PPP validation of the IGS Repro3 combination products

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- A brief summary of repro3's products is as follows:

  - 26 years (1995-2020)
  - 9 ACs
  - 4 of them have phase bias products
  - 7 of them provide quaternions
  - Some of them provide 300s satellite clocks for some years
  - Combination software: PRIDE ckcom v1.0

| AC	Orbits/Clocks	Biases	Quaternions
COD	GRE	GE	GRE
EMR/NGS	G	G	G
ESA	G	N/A	N/A
GFZ	G	N/A	G
GRG	GRE	GE	GRE
JPL	G	N/A	G
MIT	GE	N/A	N/A
TUG	GRE	GRE	GRE
WHU	GR	N/A	GR
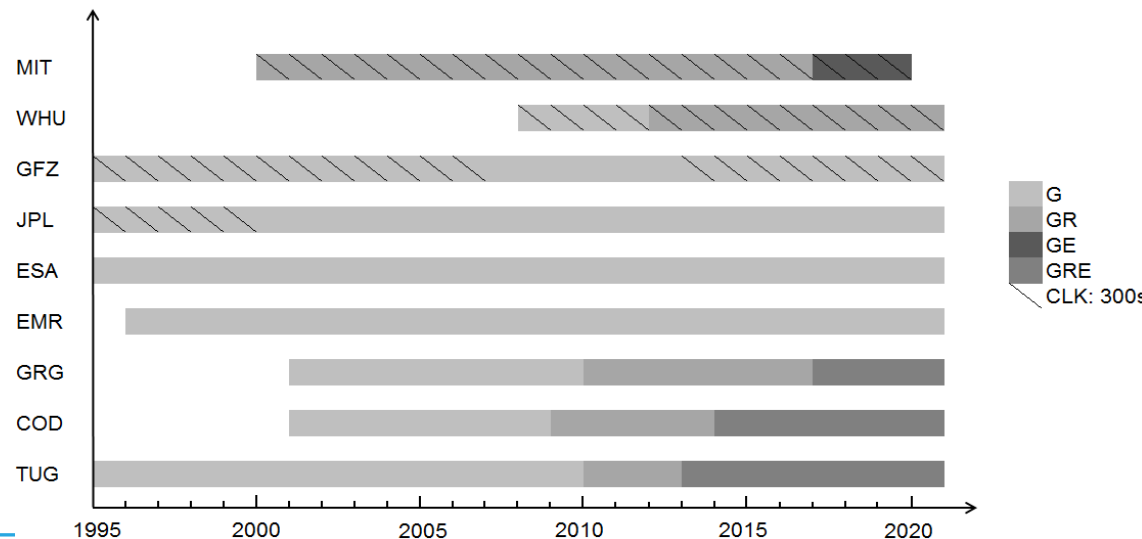
Overview of PPP validation

- Some specifications about PPP validation is listed as follows:
  - Open-source Software: PRIDE PPP-AR v2.2 (Wuhan products are not combined)
  - Mode: Static daily PPP
  - 26 years for 3 ACs' products:
    CMB (1995-2020)
    AC1 (2001-2020)
    AC2 (1995-2020)
  - 100 global stations
  - Results:
    i. Daily position RMS
    ii. Ambiguity fixing rates
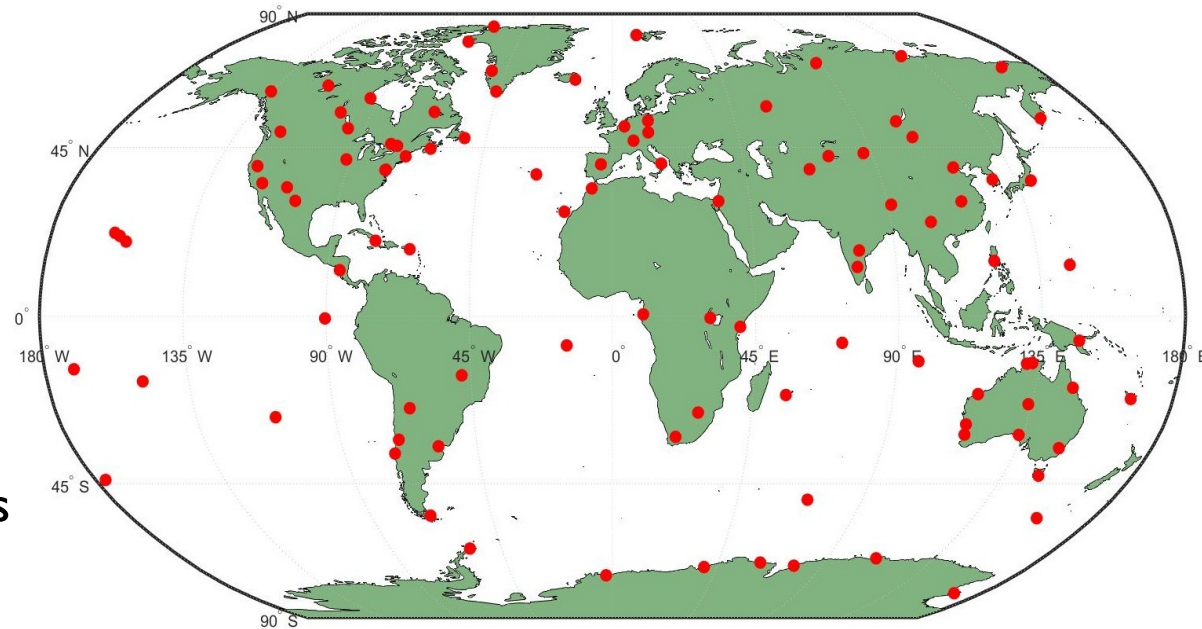
Distribution of 100 global stations

