Pride *ckcom*: Repro3 clock combination

Jianghui GENG, Shuyin MAO, Yuanxin PAN

GNSS Research Center, Wuhan University, China

Tour de l'IGS

2 June 2021

Online mini-Workshop

Why combine satellite clocks/phase biases?

- IGS combines ACs' orbits
  - IGS1: AC-specific weighting for GPS/GLONASS/Galileo combination
  - IGS2: Satellite-specific weighting for GPS/GLONASS/Galileo combination
- Combining satellite clocks/phase biases to agree with orbits
  - Satellite attitude quaternions as new products to improve clock consistency

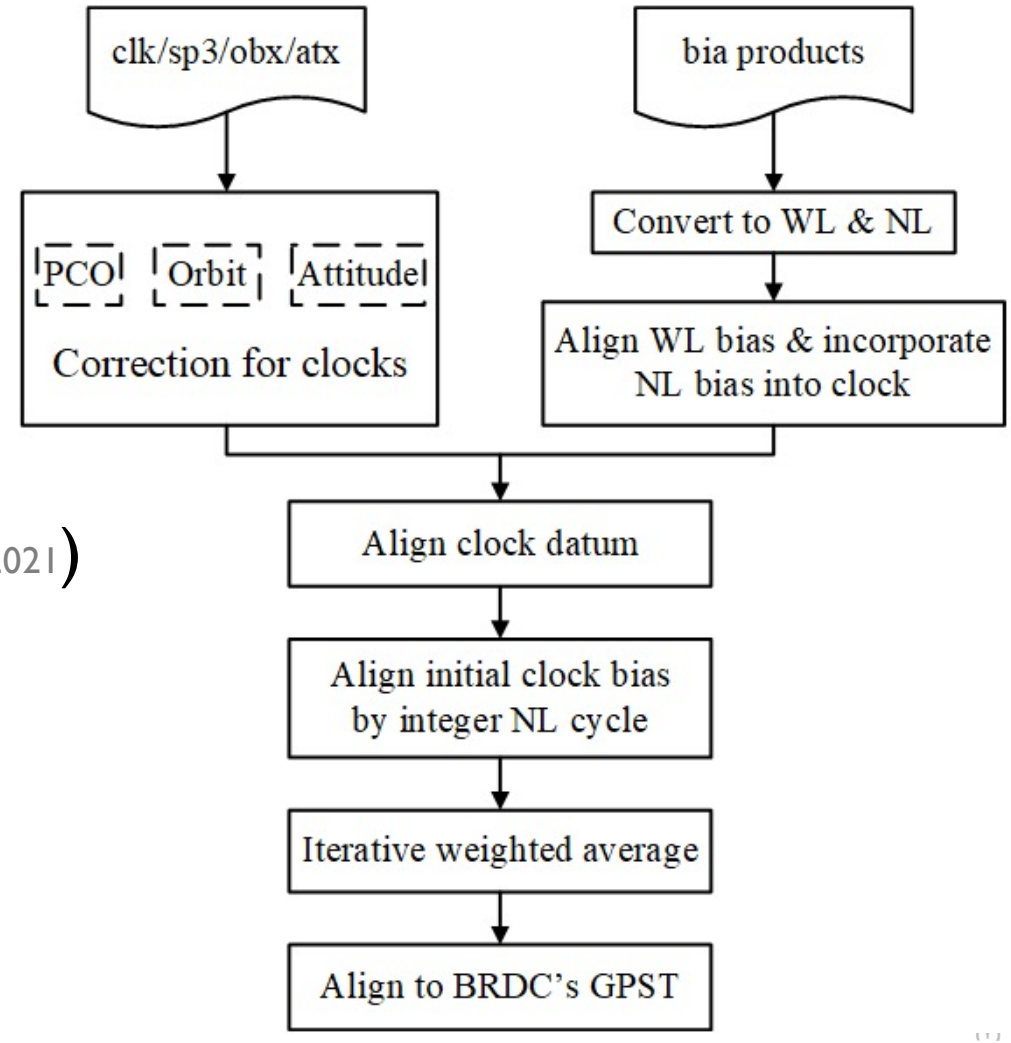
AC	Orbits/clocks	Phase biases	Quaternions
COD	GRE	GE	GRE
ESA	GRE	n/a	n/a
EMR	G	G	G
GRG	GRE	GE	GRE
JPL	G	n/a	G
TUG	GRE	GRE	GRE

Combine clock/bias products to achieve improved PPP (Banville et al. 2020)

Banville et al. (2020) On the interoperability of IGS products for precise point positioning with ambiguity resolution. JoG

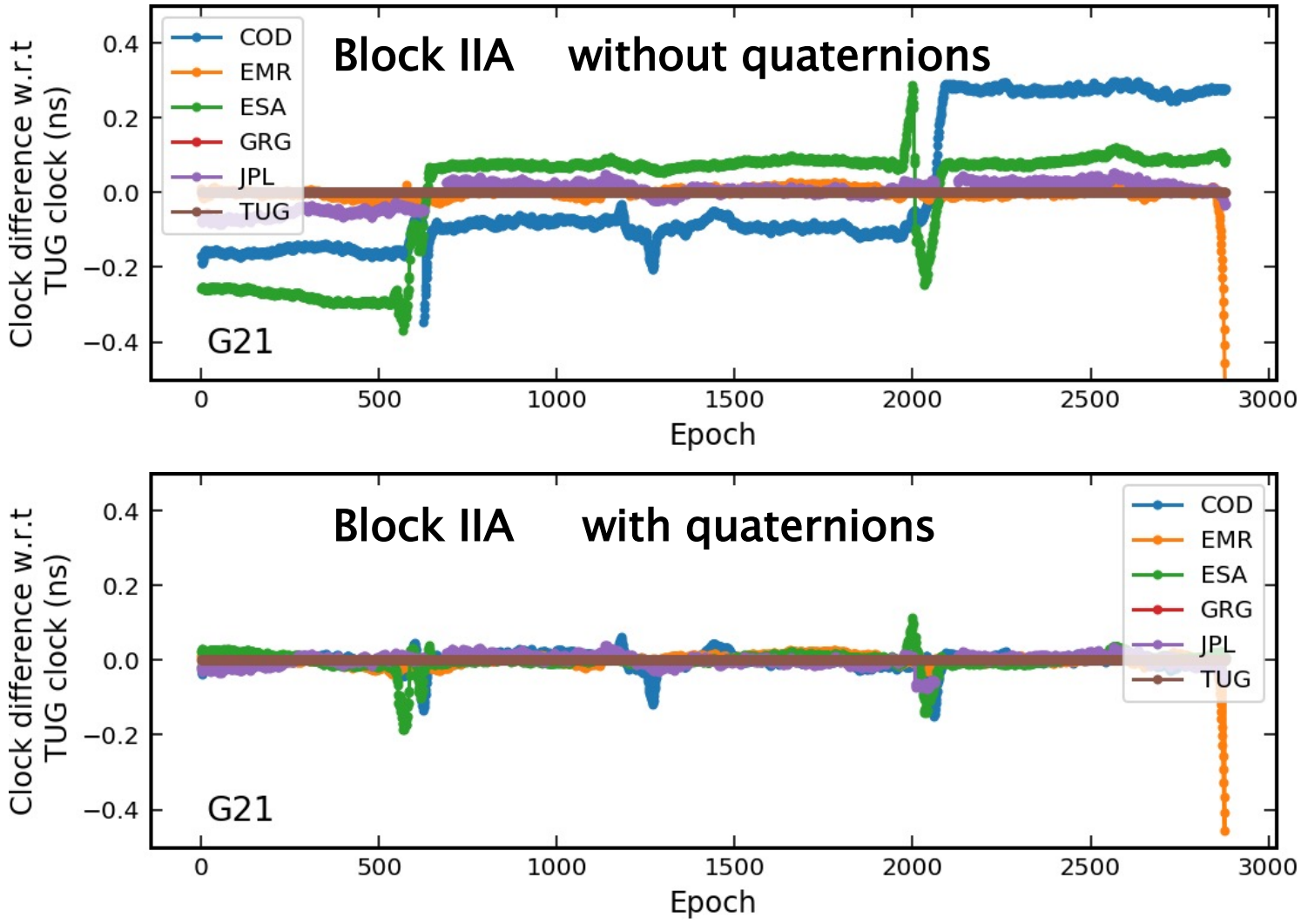
Combination method

- Orbits (we try 2 weeks here)
  - COD/ESA/EMR/GRG/JPL/TUG
- Clock weighting
  - AC-specific
  - Satellite-specific
- Quaternions applied (Loyer et al. 2021)
  - GPS/GLONASS aligned to nominal attitudes
  - Galileo aligned to GSA



