The Use of GNSS and IGS Products for UTC Computation: Past, Present and Future

Giulio Tagliaferro[1], Pascale Defraigne[2]

[1]Time Department, BIPM, Sevres, France

[2]Royal Observatory of Belgium

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Motivation

- UTC is the international time standard.
- To compute UTC GNSS techniques are fundamental.
- IGS products are extensively used in the computation of UTC.
- The evolution of IGS products make possible a better UTC.

What is UTC

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(BIPM)

Circular T 1 (1988 March 1)

1 - COORDINATED UNIVERSAL TIME UTC

(Since 1988 January 1, 0h UTC, TAI-UTC = 24s)

A - Computed values of UTC-UTC(i)

Date 1988 (0h UTC)			JAN 9	JAN 19	JAN 29
MJD			47169	47179	47189
Laboratory i			UTC-UTC(i)	(Unit = 1	microsecond)
AOS	(Borowiec)		0.49	0.69	1.02
APL	(Laurel)	(1)	0.02	0.01	0.03
ASMW	(Berlin)		0.21	0.10	0.09
AUS	(Canberra)		-11.89	-12.02	-12.15
BEV	(Wien)		-2.12	-2.51	-3.04
CAO	(Cagliari)		0.07	0.12	0.22
CH	(Berne)		1.53	1.53	1.55
CSAO	(Shaanxi)		0.89	0.75	0.78
FTZ	(Darmstadt)		14.74	14.95	15.21
IEN	(Torino)		-1.26	-1.25	-1.24
IFAG	(Wettzell)		-4.33	-4.08	-3.73
ILOM	(Mizusawa)		-35.16	-35.28	-35.36
INPL	(Jerusalem)		50.11	51.22	52.39
JATC	(Xian)	(2)	1.73	1.55	1.45

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CIRCULAR T 437

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UTC

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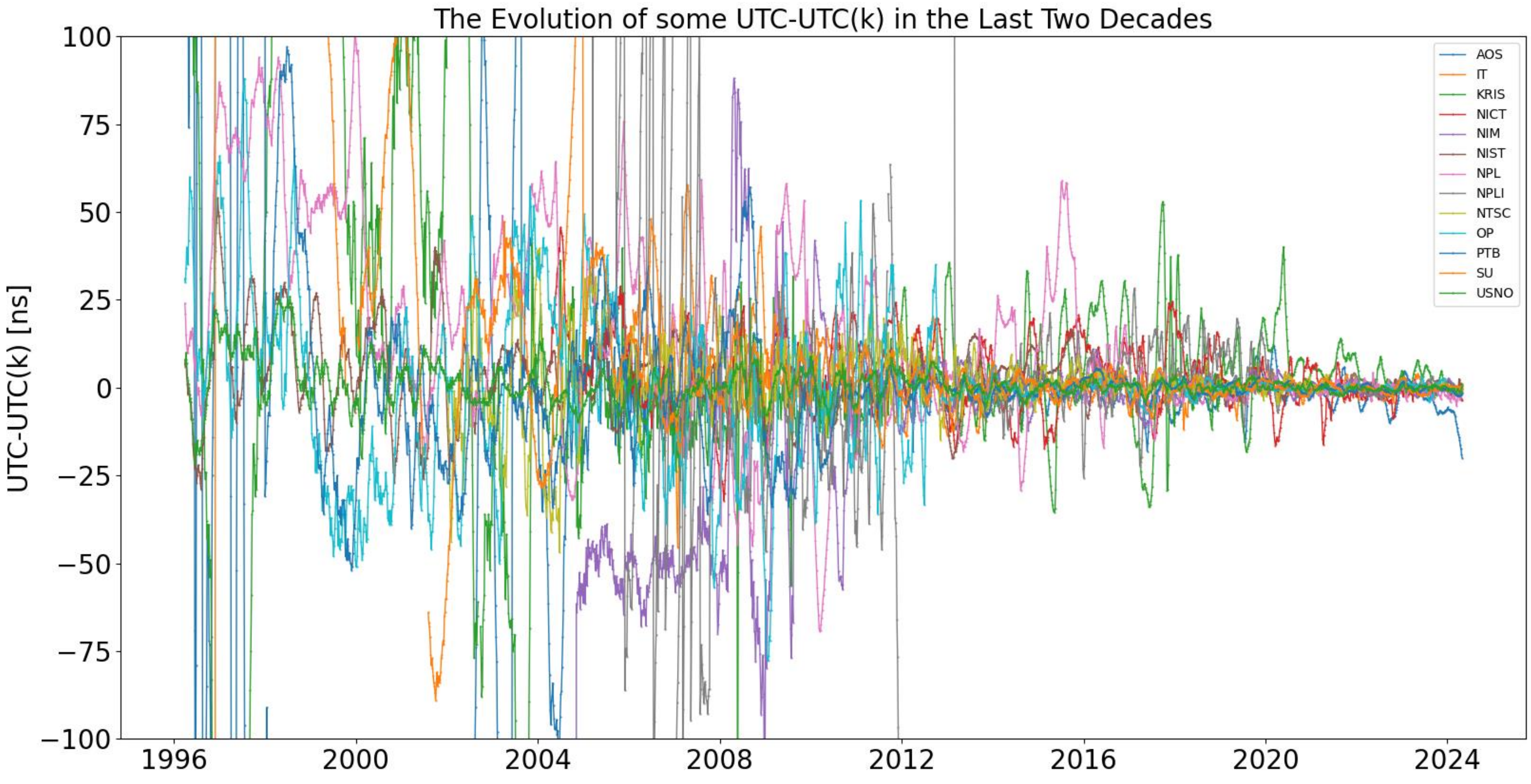
PAVILLON DE BRETEUIL F-92312 SEVRES CEDEX TEL. +33 1 45 07 70 70 tai@bipm.org