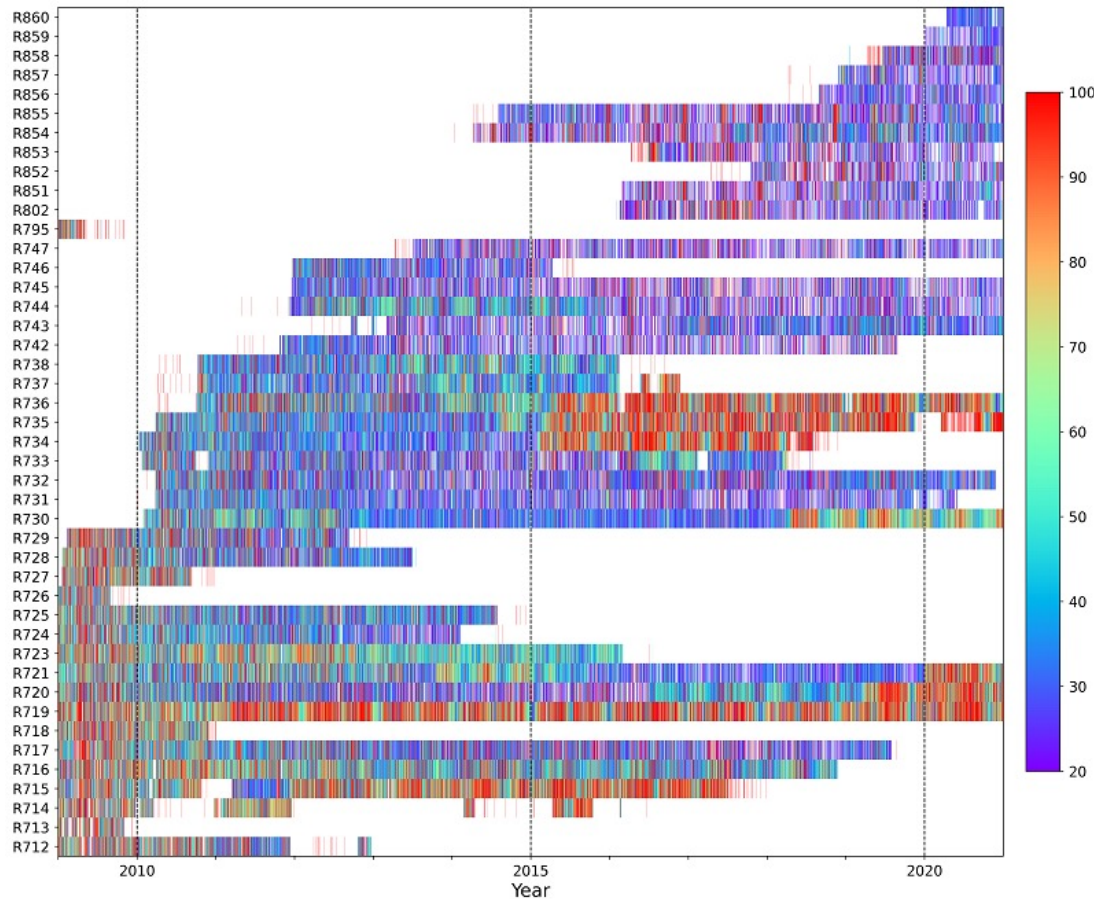# Consistency among AC clocks

- ## GPS from 1995-2020
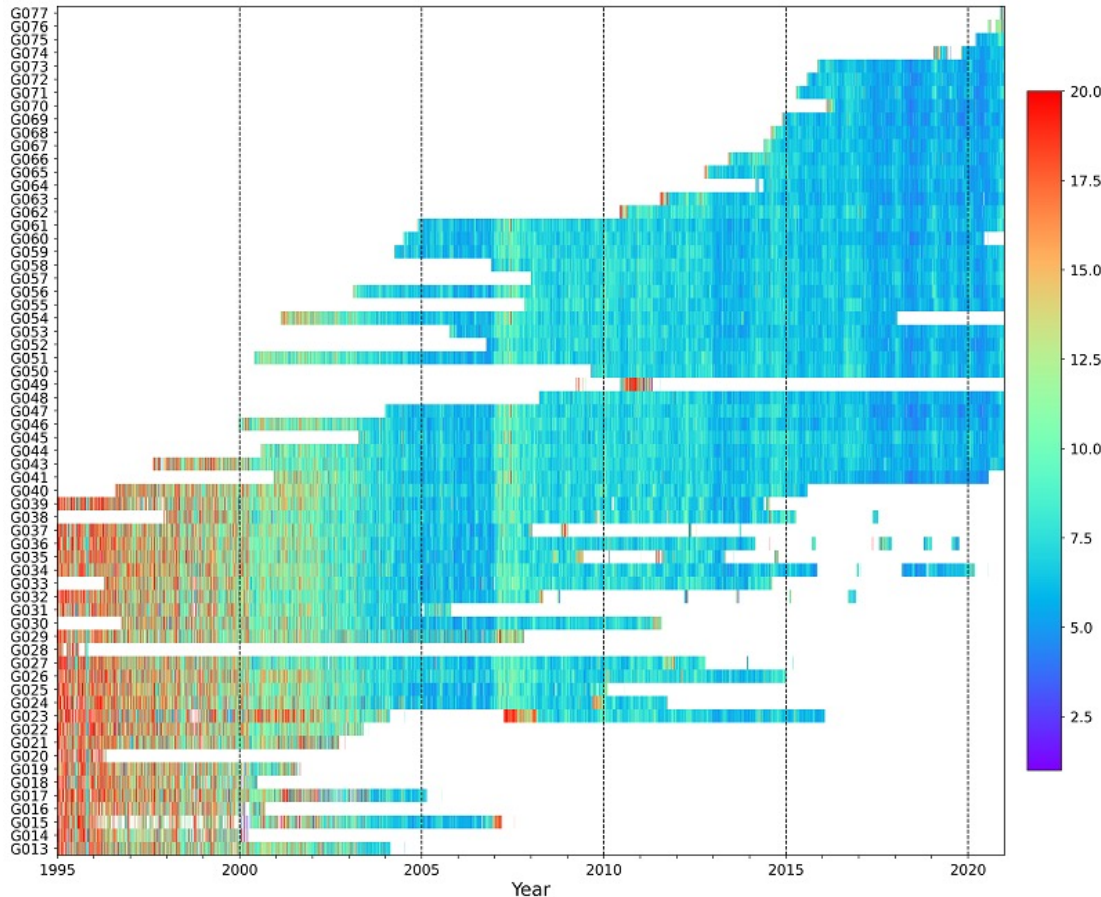
Year	Mean RMS (ps)
1995	41.5
2000	17.0
2005	9.5
2010	8.2
2015	7.9
2020	7.6