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

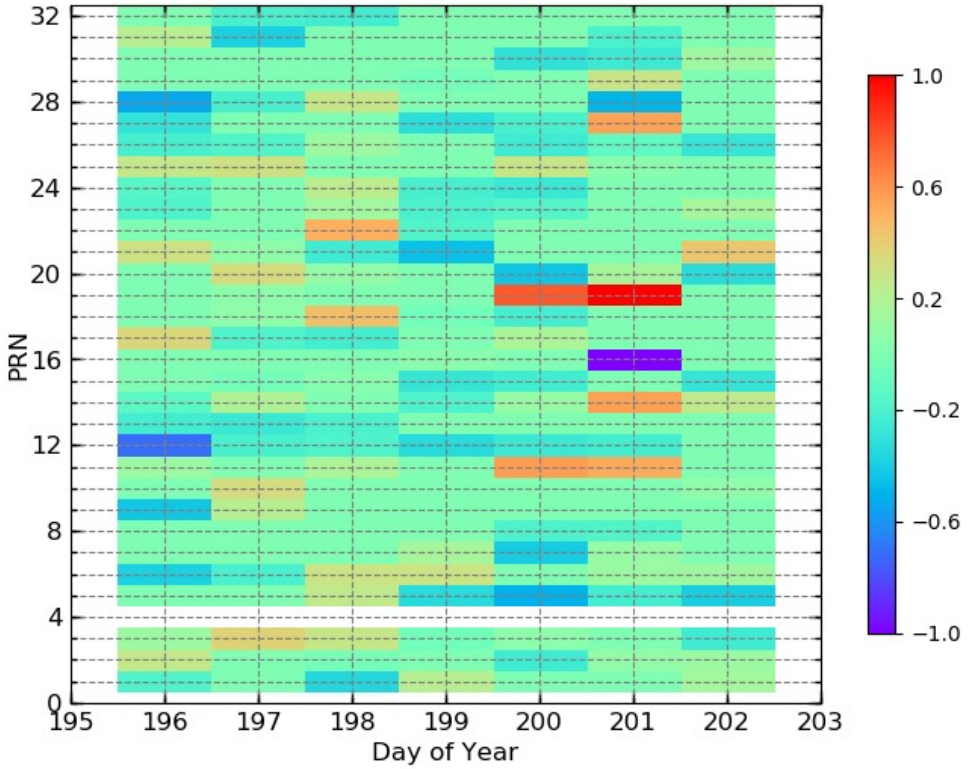
Impact of satellite attitude corrections



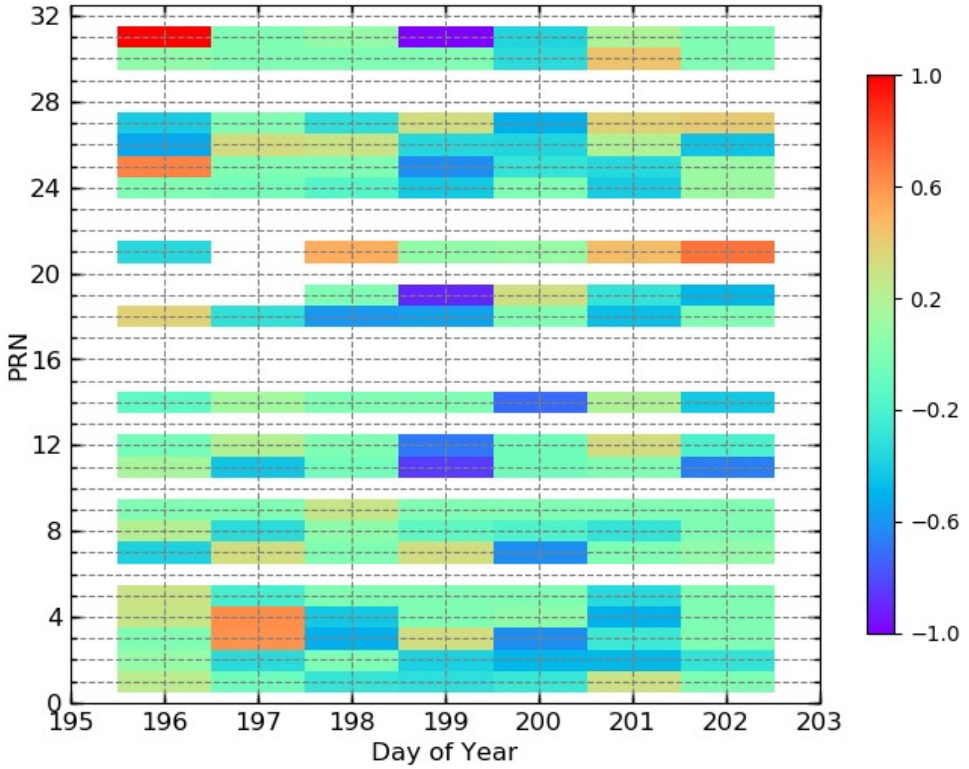
Quaternions diminish inter-AC clock discrepancies in eclipsing seasons

IGS1 vs. IGS2 based clock combinations

- IGS1-IGS2: combination clock differences (ps) in w2010
  - Clock combination strateiges follow those of the orbit combinations



GPS: 0.2ps mean



Galileo: 0.3ps mean

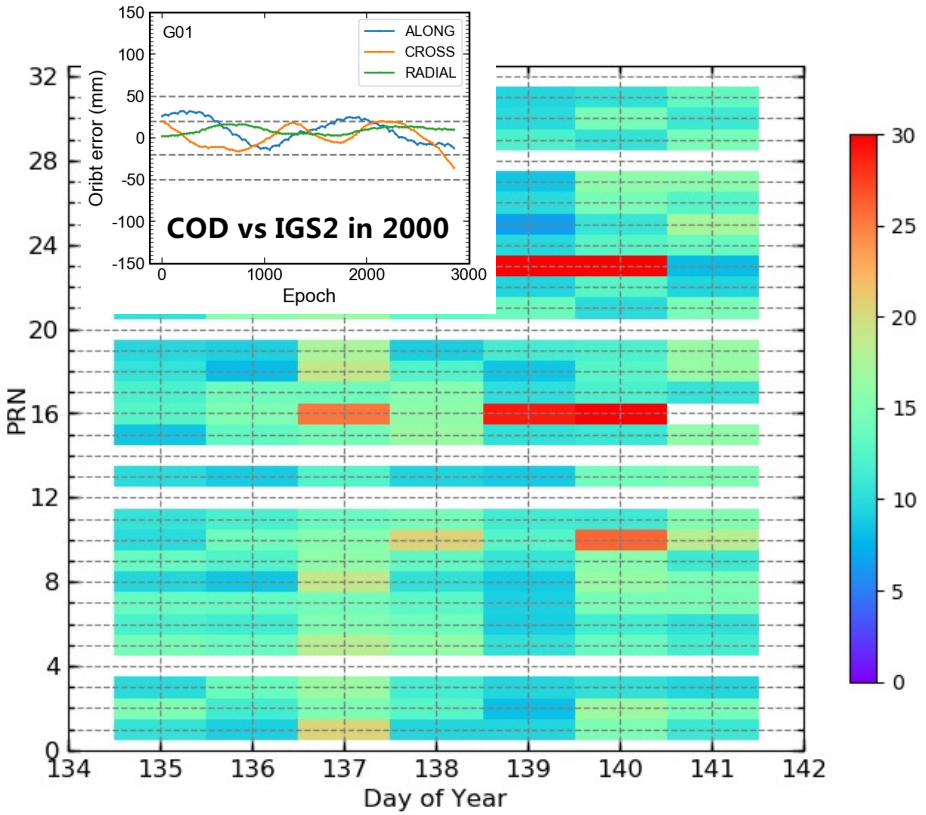
The difference between IGS1 and IGS2 based combination clocks is minimal

