Client (BNC)
- Broadcast ephemeris stream: BCEP00BKG0 on products.igs-ip.net by BKG



Shanghai Astronomical Observatory solution SSRA00SHA0

- PPP client software: BKG Ntrip Client (BNC)
- Location: IGS reference station FFMJ00DEU, Frankfurt
- Observations: 1Hz, dual frequency, GPS+GLO
- Orbit/clock corrections software: **???** by SHAO
- Orbits: ?
- Orbit/clock corrections stream: **SSRA00SHA0** on products.igs-ip.net by SHAO
- Orbit/clock corrections encoding: BKG Ntrip Client (BNC)
- Broadcast ephemeris stream: BCEP00BKG0 on products.igs-ip.net by BKG

Current Status of IGS RTS Products

Existing Issues

Specific AC

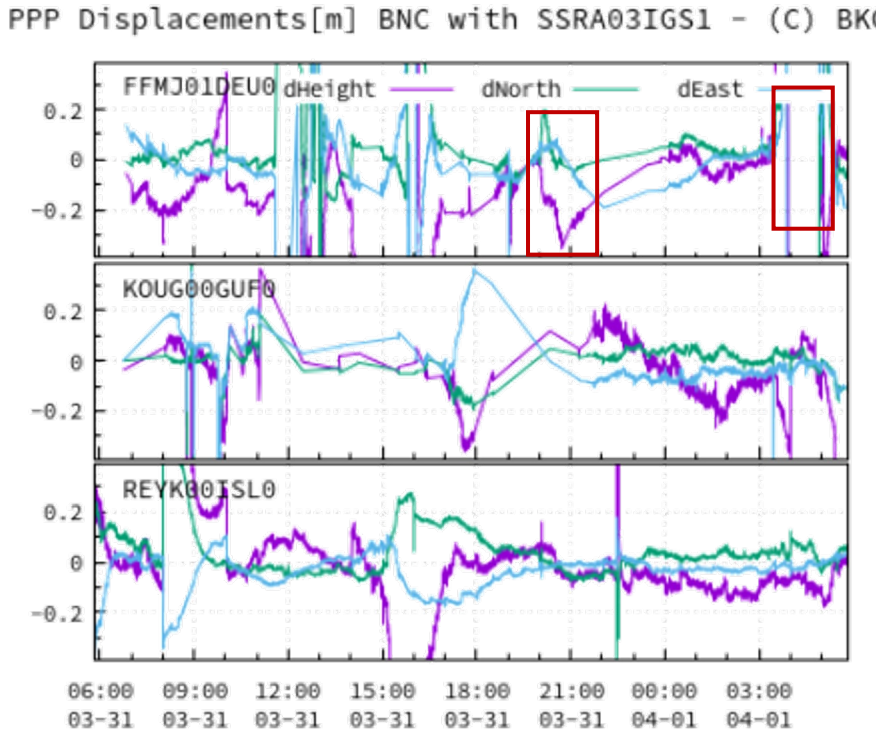
- ☐ Product interruption

IGS03(combined product)

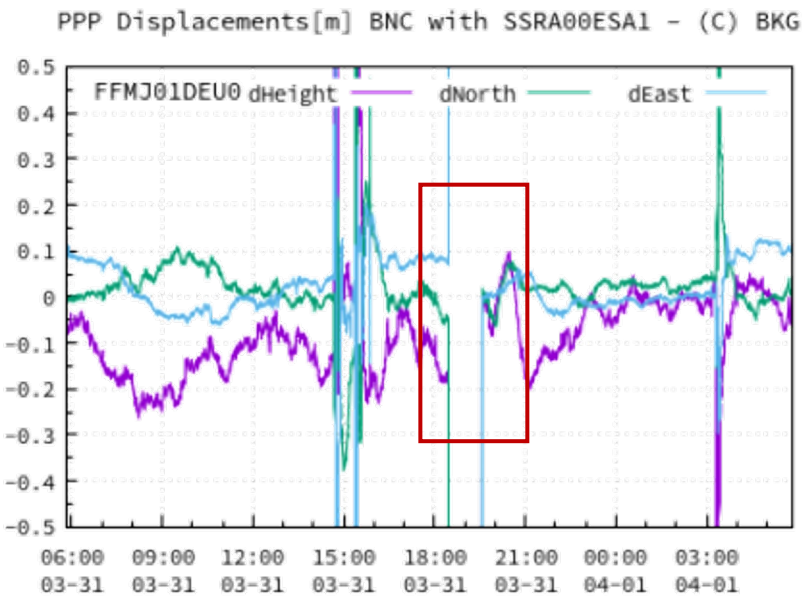
- ☐ Product interruption
- ☐ Product jumps

Limited reliability and robustness

Positioning Performance



IGS03 (combined product)



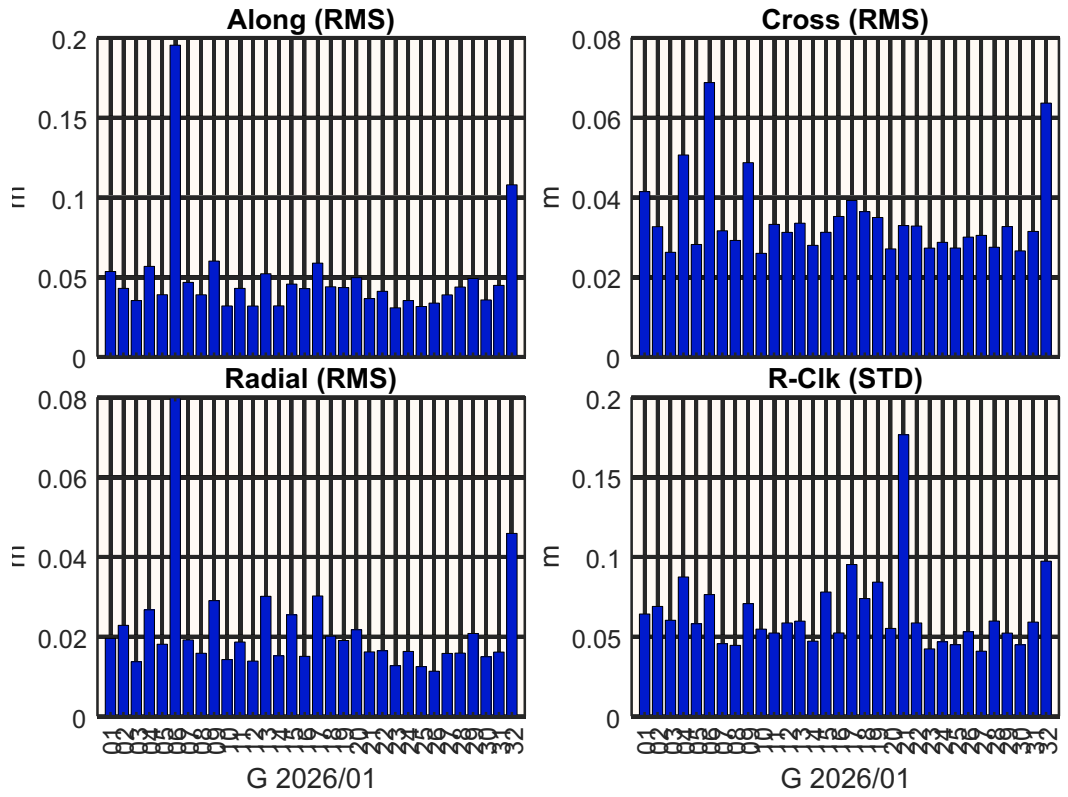
ESA

Status of IGS RTS Combined Products

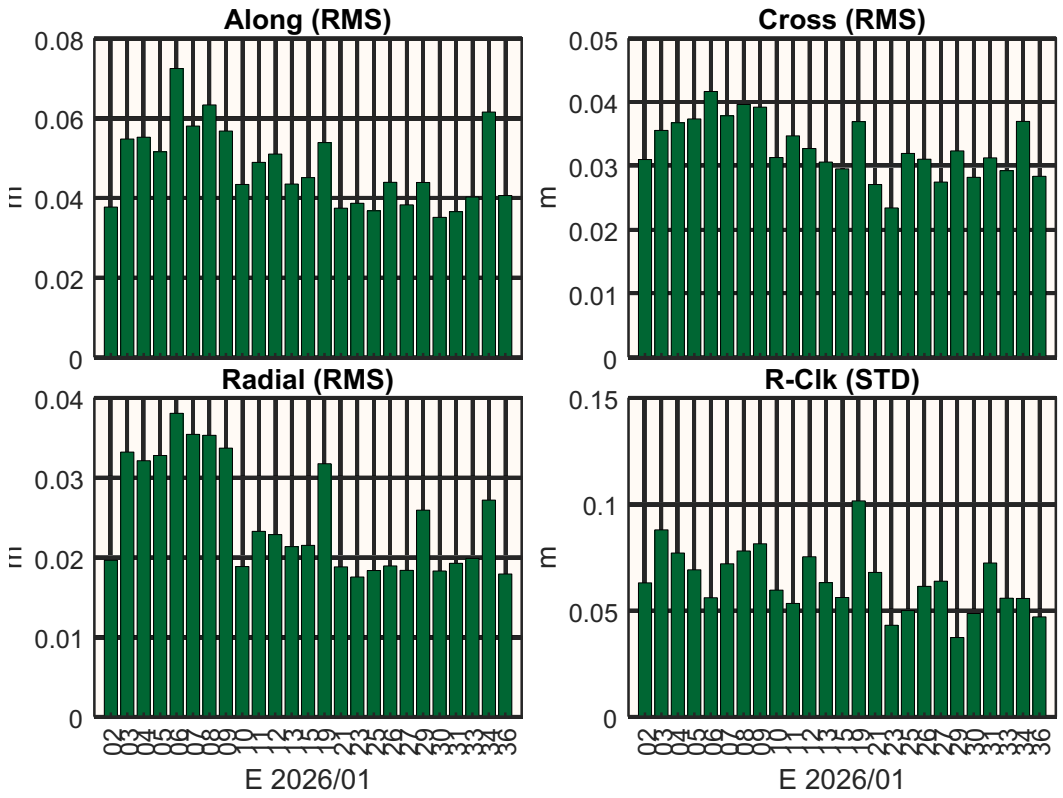
Problem Analysis

- Different ACs use different:
  - station networks
  - processing models
  - reference frames
- Product interruptions and jumps still exist
- Existing studies mainly focus on:
  - GPS-only combination
  - post-processing combination
- BDS combined products show significant jumps