- ≤ 2000.123 Legacy clock
- ＞2000.123 Integer clock

Consistency among AC clocks
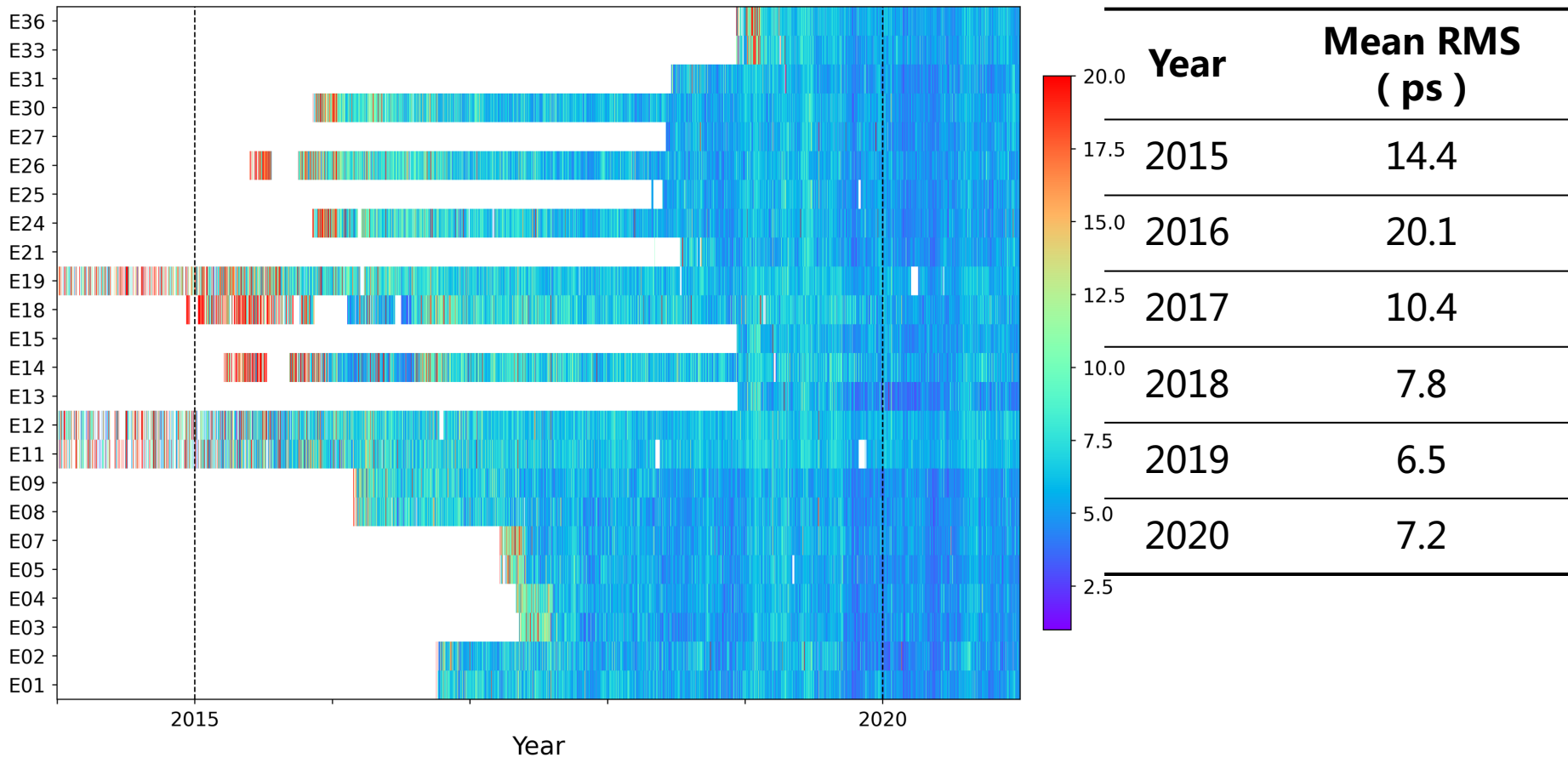
- GLONASS from 2009-2020

