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

1-5 June 2026

Jing Guo, ***Junqiang Li***, Shengyi Xu, Qile Zhao

Wuhan University, China

junqiangli@whu.edu.cn, 2026/06/01

BDS-3 high-accuracy products based on modernized B1C and B2a signals: the threat of pilot–mixed channel and signal distortion biases

ORGANIZING INSTITUTIONS

IGS INTERNATIONAL GNSS SERVICE

USACH

FACULTAD DE INGENIERÍA

DEPARTAMENTO DE INGENIERÍA GEOESPACIAL Y AMBIENTAL

PROCESSING CENTER AND GEODETIC ANALYSIS USC

igm

Background

- **BDS-3 Modernized Signals Transition**
  - ✓ Modernized B1C/B2a signals feature lower noise and wider frequency separation
  - ✓ IGS has officially switched to B1C/B2a as the baseline signals on February 8, 2026.
- **Basic Assumptions for IGS/MGEX Bias Processing**
  - – The signal biases at the receiver- and satellite-sides are independent
- **Satellite code bias has receiver correlation** (Montenbruck et al. 2023)

  Q1 P-X bias : Satellite code bias between the Pilot (P) and Mixed (X) channel signals

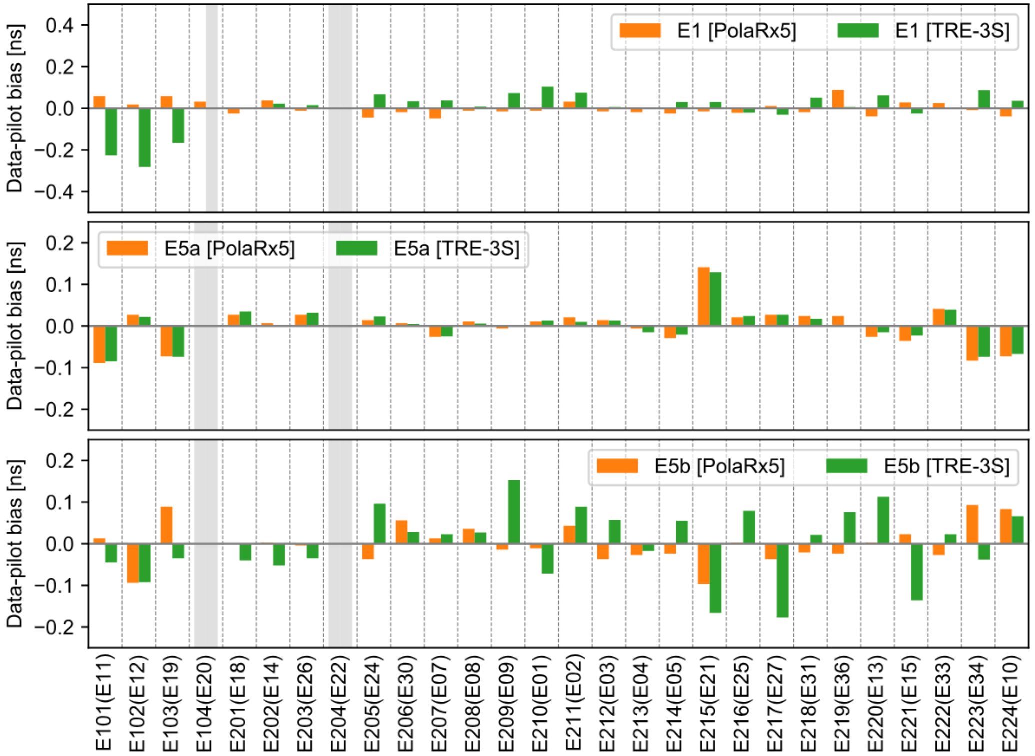
  - ✓ The receiver manufacturers adopt different signal modulation methods for the same frequency

  Q2 SDB bias: Satellite code bias tracking the same signal between different receiver types

  - ✓ Satellite code biases vary for different receiver types tracking the same navigation signal