Performance of IGS Combined Products(SSRA03IGS0)

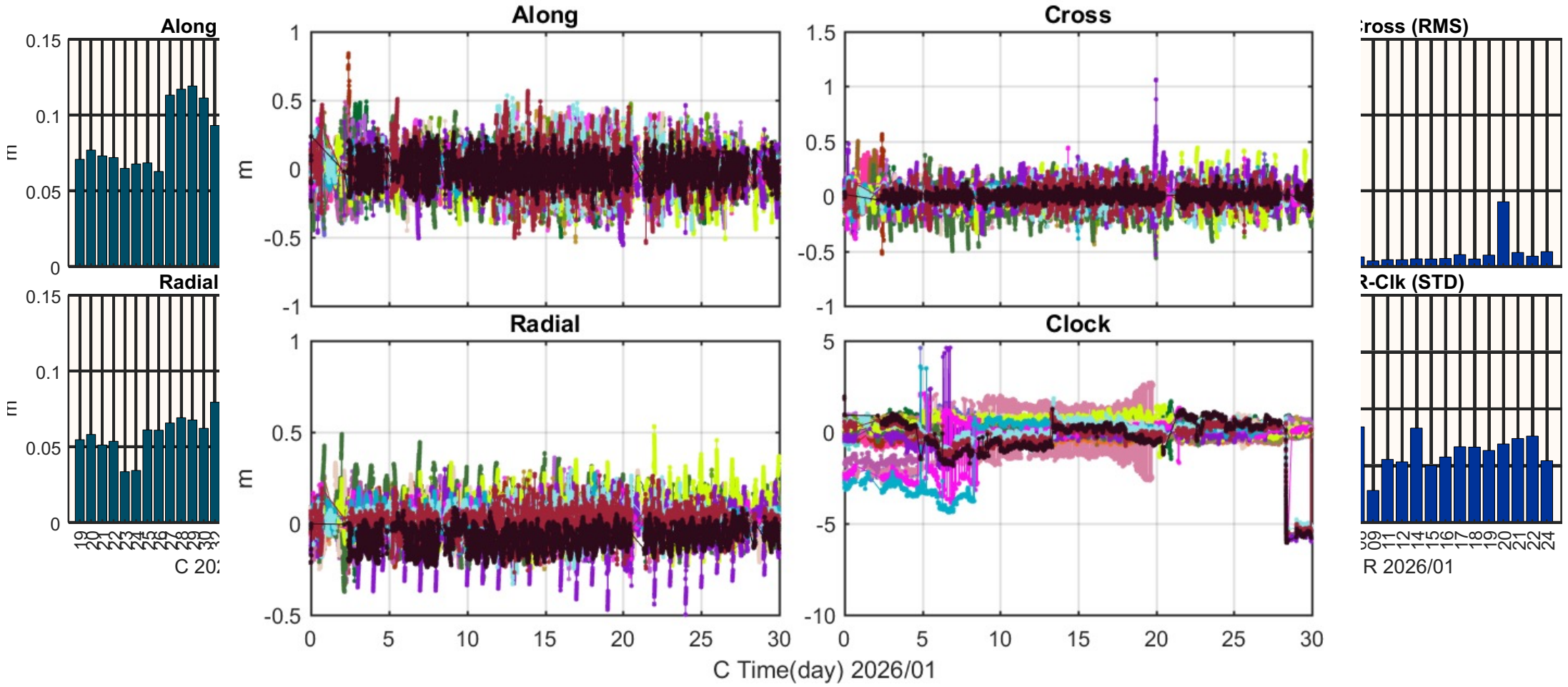


GPS



Galileo

Performance of IGS Combined Products(SSRA03IGS0)