Year	Mean RMS (ps)
2010	89.9
2015	76.1
2020	66.9

It is always legacy clock for GLONASS and the consistency among ACs is much worse than GPS and Galileo
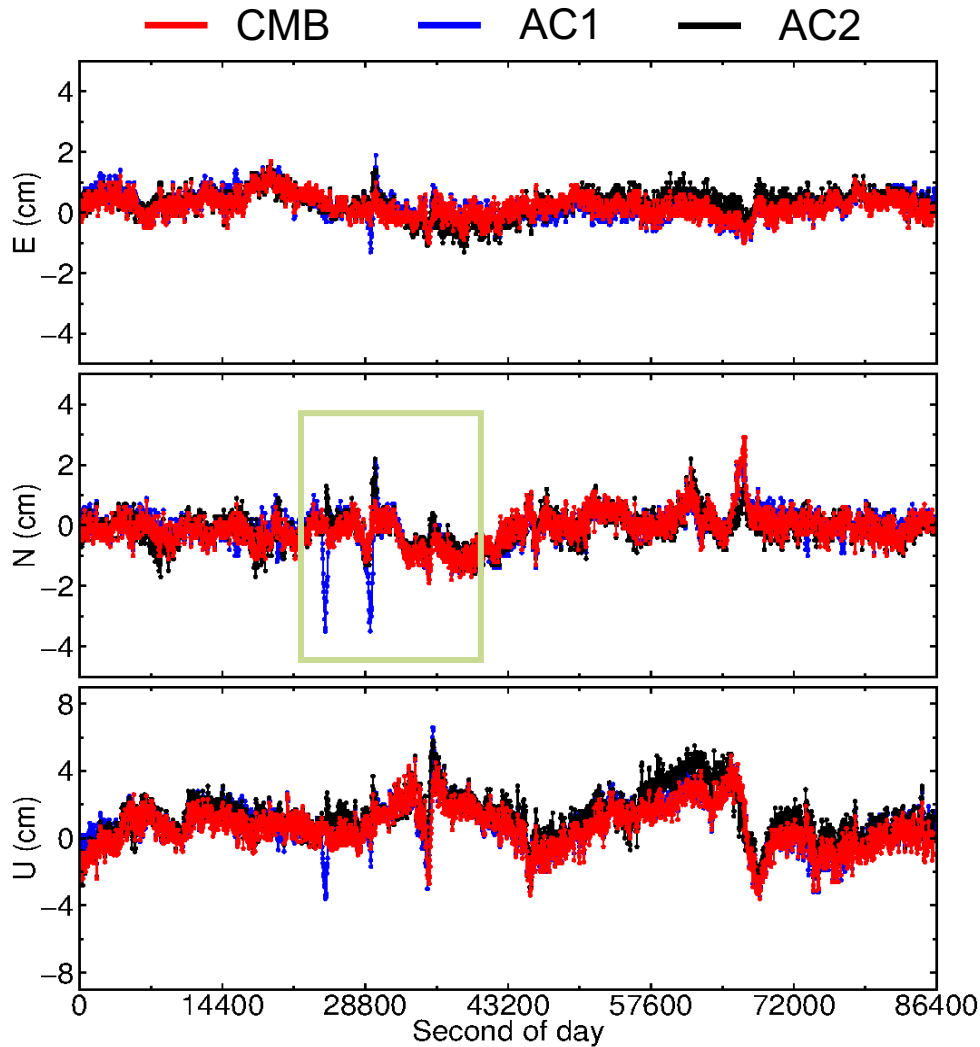
Consistency among AC clocks

- Galileo from 2014-2020

Year	Mean RMS (ps)
2015	14.4
2016	20.1
2017	10.4
2018	7.8
2019	6.5
2020	7.2

Kinematic PPP validation

- Kinematic PPP for station ALBH on 2020 300

