

Combining multi-GNSS phase bias products for improved undifferenced ambiguity resolution

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IGS phase bias products

- Phase biases are critical to retrieving integer PPP ambiguities.
- IGS Analysis Centers (ACs) have begun to release phase bias products.

AC	Orbits/clocks	Phase biases	Quaternions
COD	GREC ₂	GE	GREC ₂
ESA	GREC ₂₃	GEC ₂₃	n/a
GFZ	GREC ₂₃	GEC ₂₃	n/a
GRG	GRE	GE	GRE
TUG	GRE	GRE	GRE
WHU	GREC ₂₃	GEC ₂₃	GREC ₂₃

GEC₂₃: computed by Pan Li at GFZ using the UPD method by fixing ESA and GFZ orbits/clocks.

Combine phase bias products to achieve more stable PPP-AR ([Banville et al. 2020](#))

Combination method

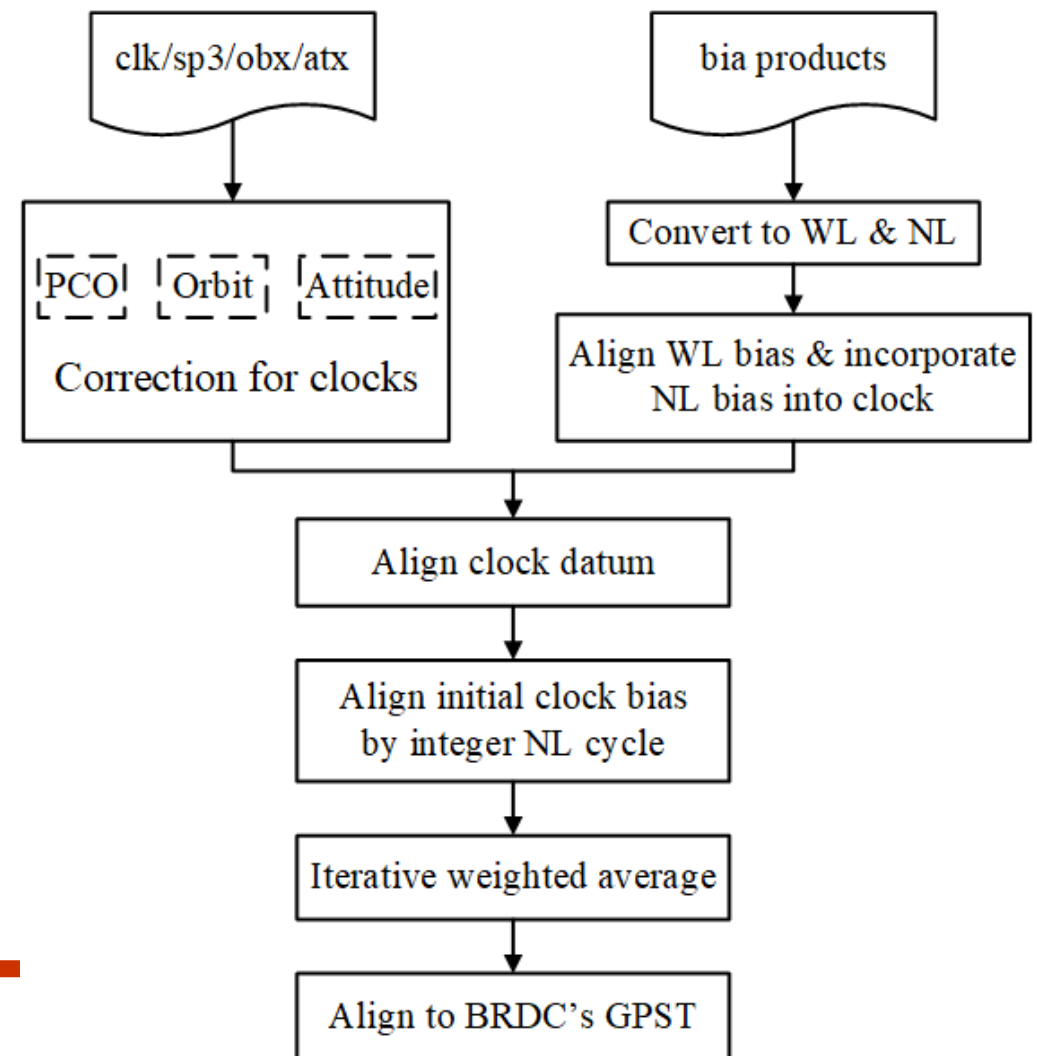
- Observable-specific biases are converted into wide- & narrow-lane forms.
- Clocks and phase biases are combined as integer clocks.

$$\begin{pmatrix} b_1 \\ b_2 \\ d_1 \\ d_2 \end{pmatrix} = \begin{pmatrix} \frac{g}{g-1} & \frac{-1}{g-1} & \frac{-g}{g+1} & \frac{-1}{g+1} \\ \alpha_{IF} & \beta_{IF} & 0 & 0 \\ 0 & 0 & 1 & -1 \\ 0 & 0 & \alpha_{IF} & \beta_{IF} \end{pmatrix}^{-1} \begin{pmatrix} b_{WL} \\ b_{NL} \\ d_{P1P2} \\ D_{clk} \end{pmatrix}$$