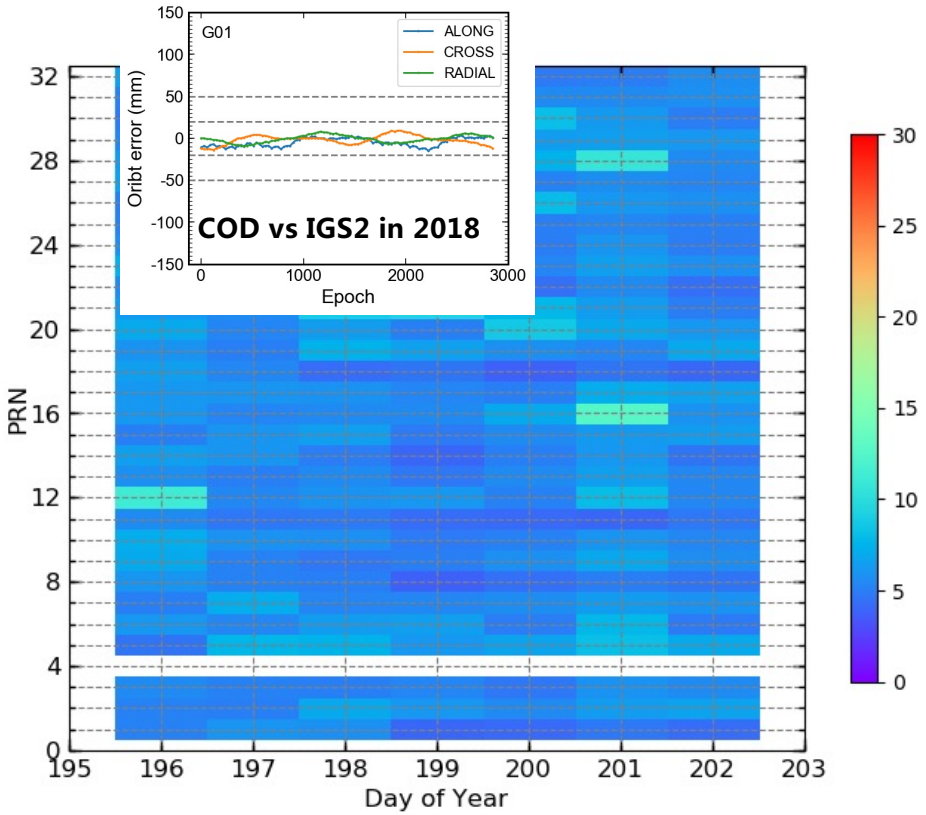
Legacy satellite clock combination

--GPS/Galileo clocks computed without undifferenced ambiguity resolution

GPS legacy satellite clock consistency

- AC-specific clocks compared to combined clocks (IGS2 orbits)





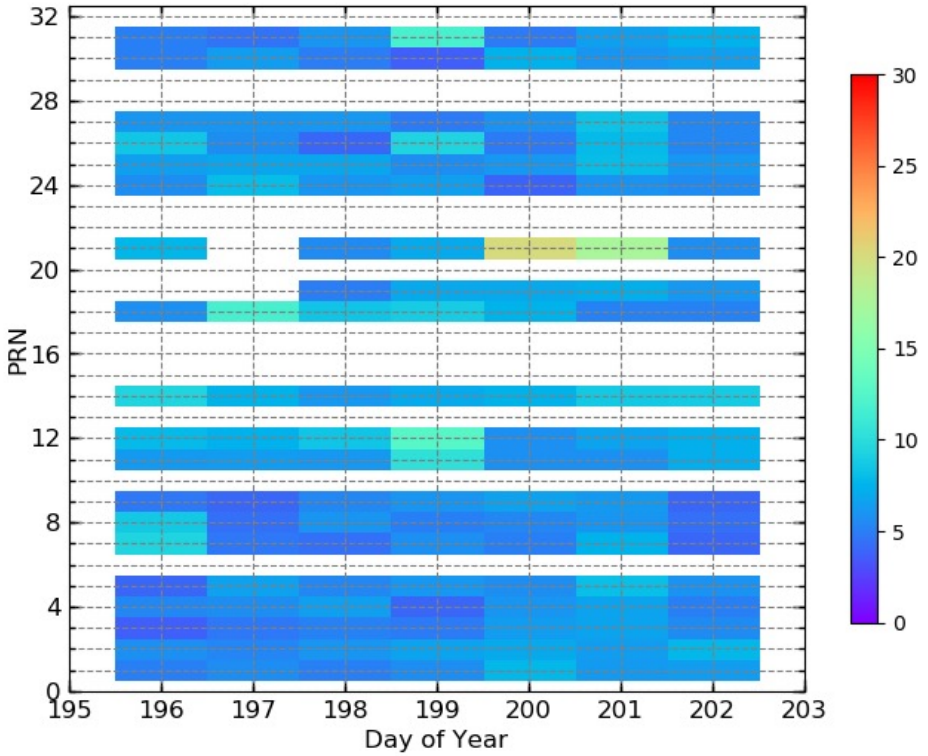
14.2ps mean (w1062 GPS 6 ACs)

6.0ps mean (w2010 GPS 6 ACs)

GPS clock consistency improves thanks to the orbit improvement

Galileo legacy satellite clock consistency

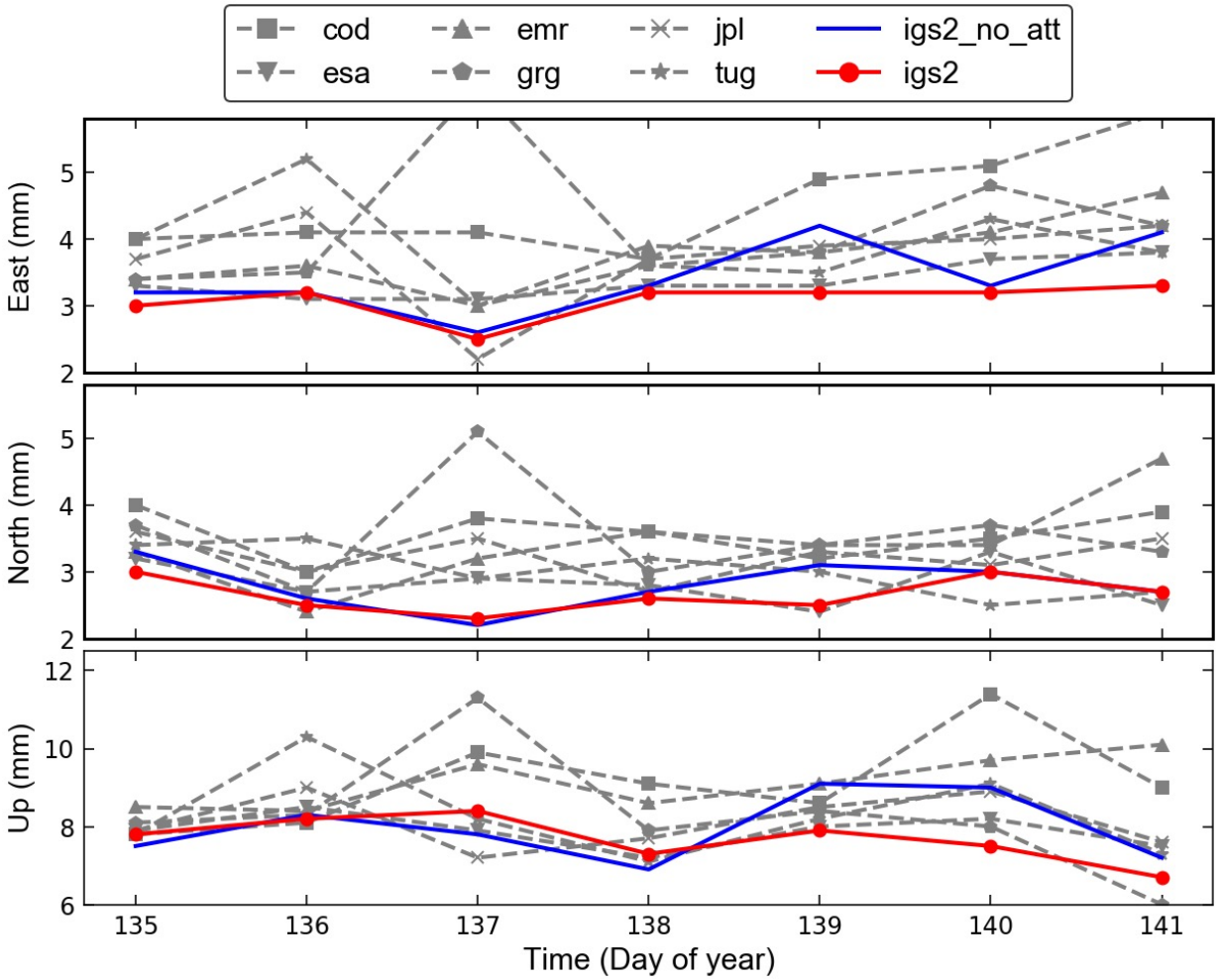
- AC-specific clocks compared to combined clocks (IGS2 orbits)



6.9ps mean (w2010 Galileo 4 ACs)

Ambiguity-float daily GPS

- w1062 GPS with IGS2 orbits
  - No quaternions were used in PPP to facilitate cross-comparison



AC	E/N/U (mm)
IGS2 (no att)	3.4/2.8/8.0
IGS2	3.1/2.7/7.7
COD	4.5/3.6/9.1
ESA	3.4/2.8/7.9
EMR	3.8/3.4/9.1
GRG	4.2/3.6/8.3
JPL	3.7/3.2/8.1
TUG	3.9/3.0/8.3