CMB — AC1 — AC2

AC	E(cm)	N(cm)	U(cm)
AC1	0.42	0.59	1.36
AC2	0.41	0.51	1.40
CMB	0.37	0.53	1.31

Combined clocks can provide more robust positioning when AC products are problematic

Static daily PPP from 1995 to 2020

● Ambiguity fixing rate for GPS from 2000 to 2020
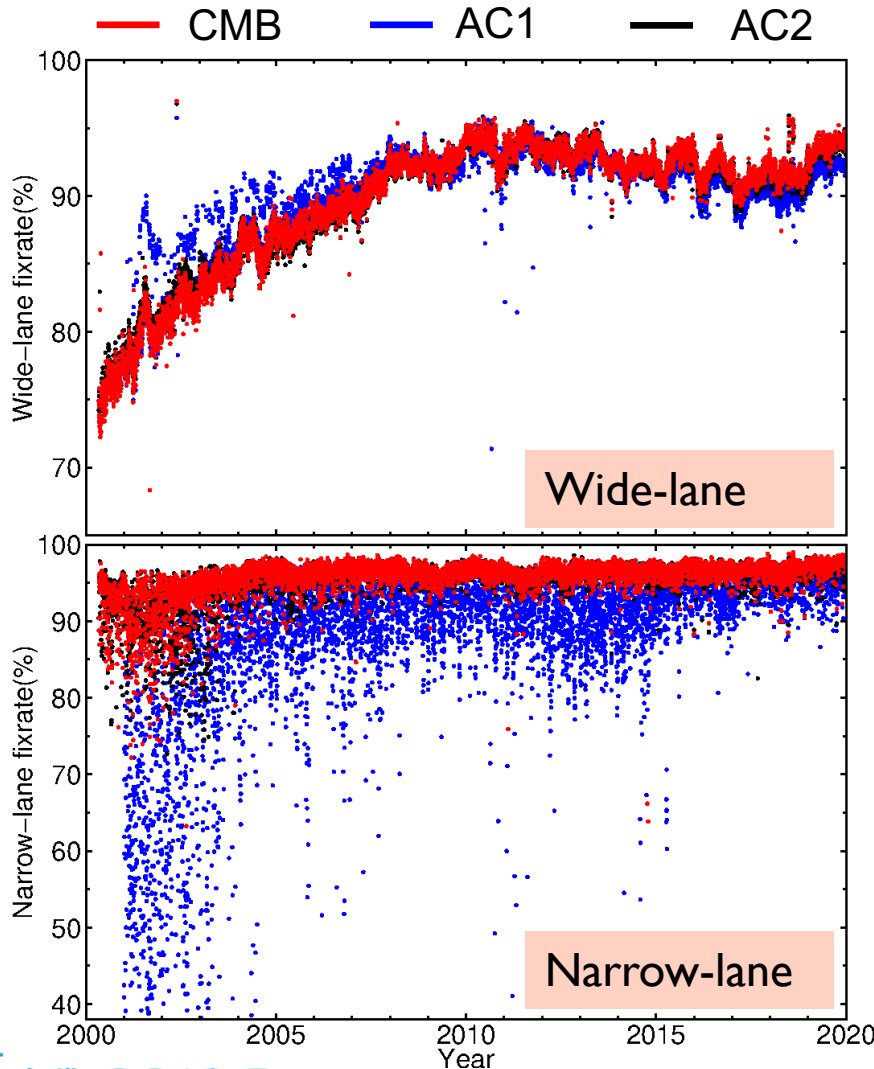
Year	CMB	AC1	AC2
2000	76.1	-	76.7
2005	87.4	88.3	87.0
2010	92.5	92.2	92.5
2015	92.4	91.7	92.4

