



CAS real-time multi-GNSS clock and bias estimation: new product streams for PPP with ambiguity resolution

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► IGS RTS Pilot Project began in 2001

- Monitor and improve observation data and broadcast ephemerides
- Provide [precise real-time corrections of orbits, clocks, biases and atmospheric delays](#)
- Combine correction data streams for IGS real-time services

► 2024 Workshop Recommendation

- Major applications of the IGS RTS rely on a [10-cm position accuracy with fixed ambiguities](#).

RTACs are encouraged to develop their products to reach this goal

→ [More RTACs](#) are needed to provide satellite clocks, code and phase biases allowing ambiguity fixing

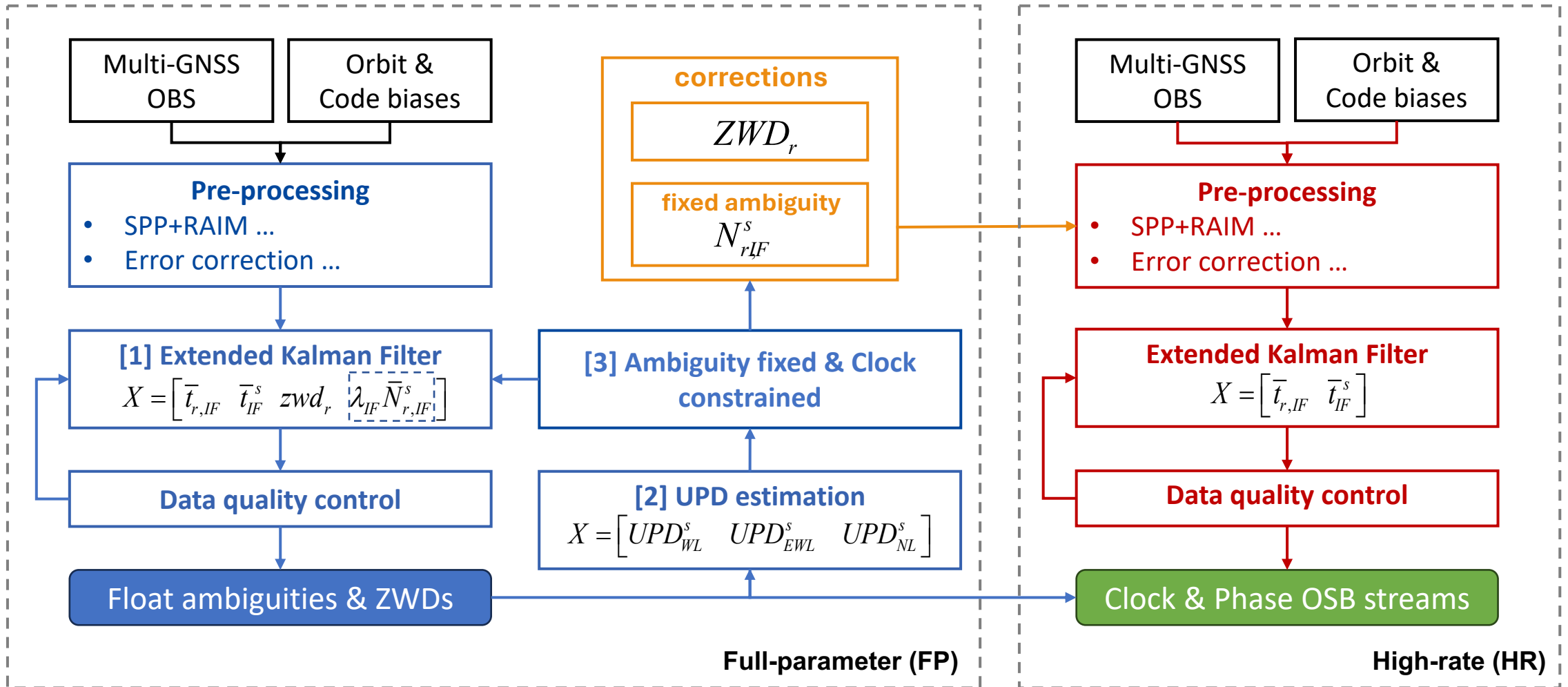
IGS Real-Time Service

RTAC	Mountpoints	Product Description	PPP	PPP-AR
APM	SSR*00APM#	G+E+C+R RT orbits and clocks.	X	
BKG	SSR*00BKG#	G+R+E RT orbits, clocks and code biases; additional yaw angle.	X	
CAS	SSR*00CAS#	G+E+C+R RT orbits and clocks.	X	
	SSR*01CAS#	G+E+C RT orbits, clocks, code & phase biases; GIM.	X	X (2025)
CHC	SSR*00CHC1	G+E+C+R RT orbits, clocks, code & phase biases.	X	X (2025)
CNE	SSR*00CNE#	G+E+C+R RT orbits, clocks, code & phase biases; GIM	X	X (2012)
GFZ	SSR*00GFZ#	G+E+C+R RT orbits, clocks and code biases.	X	
GMV	SSR*00GMV#	G+E+C+R RT orbits and clocks; RTCM format delivers code biases.	X	
JPL	SSRA##JPL0	G+E+C RT orbits and clocks.	X	
NRC	SSRA00NRC0	GPS RT orbits, clocks and code biases.	X	
SHA	SSR*00SHA#	G+E+C+R orbits, clocks and code biases.	X	
	SSR*01SHA#	G+E+C+R RT orbits, clocks, code & phase biases.	X	X (2025)
UPC	IONO00UPC1	GIM.		
WHU	SSR*00WHU#	G+E+C+R RT orbits and clocks	X	
	OSBC00WHU1	Additional code & phase biases.		X (2017)

- ▶ **CAS01 product streams have been available since June 2025 **SSR*01CAS*****
 - ▶ CAS01 streams include corrections for orbit, clock, code bias (all-frequency), **phase bias** (G: L1/L2/L5, E: E1/E5a/E5b, C: B1/B3/B2a), GIM & **GIM accuracy information**
 - ▶ Supporting GPS, Galileo and BDS-3 constellations (i.e., G+E+C)
 - ▶ Mountpoints: **SSRC01CAS1** (IGS-SSR, CoM) **SSRC01CAS0** (RTCM-SSR, CoM)
SSRA01CAS1 (IGS-SSR, APC) **SSRA01CAS0** (RTCM-SSR, APC)
 - ▶ IGS BKG caster: products.igs-ip.net
 - ▶ CAS regional caster: igs.bdsmart.cn

Yang Li, Ningbo Wang, et al. CAS real-time multi-GNSS clock and bias estimation: new product streams for precise point positioning with ambiguity resolution,
Journal of Geodesy (under review)