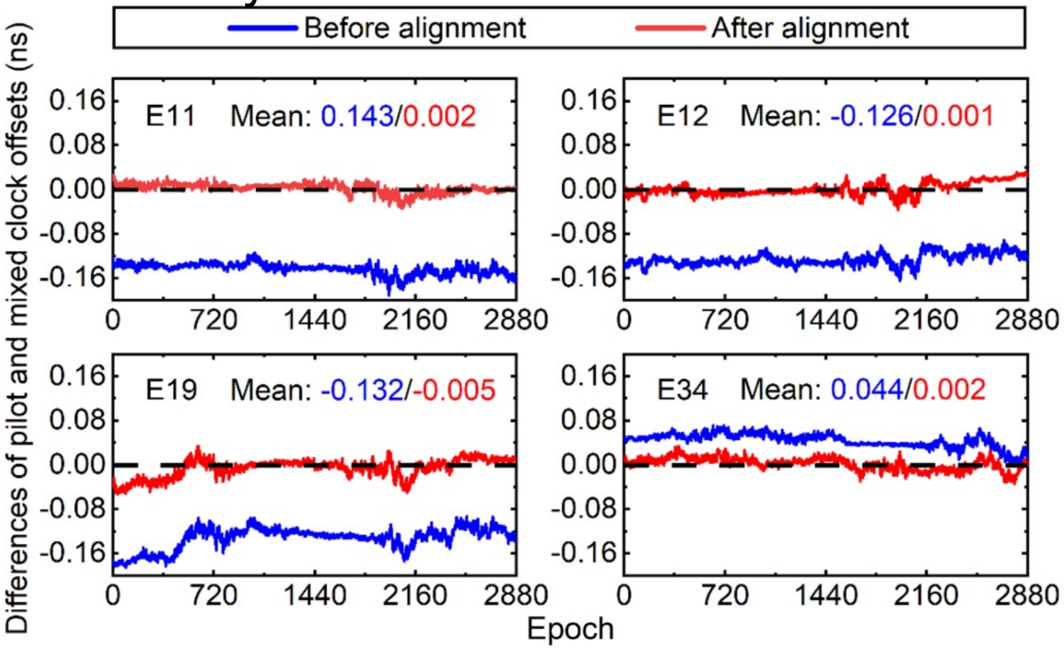
P-X bias

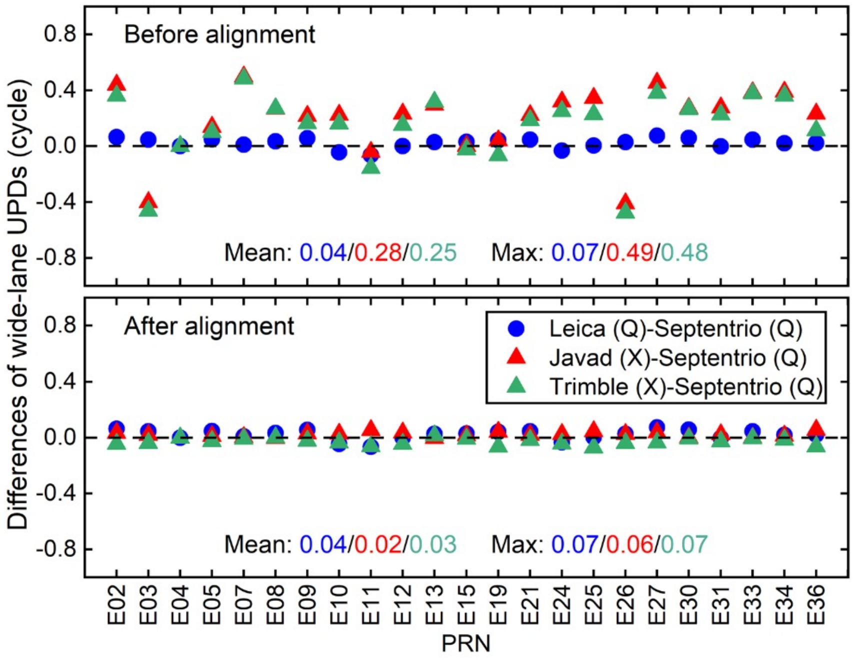
- ✓ **Mechanism:** When there is a deviation between the data (D) and pilot (P) components, mixing (X) will cause signal distortion, resulting in pseudourage errors
- ✓ Montenbruck et al. (2023) quantified this bias using dedicated receivers: the values can reach 1.5 ns, 0.3 ns and 0.6 ns for GPS, Galileo and BDS-3 respectively.



P-X bias

- Zhang et al. (2025) analyzed the differences of satellite clock and WL UPD between the P and X signals for Galileo, established an intra-frequency DCB model, and realized the unification of the Galileo code bias datum. After bias correction, the convergence time was reduced by 23%.