with

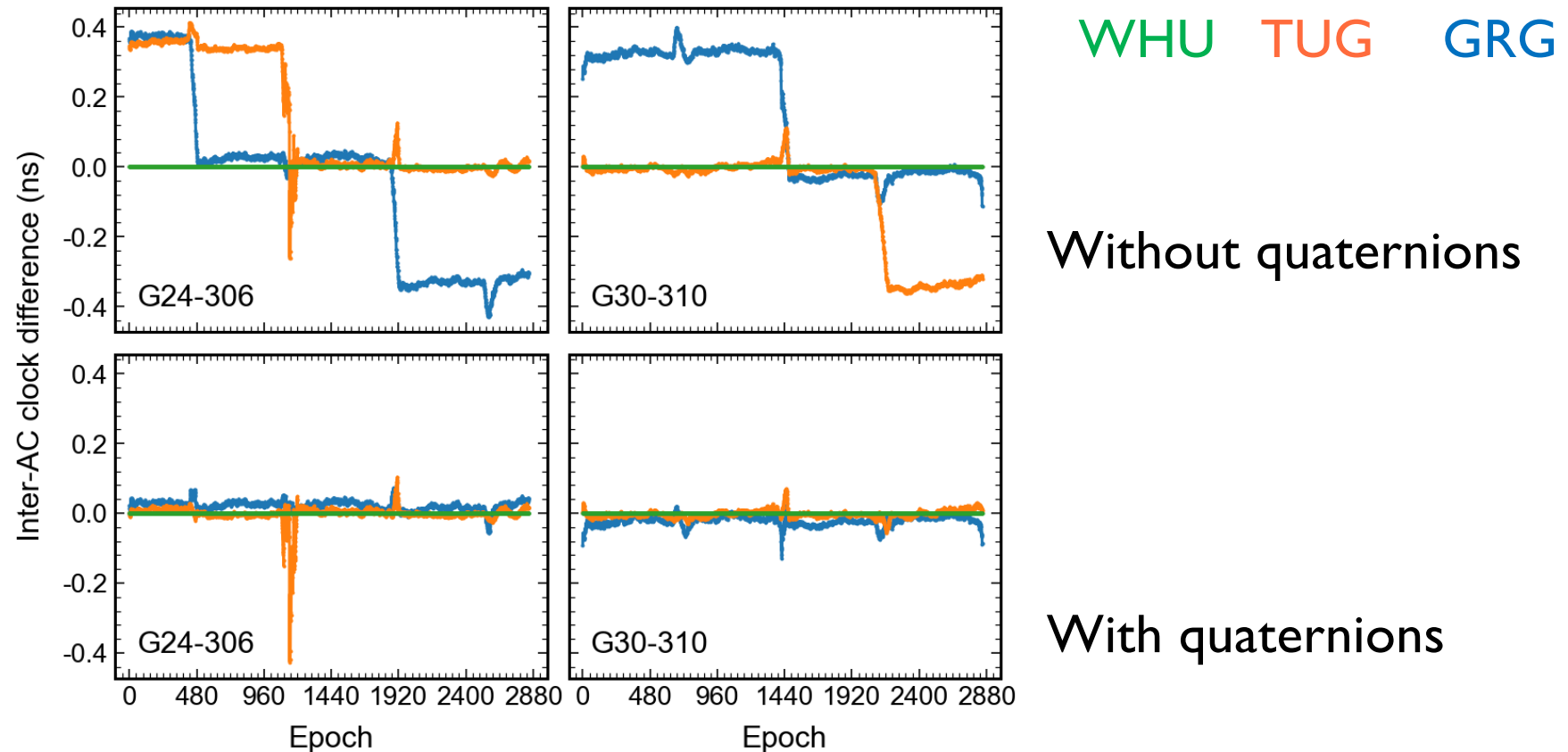
$$\begin{cases} g = \frac{f_1}{f_2} \\ \alpha_{IF} = \frac{g^2}{g^2-1} \\ \beta_{IF} = \frac{-1}{g^2-1} \\ D_{clk} = 0 \end{cases}$$

OSBs $\Leftrightarrow$ WL/NL biases



Impact of satellite attitude discrepancy

- IGS quaternion products to calibrate satellite attitudes ([Loyer et al. 2021](#)).