CAS01 Solution: processing strategies



CAS01 Solution: processing strategies

► Real-time clock corrections

- High-rate clocks are estimated using **carrier-range** observations (ambiguity-fixed clock solution)

$$\bar{dt}_r = cdt_r + b_{r,IF}/c$$

$$\bar{dt}^s = cdt^s + b_{IF}^s/c$$

$$\bar{N}_{r,IF}^s = \boxed{N_{r,IF}^s + B_{r,IF} - B_{IF}^s - (b_{r,IF} - b_{IF}^s)/\lambda_{IF}}$$

Estimated and fixed in FP thread

Eliminated in HR thread

- Clock solutions consistent with the IGS legacy clock model
- CAS daily code OSB products ([CAS1IGSRAP](#)) applied, using mixed GPS C1C/C1W and C2C/C2W, Galileo C1C/C1X and C5Q/C5X observations

CAS01 Solution: processing strategies

► Real-time phase bias corrections

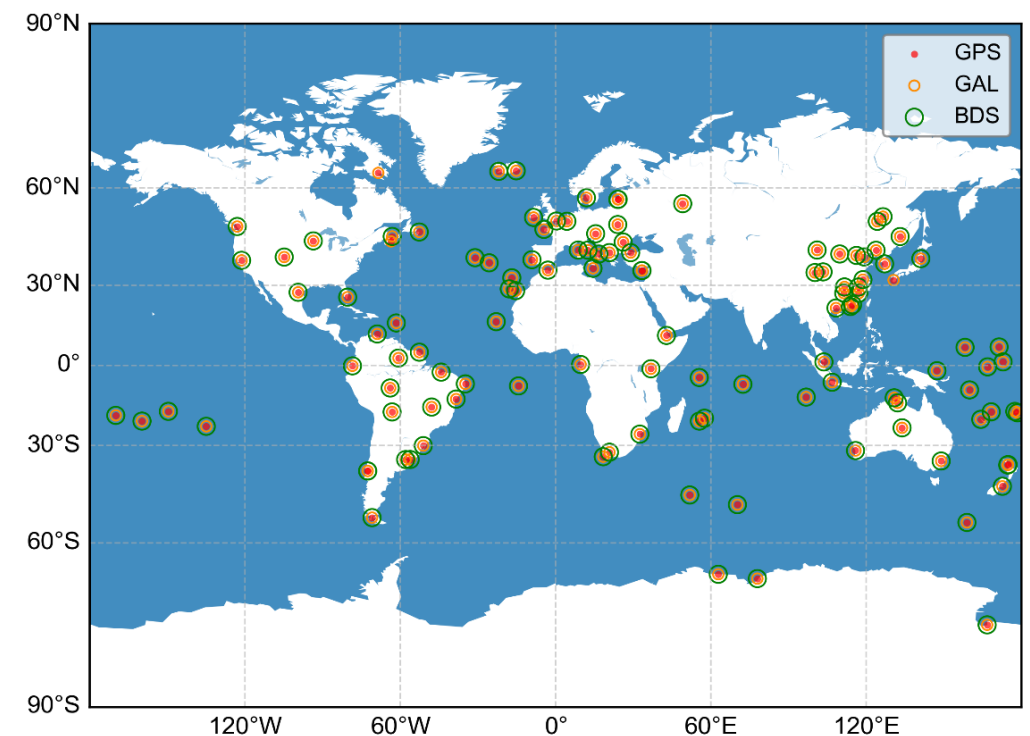
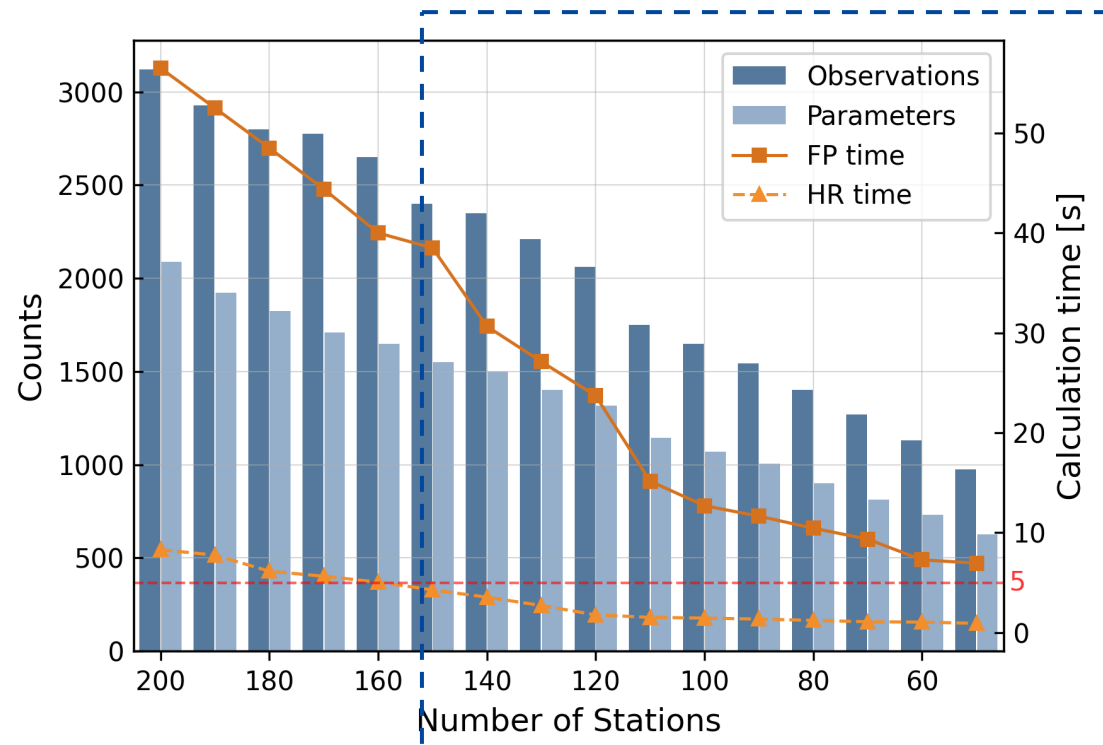
- WL and EWL UPDs from HMW combinations; NL UPDs from precise clock estimation (PCE)
float ambiguities

$$\bar{N}_{r,NL,IF} = \frac{1}{\lambda_{NL}} \left(\underbrace{\lambda_r^{-s}}_{\text{From PCE}} \right) \frac{cf_j^N}{ff_j^{22}} \frac{s}{r, WL}$$