Year	CMB	AC1	AC2
2000	70.6	-	71.5
2005	84.3	78.9	83.8
2010	89.2	85.3	89.2
2015	89.7	86.0	89.6

Static daily PPP from 2016 to 2020

- Ambiguity fixing rate for Galileo from 2016 to 2020
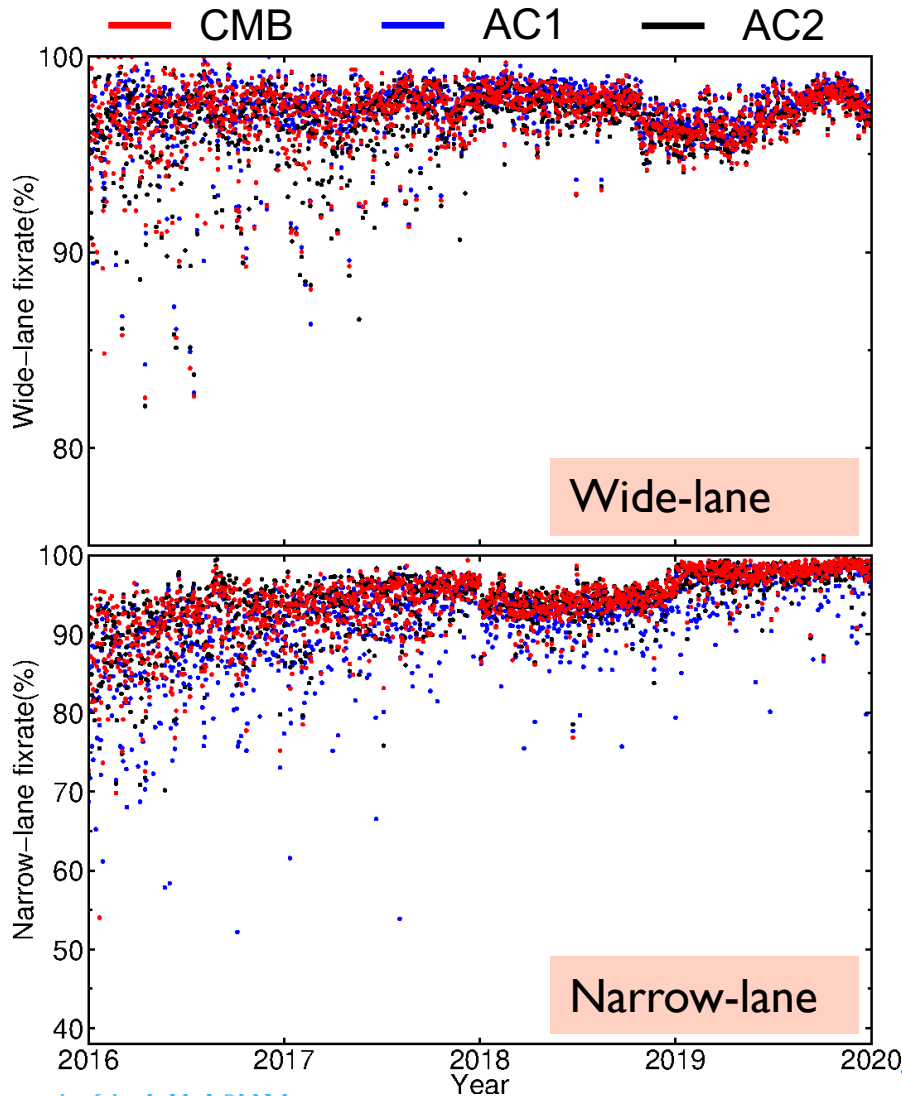
Year	CMB	AC1	AC2
2016	96.9	97.1	96.6
2017	97.2	97.4	96.8
2018	97.5	97.7	97.3
2019	97.0	97.2	96.9
2020	97.7	98.0	97.6

