IGS 2026 WORKSHOP
SANTIAGO DE CHILE
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IGS INTERNATIONAL GNSS SERVICE

CAS real-time multi-GNSS clock and bias estimation:

new product streams for PPP with ambiguity resolution

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IGS Real-Time Service

- **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

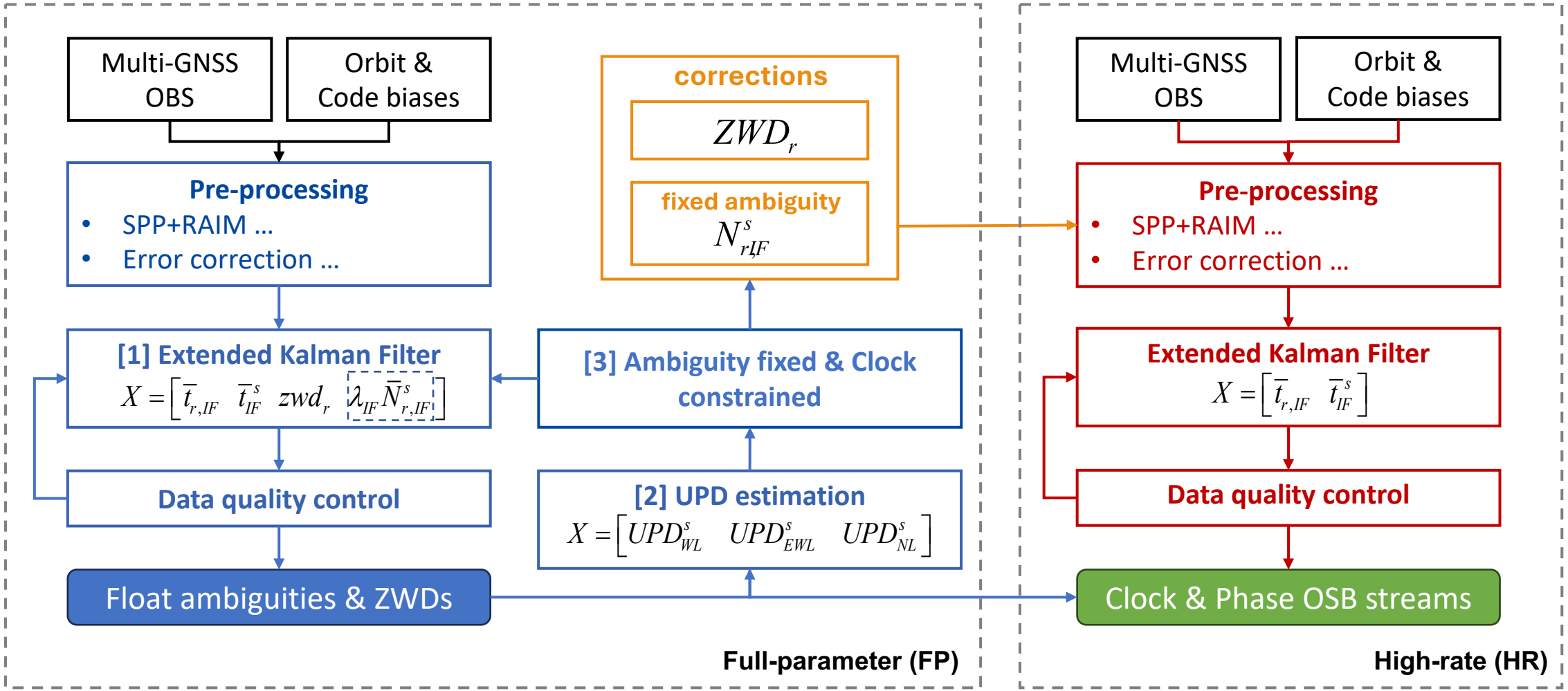
RTAC	Mountpoints	Product Description	PPP	PPP-AR
APM	SSR*00APM#	G+E+C+R RT orbits and clocks.	X	
BKG	SSR*00BKG#	G+R+E RT orbits, clocks and code biases; additional yaw angle.	X	
CAS	SSR*00CAS#	G+E+C+R RT orbits and clocks.	X	
	SSR*01CAS#	**G+E+C RT orbits, clocks, code & phase biases; GIM.**	**X**	**X (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)**

IGS Real-Time Service

- **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)

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

$$\bar{dt}^s = cdt^s + b^s_{\mathrm{IF}}/c$$

$$\bar{N}^s_{r,\mathrm{IF}} = N^s_{r,\mathrm{IF}} + B_{r,\mathrm{IF}} - B^s_{\mathrm{IF}} - \left(b_{r,\mathrm{IF}} - b^s_{\mathrm{IF}}\right)/\lambda_{\mathrm{IF}}$$