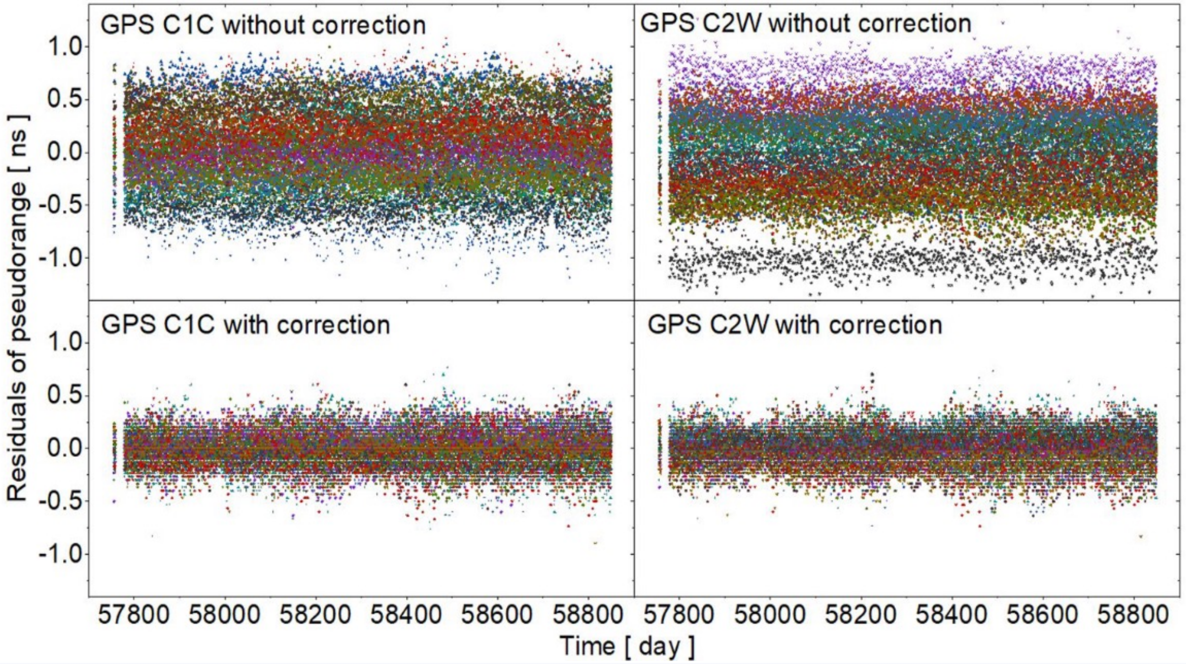


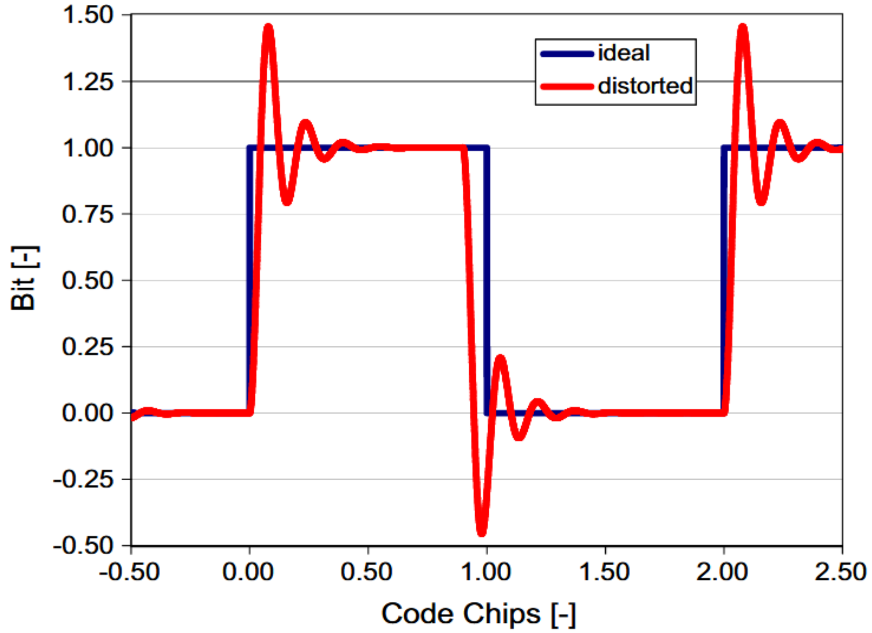


SDB bias

- ✓ **Mechanism:** Navigation signal waveform distortion causes code bias. Coupled with differences in receiver front-end bandwidth and correlator design, the satellite code bias exhibits receiver correlation. This satellite code bias related to receiver types is defined as Signal Distortion Bias (SDB).
- ✓ SDB was discovered in 1993, causing a significant degradation in differential positioning