- Inter-frequency clock bias (IFCB) estimation only for GPS L5 based on the geometry-free ionosphere-free (GFIF) combinations
- Phase OSB corrections generated by the linear transformation from UPDs

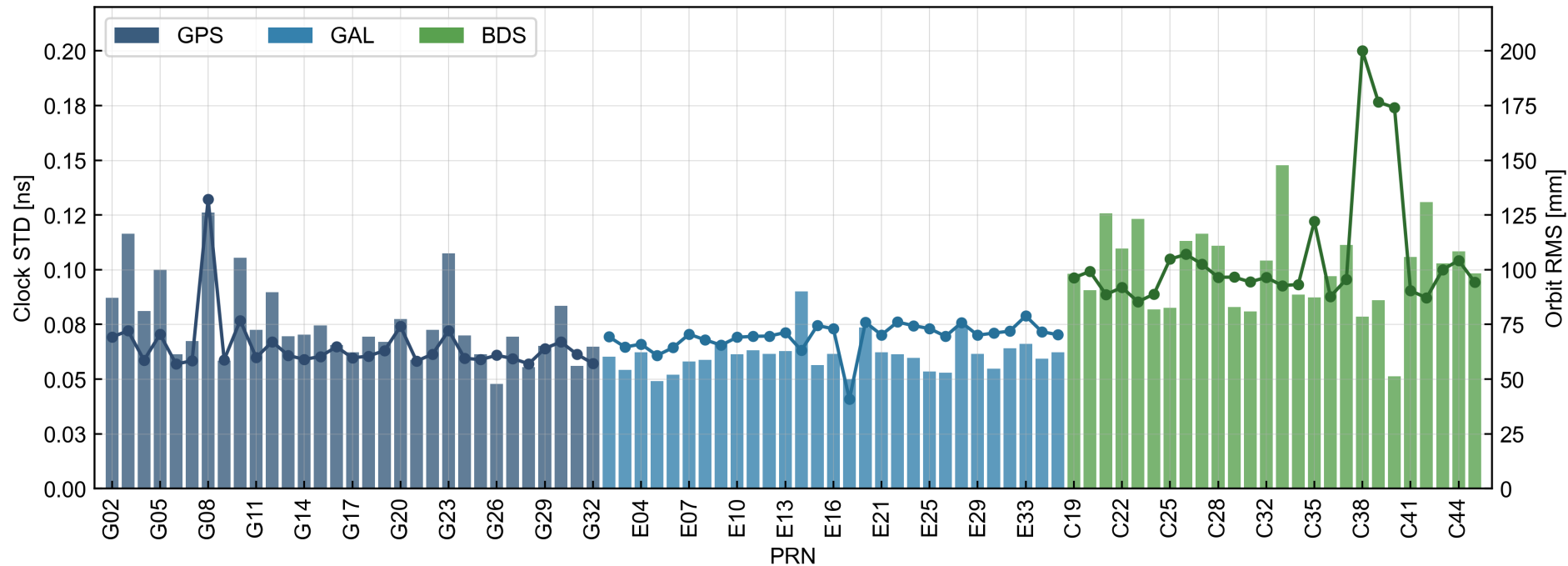
CAS01 Solution: processing strategies

- ▶ CAS cloud servers: 32-core CentOS-7 operating system, CPU frequency 3.6 GHz.
- ▶ RT GNSS stations: IGS (100) + CAS (20), mean latency: < 2.0 seconds.
- ▶ Input orbits: CAS combined 1-hour ultra-rapid product (CAS, GBM & WHU)



CAS01 Solution: quality assessment

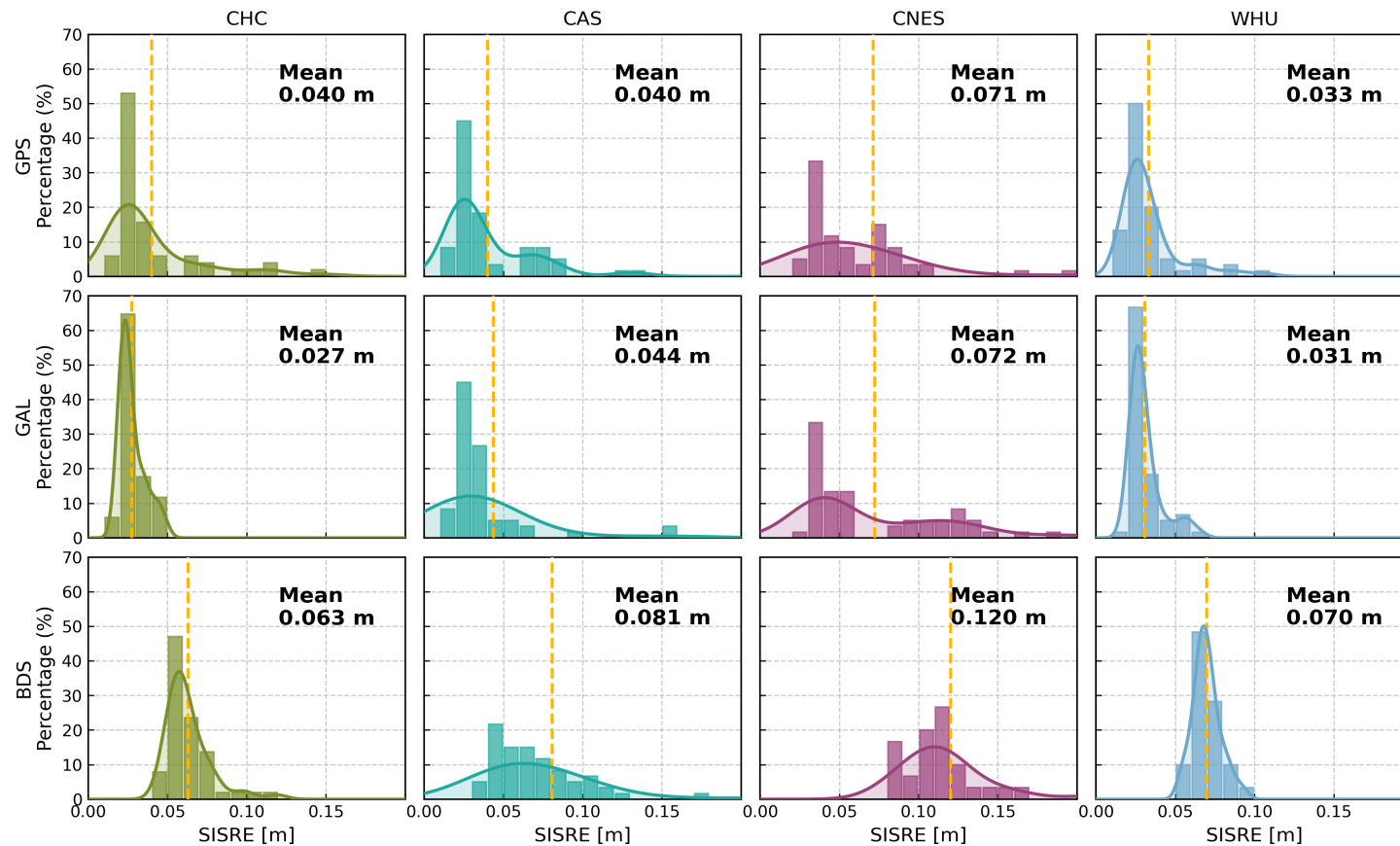
- Comparison b.w.t. RT-clock & GFZ rapid product (GFZMGXRAP, 1 week)