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

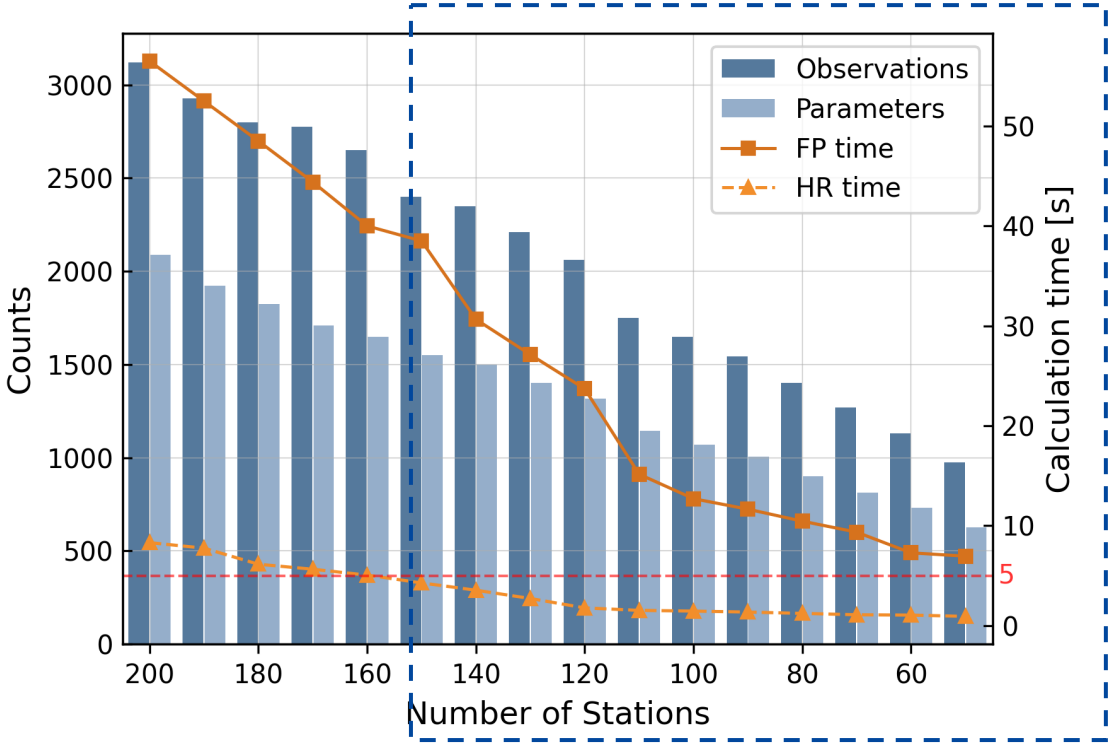
$$\overline{N}_{r,\mathrm{NLIF,IF}}^{s} = \frac{1}{\lambda_{\mathrm{NL}}}\left(\lambda_{r}^{s} - \frac{cf_j \overline{N}_{r,\mathrm{WL}}^{s}}{f_i^2 - f_j^2}\right)$$