Year	CMB	AC1	AC2
2016	88.7	86.5	88.9
2017	92.1	91.0	92.0
2018	91.7	90.3	91.5
2019	95.0	94.1	94.5
2020	95.9	95.2	95.8

Static daily PPP from 1995 to 2015

- Daily position RMS (mm) for GPS from 1995 to 2015
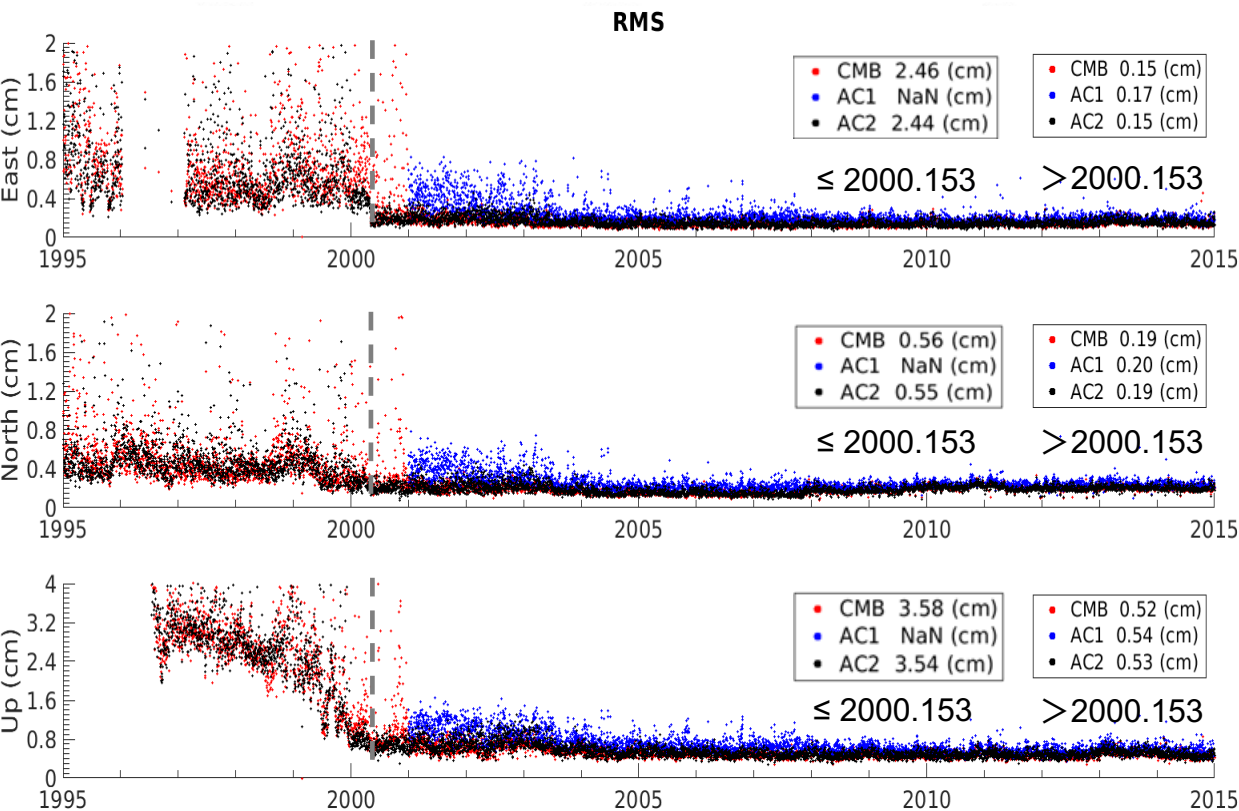
Year	CMB		AC1	AC2
1995	E	4.3	–	3.8
	N	3.0	–	2.4
	U	22.7	–	23.1
2000	E	2.0	–	1.8
	N	1.8	–	1.6
	U	5.1	–	5.0
2005	E	1.1	1.7	1.2
	N	1.3	1.8	1.3
	U	4.3	5.7	4.5
2010	E	1.1	1.5	1.1
	N	1.5	1.8	1.5
	U	3.9	4.8	3.9
2015	E	1.2	1.4	1.2
	N	1.6	1.7	1.6
	U	3.8	4.1	3.9