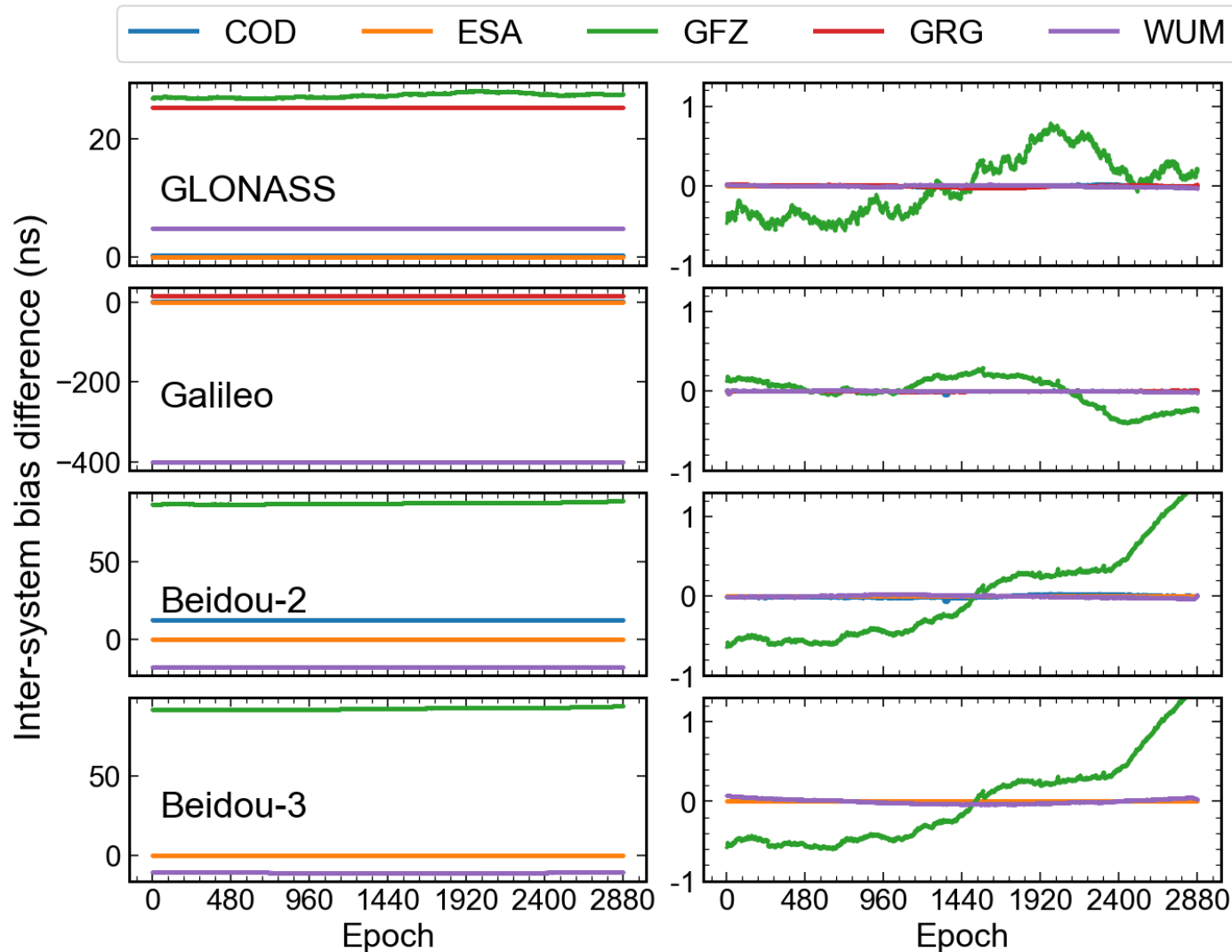


Quaternions diminish inter-AC clock discrepancies in eclipsing seasons

Loyer et al. (2021) Exchanging satellite attitude quaternions for improved GNSS data processing consistency. ASR

Impact of multi-GNSS inter-system biases (ISBs)

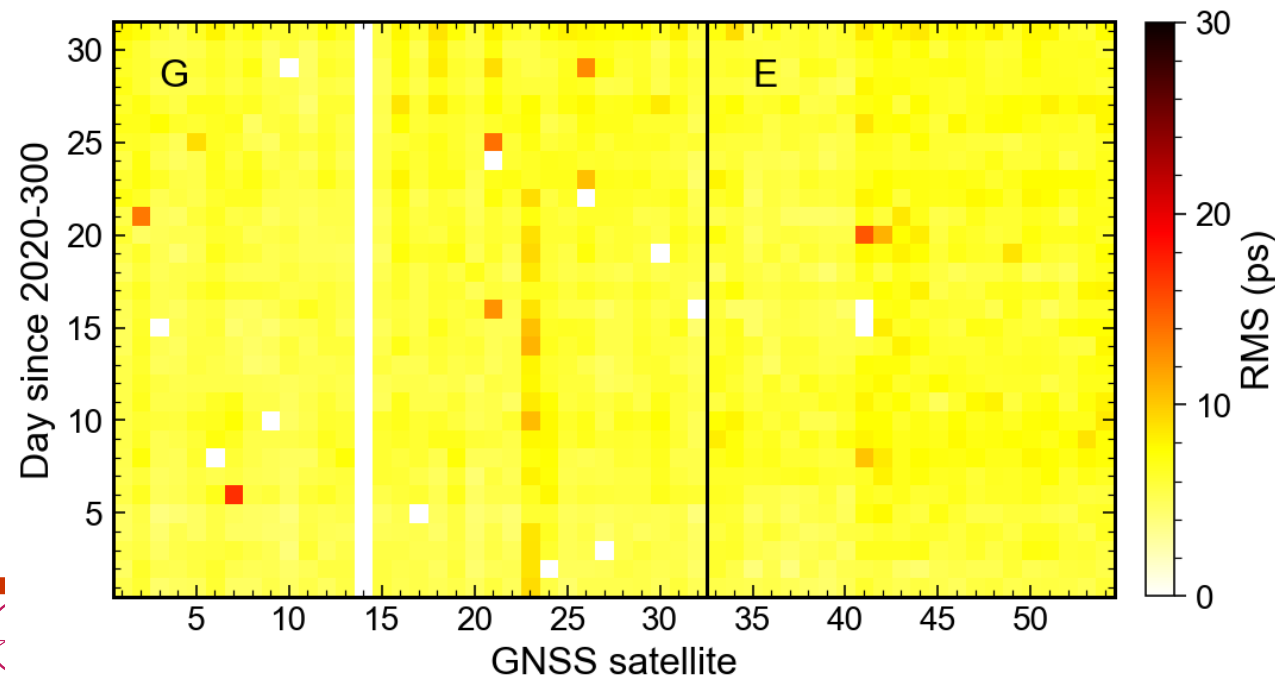
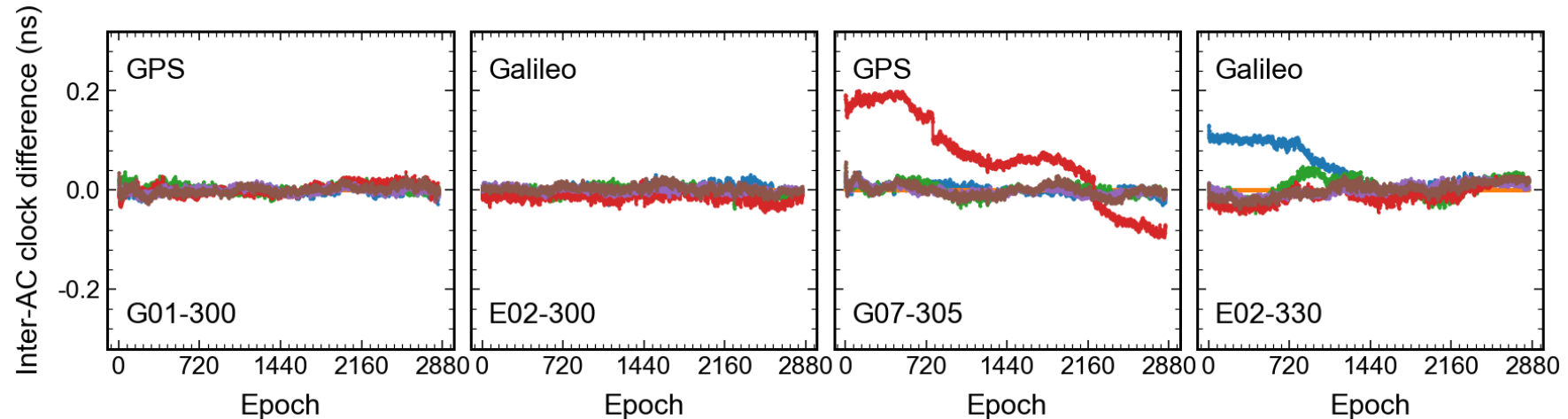
- AC-specific MGEX clocks might have time-variable ISBs.