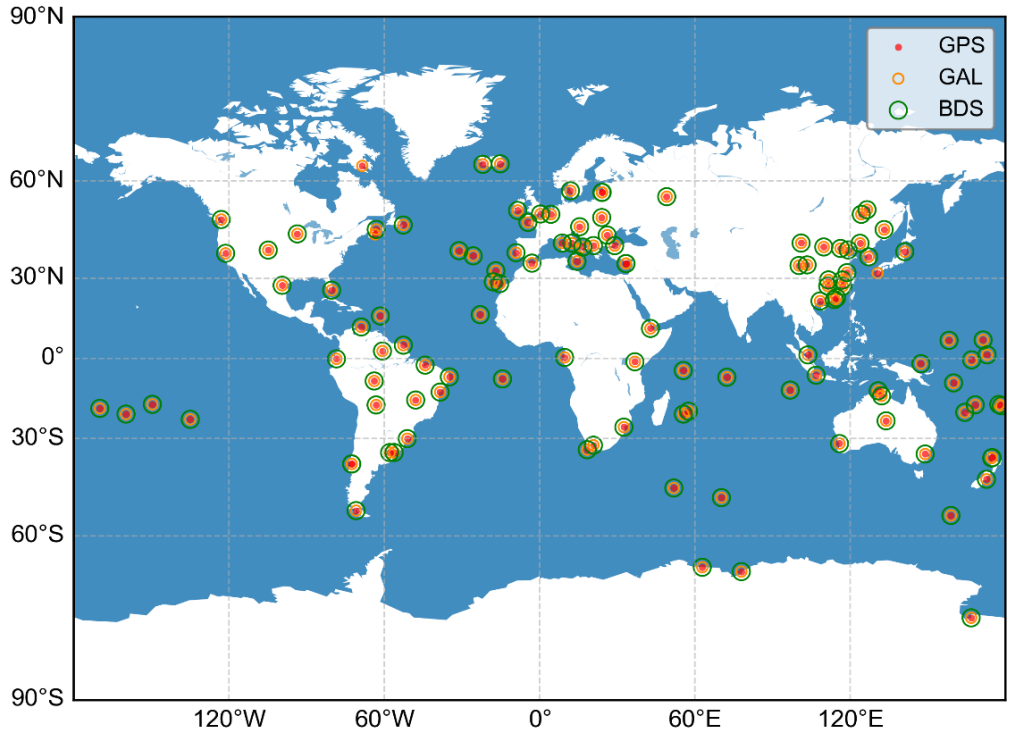
From PCE

  - 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

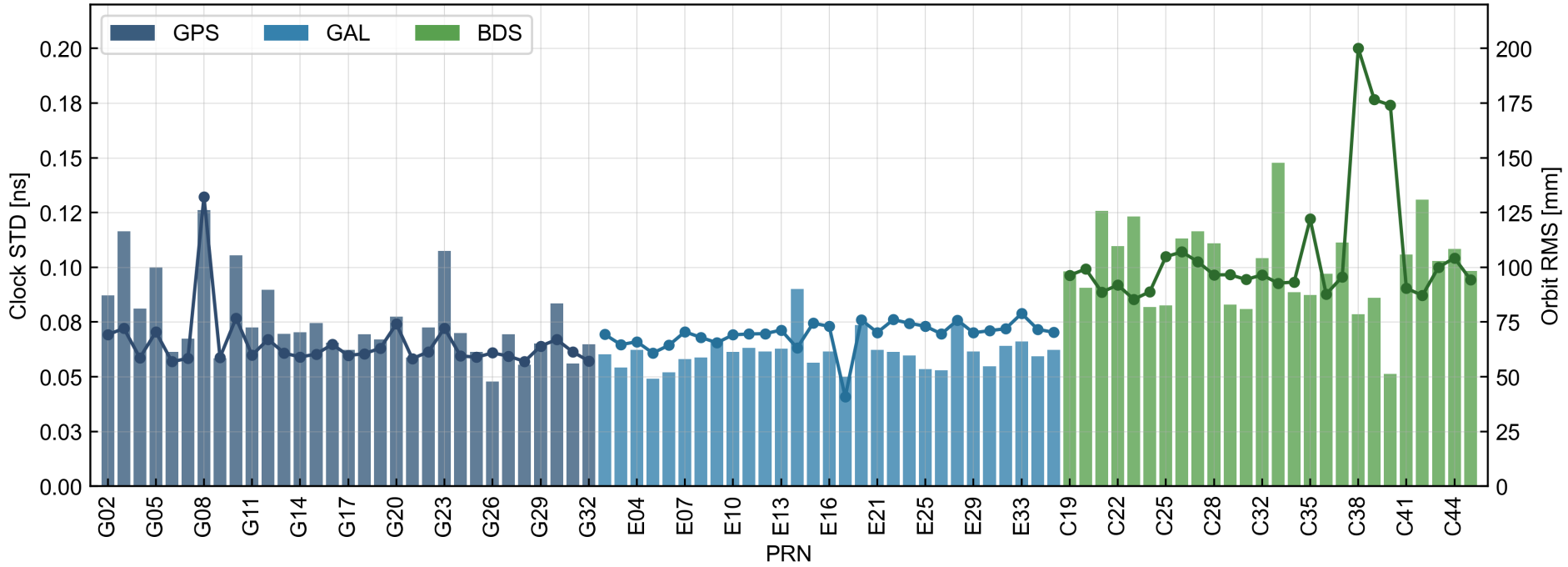
- CAS cloud servers: 32-core CentOS-7 operating system, CPU frequency 3.6 GHz.