Real-time clock STD and orbit RMS on DOYs 225-232, 2025

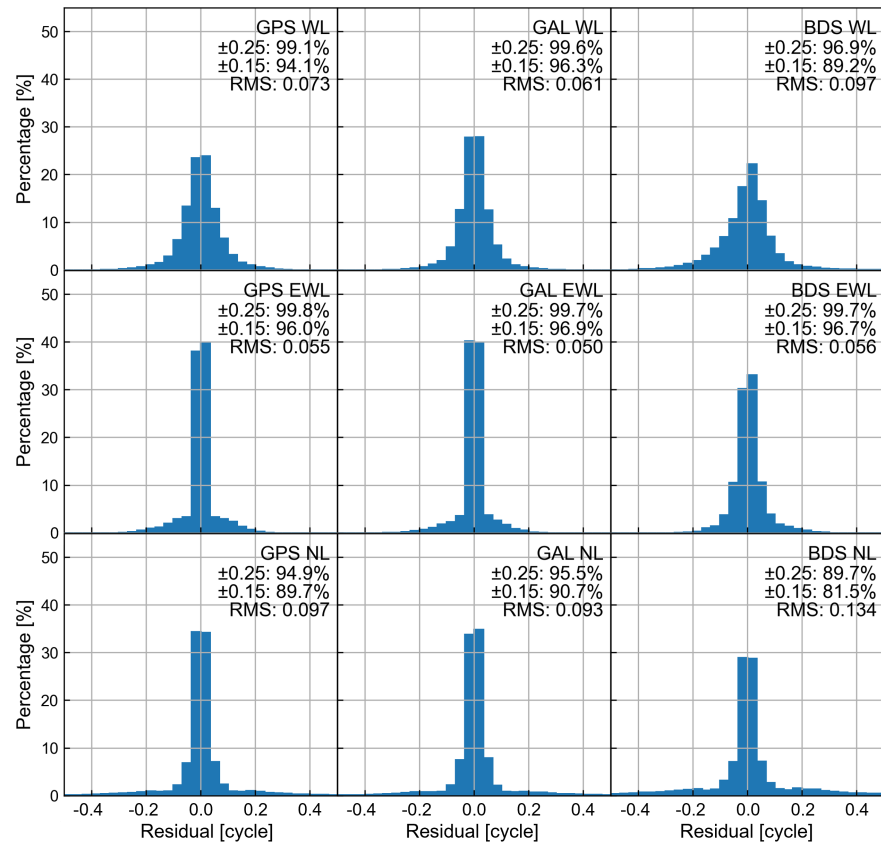
CAS01 Solution: quality assessment

- SISRE analysis: 2-months (DOY 213-273, 2025), GFZ rapid product



CAS01 Solution: quality assessment

► Residual analysis of real-time WL, EWL and NL ambiguities

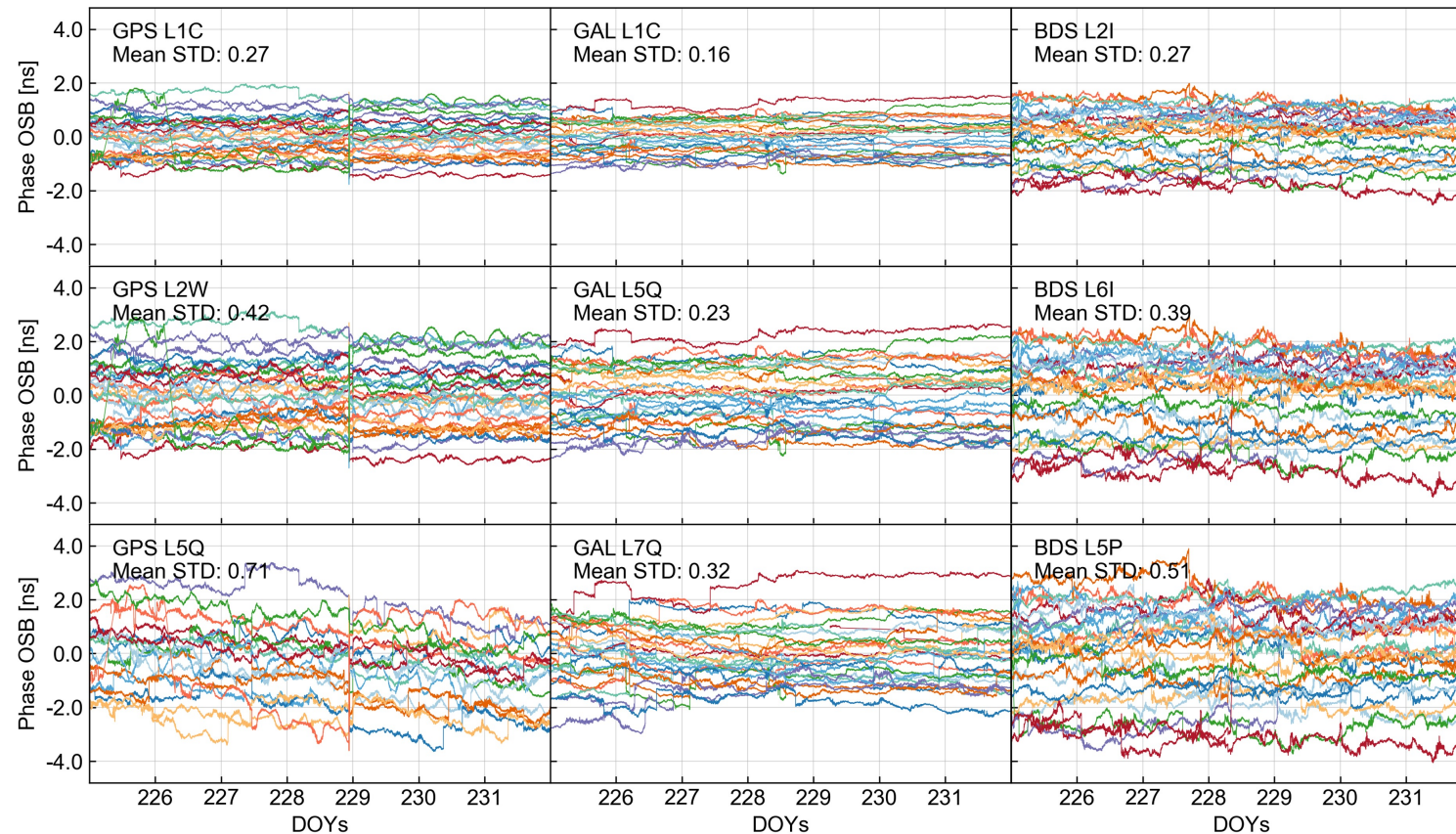


Ambiguity residual distribution

GNSS	WL[cycle]		EWL[cycle]		NL[cycle]	