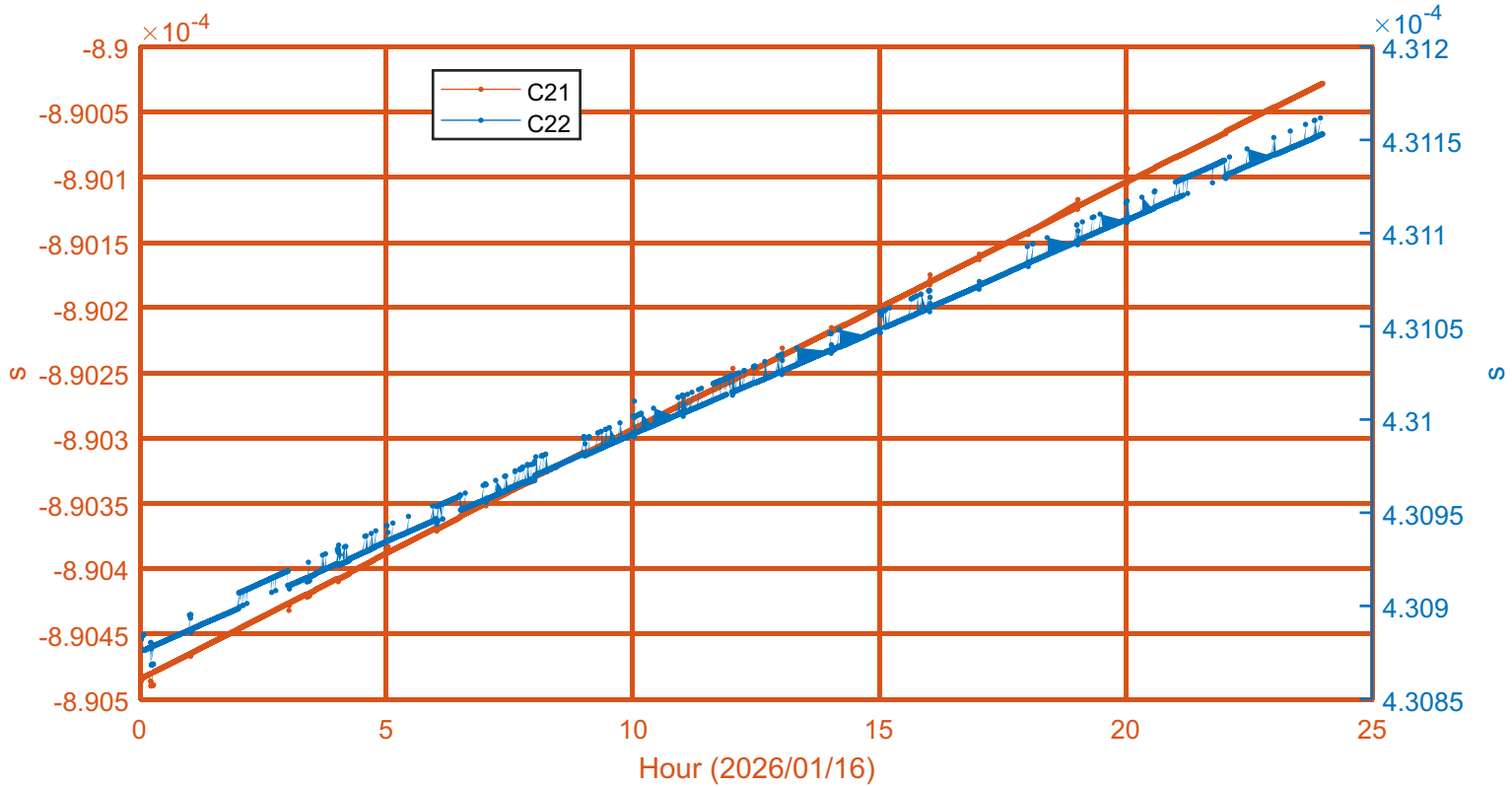


IGS BDS Combined Orbit Products

Coordinates of BDS C28 at adjacent epochs

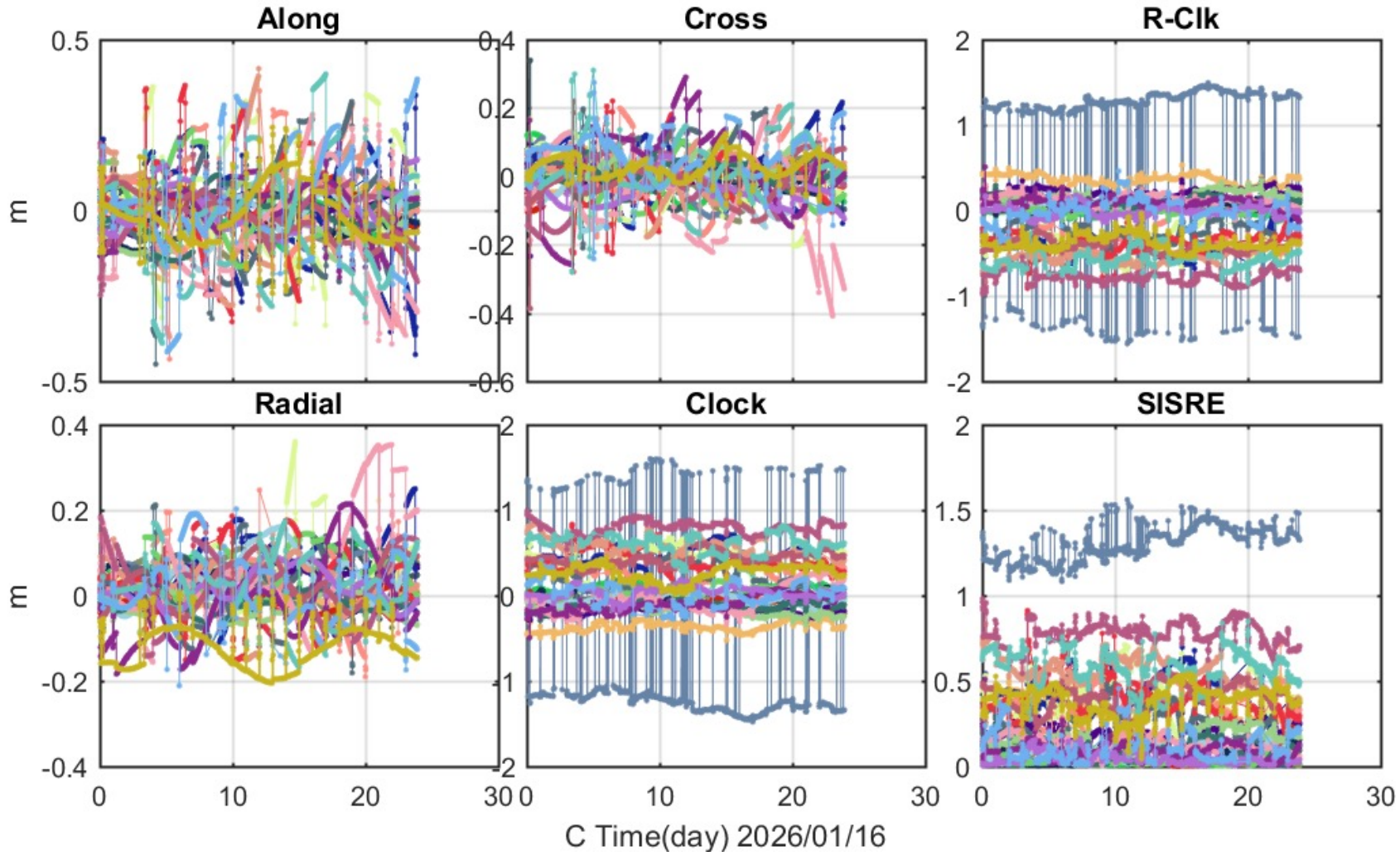
	X(km)	Y(km)	Z(km)	X(m)	Y(m)	Z(m)
	* 2026 01 16 03 20 00					
IGS03	22394.174587	-2557.292760	-16451.960500	-0.009	0.082	-0.047
WUM	22394.174596	-2557.292842	-16451.960453			
	* 2026 01 16 03 25 00					
IGS03	21964.462656	-2173.372020	-17074.267832	-0.131	0.245	-0.123
WUM	21964.462787	-2173.372265	-17074.267709			

IGS BDS Combined Clock Products



Clock Series of BDS C21 and C22

Performance of IGS BDS Combined Products



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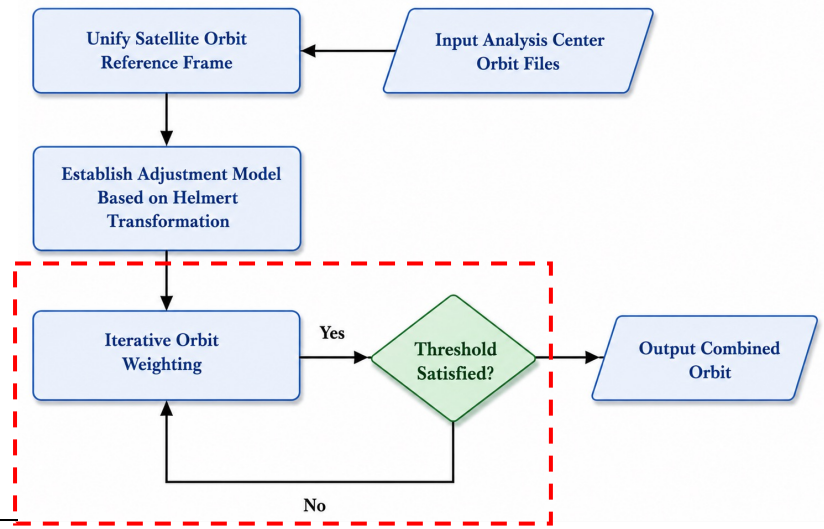
Real-time Orbit and Clock Combination

Conventional Combination Method for Post-processing

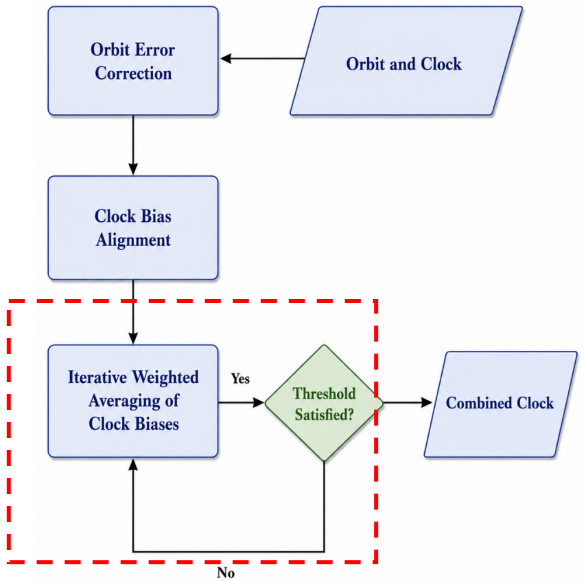
Orbit Combination

$$orb_{com} = \frac{\sum_{i=1}^{n} P^i \times orb_j^i}{\sum_{i=1}^{n} P^i}$$



Clock Combination

$$clk_{com}^i = \frac{\sum_{j=1}^{n} P_j^i \times clk_j^i}{\sum_{i=1}^{n} P_j^i}$$



Combination Method

Post-process

- **Iterative weighted averaging**
- Accuracy assessment

Real-time

- ☐ Preprocessing
- ☐ Weighting strategy
- ☐ Accuracy evaluation

[1] Kouba J, Mireault Y and Lahaye F. (1995). 1994 IGS orbit/clock combination and evaluation. Appendix of the Analysis Coordinator Report, International GPS Service for Geodynamics IGS 1994 Annual Report, pp. 70-94.

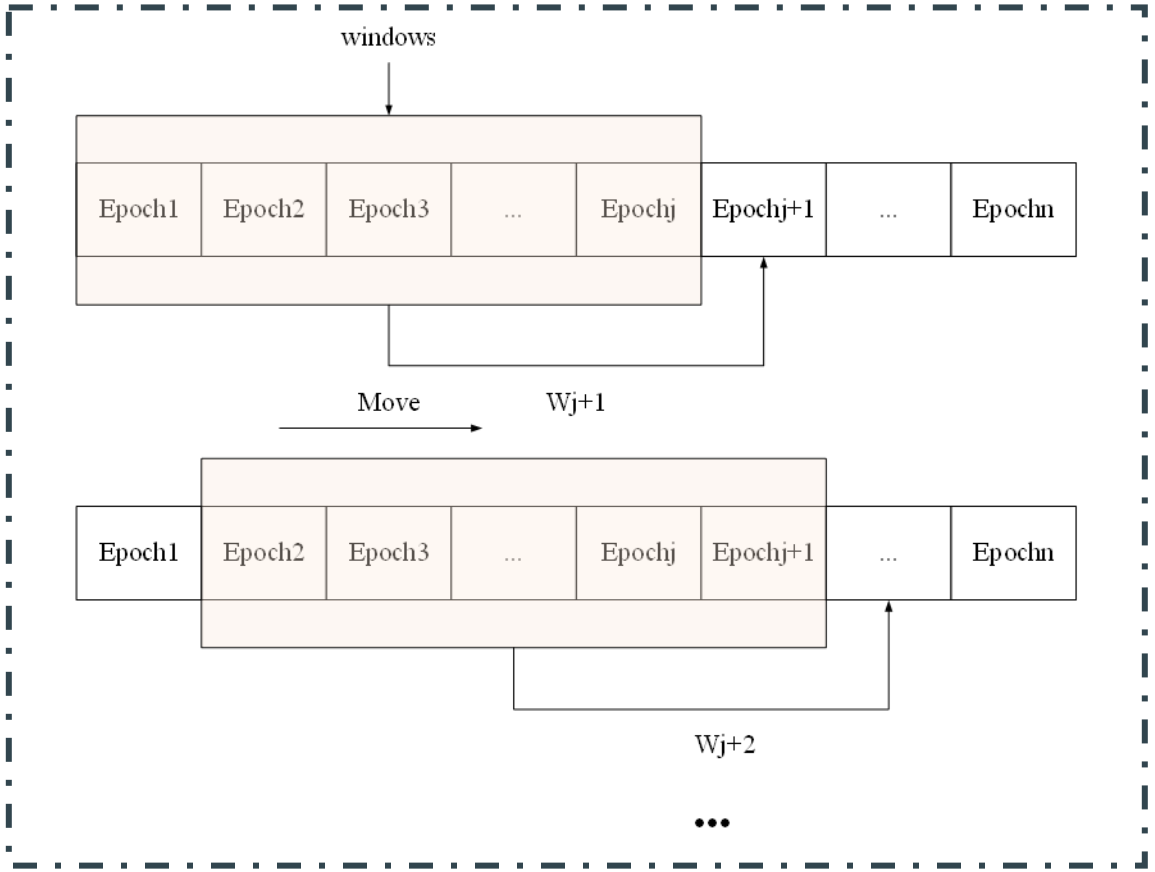
[2] Sakic, P., Mansur, G., & Männel, B. (2020). A prototype for a Multi-GNSS orbit combination. 2020 European Navigation Conference (ENC), 1-11.