- RT GNSS stations: IGS (100) + CAS (20), mean latency: < 2.0 seconds.
- Input orbits: CAS combined 1-hour ultra-rapid product (CAS, GBM & WHU)





CAS01 Solution: quality assessment

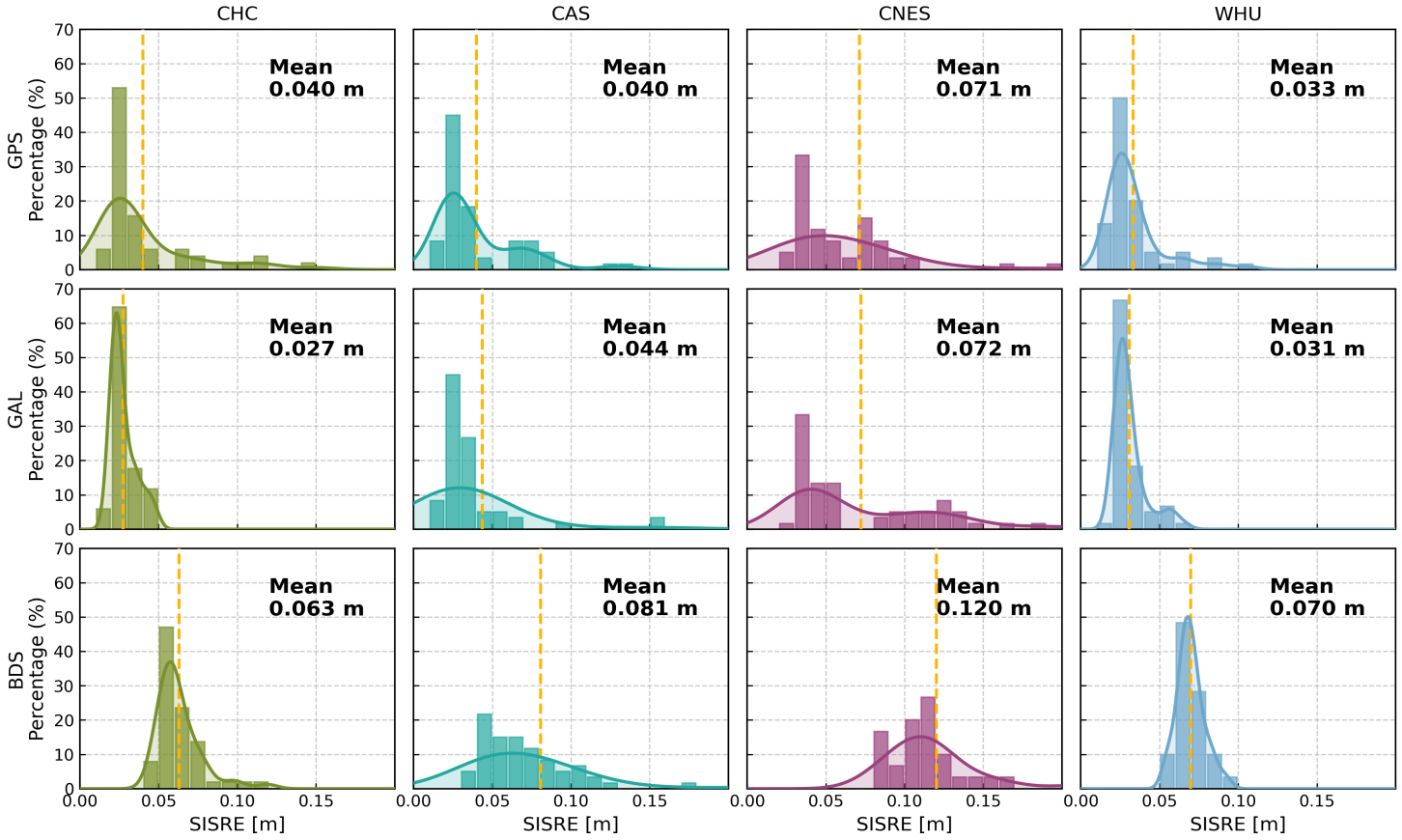
- Comparison b.w.t. RT-clock & GFZ rapid product (GFZMGXRAP, 1 week)