GFZ clocks have
inconstant ISBs
over the day

GPS/Galileo clock/bias consistency

- Inter-AC clock/bias consistency after outlier rejection (day 300-330, 2020)

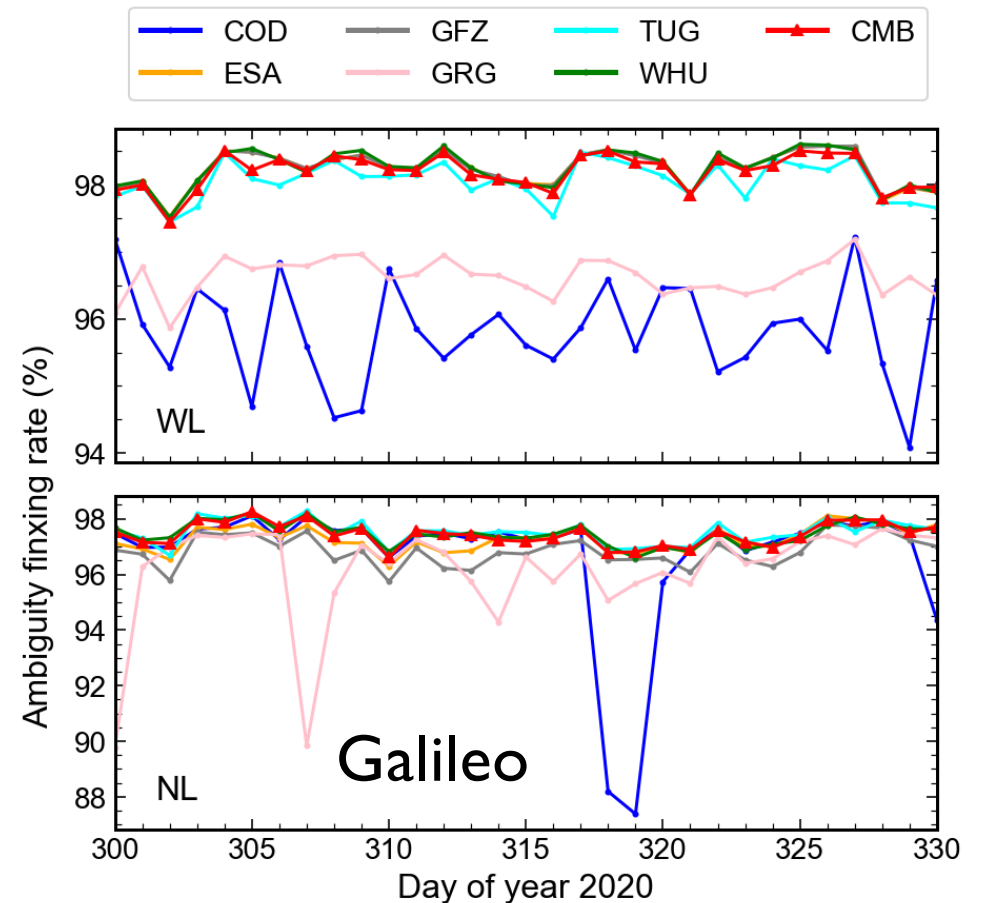
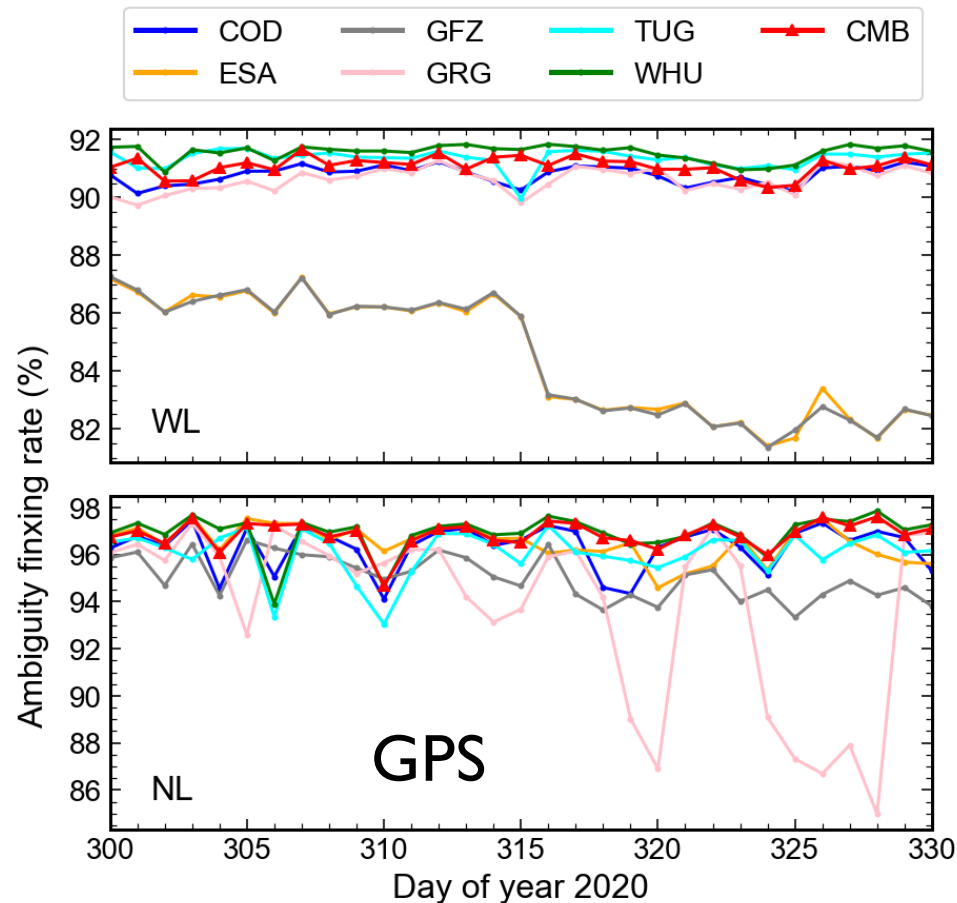