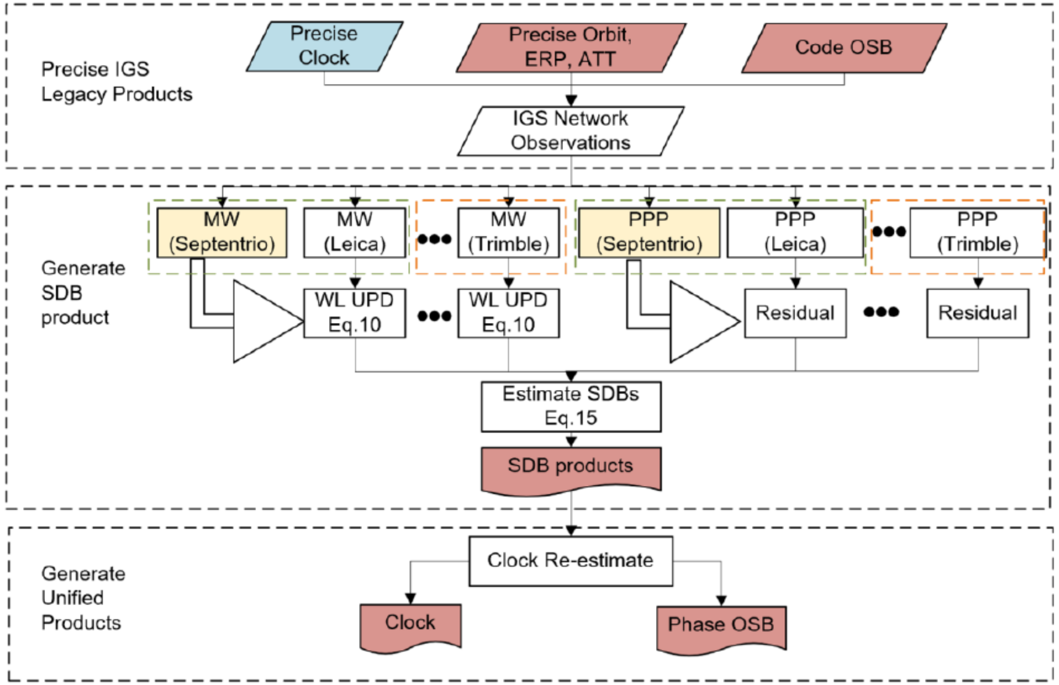
ma





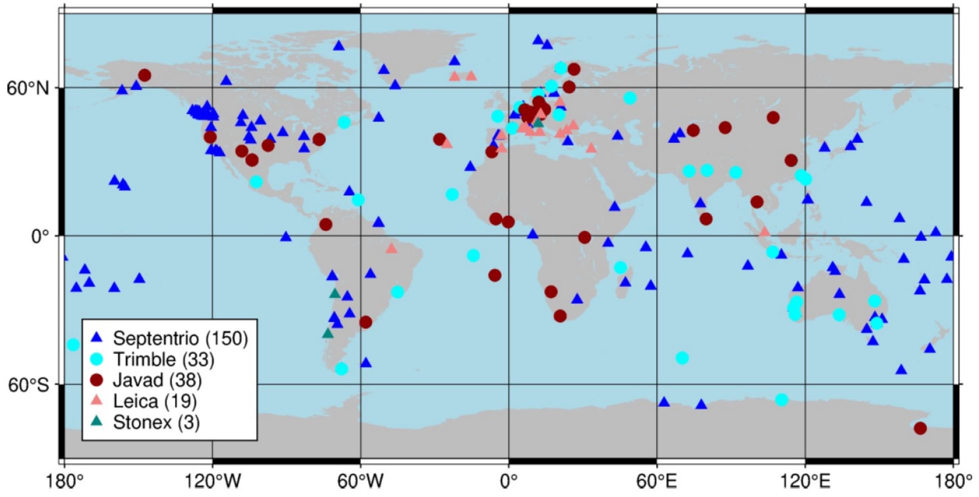
Method: calibration

$$
\begin{cases}
P_{r,sig(i)}^{s} = R_r^s + c \cdot \left(t_r - t^s + d_{r,sig(i)} + d_{sig(i)}^{s} + \boxed{SDB_{group(r),sig(i)}^{s}}\right) + \gamma_{r,sig(i)}^{s} \cdot I_r^s + M_r^s \cdot T_r + \xi P_{r,sig(i)}^{s} \\
L_{r,sig(i)}^{s} = R_r^s + c \cdot \left(t_r - t^s + b_{r,sig(i)} + b_{sig(i)}^{s}\right) - \gamma_{r,sig(i)}^{s} \cdot I_r^s + M_r^s \cdot T_r + \lambda_{sig(i)}^{s} \cdot N_{r,sig(i)}^{s} + \xi L_{r,sig(i)}^{s}
\end{cases}
$$



Receiver Manufacturer (count)	Type (count)	Signals
Septentrio (150)	POLARX5 (107) POLARX5TR (35) POLARX5S (2)	C1PC5P, C2IC6I, C7D
	POLARX5E (1)	C1PC5P, C2IC6I
	ASTERX4 (5)	C1PC5P, C2IC6I, C7D
Leica (19)	GR30 (2) GR50 (17)	C1PC5P, C2IC6I, C7D
Trimble (33)	ALLOY (33)	C1XC5X, C2IC6I, C7D
Javad (38)	TRE_3 (9) TRE_3S (2) TRE_3 DELTA (27)	C1XC5X, C2IC6I, C7ZC8X
Stonex (3)	SC2200 (3)	C1PC5P, C2IC6I, C7D

Strategy



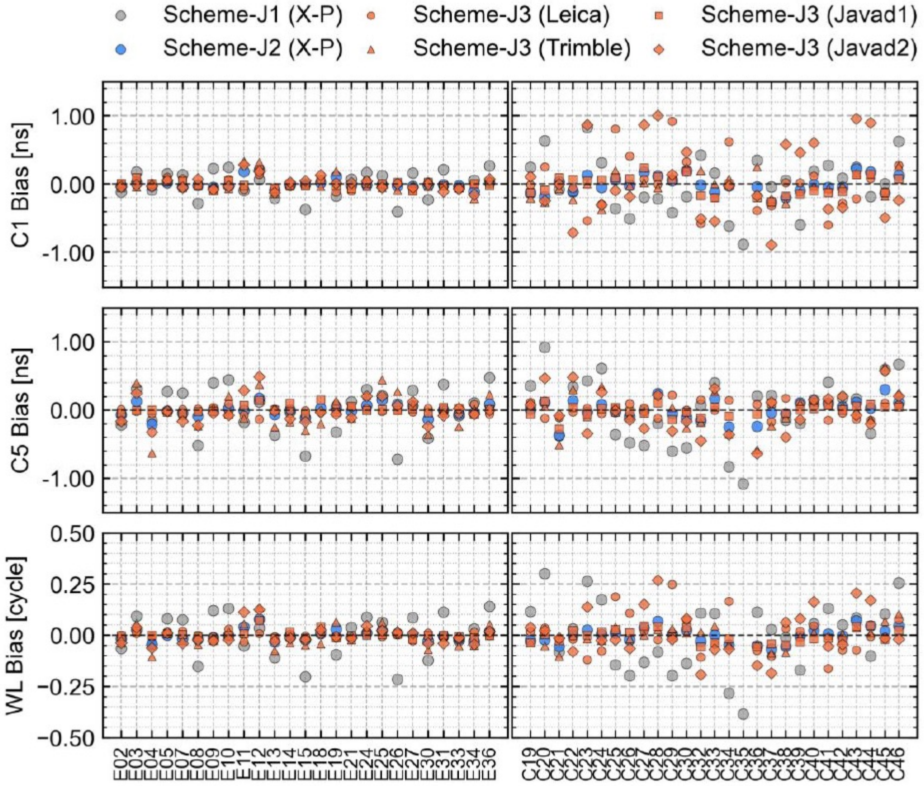
Solutions	Stations	Bias Correction
Scheme P	P-based (Septentrio only)	/
Scheme J-1	QX-joint (Septentrio, Trimble, Javad and Leica)	/
Scheme J-2		Pilot-Mixed channel bias correction only
Scheme J-3		Pilot-Mixed channel and SDB bias correction