[3] Chen, L., Song, W., Yi, W. et al. Research on a method of real-time combination of precise GPS clock corrections. GPS Solut 21, 187–195 (2017).

Real-Time Orbit Combination

Orbit combination

- $RMS_i = orb_i - mean_{orb}$, Use average orbit as initial reference
- $W_{i,j} = \frac{RMS_i}{\sum_{i=1}^{num\_AS} RMS_i}$, Normalize AC weights epoch by epoch
- $orb_j = \sum_{i=1}^{num\_AS} W_{i,j} \cdot orb_{i,j}$, Iterative weighted averaging



Sliding Window Weighting

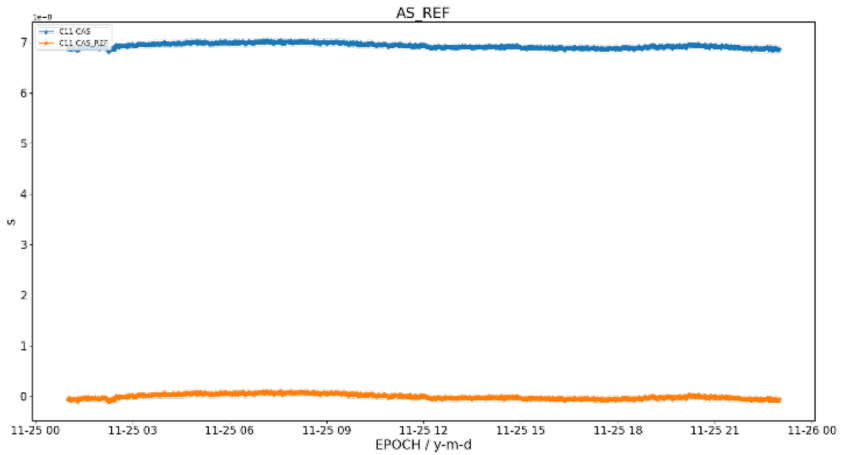
Real-Time Clock Combination

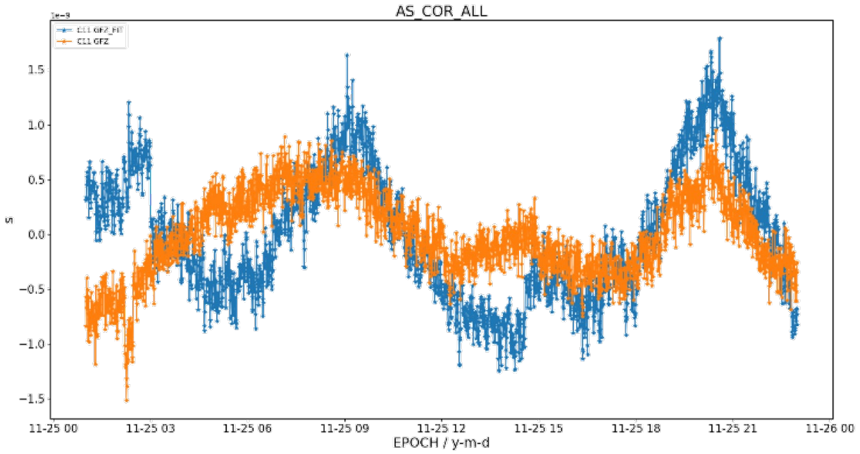
Radial correction based on combined orbit

$$\Delta\, orb_t^{Sat} = \frac{(X_{AC,t}^{Sat} - X_{ref,t}^{s}) \cdot X_{AC,t}^{Sat}}{c \cdot R_t^{Sat}}$$

Clock datum correction

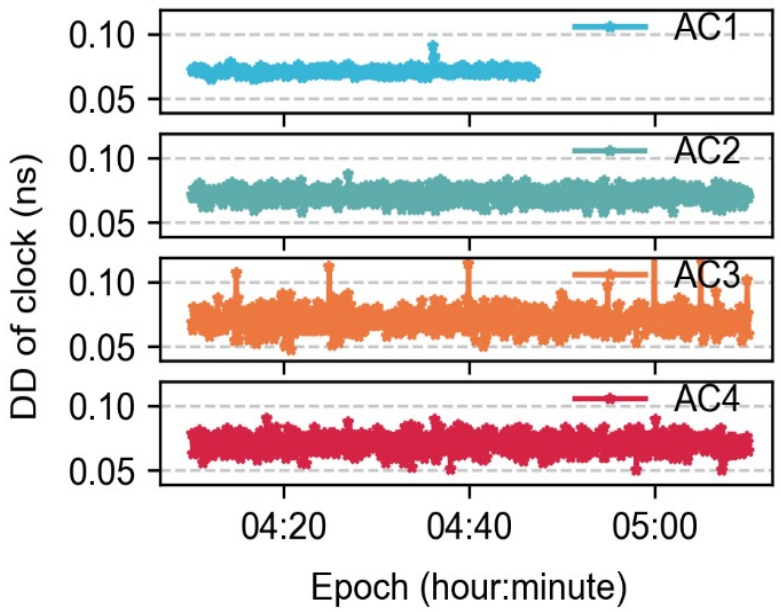
- Linear trend removal using IGS strategy
- Initial clock alignment