Static daily PPP from 2016 to 2020

- Daily position RMS (mm) for GPS/GLONASS/Galileo from 2016 to 2020
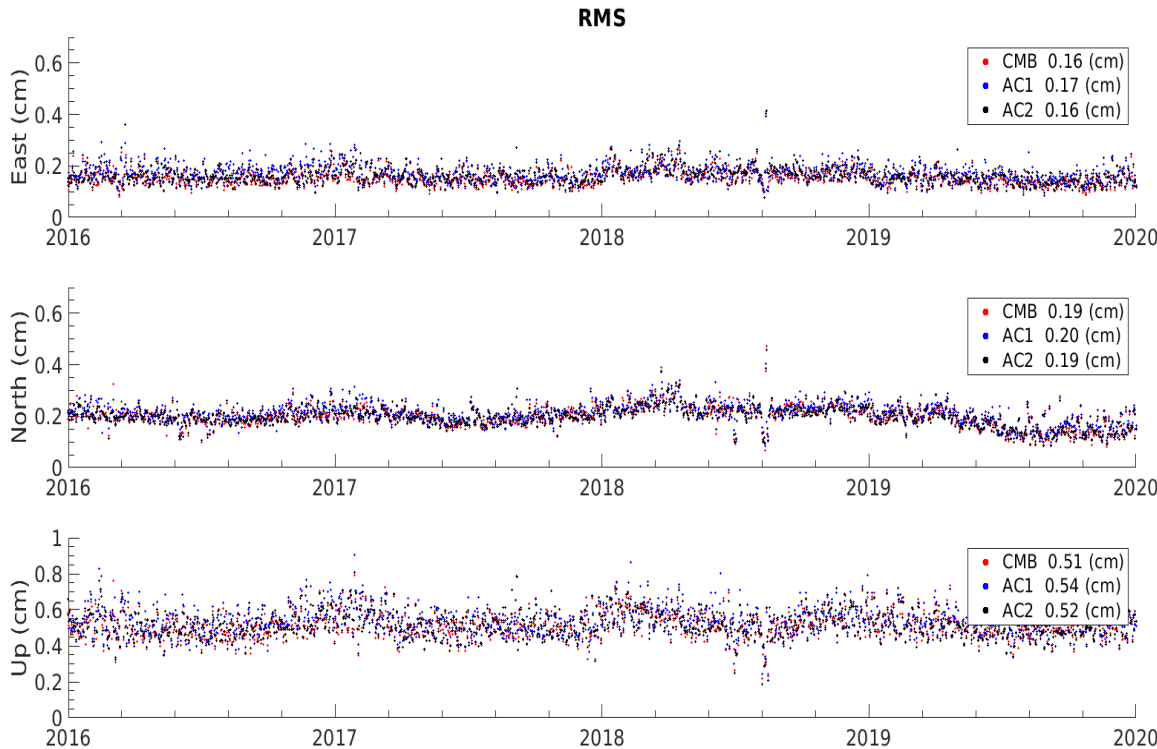
Year	CMB		AC1	AC2
2016	E 1.2		1.4	1.2
	N 1.5		1.6	1.5
	U 3.9		4.2	3.9
2017	E 1.2		1.4	1.2
	N 1.5		1.6	1.5
	U 3.9		4.2	4.0
2018	E 1.3		1.4	1.4
	N 1.8		1.8	1.7
	U 4.0		4.2	4.0
2019	E 1.1		1.2	1.1
	N 1.2		1.4	1.2
	U 3.7		3.9	3.7
2020	E 1.1		1.2	1.1
	N 1.1		1.3	1.1
	U 3.6		3.7	3.6

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Summary

- 26 years of combined satellite clock/bias products have been accomplished
    - 1995--2000d123 (legacy clock)
    - 2000d124--2020 (phase clock && phase bias)

- The clock/bias consistency improves over the years
    - GPS/Galileo can now reach 6-10 ps
    - GLONASS can now reach around 60 ps

- 26 years of daily PPP validation show that the combined clocks and phase biases can provide more robust solutions than AC-specific products

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