	±0.25	±0.15	±0.25	±0.15	±0.25	±0.15
GPS	99.1%	94.1%	99.8%	96.0%	94.9%	89.7%
GAL	99.6%	96.3%	99.7%	96.9%	95.5%	90.7%
BDS-3	96.9%	89.2%	99.7%	96.7%	89.7%	81.5%

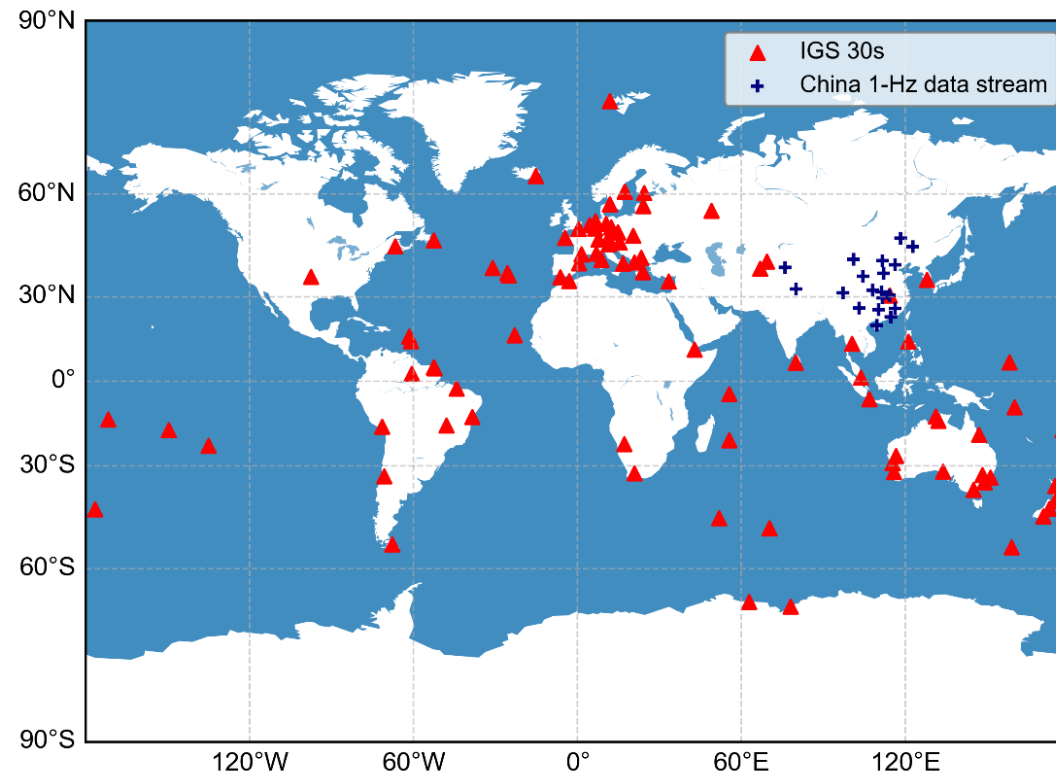
CAS01 Solution: quality assessment

► Stability of real-time OSB corrections



CAS01 Solution: PPP-AR performance

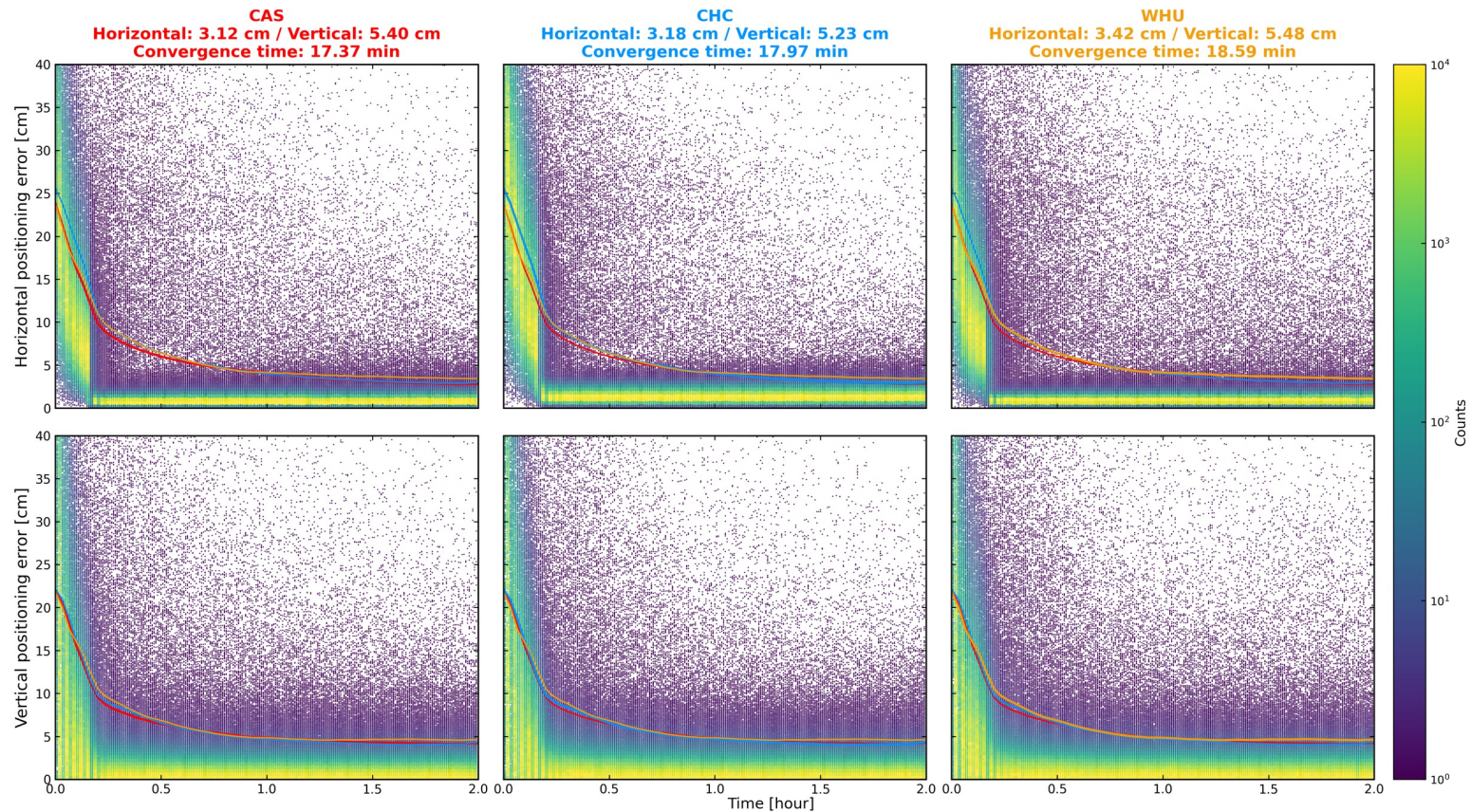
- **PPP-AR experiments:** 100 global IGS stations & 20 regional CAS stations