- GPS+Galileo+GLONASS+BDS-3 (2024/092-2024/121)

Feature	Strategy
Observable	Undifferenced ionosphere-free dual-frequency code and phase combination
POD arc length	24 h
Elevation angle cutoff	7°
Weighting	Code: 0.2 m; phase: 2 mm
	Elevation-dependent weighting: $e > 30°$: 1; $e \leq 30°$: $2sin(e)$
Ambiguity Fixing	UDAR
Antenna PCO/PCV	igs20_bds.atx for satellites and stations
Tidal displacement	Soliad Earth tide (IERS 2010, Petit and Luzum 2010)
	Ocean tide loading (FES2014b)
Tropospheric delay	Global Pressure and Temperature (GPT) model
	with Global Mapping Function (GMF) Boehm et al (2006)
	Piece-wise constant Zenith Total Delay (ZTD) for each hour
	Constant gradients for the whole arc
Earth rotation	IERS Bulletin A
	Ocean tidal: diuranal/semidiurnal varriations applied
	High-frequency nutation applied
	UT1 libration applied
	HF EOP based on Desai model
	Fixed UT1UTC;
	x- and y-pole coordinates, dx, dy, and Length Of Day (LOD) are estimated
Solar radiation	BDS-3 MEO: ECOM1 with a priori SRP model(Guo et al, 2023)
	Galileo: ECOM1 with a priori SRP model(Montenbruck et al, 2015b)
	GPS and GLONASS: Box-wing+ECOM2
Attitude model	BDS-3 CAST satellites(Wang et al, 2018)
	BDS-3 SECM satellites(Yang et al, 2023)
Earth albedo radiation	Applied based on (Rodriguez-Solano et al, 2012)
Satellite antenna thrust	Applied consistently with IGS MGEX metadata
	(https://files.igs.org/pub/station/general/igs_satellite_metadata.snx)

Pilot–Mixed Channel and Signal Distortion

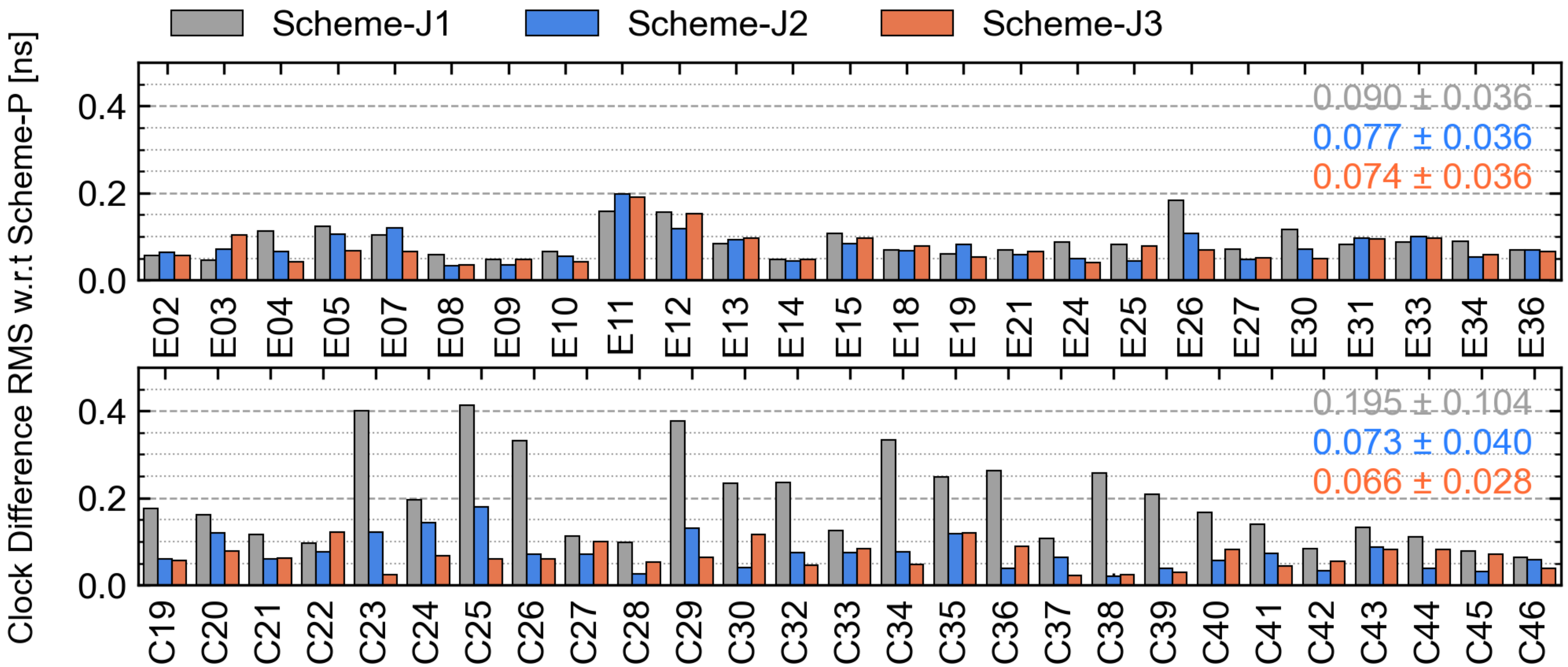
- **Uncorrected biases are substantial**: Without any correction (J1), BDS-3 C1/C5 code biases and wide-lane biases are **~2× larger** than those of Galileo.
- **Generic P-X correction is insufficient**: Pilot-mixed channel-only correction (J2) reduces overall biases by ~70%, but **fails to eliminate receiver-specific differences**. Large residual biases persist for Leica and Javad2 receivers.