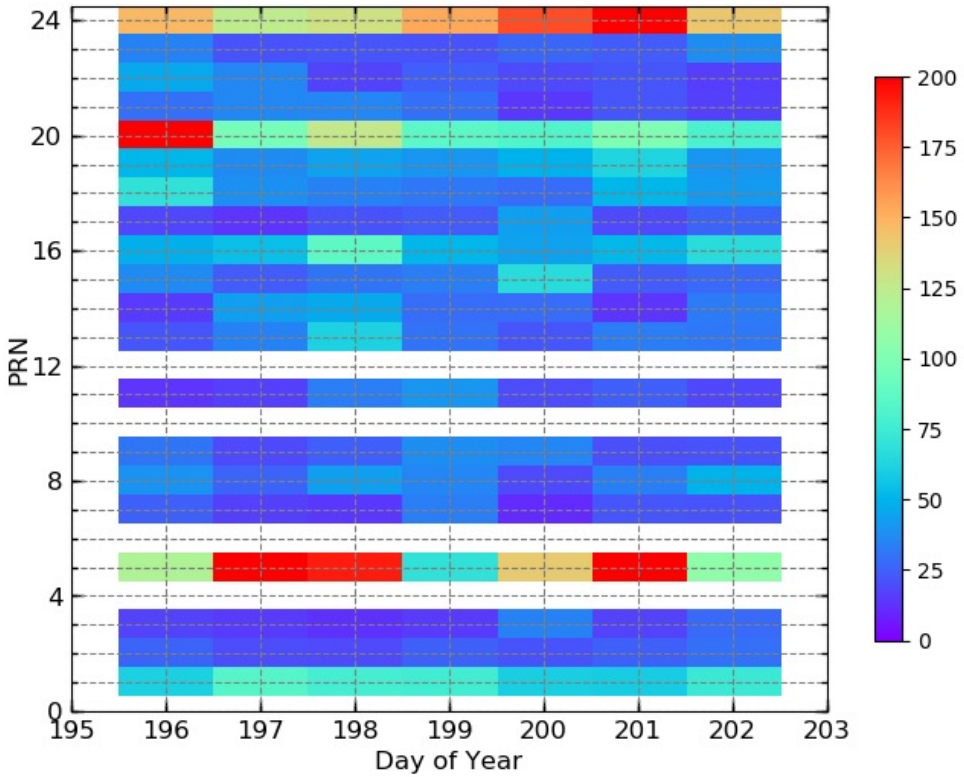
no att: combination without quaternions

Legacy satellite clock combination

--Issues with GLONASS clocks and solutions

GLONASS satellite clock consistency

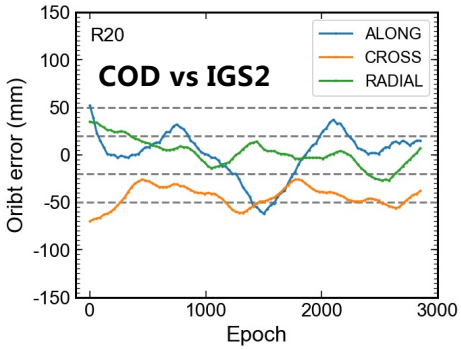
- AC-specific clocks compared to combined clocks (IGS2 orbits)

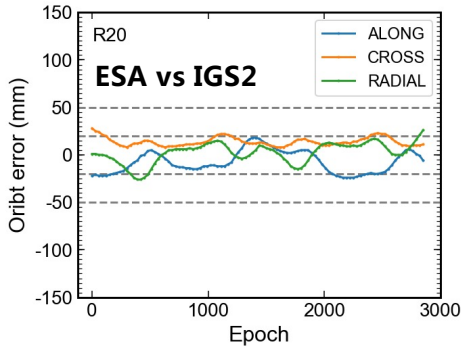


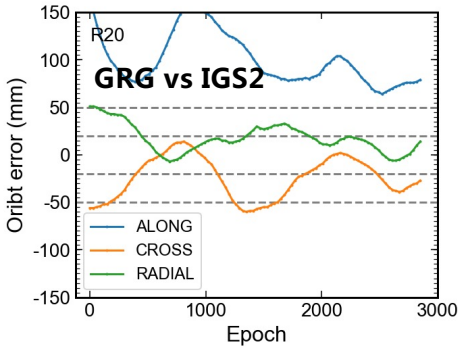
68.9ps mean (w2010 GLONASS 6 ACs)

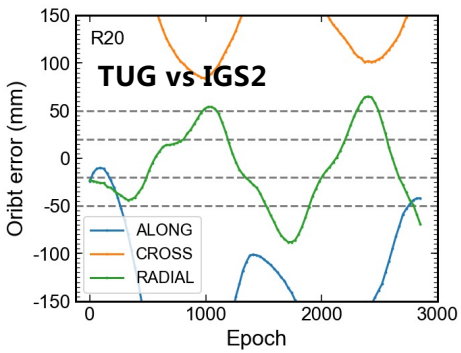
GLONASS orbit/clock consistency among ACs

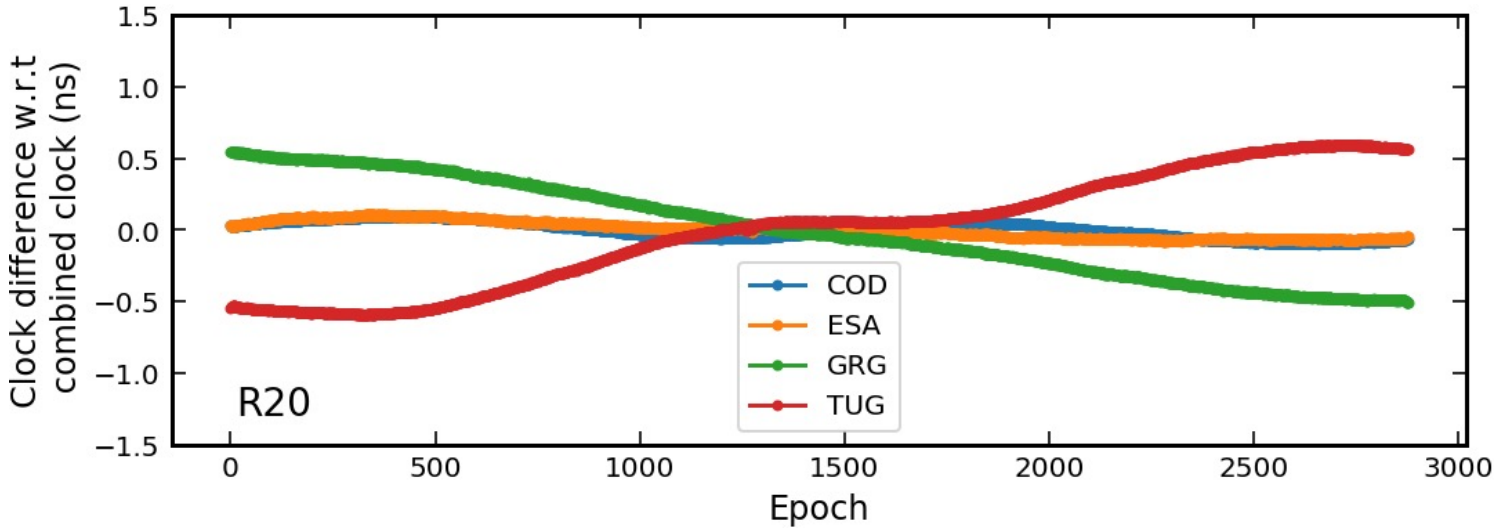
- Day 196 of 2018: orbits/clocks compared to their combinations











GLONASS along/cross-track orbit discrepancy harms the clock combination

GLONASS impact on daily solutions

- All ACs were used for GLONASS clock combination (w2010)
  - GPS clocks were also screened for outlier satellites

mm (E/N/U)	Raw	>50ps removed	>150ps removed
G	3.3/1.8/6.3	3.3/1.8/6.3	3.3/1.8/6.3
GR	3.3/1.7/5.9	3.1/1.6/5.9	3.2/1.6/5.8