Item	Strategy
Observations	GPS L1/L2/L5 GAL E1/E5a/E5b BDS-3 B1/B3/B2a
Cutoff elevation	PPP: 10° PPP-AR: 15°
Mode	Undifferenced & uncombination
PCO/PCV	Corrected by igs20_2370.atx
WL ambiguity	Rounding
NL ambiguity	Lambda (ratio 2)

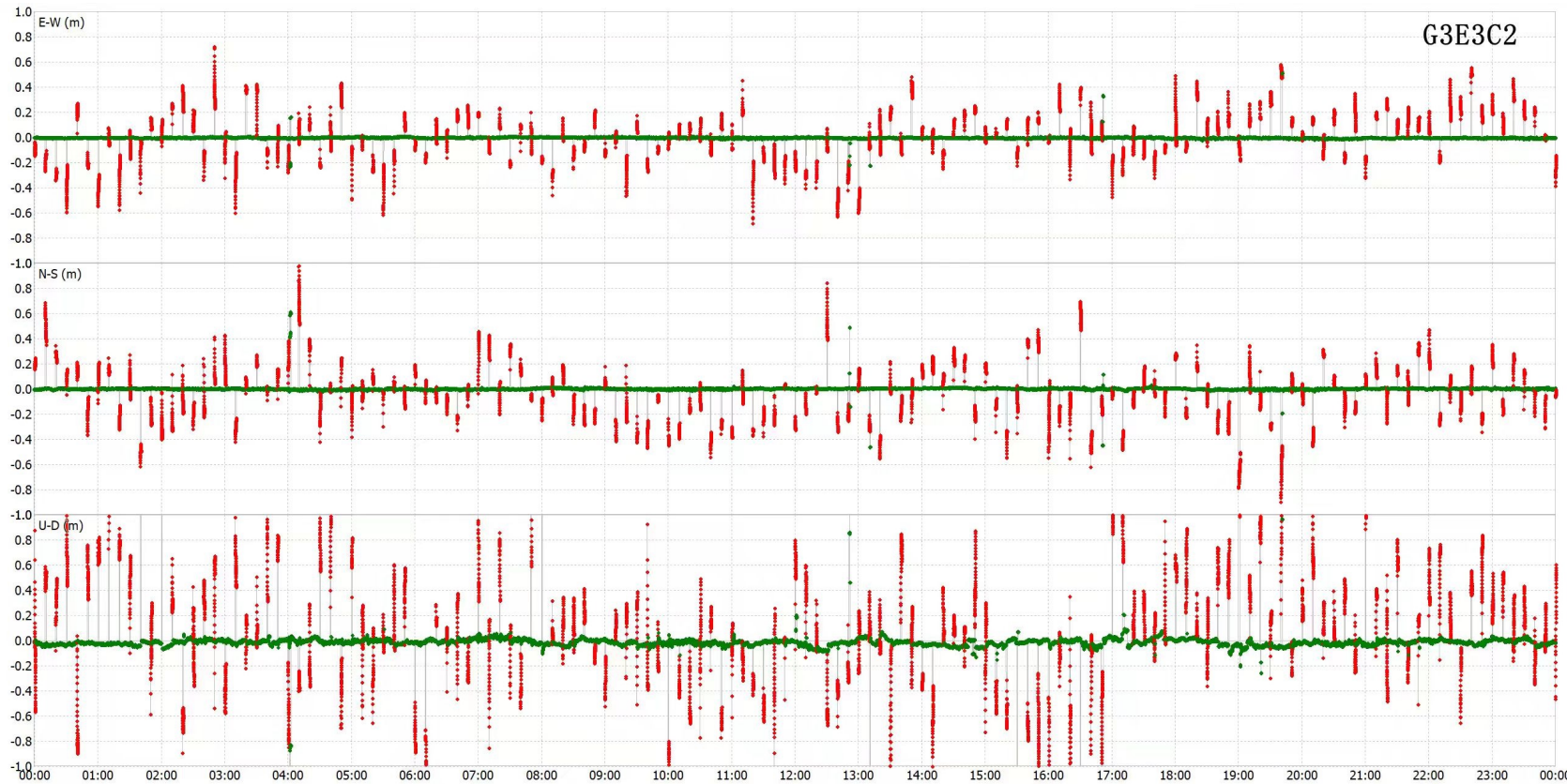
CAS01 Solution: PPP-AR performance

- PPP-AR experiments: 100 IGS stations, 30-s data, 2-hour reconvergence



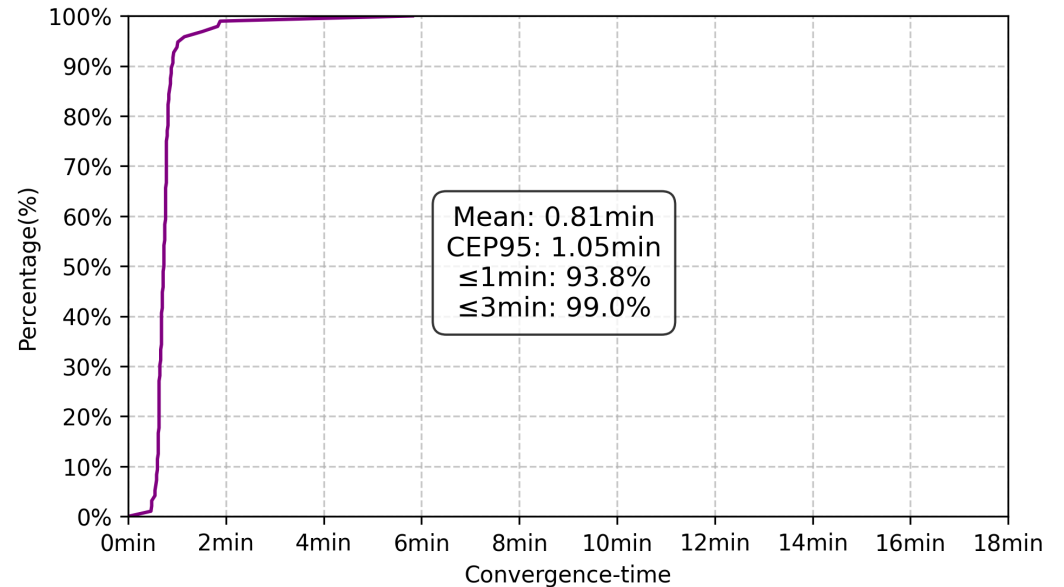
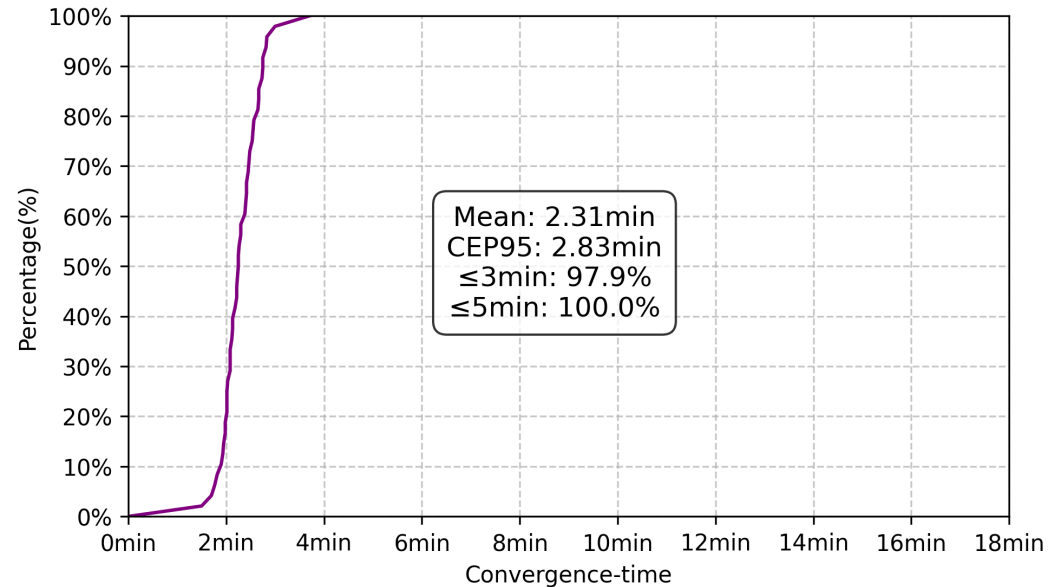
CAS01 Solution: PPP-AR performance