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

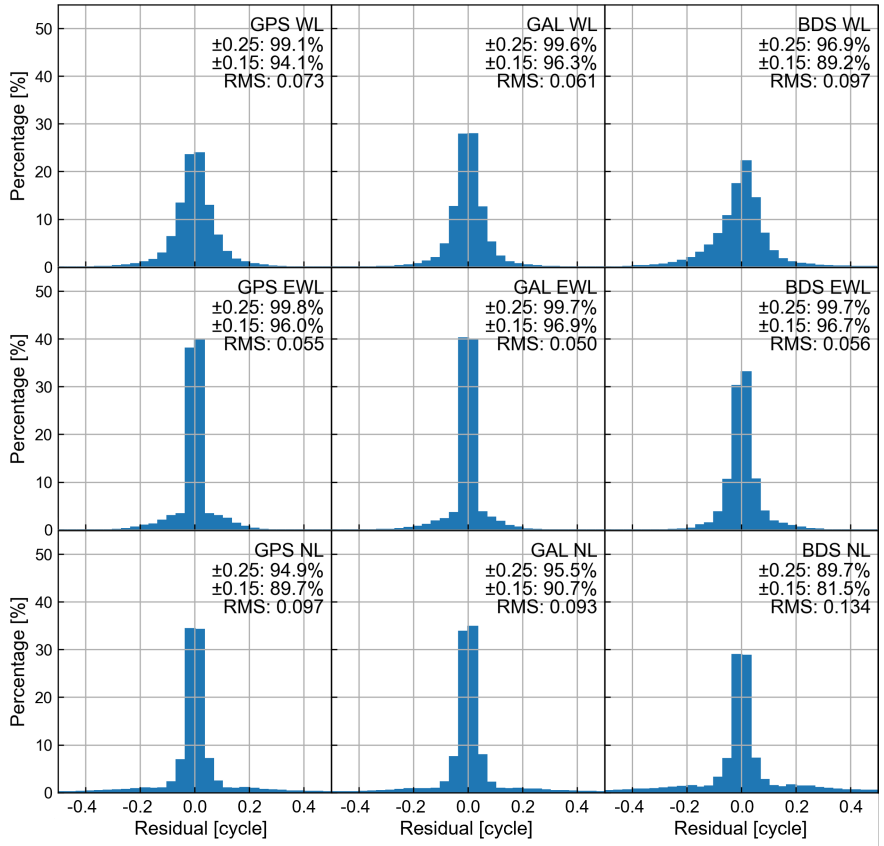
CAS01 Solution: quality assessment

- 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

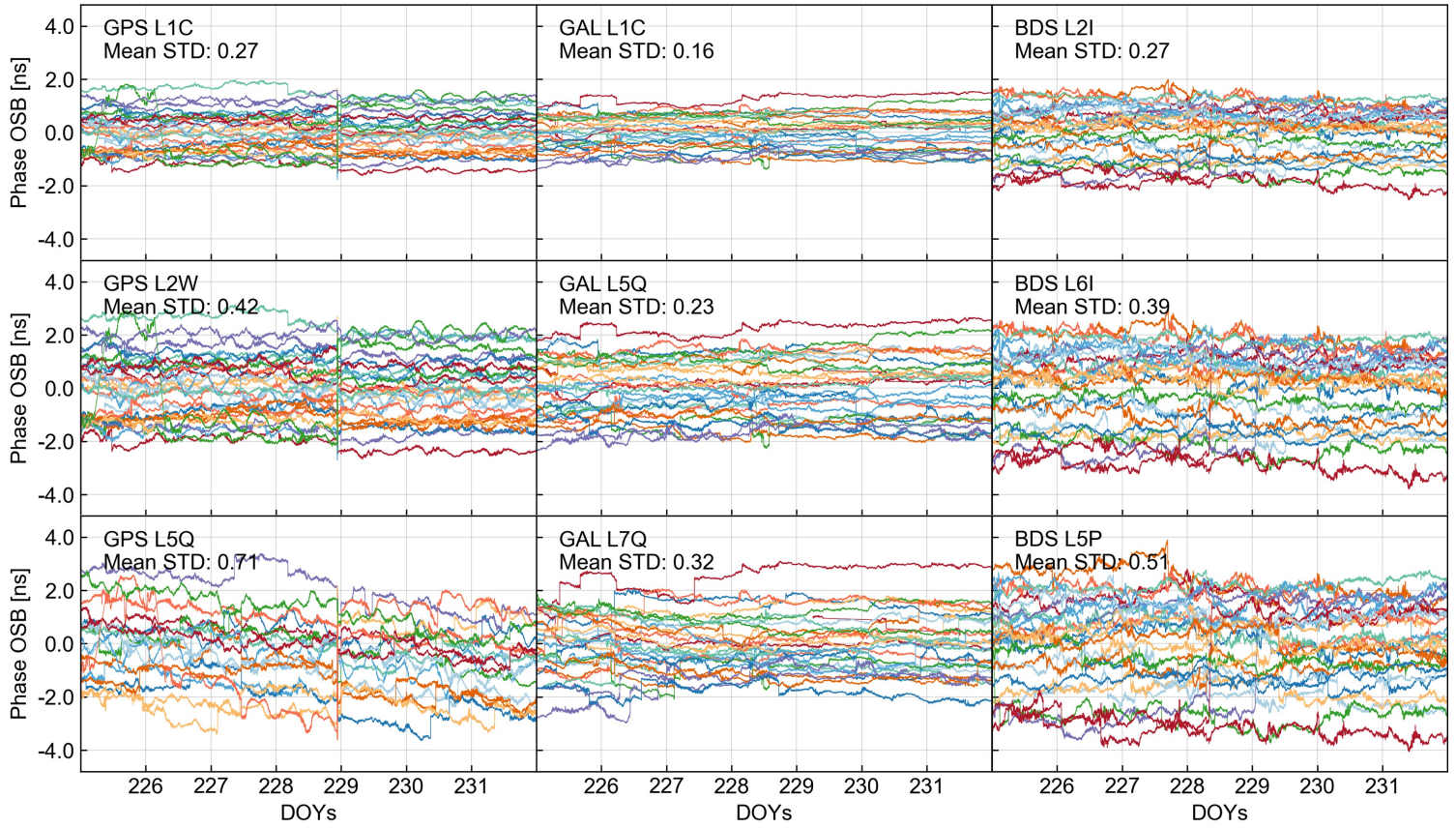


Ambiguity residual distribution

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%**