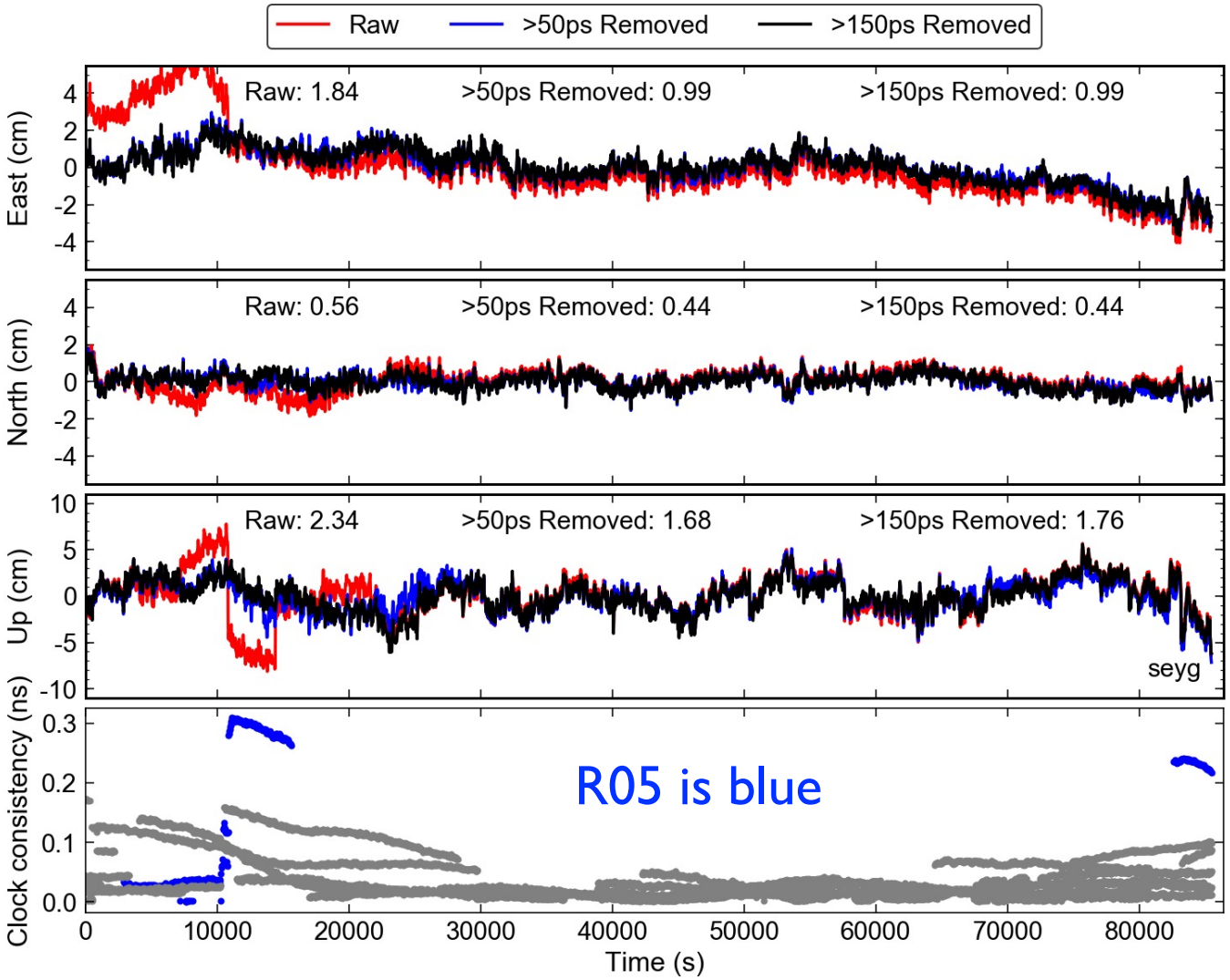
Raw: use all GLONASS satellites

>50ps: remove satellites with >50ps clock RMSE

>150ps: remove satellites with >150ps clock RMSE

GLONASS impact on kinematic solutions

- SEYG kinematic solutions by GPS/GLONASS
  - Remove GLO. satellites with large clock combination residuals



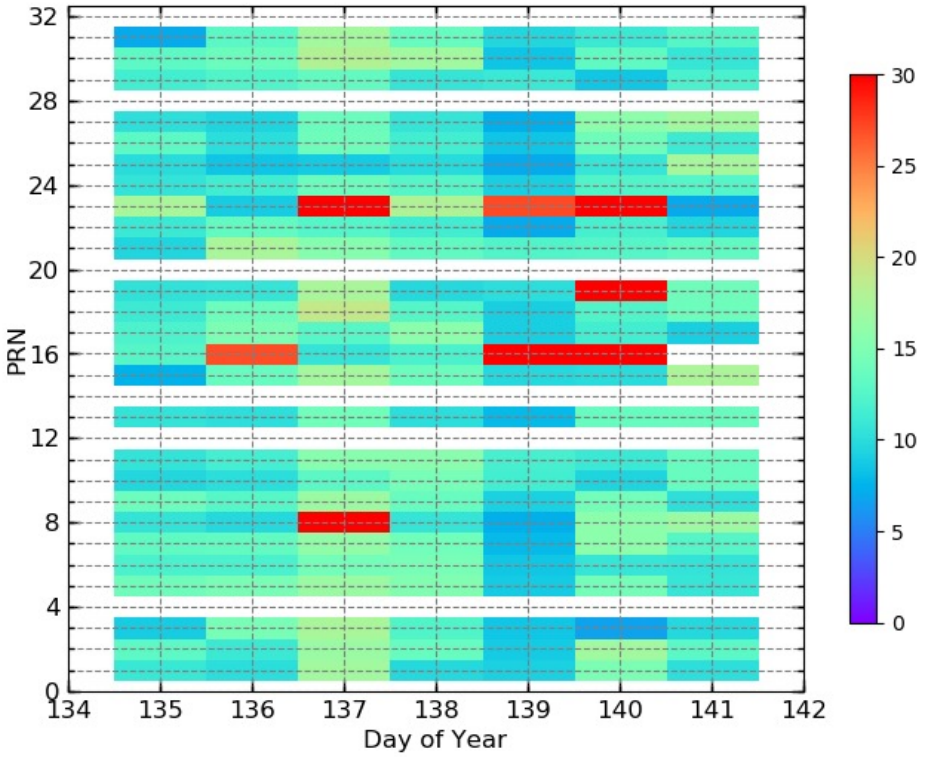
GLONASS can still be useful in clock combination if a proper quality control is applied

Integer satellite clock combination

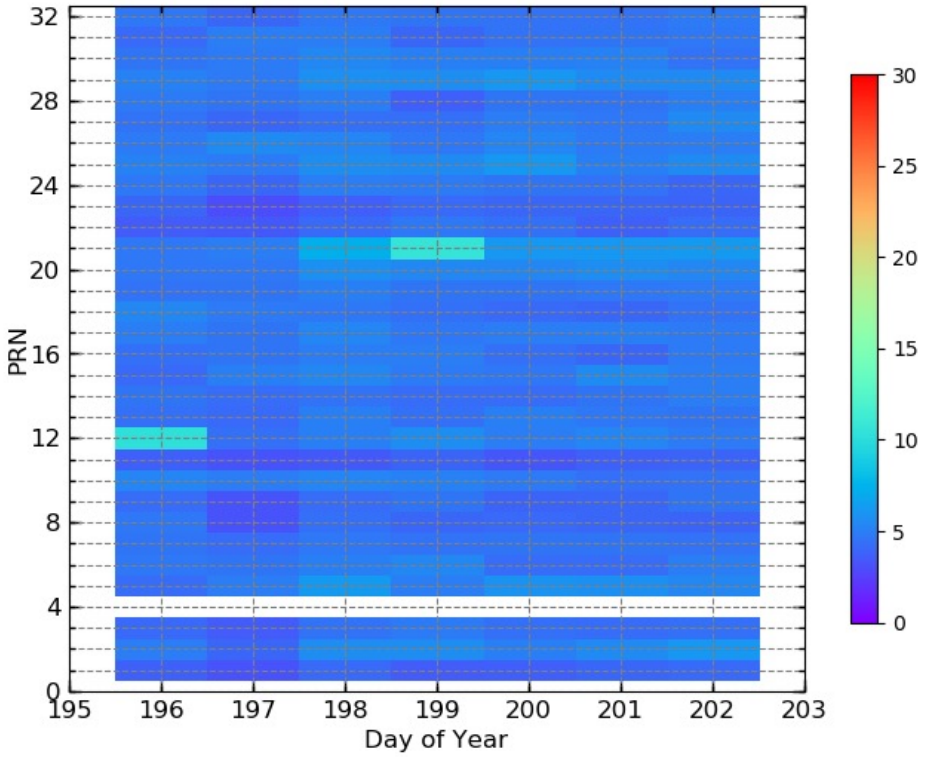
----GPS/Galileo clocks computed with undifferenced ambiguity resolution

GPS integer satellite clock consistency

- AC-specific clocks compared to combined clocks (IGS2 orbits)