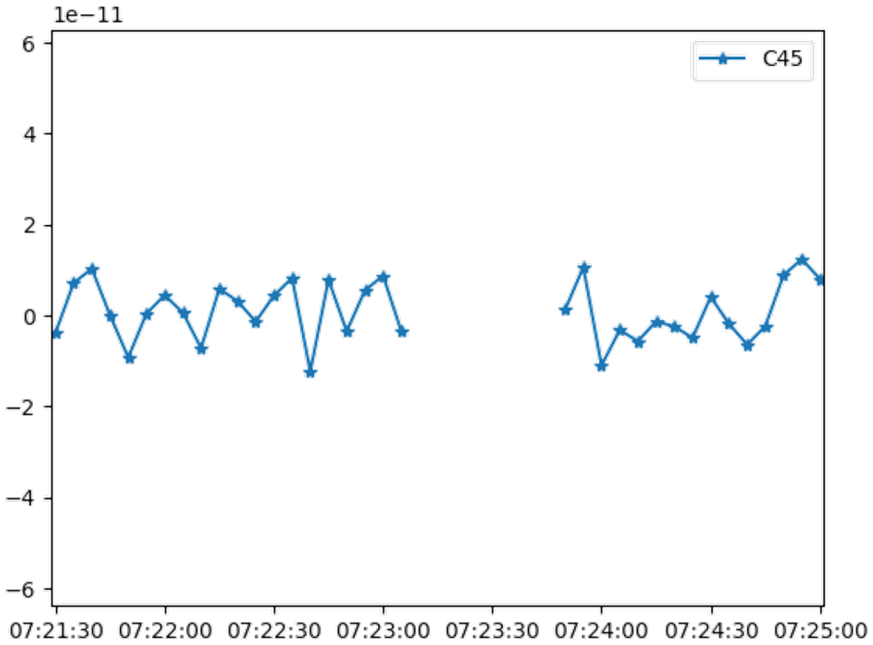


Issues in Real-time Clock Combination

AC data interruption



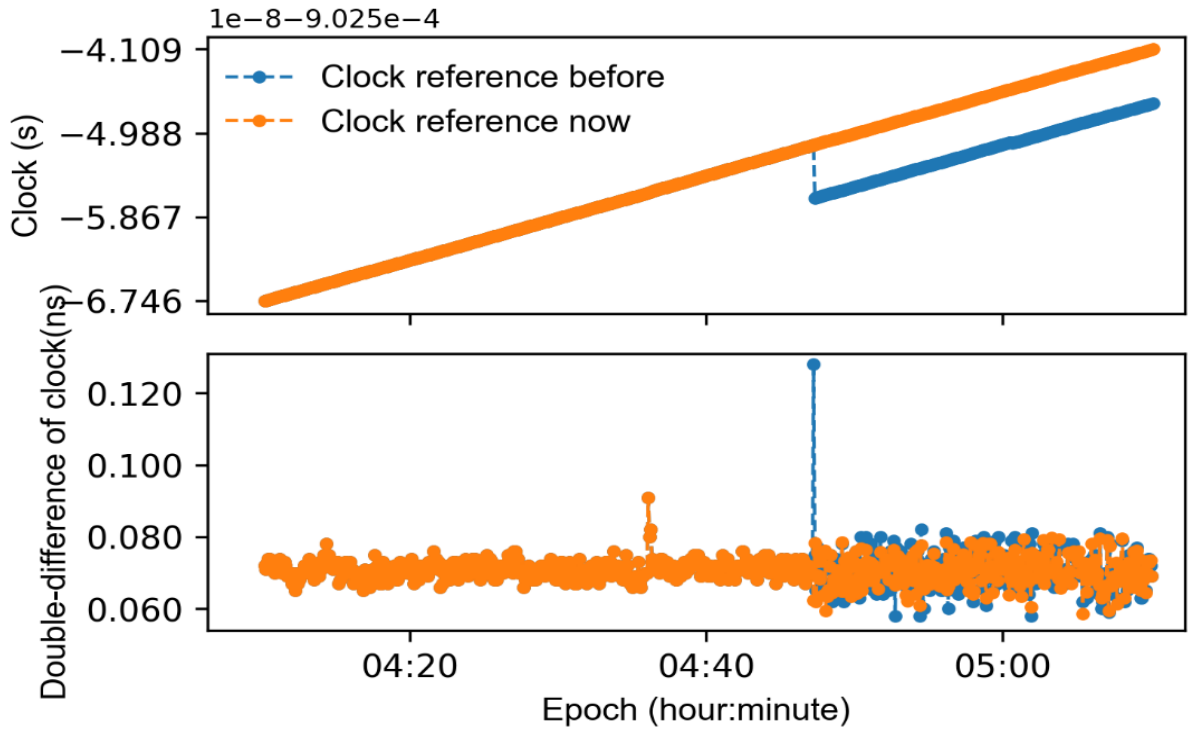
Single satellite data interruption



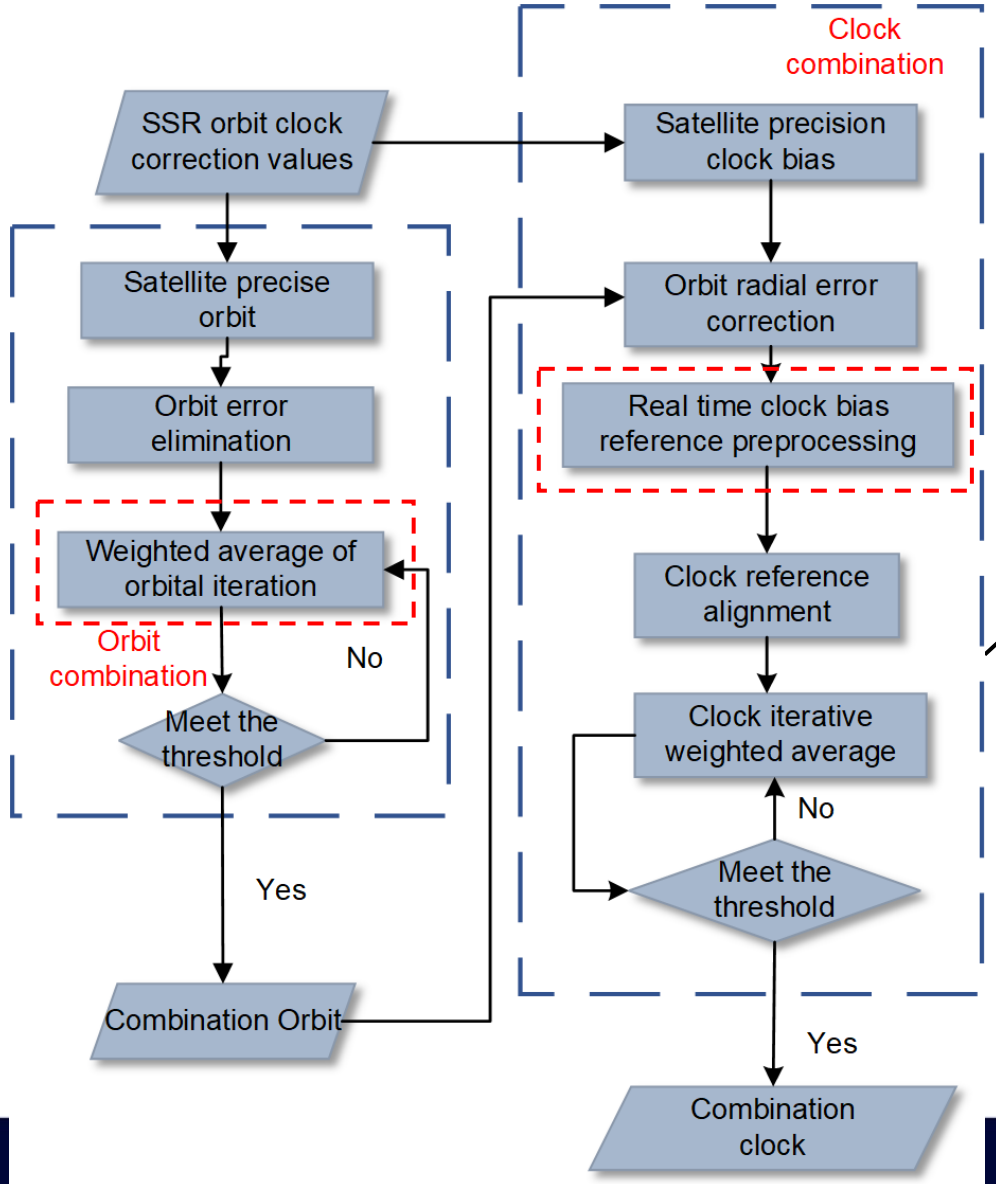
Solution

Determine clock datum by inter-epoch differences

$$CLK^{i}_{ref,j} = \frac{1}{n-1}\sum_{k=1}^{n}\left(CLK^{k}_{AC,j} - CLK^{k}_{AC,j-1} + CLK^{i}_{AC,j-1}\right) \qquad k \neq i$$



Workflow of Real-time Orbit and Clock Combination



$$clk_{com}^{i} = \frac{\sum_{j=1}^{n} P_j^i \times clk_j^i}{\sum_{i=1}^{n} P_j^i}$$

$$P_j^i = \frac{AS_{clk} - Ref_{clk}}{\sum_{i=1}^{n} RMS_i}$$

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Results

Data

One week of BDS real-time products (DOY 329–335, 2024)

Products	Interval/s
SSRA00APM0	5
SSRA00CNE0	5
SSRA00GFZ0	5
SSRA00WHU0	5
SSRA03IGS0	10

Orbit Combination Weights:

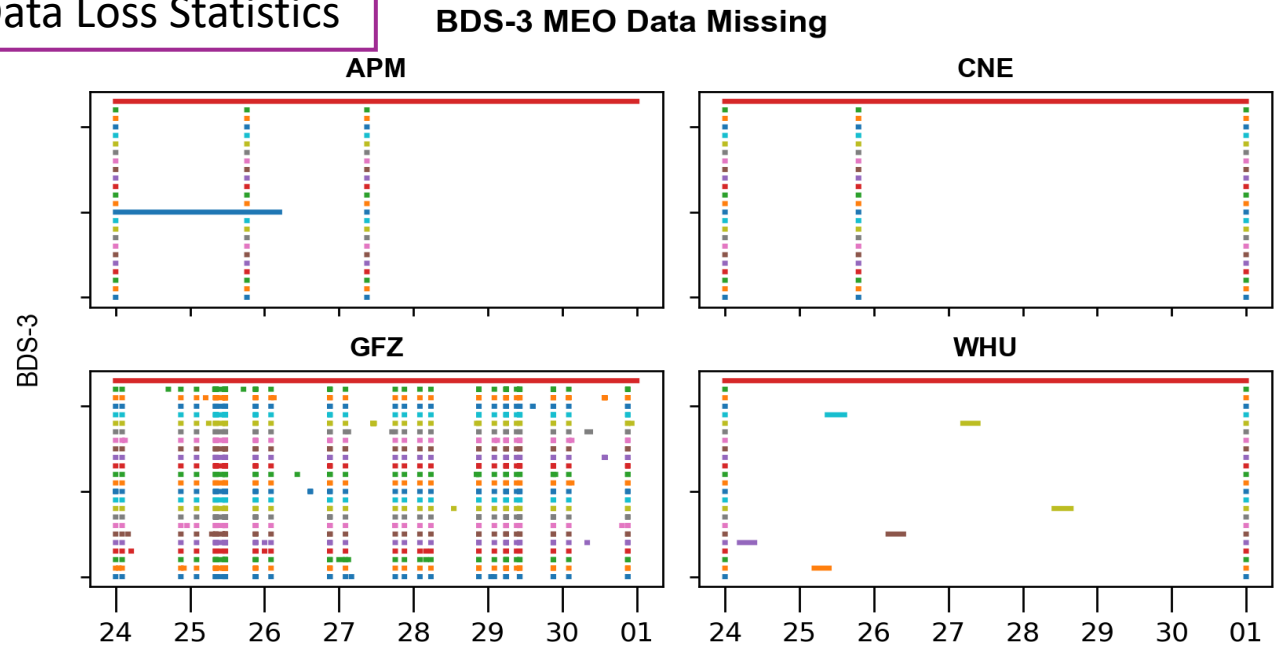
APM: 0.31; CNES: 0.11; GFZ: 0.25; WHU: 0.33