System	Scheme	C1/ns		C2/ns		WL/cycle	
		RMS	PP	RMS	PP	RMS	PP
GALILEO	Scheme-J1 (X-P)	0.197	0.666	0.452	1.195	0.105	0.356
	Scheme-J2 (X-P)	0.069	0.316	0.088	0.386	0.026	0.118
	Scheme-J3 (Leica)	0.063	0.258	0.050	0.228	0.015	0.063
	Scheme-J3 (Trimble)	0.120	0.552	0.257	1.076	0.055	0.241
	Scheme-J3 (Javad1)	0.064	0.317	0.058	0.219	0.020	0.099
	Scheme-J3 (Javad2)	0.095	0.439	0.182	0.807	0.044	0.188
BDS-3	Scheme-J1 (X-P)	0.403	1.713	0.489	1.998	0.168	0.688
	Scheme-J2 (X-P)	0.128	0.487	0.151	0.664	0.037	0.137
	Scheme-J3 (Leica)	0.384	1.519	0.113	0.392	0.096	0.410
	Scheme-J3 (Trimble)	0.179	0.637	0.262	1.216	0.047	0.205
	Scheme-J3 (Javad1)	0.137	0.493	0.088	0.409	0.033	0.105
	Scheme-J3 (Javad2)	0.556	1.901	0.307	1.213	0.116	0.460

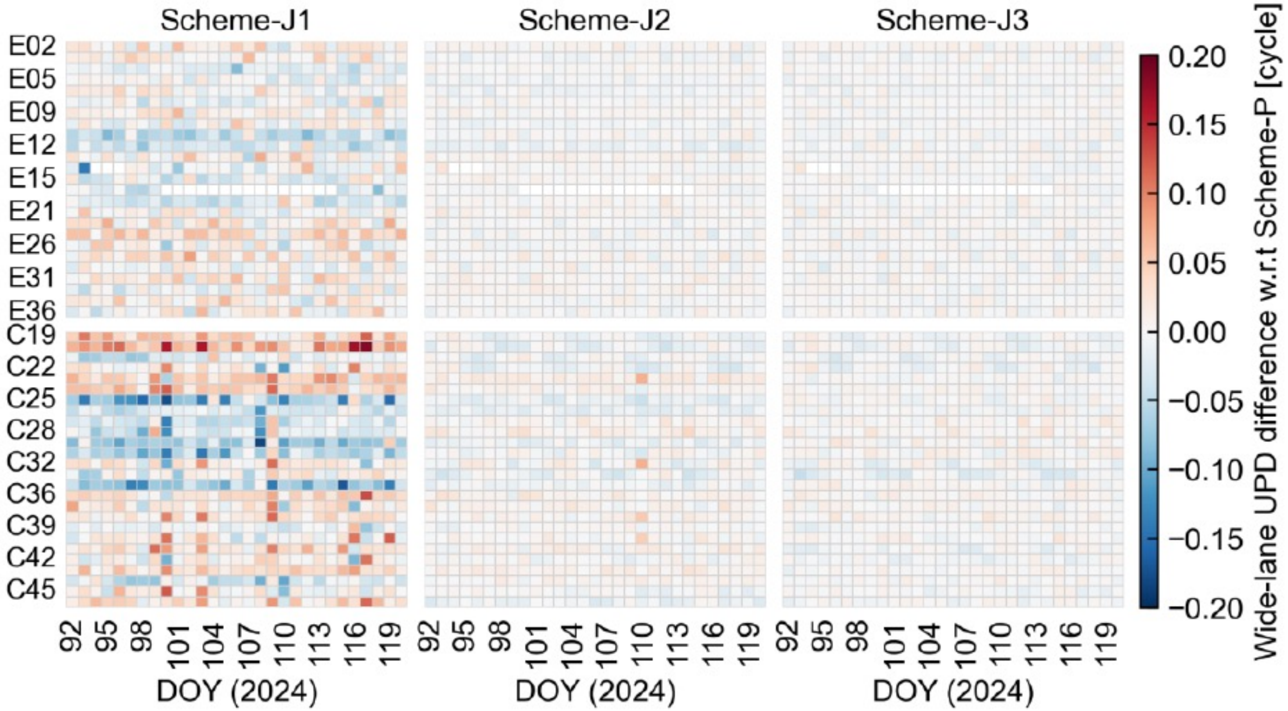
Impact on Satellite Clock

- **Dramatic improvement for BDS-3**: Mean clock RMS drops from **0.195 ns (J1) → 0.073 ns (J2) → 0.066 ns (J3)**
- SDB modeling provides an **additional 10% improvement** J2
- **Parity with Galileo achieved**: After full correction (J3), BDS-3 clock consistency reaches the same level as Galileo (~0.06–0.07 ns)