The contents of the sections of BIPM *Circular T* are fully described in the document " Explanatory supplement to BIPM Circular T "
available at https://webtai.bipm.org/ftp/pub/tai/other-products/notes/explanatory_supplement_v0.7.pdf

1 - Difference between UTC and its local realizations UTC(k) and corresponding uncertainties. From 2017 January 1, 0h UTC, *TAI-UTC* = 37 s.

Date 2024 0h UTC			APR 29	MAY 4	MAY 9	MAY 14	MAY 19	MAY 24	MAY 29	Uncertainty/ns			Notes
		MJD	60429	60434	60439	60444	60449	60454	60459	u_A	u_B	u	
Laboratory *k*			[*UTC-UTC(k)*]/ns										
AGGO	(La Plata)		693.8	697.1	677.3	685.1	659.0	645.8	633.3	0.7	2.9	3.0	
AOS	(Borowiec)		-20.0	-20.9	-22.8	-24.7	-26.4	-27.5	-27.3	0.2	3.4	3.4	
APL	(Laurel)		-0.4	0.4	1.6	3.0	1.2	0.7	-0.2	0.2	NC	-	
AUS	(Sydney)		-243.6	-238.0	-233.9	-203.4	-203.0	-190.2	-173.6	0.2	2.9	2.9	
BEV	(Wien)		-20.6	-19.3	-12.9	-7.2	-4.8	0.5	-3.9	0.2	2.9	2.9	
BFKH	(Budapest)		10647.2	10696.1	10737.9	10794.9	10844.1	10886.7	10934.6	0.7	7.2	7.2	
BIM	(Sofiya)		404.0	451.7	504.2	556.2	605.6	655.7	709.9	0.2	2.9	2.9	
BIRM	(Beijing)		-1.6	-0.5	1.6	0.2	-1.5	-1.3	-0.1	0.2	3.3	3.3	
BY	(Minsk)		-2.0	-1.8	-1.7	-2.0	-1.5	-1.4	-1.2	1.5	3.1	3.4	
CAO	(Cagliari)		-12679.6	-12799.2	-12912.9	-13020.6	-13129.8	-13251.6	-13368.7	0.7	NC	-	
CH	(Bern-Wabern)		-1.8	-0.1	-0.4	0.1	-1.4	-2.9	-1.2	0.2	1.7	1.7	
CNES	(Toulouse)		2.3	-1.9	-7.7	-4.5	-1.7	-0.2	-1.0	0.2	2.9	2.9	
CNM	(Queretaro)		0.4	-2.0	-2.3	-6.7	-4.9	-2.5	-2.0	2.0	4.2	4.6	
CNMP	(Panama)		-10.4	-4.9	13.6	6.8	9.2	4.6	-6.9	0.5	5.4	5.4	
DFM	(Horsholm)		4.7	4.6	5.3	5.4	5.4	-1.6	-1.0	0.2	2.9	2.9	
DFNT	(Tunis)		-2488.4	-2588.4	-2689.8	-2786.8	-2879.2	-2977.8	-3067.1	0.7	NC	-	

What is UTC



The Evolution of some UTC-UTC(k) in the Last Two Decades
UTC-UTC(k) [ns]
100
75
50
25
0
−25
−50
−75
−100
1996
2000
2004
2008
2012
2016
2020
2024
AOS
IT
KRIS
NICT
NIM
NIST
NPL
NPLI
NTSC
OP
PTB
SU
USNO