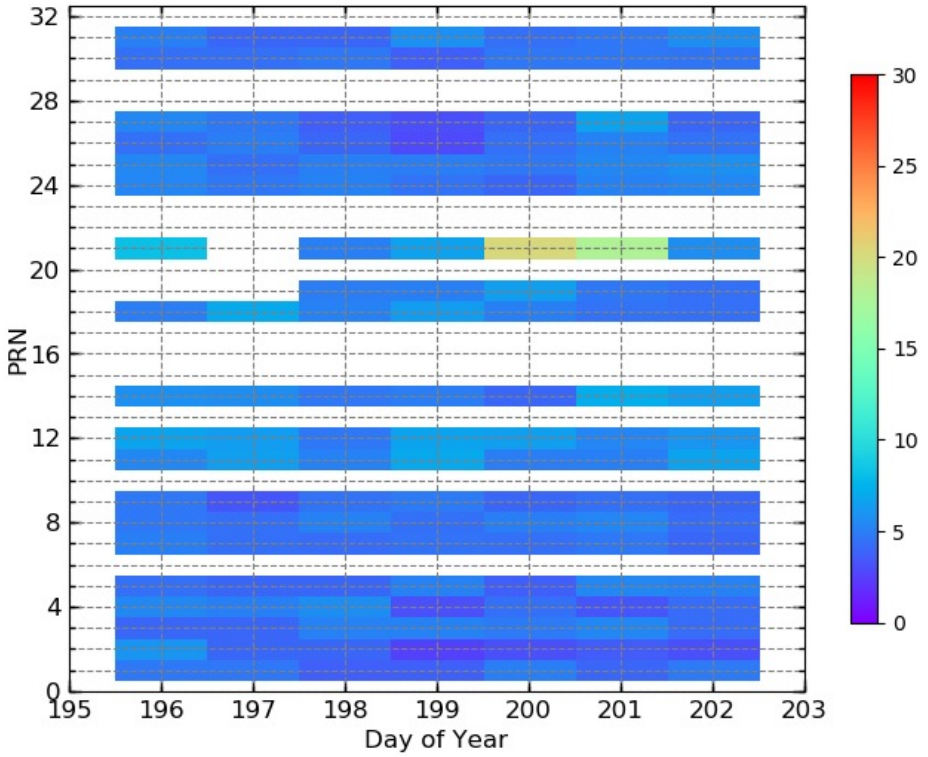
16.6ps mean (w1062 GPS 6 ACs)



4.8ps mean (w2010 GPS 6 ACs)

Galileo integer satellite clock consistency

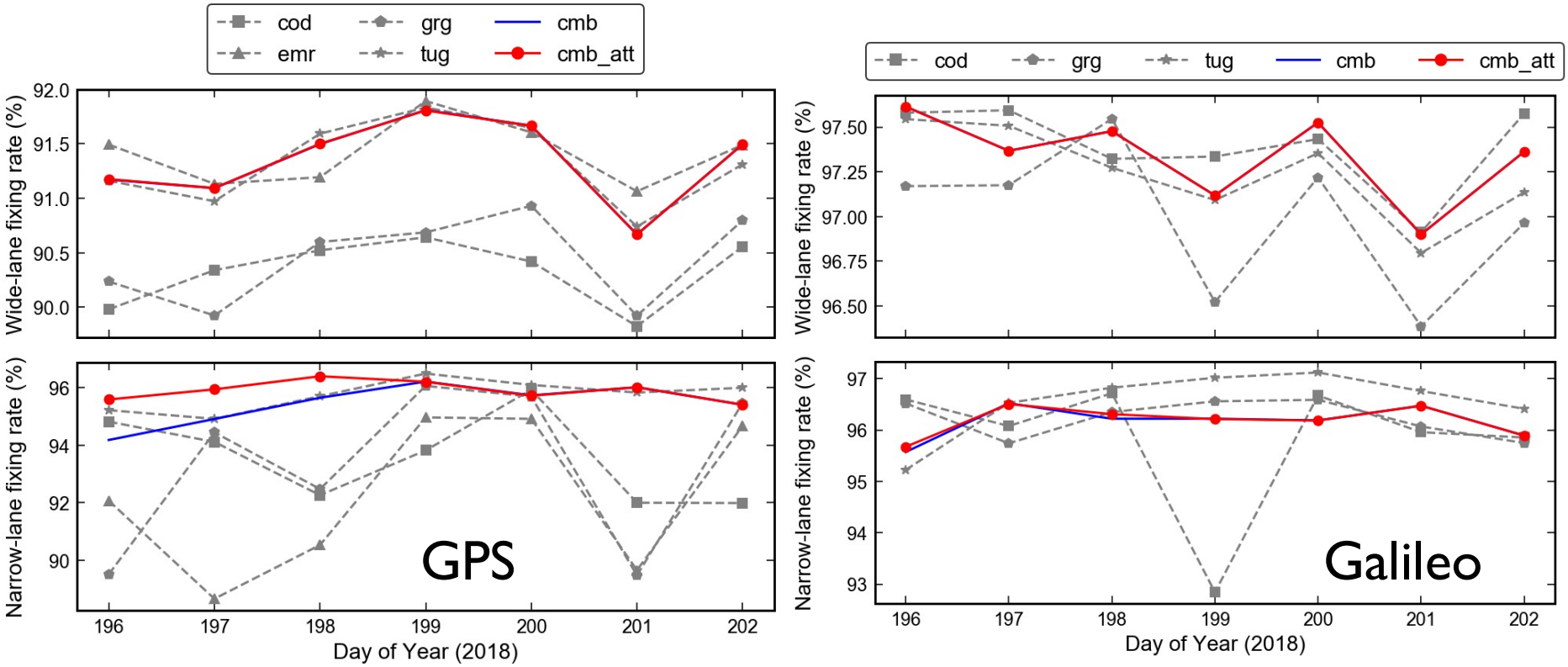
- AC-specific clocks compared to combined clocks (IGS2 orbits)



5.4ps mean (w2010 Galileo 4 ACs)

Ambiguity fixing rates

- w2010 GPS/Galileo fixing rates

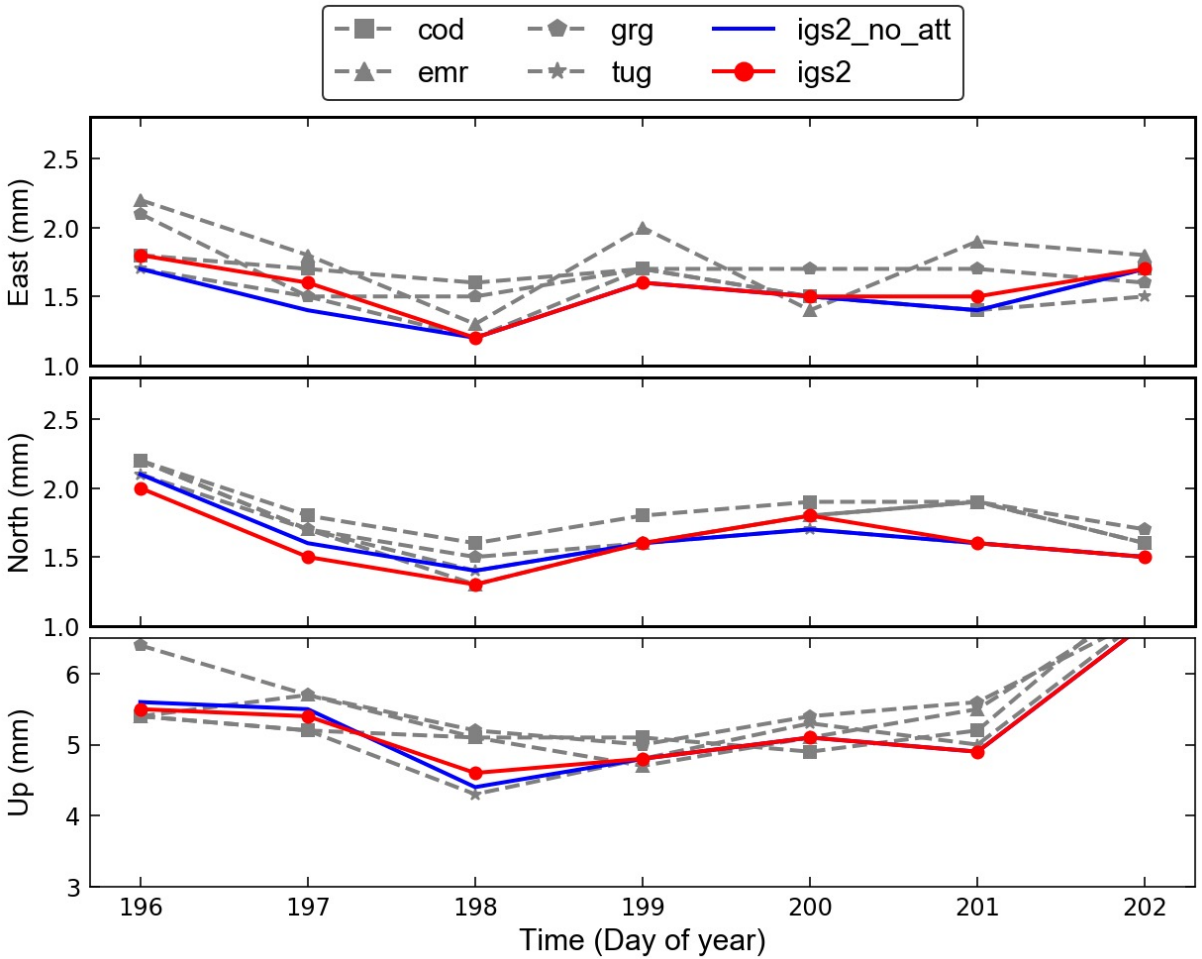


Fixing rates	GPS WL/NL (%)	Galileo WL/NL(%)
cmb (no att)	91.34/95.44	97.34/96.15
cmb	91.34/95.89	97.34/96.18

no att: combination without quaternions

Ambiguity-fixed daily GPS

- w2010 GPS with IGS2 orbits
  - No quaternions were used in PPP to facilitate cross-comparison