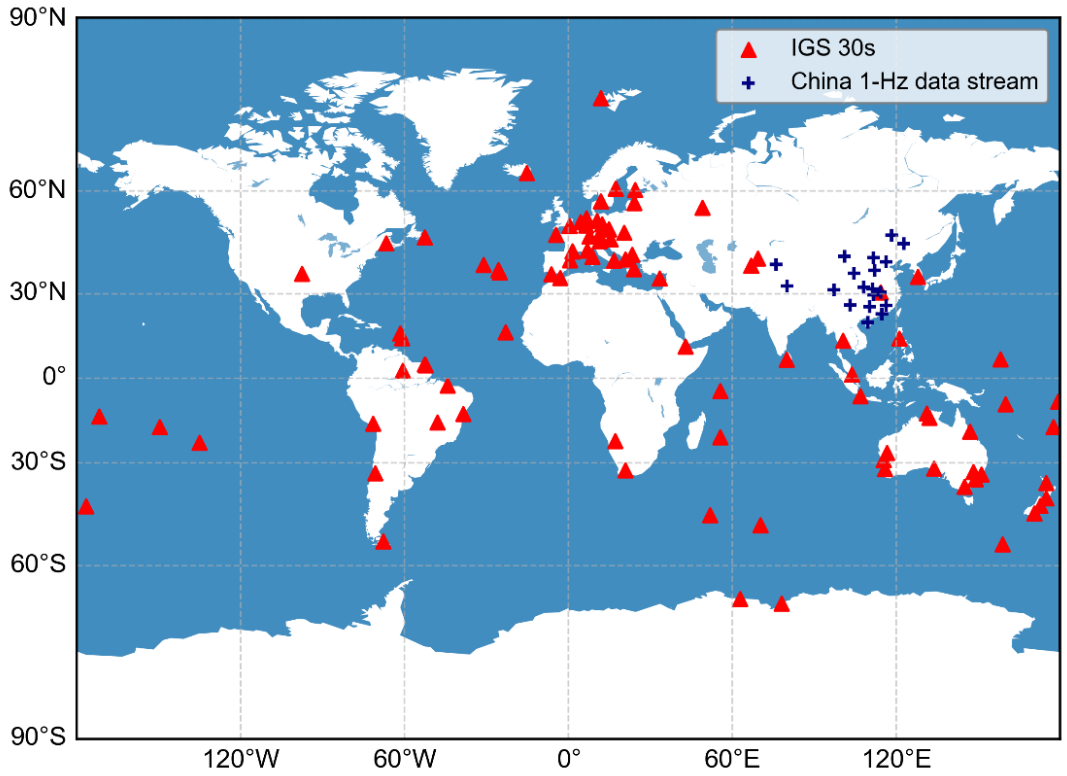
CAS01 Solution: quality assessment

- Stability of real-time OSB corrections



CAS01 Solution: PPP-AR performance

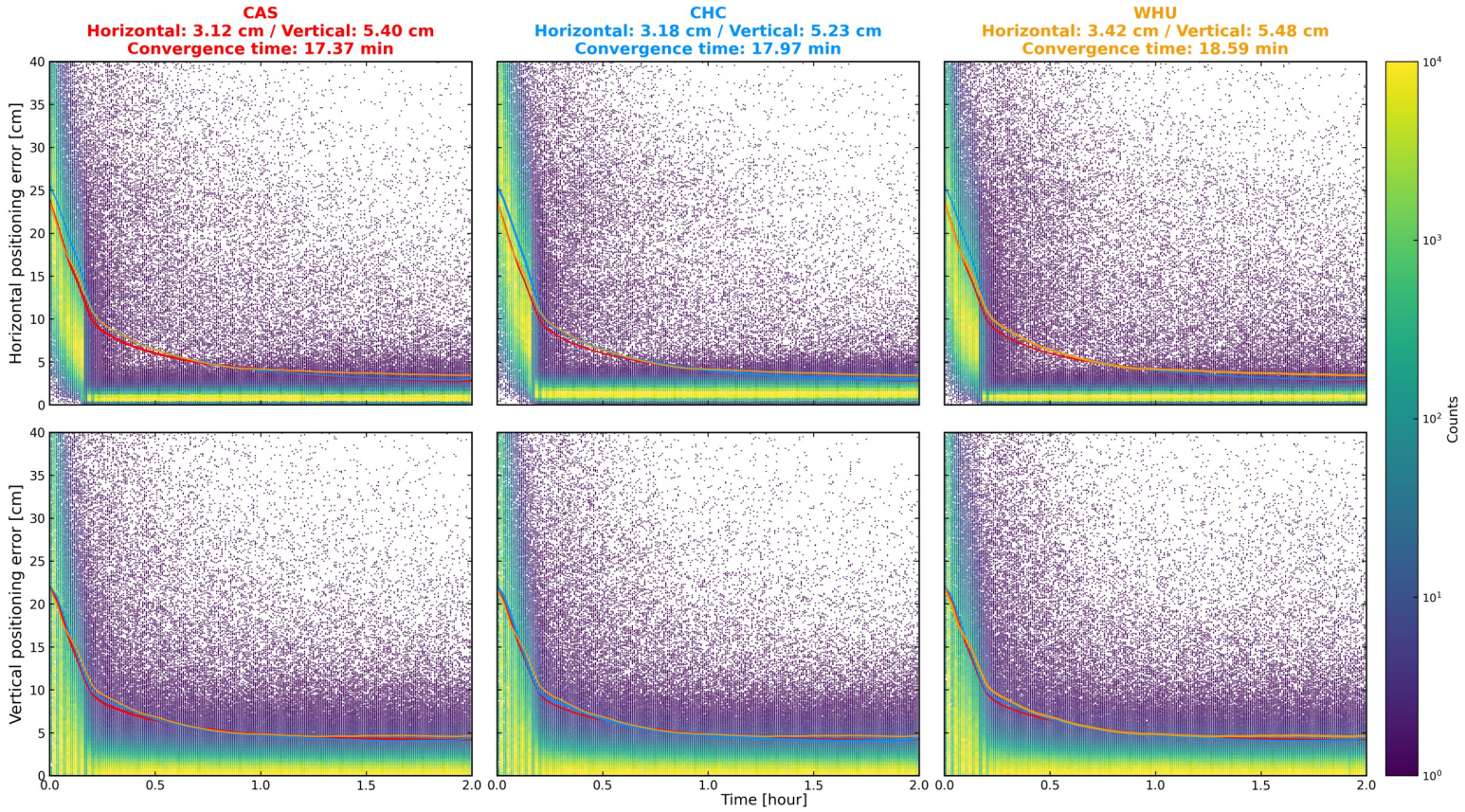
- **PPP-AR experiments**: 100 global IGS stations & 20 regional CAS stations



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)