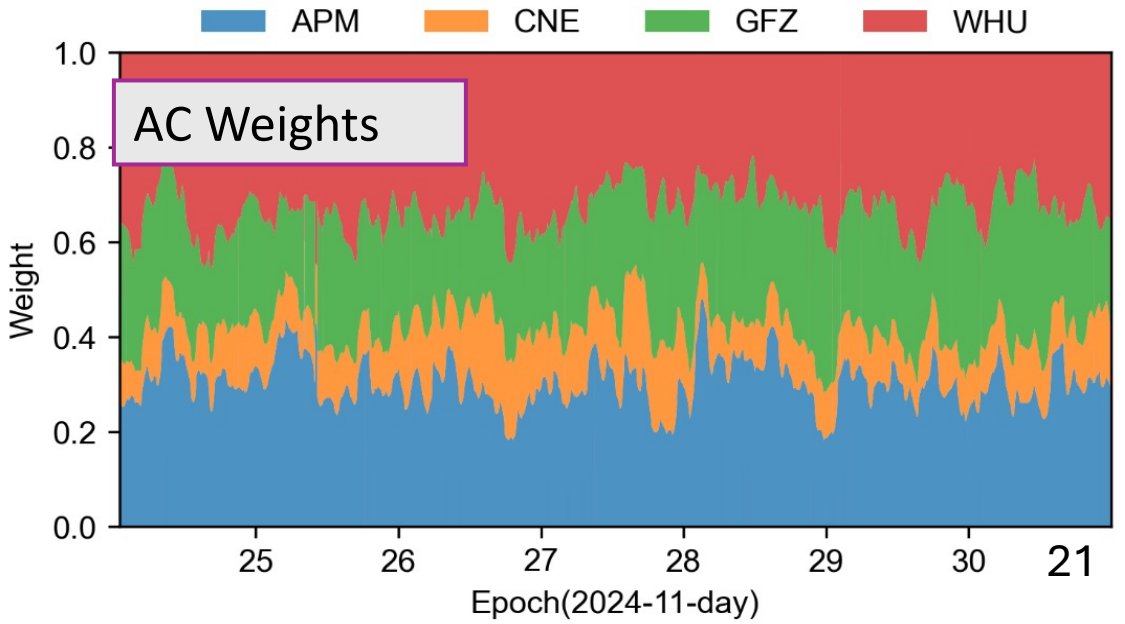
Weights are consistent with orbit accuracy.

Orbit Accuracy

AC	3D/m
APM	0.095
CNE	0.242
GFZ	0.112
WHU	0.080

Data Loss Statistics

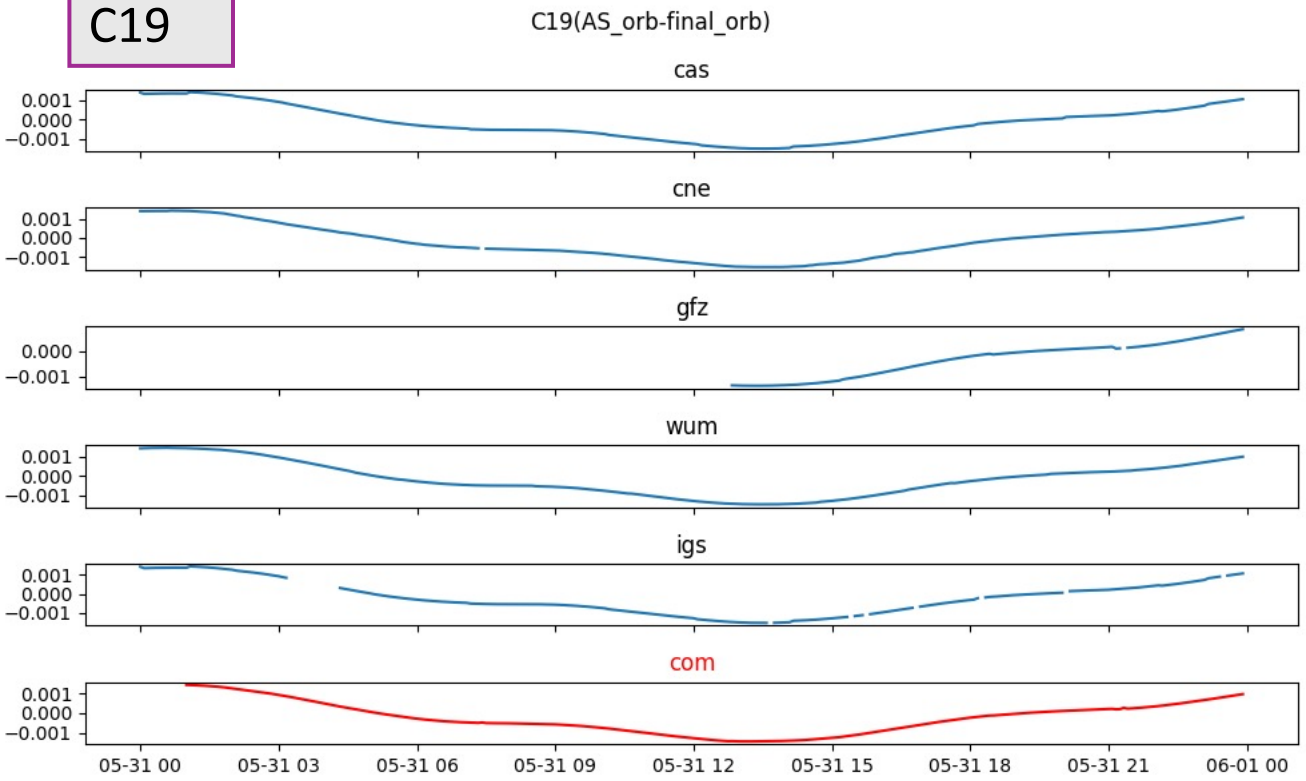




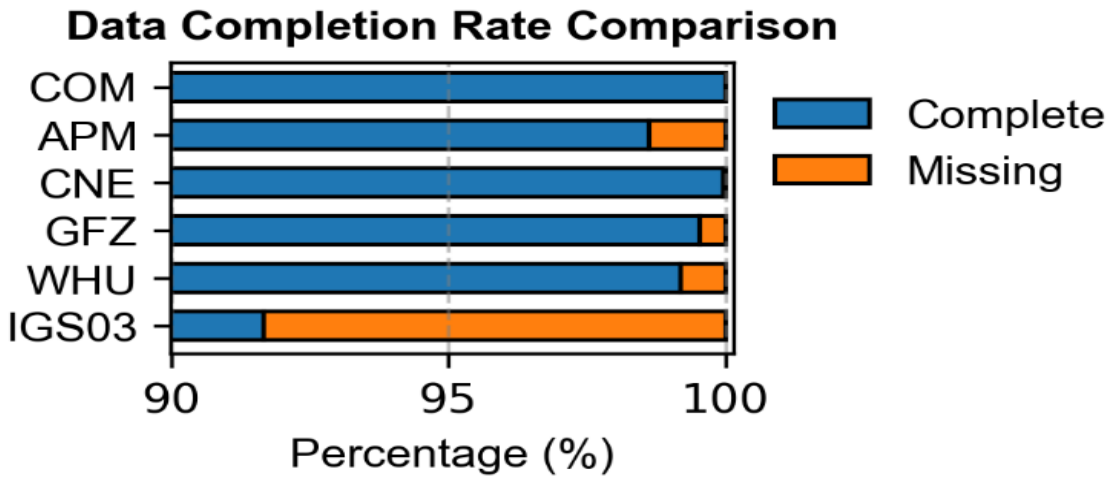
Product Completeness

Completeness $AVA_{AS} = \frac{\sum_{s=1}^{n} N_{ava,AS}^{s}}{\sum_{s=1}^{n} N_{full,AS}^{s}}$

C19



Combined product completeness reaches 99.9%, 12.7% higher than IGS03.



Orbit Accuracy

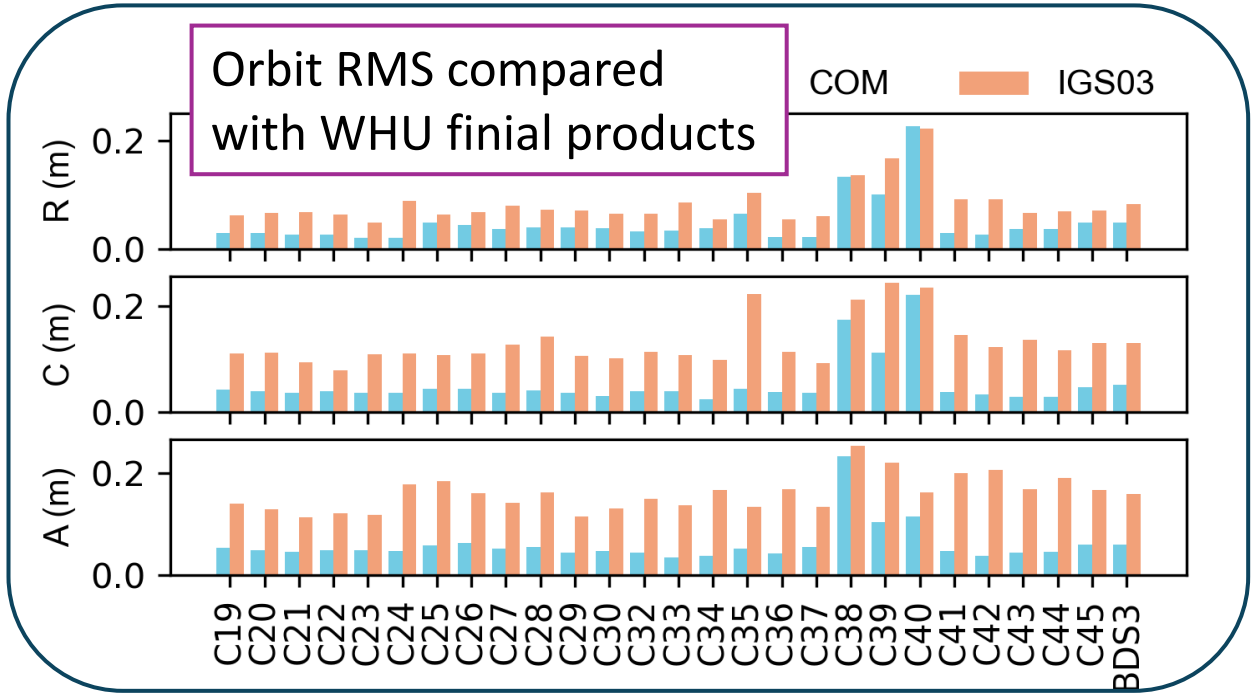
Unit (m)		Along	Cross	Radial
COM	MEO	0.049	0.037	0.034
	IGSO	0.151	0.169	0.151
IGS03	MEO	0.167	0.131	0.071
	IGSO	0.213	0.230	0.175