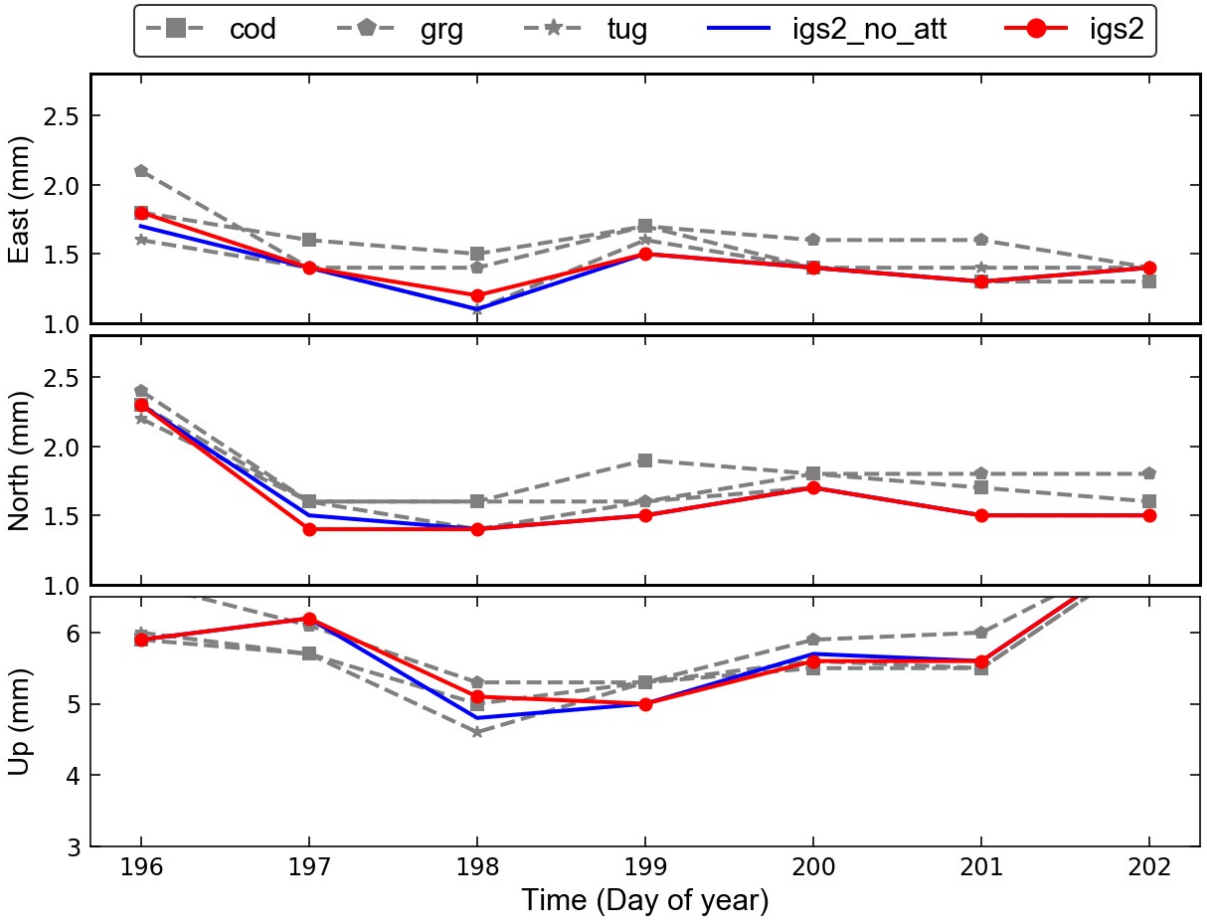


AC	E/N/U (mm)
IGS2 (no att)	1.5/1.6/5.3
IGS2	1.5/1.6/5.3
COD	1.6/1.8/5.4
EMR	1.8/1.7/5.5
GRG	1.7/1.8/5.7
TUG	1.5/1.7/5.3

no att: combination without quaternions

Ambiguity-fixed daily GPS/Galileo

- w2010 GPS/Galileo with IGS2 orbits
  - No quaternions were used in PPP to facilitate cross-comparison



AC	E/N/U (mm)
IGS2 (no att)	1.4/1.6/5.8
IGS2	1.4/1.6/5.8
COD	1.5/1.8/5.7
GRG	1.6/1.8/6.1
TUG	1.4/1.6/5.7

no att: combination without quaternions

Summarized results

- Orbit/clock/bias consistency
- Daily positioning precision

	Orbit A/C/R RMSE from combined orbits IGS2 (cm)			Clock RMSE from combined clocks (ps)			Daily E/N/U positioning precision (mm)		
	GPS	Gal.	GLO.	GPS	Gal.	GLO.	GPS	GPS/GLO.	GPS/Gal.
w1062-f	2.3/1.7/1.6	n/a	n/a	14.2	n/a	n/a	3.5/2.8/7.9	n/a	n/a
w1062-x				16.6	n/a	n/a	2.4/2.6/7.6	n/a	n/a
w2010-f	1.0/0.8/0.8	1.3/0.9/2.1	3.0/2.5/1.6	6.0	6.9	68.9	3.3/1.9/6.1	3.3/1.7/5.9	2.8/1.8/6.3
w2010-x				4.8	5.4	n/a	1.5/1.6/5.3	n/a	1.4/1.6/5.8

- GLONASS clock consistency is the worst
- Integer clock consistency outperforms legacy clock consistency

Conclusions

- The new IGS quaternion product should be applied to improve clock consistency among ACs
- Inter-AC satellite legacy clock consistency is around 6 ps for GPS/Galileo
- Inter-AC satellite integer clock consistency is improved by about 20% to 5 ps after combining legacy clock with phase biases for GPS/Galileo
- GLONASS clock combination can still be useful if a qaulity control based on clock consistency is applied

Thank you!