- **PPP-AR experiments:** 20 CAS stations, 1-Hz data, 10-min reconvergence



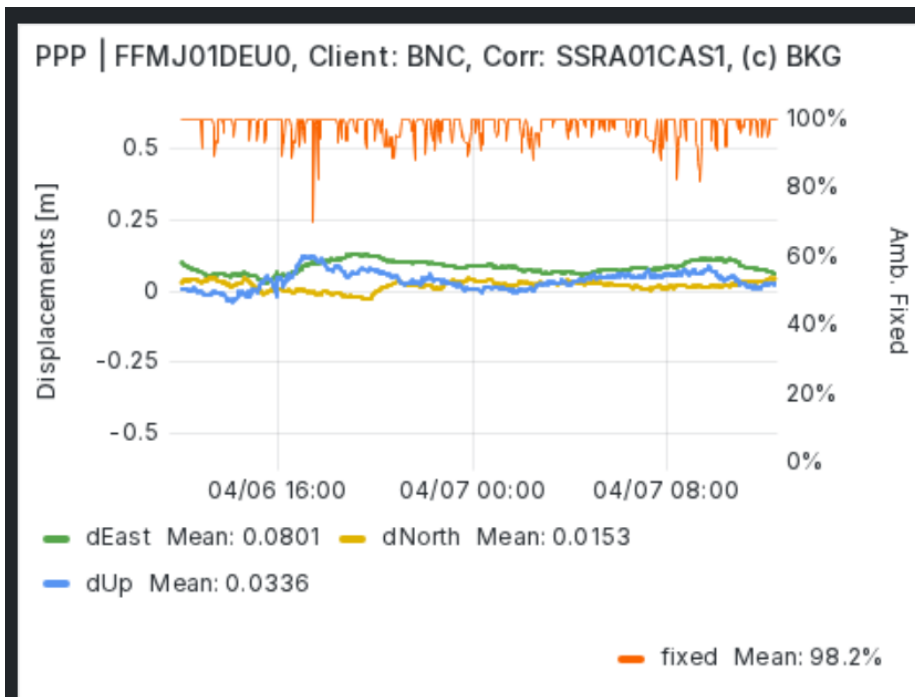
CAS01 Solution: PPP-AR performance

- **PPP-AR experiments:** 20 CAS stations, 1-Hz data, 10-min reconvergence



CAS01 Solution: PPP-AR performance

► IGS BKG RT-PPP performance monitoring



IGS RTS AC CAS solution SSRA01CAS1

- PPP client software: BKG Ntrip Client ([BNC](#))
- OBS: FFMJ01DEU0, Frankfurt
- SSR: SSRA01CAS1 by CAS ([IGS RTS CAS product](#))
- BCE: BCEP00BKG0 by BKG ([IGS RTS ephemeris products](#))