Mean clock/bias consistency is around 6 ps.



GPS/Galileo combined phase biases

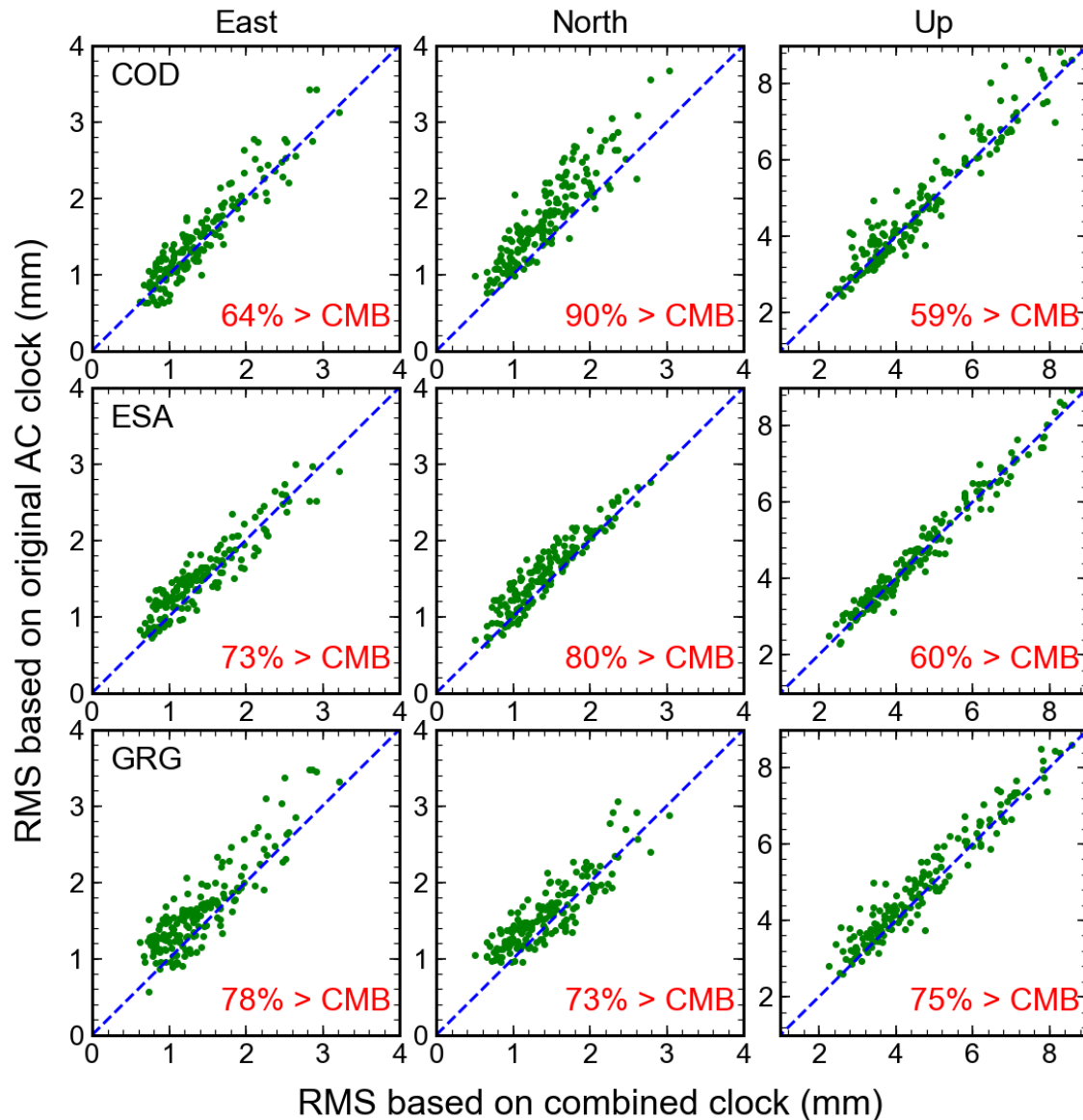
- GPS/Galileo PPP ambiguity fixing rates (day 300-330, 2020)