Impact on Wide-lane UPD

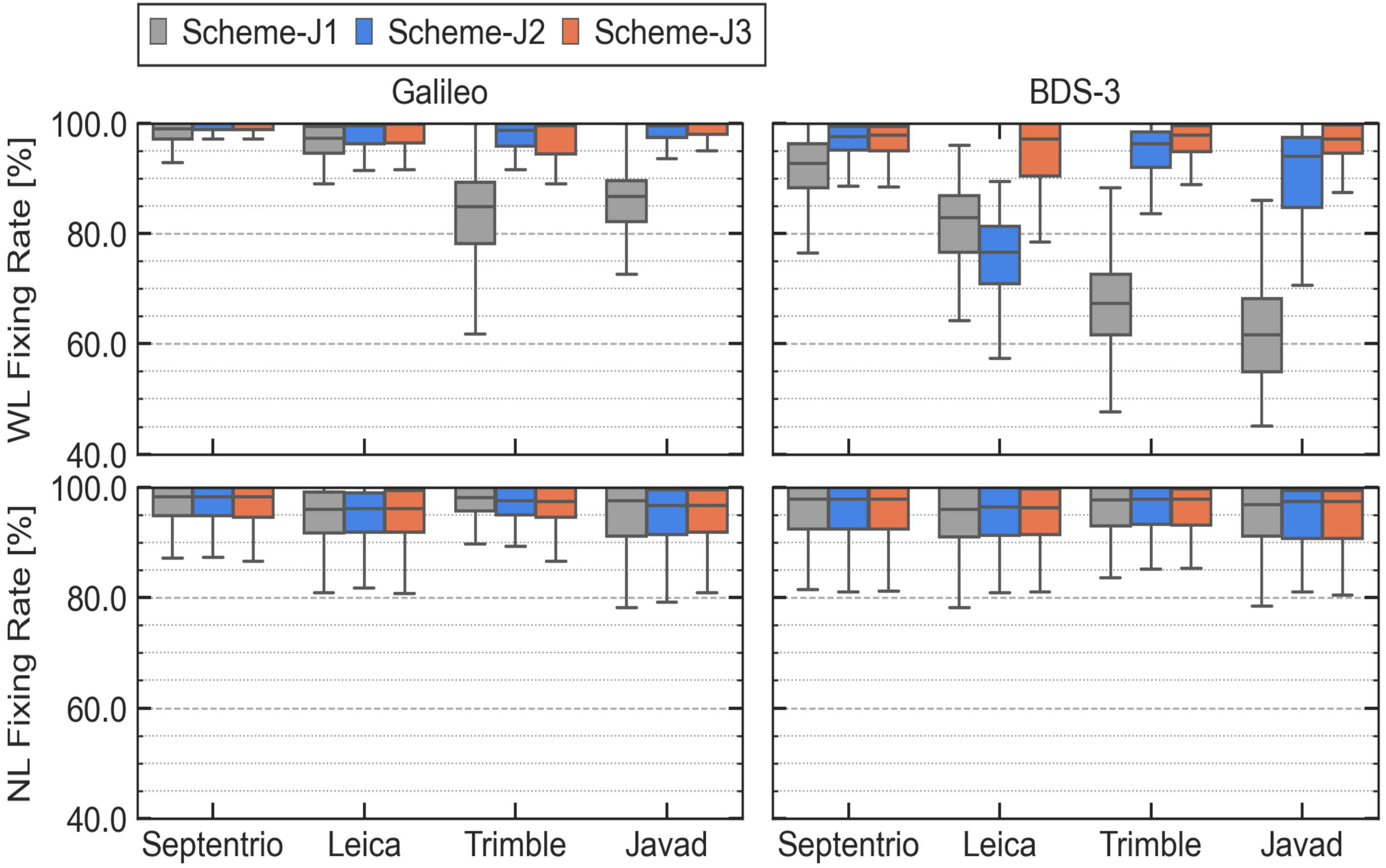
- **Uncorrected BDS-3 UPDs are twice as large as Galileo**: Peak-to-peak (PP) value reaches **0.162 cycles** (vs. 0.088 cycles for Galileo) in Scheme-J1
- **Full correction eliminates UPD inconsistencies**: PP value drops to **0.021 cycles** for BDS-3, identical to Galileo
- **SDB modeling delivers dominant improvement**: Provides an **additional 44% reduction** in UPD RMS over generic P-X correction alone



System	Scheme	RMS	PP
GALILEO	Scheme-J1	0.021	0.088
	Scheme-J2	0.005	0.021
	Scheme-J3	0.002	0.007
BDS-3	Scheme-J1	0.042	0.162
	Scheme-J2	0.009	0.033
	Scheme-J3	0.005	0.021