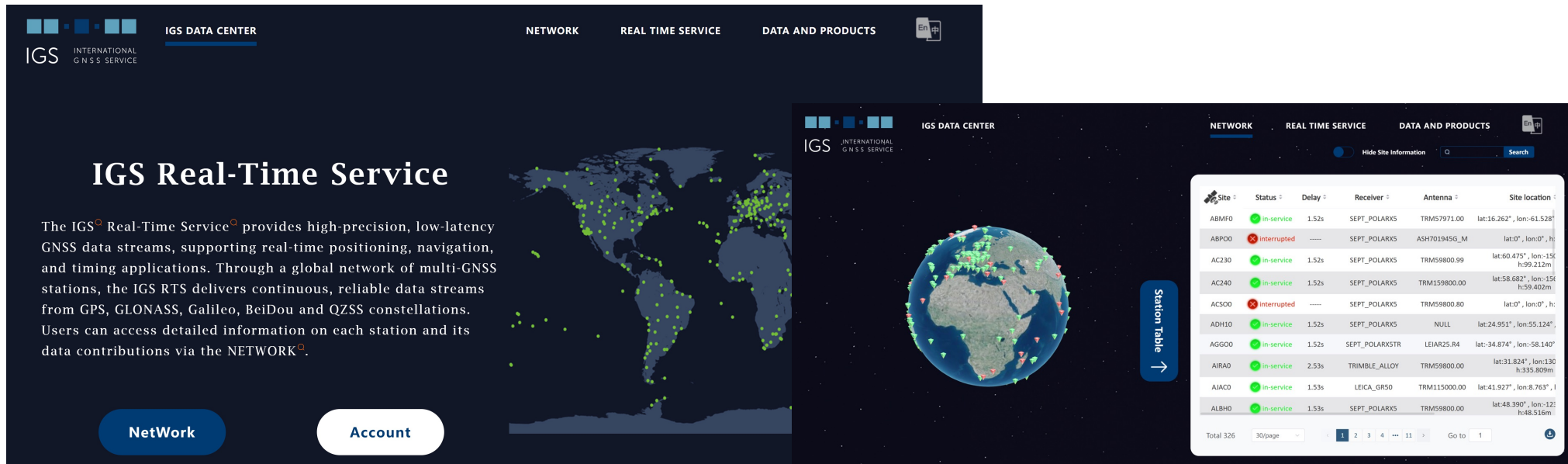
Summary

- ▶ CAS new product streams supporting PPP-AR available since [June 2025](#)
- ▶ Real-time orbit, clock, code & phase bias corrections for GPS, Galileo and BDS-3
- ▶ 30-s PPP-AR TTFF: [14.2 min](#) for DF solution, [12.6 min](#) for TF solution
- ▶ 1-Hz PPP-AR TTFF: [140 seconds](#) for DF solution, [50 seconds](#) for TF solution
- ▶ CAS solution adaptation to BDS-3 satellite PRN reassignment since 7 May 2025
- ▶ Publicly accessible via IGS caster (products.igs-ip.net) or CAS caster (igs.bdsmart.cn)

CAS regional data center

► CAS regional IGS caster

- IGS real-time data and product distribution: <https://igs.bdsmart.cn>
- Access permission for registered accounts: 1,000 streams per device (10 devices in total)



IGS DATA CENTER

NETWORK REAL TIME SERVICE DATA AND PRODUCTS

IGS Real-Time Service

The IGS[®] Real-Time Service[®] provides high-precision, low-latency GNSS data streams, supporting real-time positioning, navigation, and timing applications. Through a global network of multi-GNSS stations, the IGS RTS delivers continuous, reliable data streams from GPS, GLONASS, Galileo, BeiDou and QZSS constellations. Users can access detailed information on each station and its data contributions via the NETWORK[®].

NetWork **Account**

Site	Status	Delay	Receiver	Antenna	Site location
ABMF0	In-service	1.52s	SEPT_POLARXS	TRMS7971.00	lat:16.262°, lon:-61.528°
ABPO0	Interrupted	-----	SEPT_POLARXS	ASH701945G_M	lat:0°, lon:0°, h:0m
AC230	In-service	1.52s	SEPT_POLARXS	TRMS9800.99	lat:60.475°, lon:-155° h:99.212m
AC240	In-service	1.52s	SEPT_POLARXS	TRM159800.00	lat:58.682°, lon:-155° h:59.402m
AC500	Interrupted	-----	SEPT_POLARXS	TRMS9800.80	lat:0°, lon:0°, h:0m
ADH10	In-service	1.52s	SEPT_POLARXS	NULL	lat:24.951°, lon:55.124°
AGG00	In-service	1.52s	SEPT_POLARXSTR	LEIAR25.R4	lat:-34.874°, lon:-58.140°
AIR40	In-service	2.53s	TRIMBLE_ALLOY	TRMS9800.00	lat:31.824°, lon:130° h:335.809m
AJAC0	In-service	1.53s	LEICA_GR50	TRM115000.00	lat:41.927°, lon:8.763°, l
ALBHD	In-service	1.53s	SEPT_POLARXS	TRMS9800.00	lat:48.390°, lon:121° h:48.516m

Total 326 30/page 1 2 3 4 11 Go to 1



1-5
June
2026



Thank You!

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CAS data center: <https://data.bdsmart.cn>

ORGANIZING INSTITUTIONS



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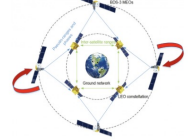
WeChat

- Widely covered by European and American tech media
- Over 65% of website traffic from international visitors



New satellite orbit determination method could boost navigation precision for future mega-constellations

August 2023 - The Next Issue



Credit: Satellite Navigation

The rotation-connected integrated POC method holds significant promise for global navigation augmentation, autonomous LEO-based navigation systems, and real-time positioning services.

Modern satellite constellations such as OneWeb, Starlink, and GPS/BeiDou provide global communications and navigation capabilities using low Earth and LEO constellations. However, their precise and autonomous POC requires dense ground station networks — costly and often limited by geographical or geopolitical constraints.

Inter-satellite links (ISLs) help reduce ground dependence but suffer from "visibility unavailability," where the entire constellation works in operation due to the lack of an absolute space reference. Existing free other visible satellite infrastructure or high-quality GNSS products, which increase delay and operational complexity.

Because of these challenges, a more autonomous, low-energy approach that leverages existing onboard capabilities is needed to ensure reliable, high-accuracy access for mega-constellations.

Wuhan University researchers have developed and validated a rotation-connected integrated POC method that uses ISL measurements with ground-based GPS-BDS-5 GNSS observations. Published 2023.



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New Study Showcases Enhanced GNSS Accuracy in Smartphones for Urban and Open-Sky Navigation



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New Study Showcases Enhanced GNSS Accuracy in Smartphones for Urban and Open-Sky Navigation

by Simon Hasselblad

Sydney, Australia (APR) Aug 20, 2024

A recent study has highlighted the advancements in smartphone positioning technology, specifically examining the multi-frequency Global Navigation Satellite System (GNSS) capabilities of the Redmi K60 Ultra. The research underscores major improvements in positioning accuracy, speed, and reliability, representing a key development in the field of high-



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