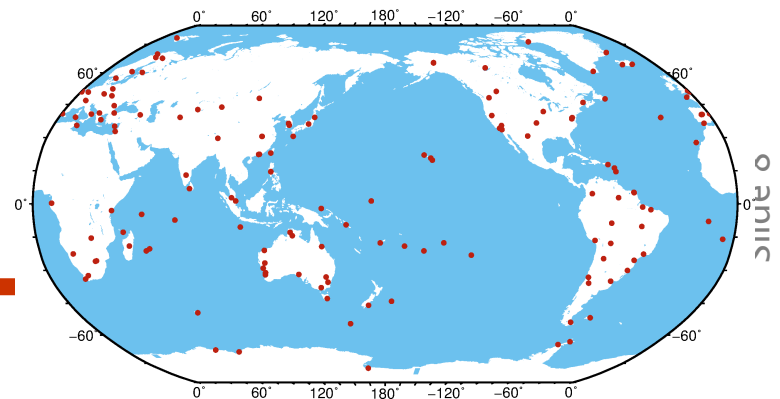
CMB products rank the top roughly in terms of ambiguity fixing rates

GPS/Galileo combined phase biases

- Daily position repeatabilities (mm) after PPP-AR (day 300-330, 2020)

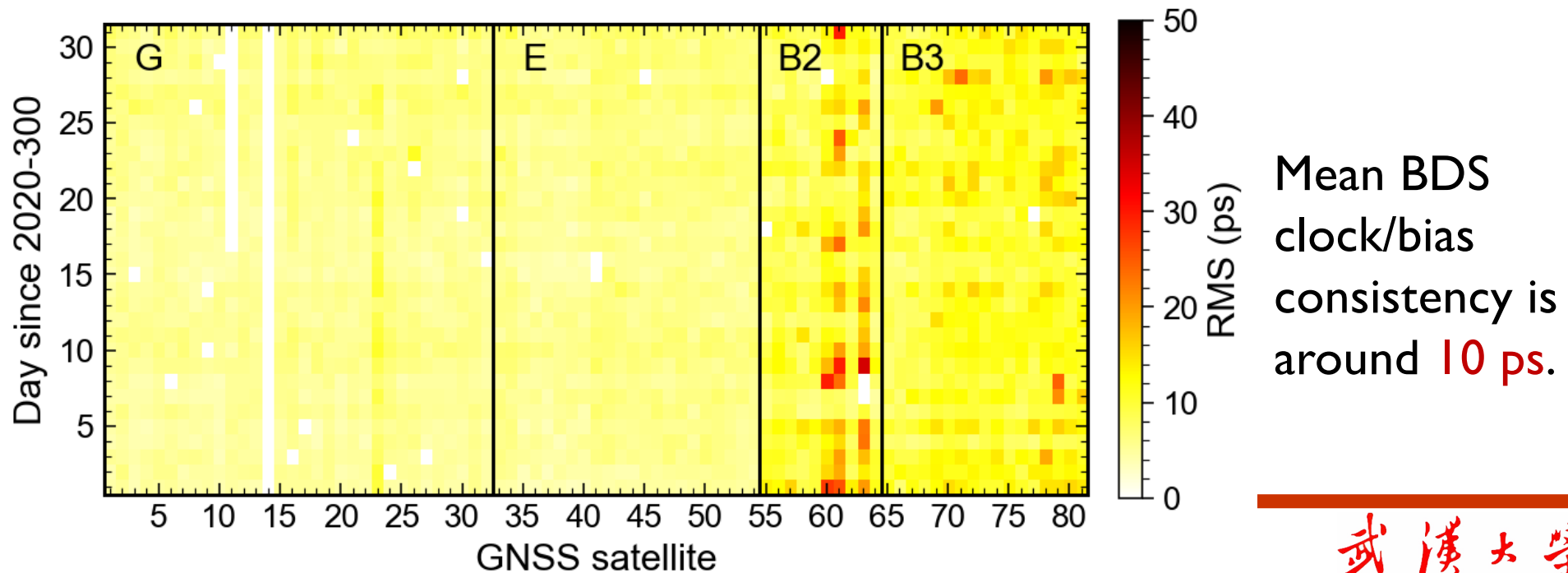
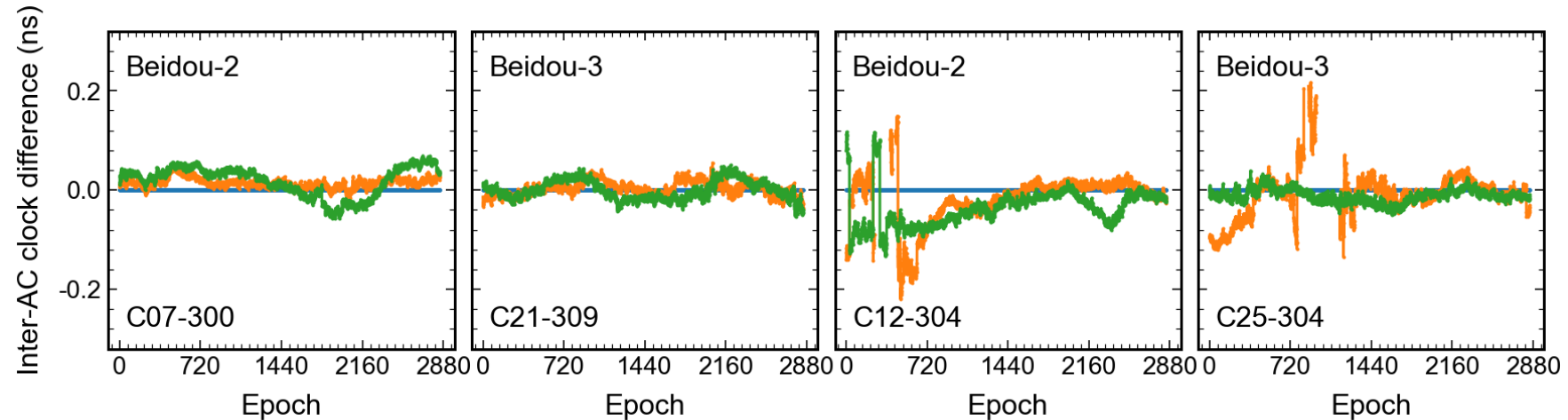