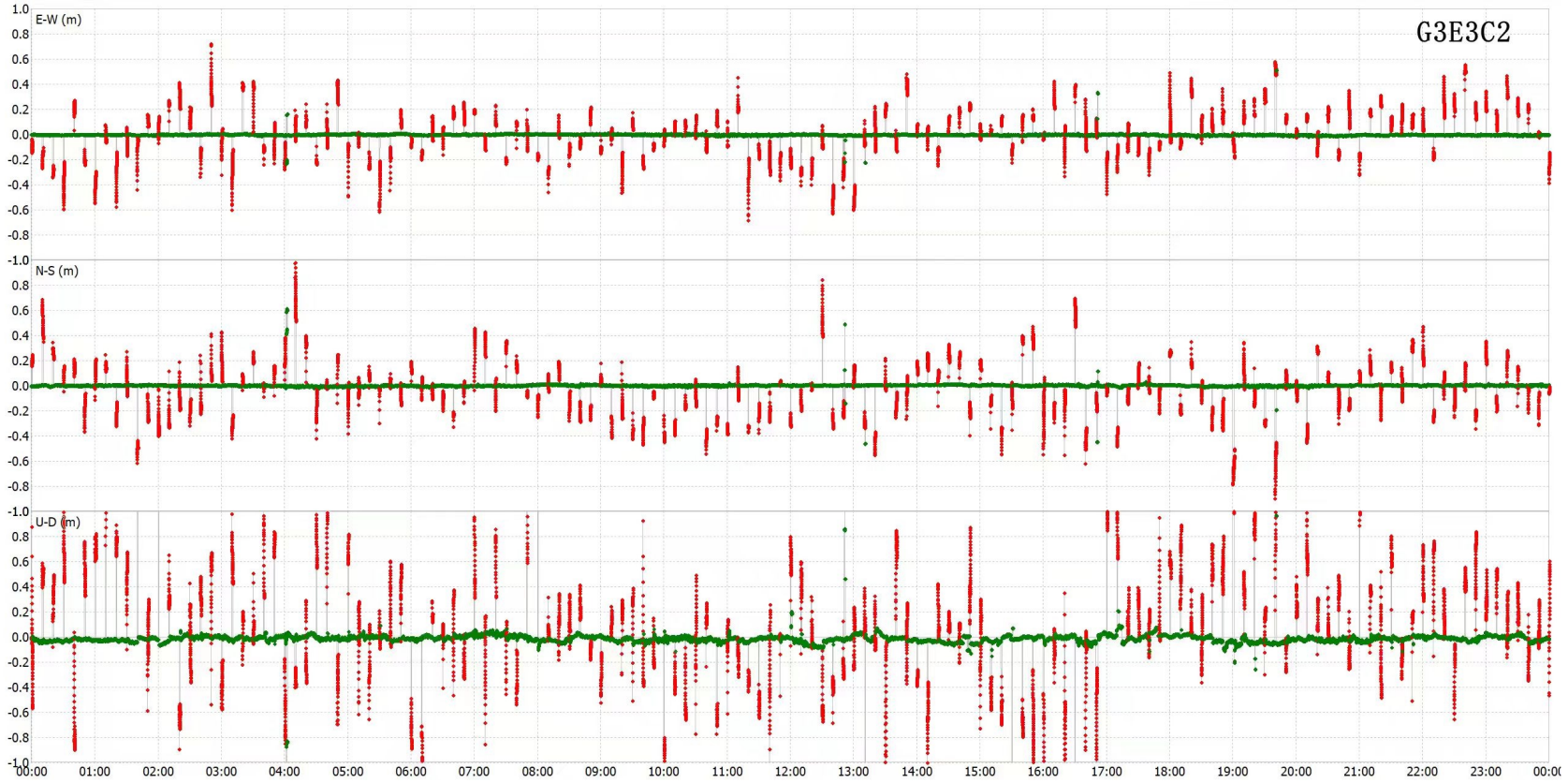
CAS01 Solution: PPP-AR performance

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



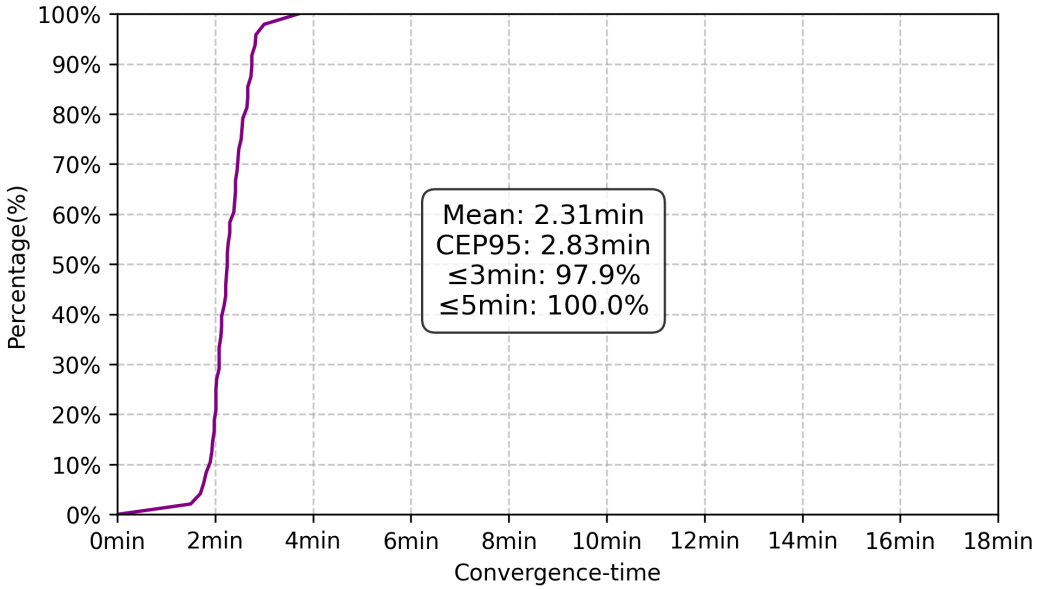
CAS01 Solution: PPP-AR performance

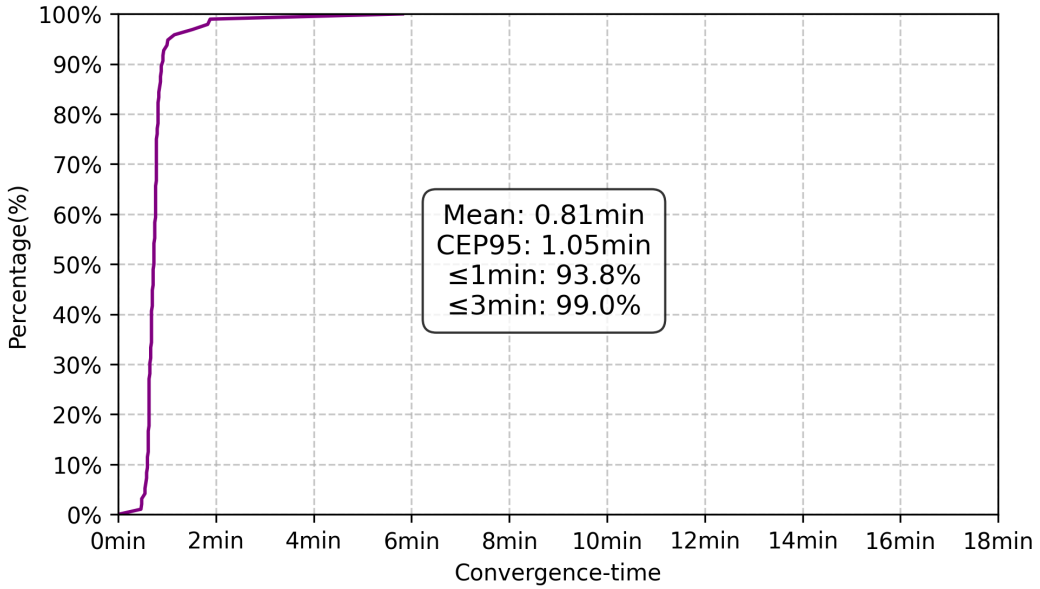
- **PPP-AR experiments**: 20 CAS stations, 1-Hz data, 10-min reconvergence