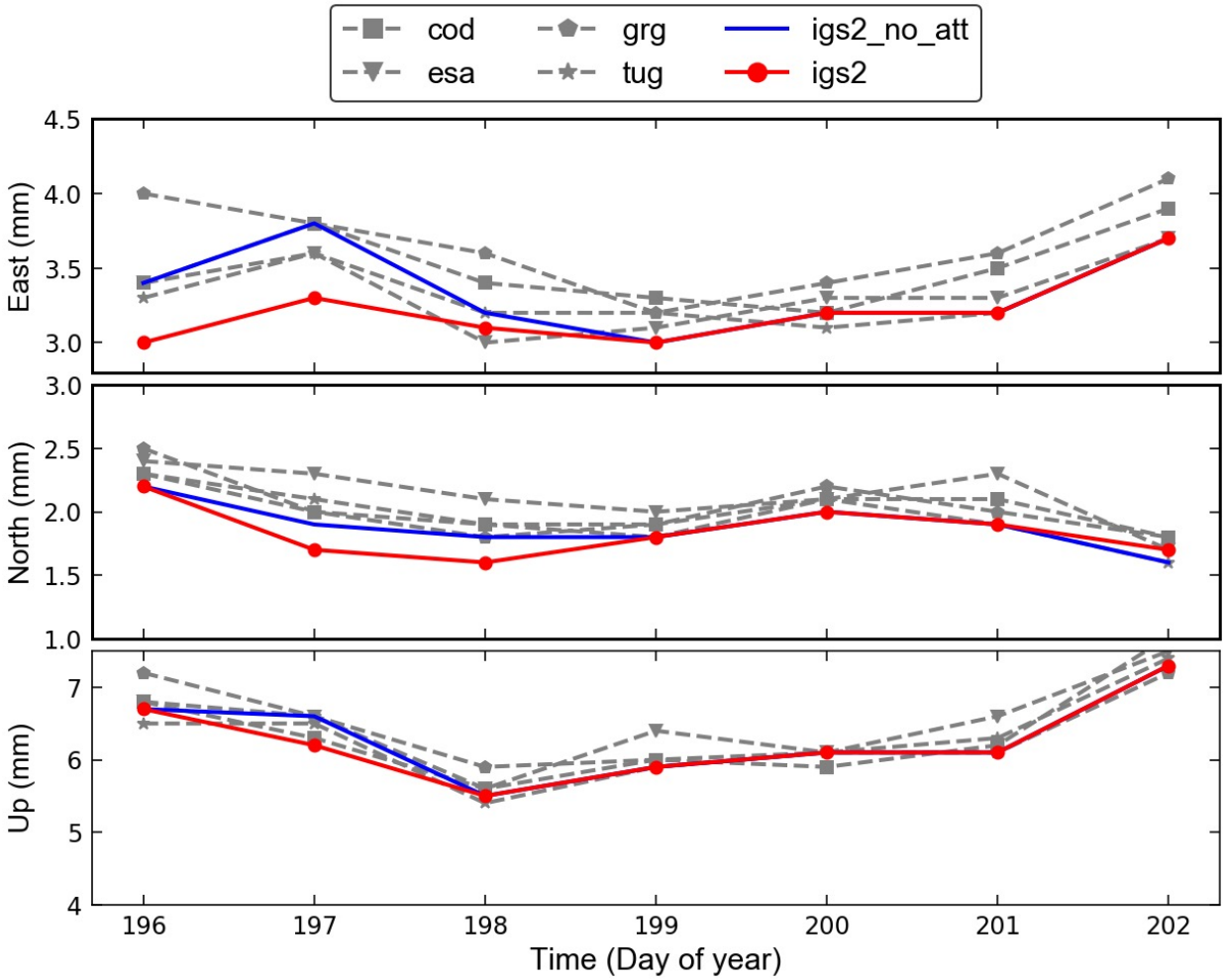
Jianghui GENG

pride.whu.edu.cn

jgeng@whu.edu.cn

Ambiguity-float daily GPS

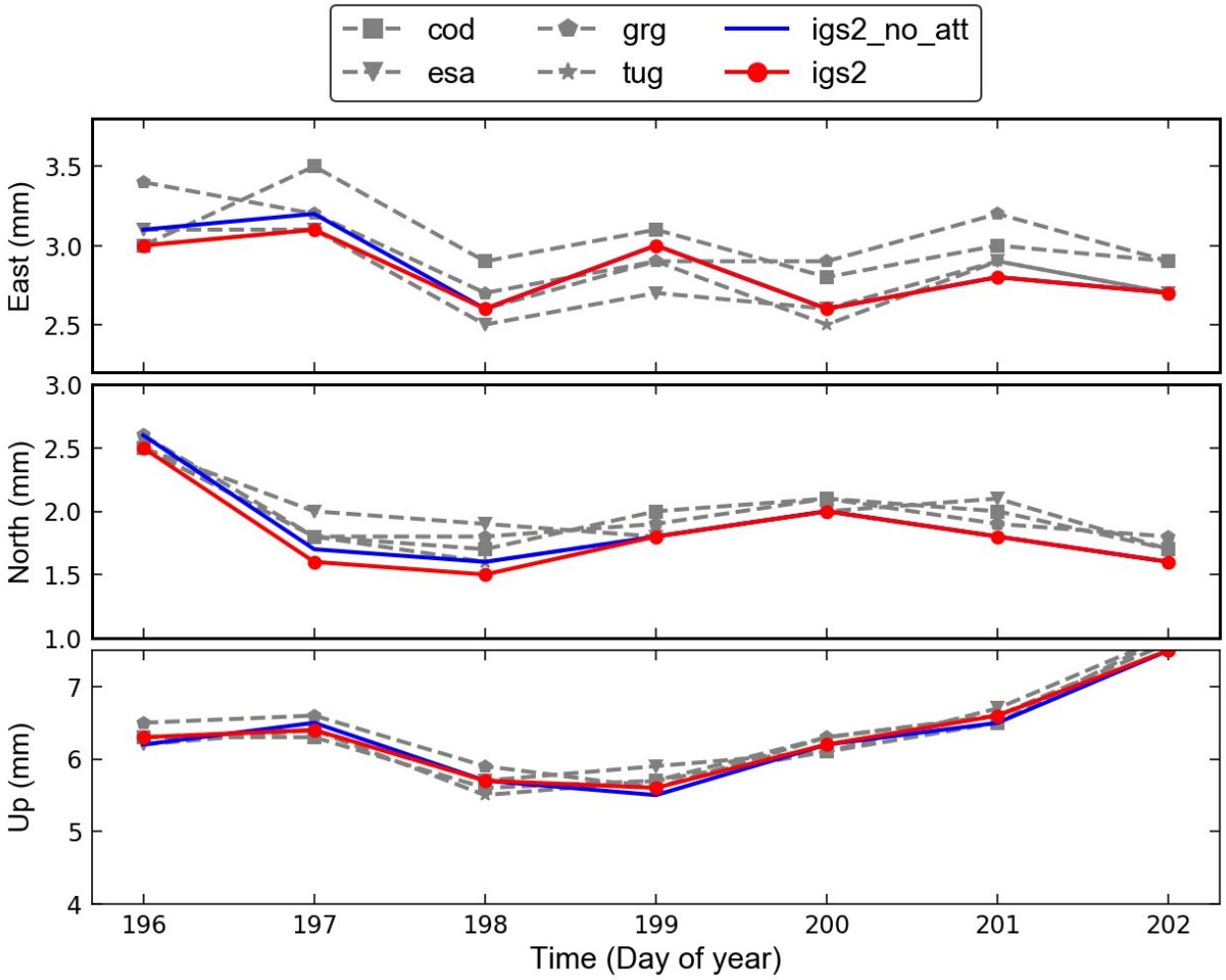
- w2010 GPS with IGS2 orbits



AC	E/N/U (mm)
IGS2 (no att)	3.4/1.9/6.3
IGS2	3.2/1.8/6.3
COD	3.5/2.0/6.4
ESA	3.3/2.1/6.5
GRG	3.7/2.0/6.4
TUG	3.3/2.0/6.3

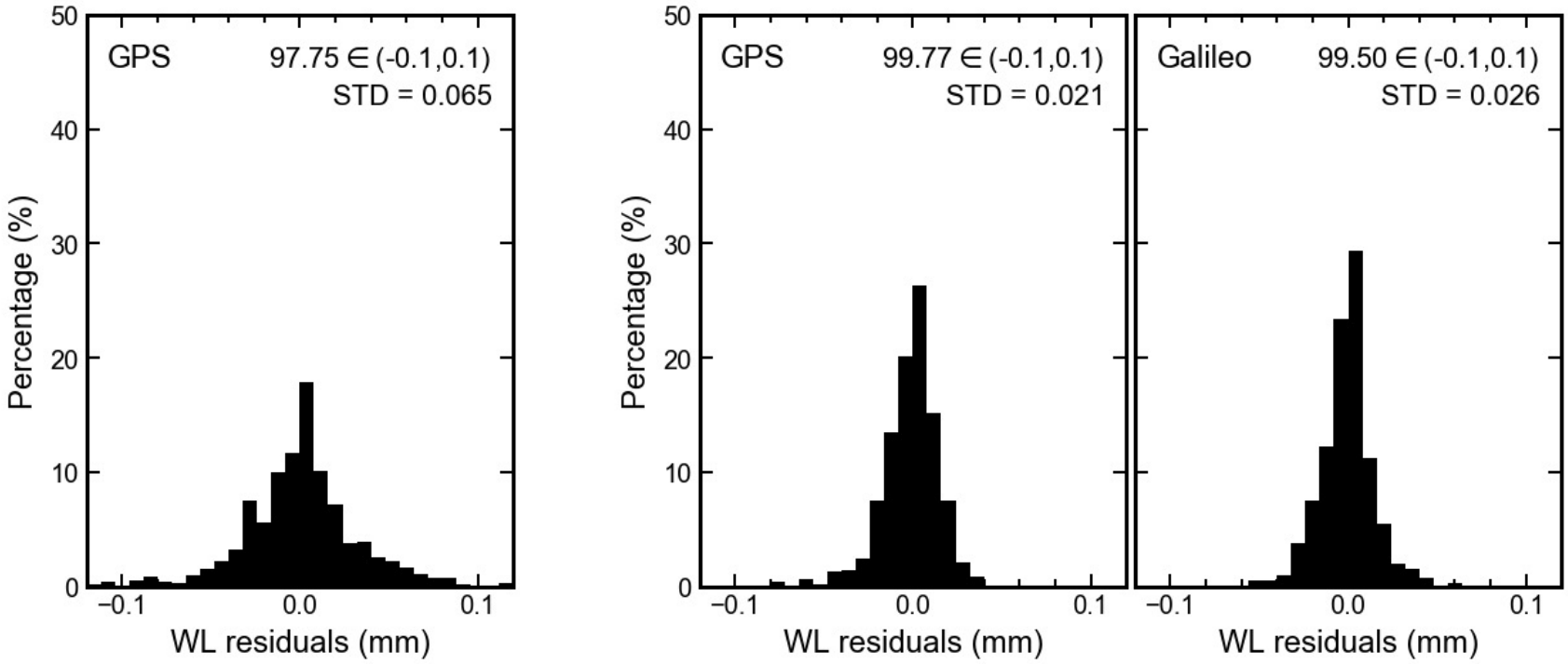
Ambiguity-float daily GPS/Galileo

- w2010 GPS/Galileo with IGS2 orbits



AC	E/N/U (mm)
IGS2 (no att)	2.9/1.9/6.3
IGS2	2.8/1.8/6.3
COD	3.0/2.0/6.3
ESA	2.8/2.0/6.4
GRG	3.0/2.0/6.4
TUG	2.8/1.9/6.3

Mean Wide-lane bias consistency in 2000 & 2018



2000 w1062

2018 w2010