AC	Mean (mm)		
	E	N	U
COD	1.5	1.8	4.9
ESA	1.5	1.6	4.8
GFZ	1.5	1.5	4.9
GRG	1.6	1.6	5.0
TUG	1.5	1.8	4.8
WHU	1.4	1.5	4.7
CMB	1.4	1.4	4.8



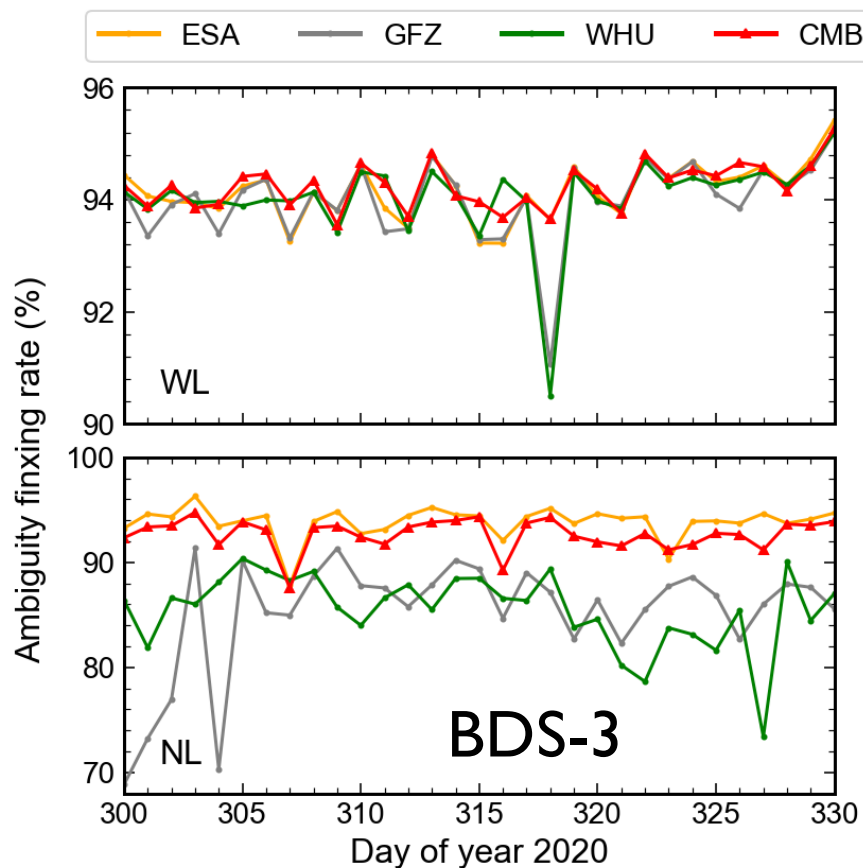
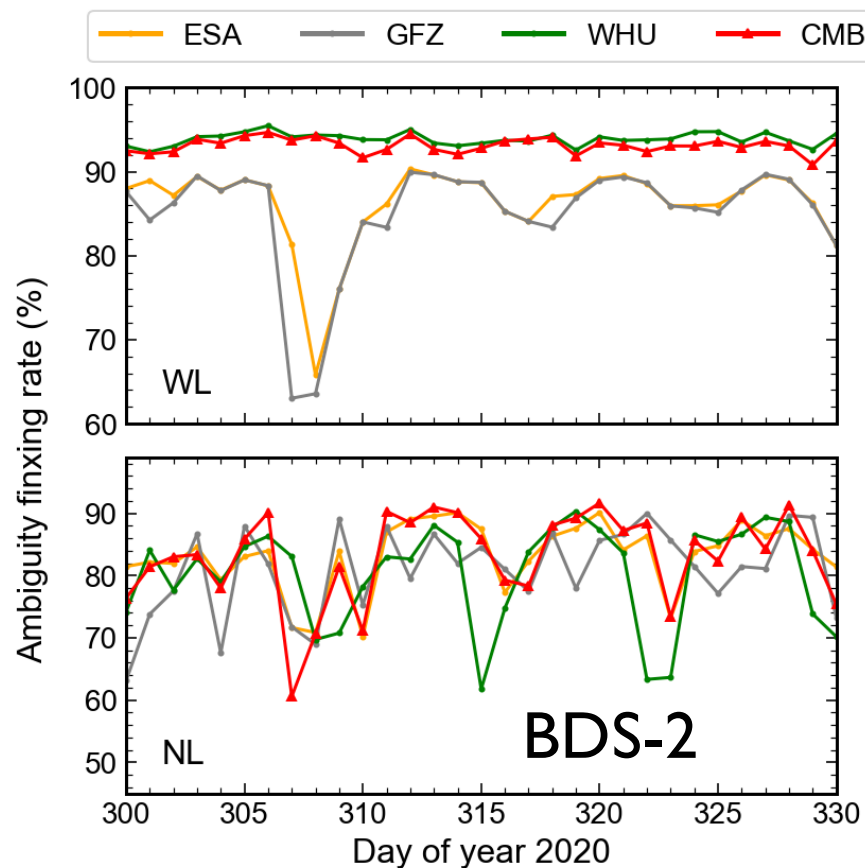
BDS-2/3 clock/bias consistency

- Inter-AC clock/bias consistency after outlier rejection (day 300-330, 2020)