CAS01 Solution: PPP-AR performance

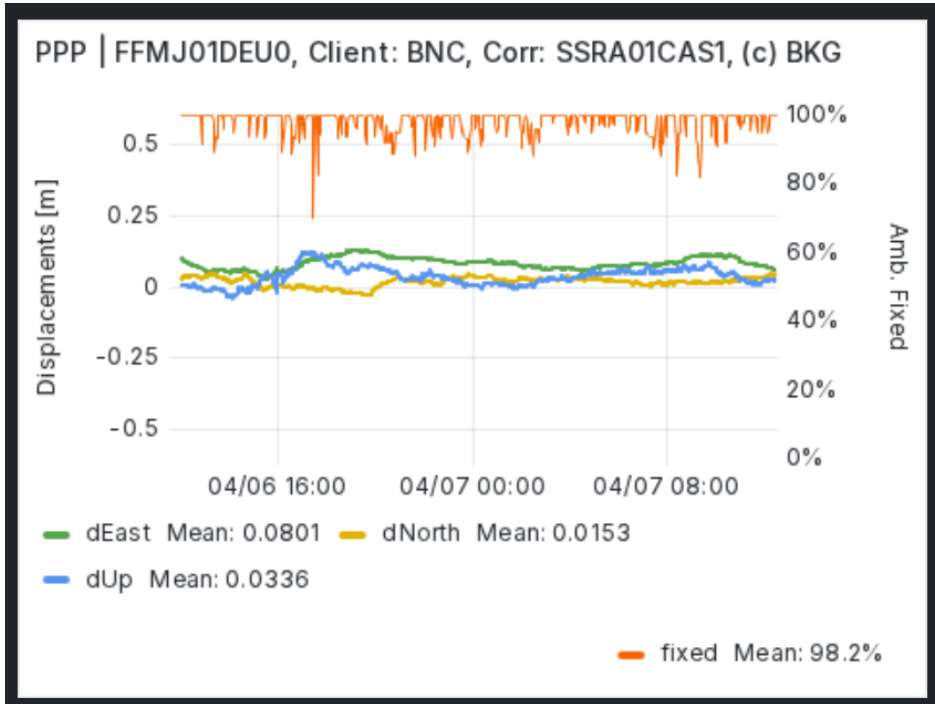
- **PPP-AR experiments**: 20 CAS stations, 1-Hz data, 10-min reconvergence





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)

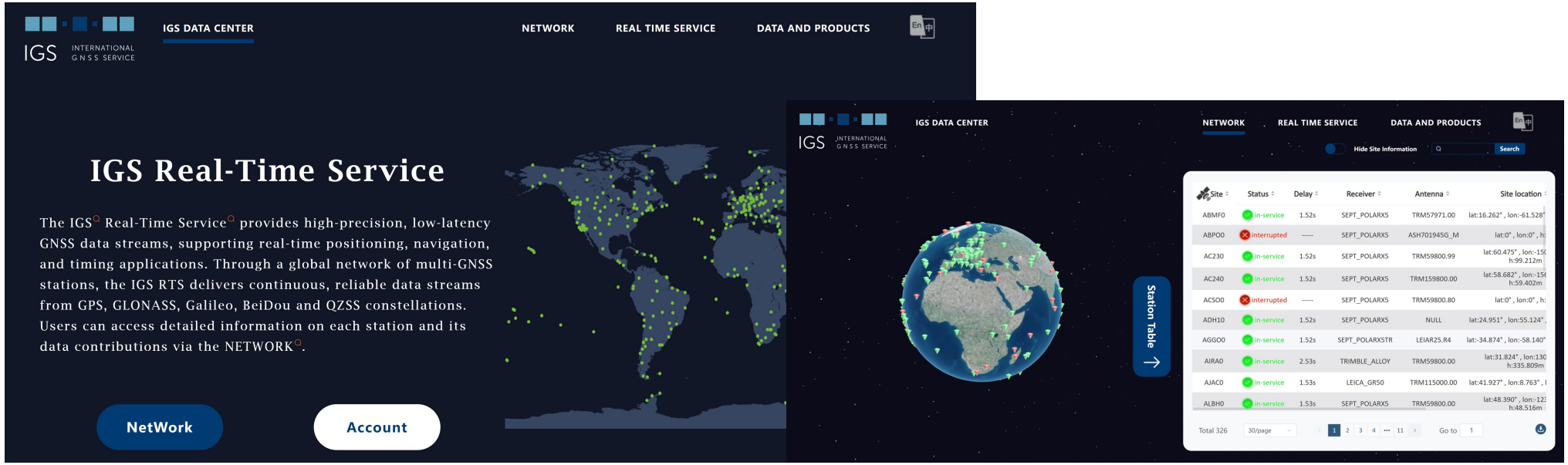
IGS BKG monitoring: *https://igs.bkg.bund.de/ntrip/ppp*

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)



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1–5 June 2026

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Thank You!

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CAS caster: https://igs.bdsmart.cn

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

《Satellite Navigation》 Journal Recommendation

SANA Satellite Navigation

Established in 2020 → **Indexed by SCI in 2023**

- **Latest Impact Factor: 10.1**
- **Latest CiteScore: 17.3**
- **Ranked Q1 in all three disciplines!**

Aerospace, Remote Sensing and Telecommunications

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Research Areas: GNSS System and Orbit Determination, Multi-Sensor and Intelligent Navigation, GNSS Remote Sensing and Environment, GNSS Geodesy and Geosciences, etc.

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