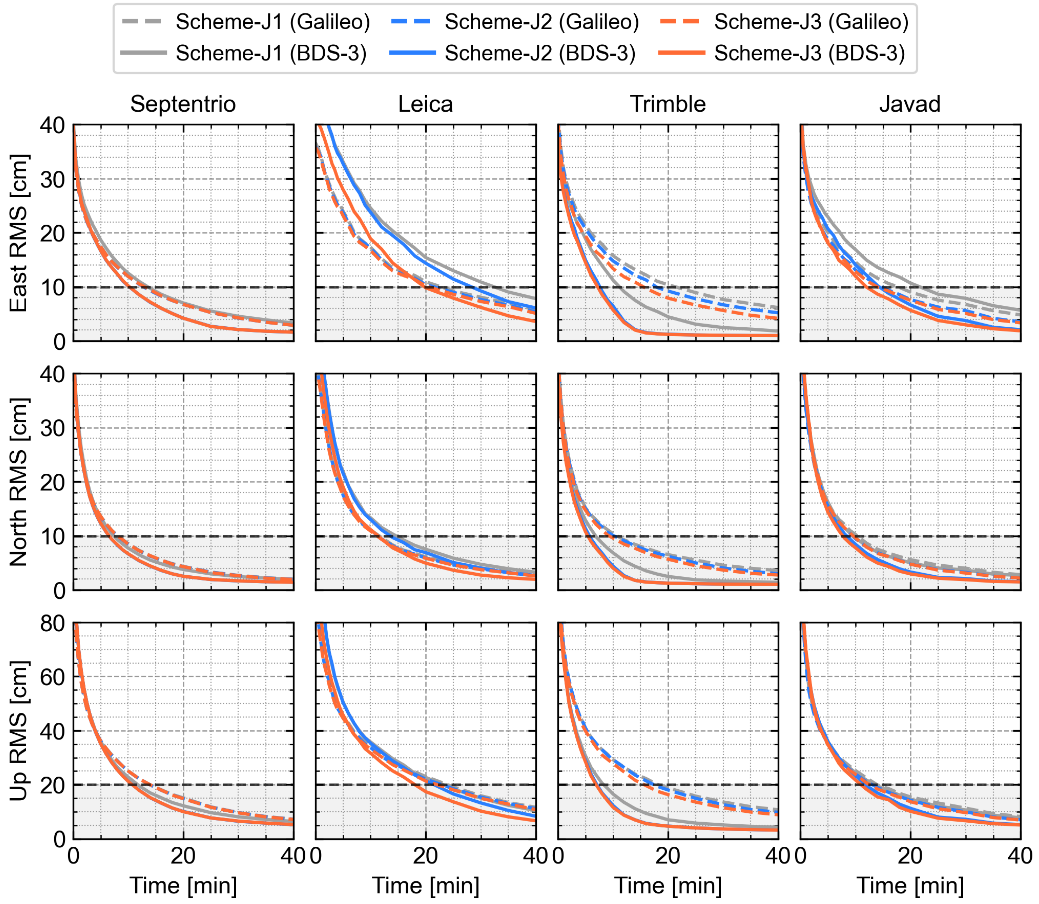
Impact on Fixing Rate

- **Galileo WL fixing rate is inherently stable**
- **BDS-3 is highly sensitive to bias modeling**
- **Generic P-X correction (J2)**: Improves Trimble/Javad but *degrades Leica performance* (biased toward dominant Septentrio characteristics)
- **Full correction (J3) achieves uniform performance**
- Leica receivers improve from **~70% (J1)** to **>95% (J3)**
- **Narrow-lane (NL) fixing rate remains consistently high (>96%)** across all schemes and systems



Impact on PPP-AR

- **Full correction delivers dramatic speedup for BDS-3**: Convergence time reduced by **20%–44%** for Leica and Javad receivers
- Leica East component: 32.5 min (J1) → 28.5 min (J2) → **20.0 min (J3)** (38% total reduction)
- **BDS-3 parity with Galileo achieved**: After full SDB correction, BDS-3 B1C/B2a performance is **comparable to or better than** Galileo E1/E5a



Summary and Conclusion

- 1. Core Contributions
- Proposed the **unified framework** for simultaneous estimation of pilot-mixed (P-X) channel biases and signal distortion biases (SDBs) for BDS-3 B1C/B2a signals
- 2. Main Findings
- SDBs are a non-negligible error source:
  - Additional **10% improvement** in satellite clock consistency over P-X-only correction
  - Additional **44% improvement** in wide-lane UPD consistency over P-X-only correction
- Full bias correction achieves uniform performance across all receivers:
  - Leica WL fixing rate: ~70% → **>95%**
  - Kinematic convergence time reduced by **20%–44%**
- **BDS-3 parity with Galileo achieved**: After full correction, BDS-3 B1C/B2a PPP-AR performance is comparable to or better than Galileo E1/E5a

Summary and Conclusion

- 3. Future Work

- Recommend IGS analysis centers adopt B1C/B2a as BDS-3 baseline signals and integrate SDB modeling
- Next-generation BDS signals: Future signal designs with adjusted bandwidth and modulation schemes are expected to reduce receiver-specific signal distortion biases at the source, further simplifying high-accuracy data processing

THANK YOU!

junqiangli@whu.edu.cn
jingguo@whu.edu.cn