BDS-2/3 combined phase biases

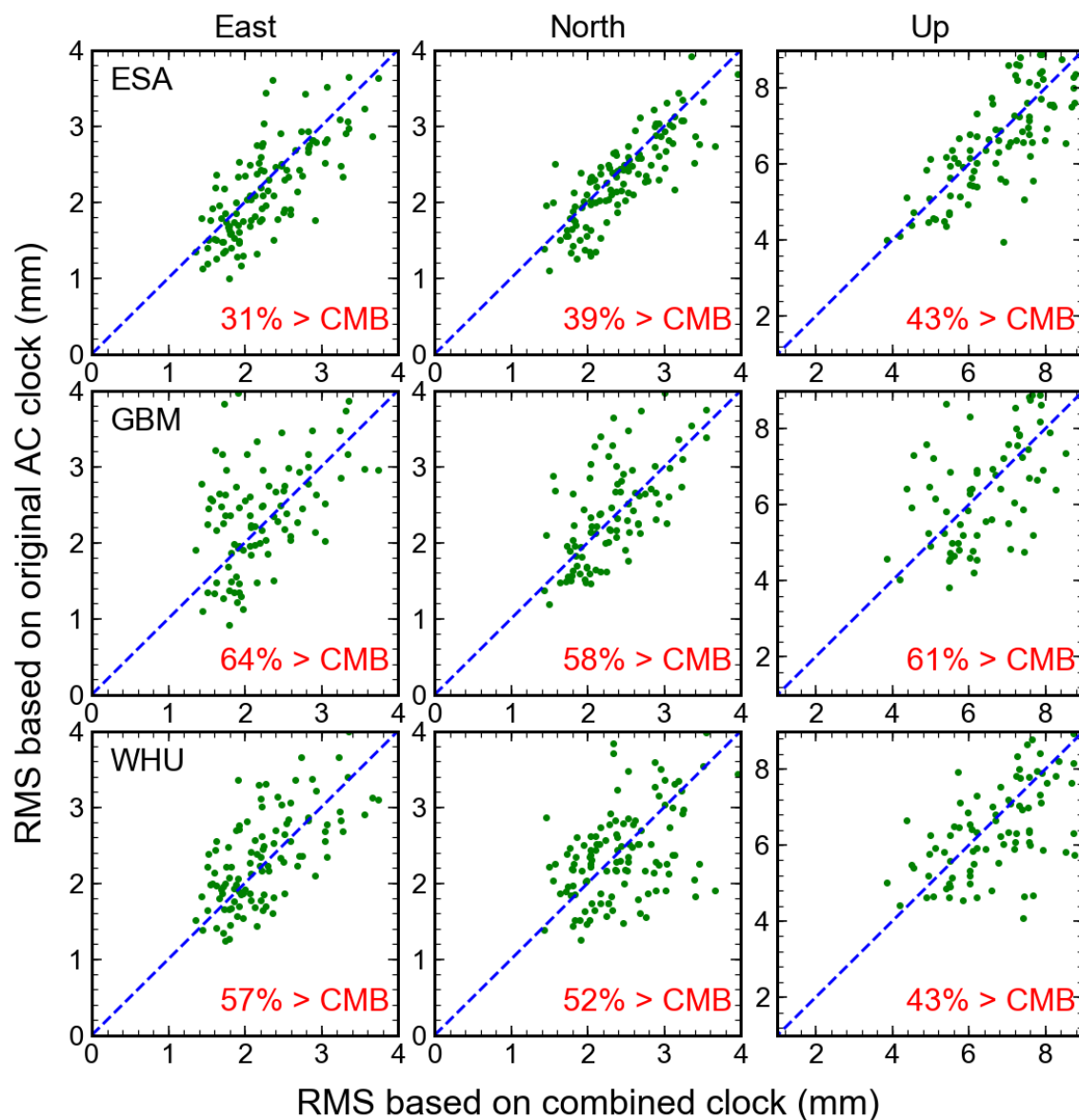
- BDS-2/3 PPP ambiguity fixing rates (day 300-330, 2020)



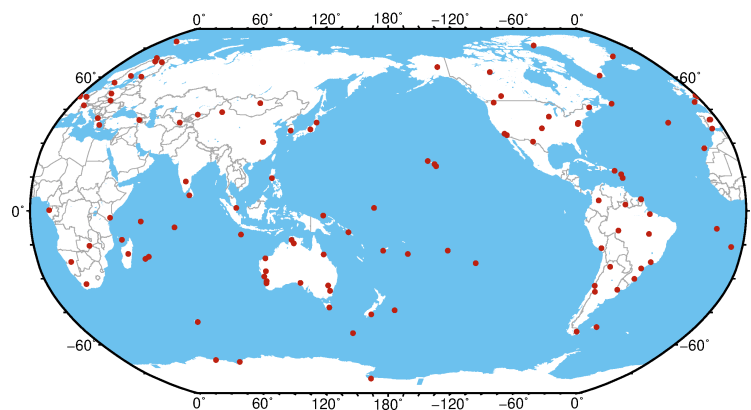
CMB products rank the top, and BDS-3 outperforms BDS-2

BDS-2/3 combined phase biases

- Daily position repeatibilities (mm) after PPP-AR (day 300-330, 2020)



AC	Mean (mm)		
	E	N	U
ESA	2.3	2.4	7.3
GFZ	3.5	3.0	8.6
WHU	2.6	2.5	7.4
CMB	2.4	2.5	7.6



Conclusions

- Inter-AC satellite clock/bias consistency is around **6 ps** for GPS/Galileo, and **10 ps** for BDS-2/3.
- Combined satellite clock/bias products guarantee the highest ambiguity fixing rates and positioning precisions among all AC-specific products.
- Phase bias combination improves robustness of satellite products.