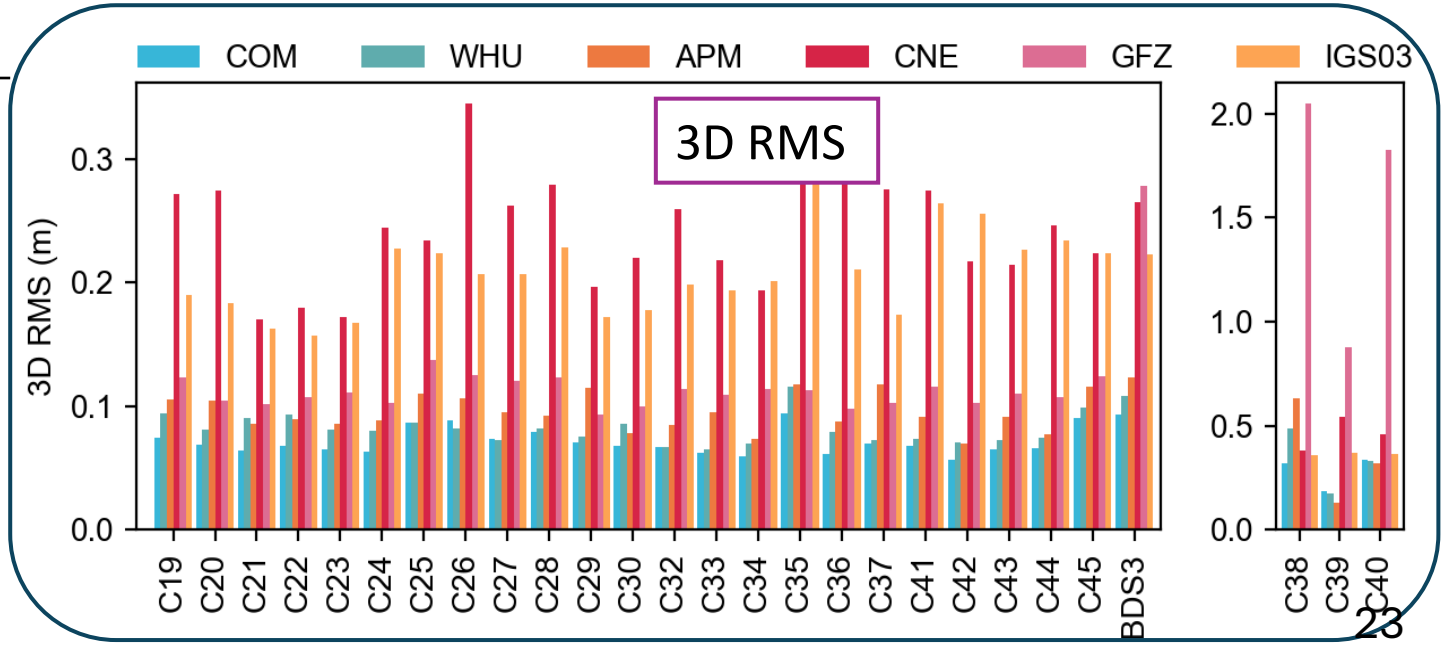
Combined products improve orbit accuracy by:

50–60% for MEO

10–30% for IGSO

Better stability and completeness than individual AC products





Clock Accuracy

Clock STD: 0.16–0.30 ns

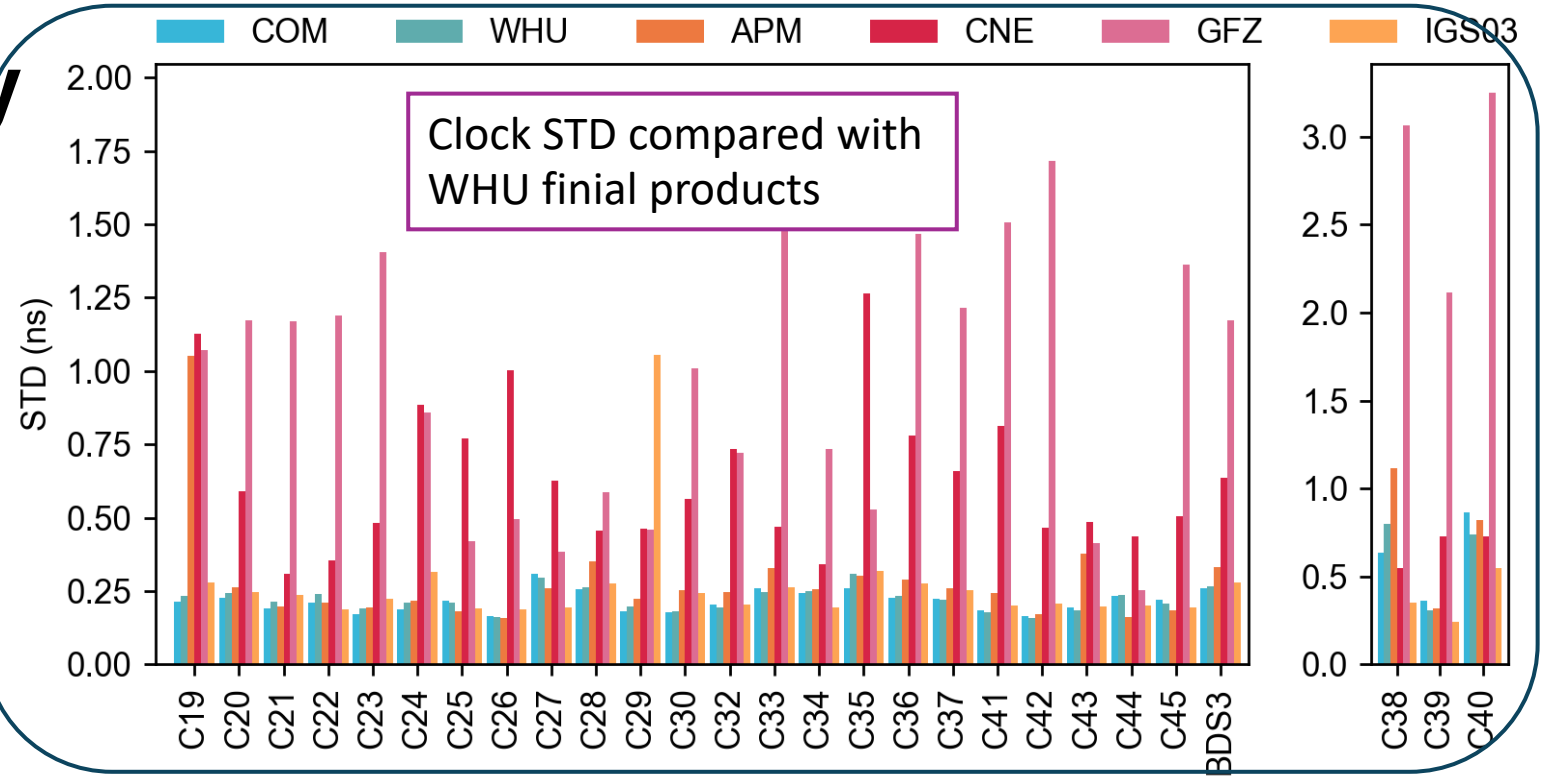
Better than most AC products

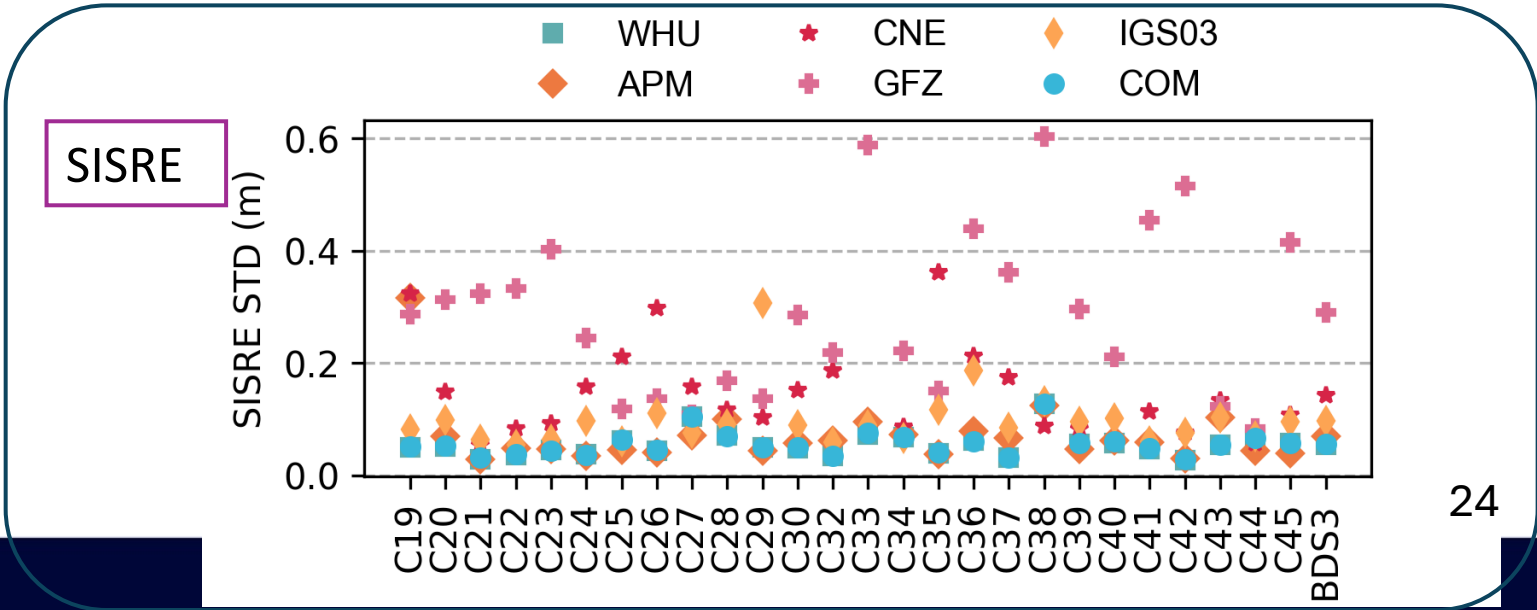
Improved over IGS03:

7% for MEO

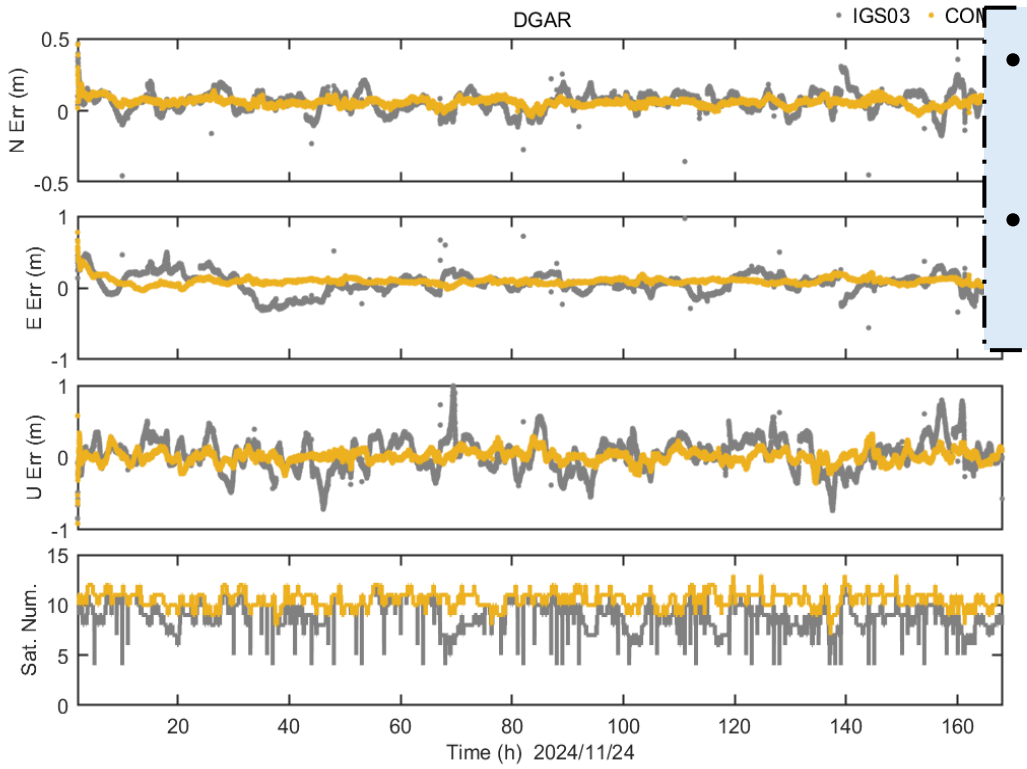
20% for IGSO

Combined SISRE STD reaches 0.052 m, 46% better than IGS03 and 20–80% better than other AC products.

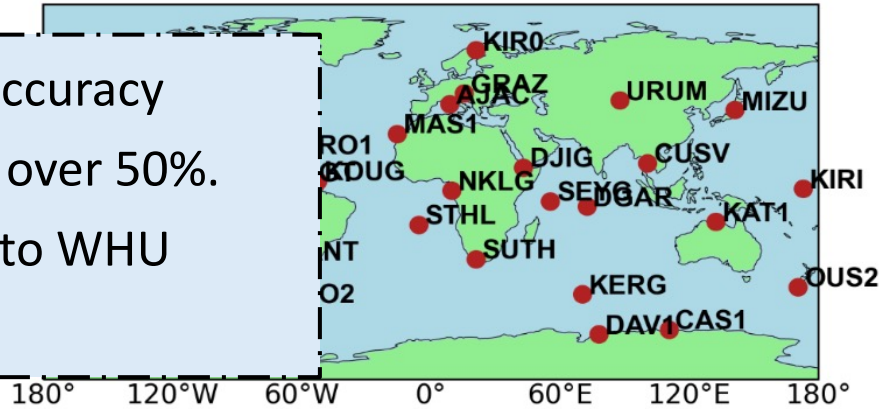




Kinematic PPP Validation

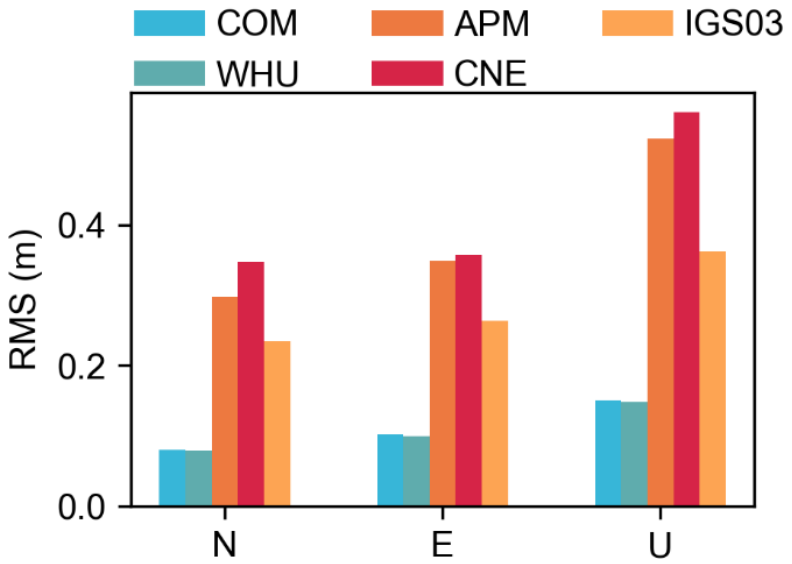


- Positioning accuracy improved by over 50%.
- Comparable to WHU products.



Tested 27 stations

AC	DGAR		
	N(m)	E(m)	U(m)
IGS03	0.103	0.167	0.286
COM	0.063	0.097	0.097



All stations

Conclusions

- Sliding-window weighting improves real-time combination.
- Datum switching and satellite interruption issues are resolved.
  - Orbit and clock accuracy are significantly improved.
  - Satellite availability and completeness are enhanced.
- PPP accuracy improves by more than 50%.
- SHAO real-time combined products is under test at (129.211.69.159:22, SSRA00COM0).
- We are prepare to contribute to IGS RTS combination!

MountPt	SSRA01SHA0	SSRC01SHA0	SSRA01SHA1	SSRC01SHA1	SSRA00COM0
UpTime	10:42:55 Up(36/7)	05:38:32 Up(110/3)	03:35:02 Up(107/3)	05:38:32 Up(98/3)	10:43:00 Up(2/4)
Input	399.844 MB	373.363 MB	371.964 MB	372.832 MB	228.498 MB
Output	399.515 MB	676.823 MB	371.761 MB	372.552 MB	0 Bytes
Clients	1 / 82 [R]	1 / 105 [R]	1 / 76 [R]	1 / 78 [R]	0 / 0 [R]

Thank you!

- http://www.shao.ac.cn/shao_gnss_ac
- http://www.shao.ac.cn/shao_gnss_ac/products/
- *Email*: zhyize@shao.ac.cn

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Backup Slides

Different ACs in May 2026

Table 1 Combination strategies using different numbers of ACs

Product	WHU	APM	GMV	CHC	CAS	CNE	SHA
3ACs	○	○				○	
4ACs	○	○			○	○	
5ACs	○	○	○	○	○		
6ACs	○	○	○	○	○	○	
7ACs	○	○	○	○	○	○	○

Orbit

Clock