What Is the role of GNSS in UTC

Labs measure:
$UTC(k) - Clock_n$

Receiver provide:
$Sat_n - UTC(k)$

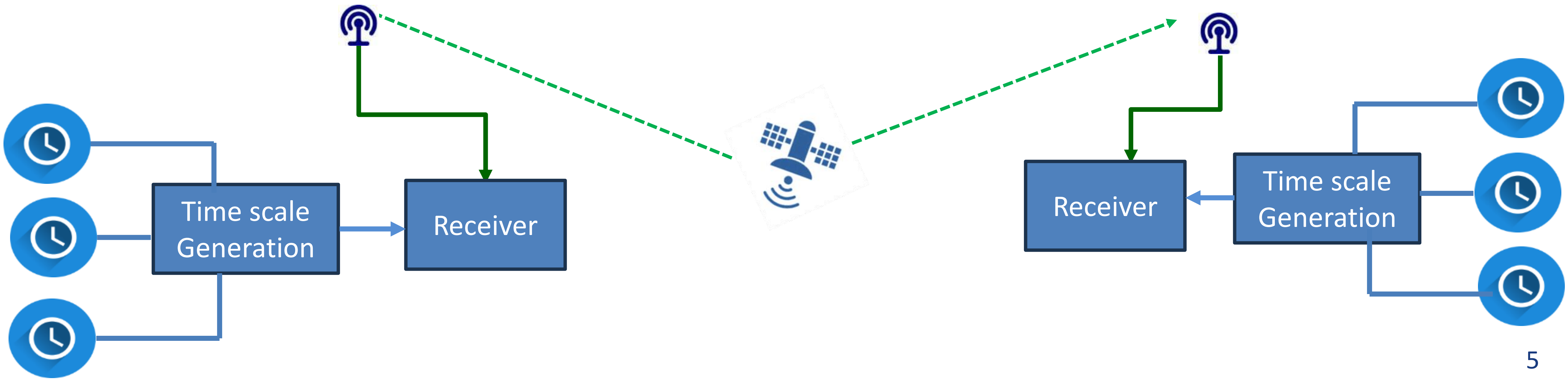
From Nav message or PE we know: $GNSS_{time} - Sat_n$

And we can adjust the measurements to have:

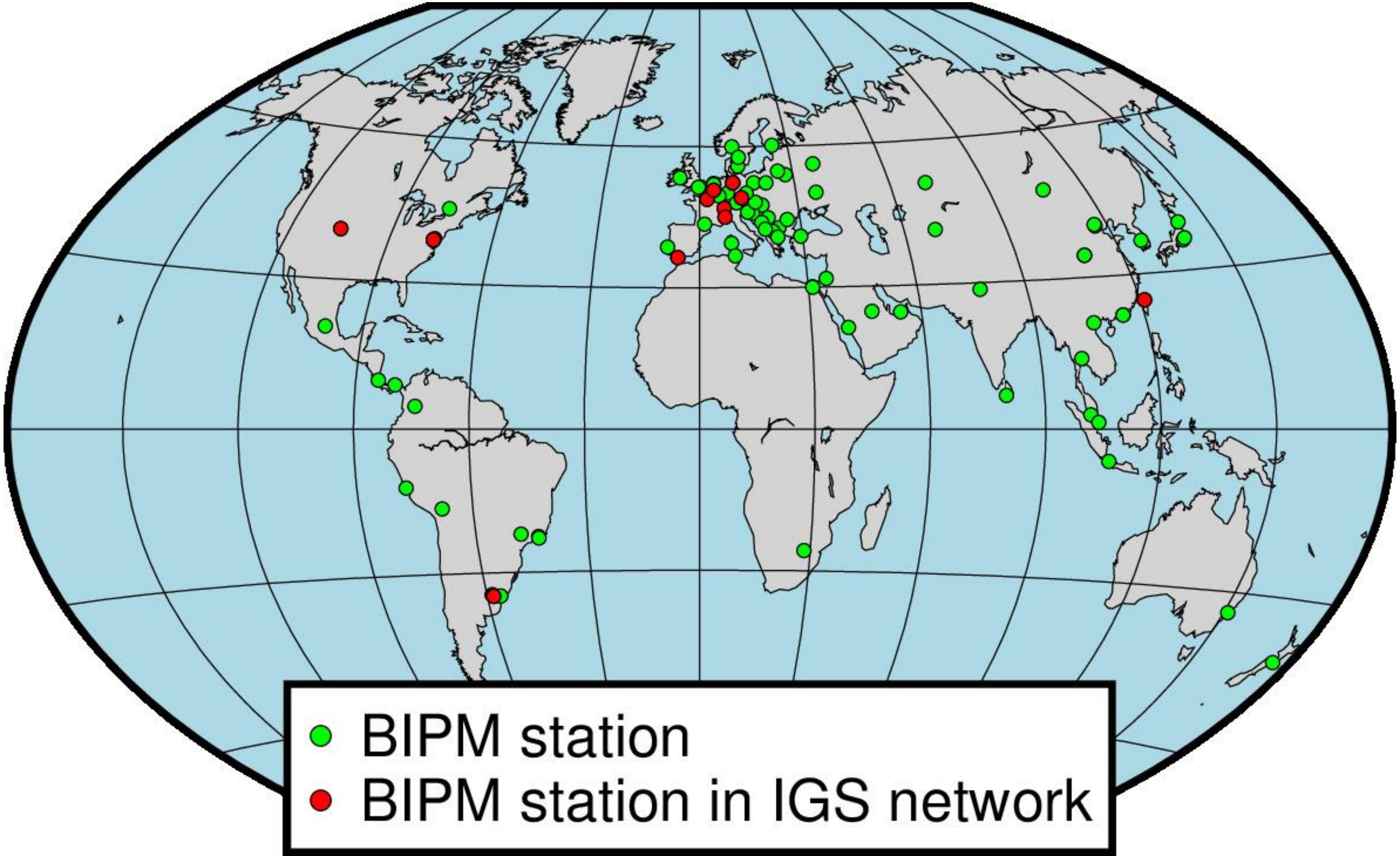
$$GNSS_{time} - UTC(k)$$

We can then compute:

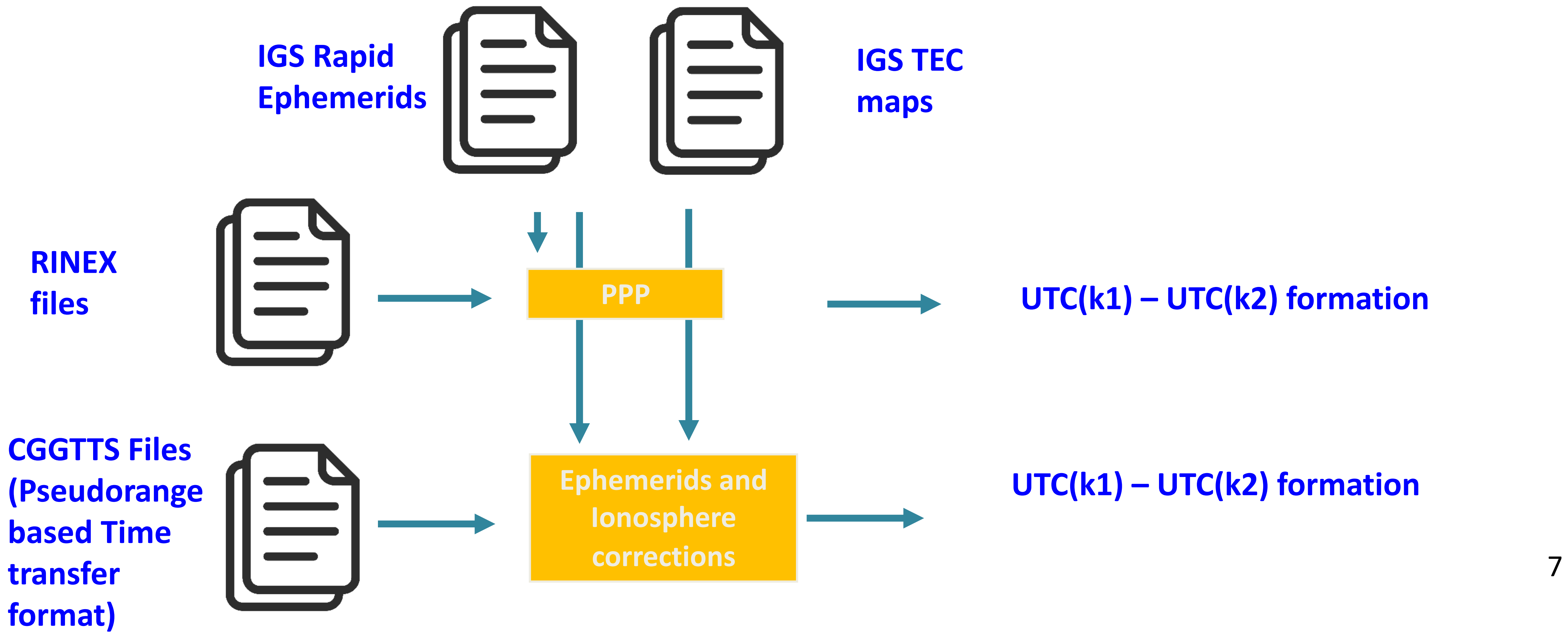
$GNSS_{time} - UTC(k1) - (GNSS_{time} - UTC(k2))$
$= UTC(k2) - UTC(k1)$



UTC receivers and Intersection with IGS network



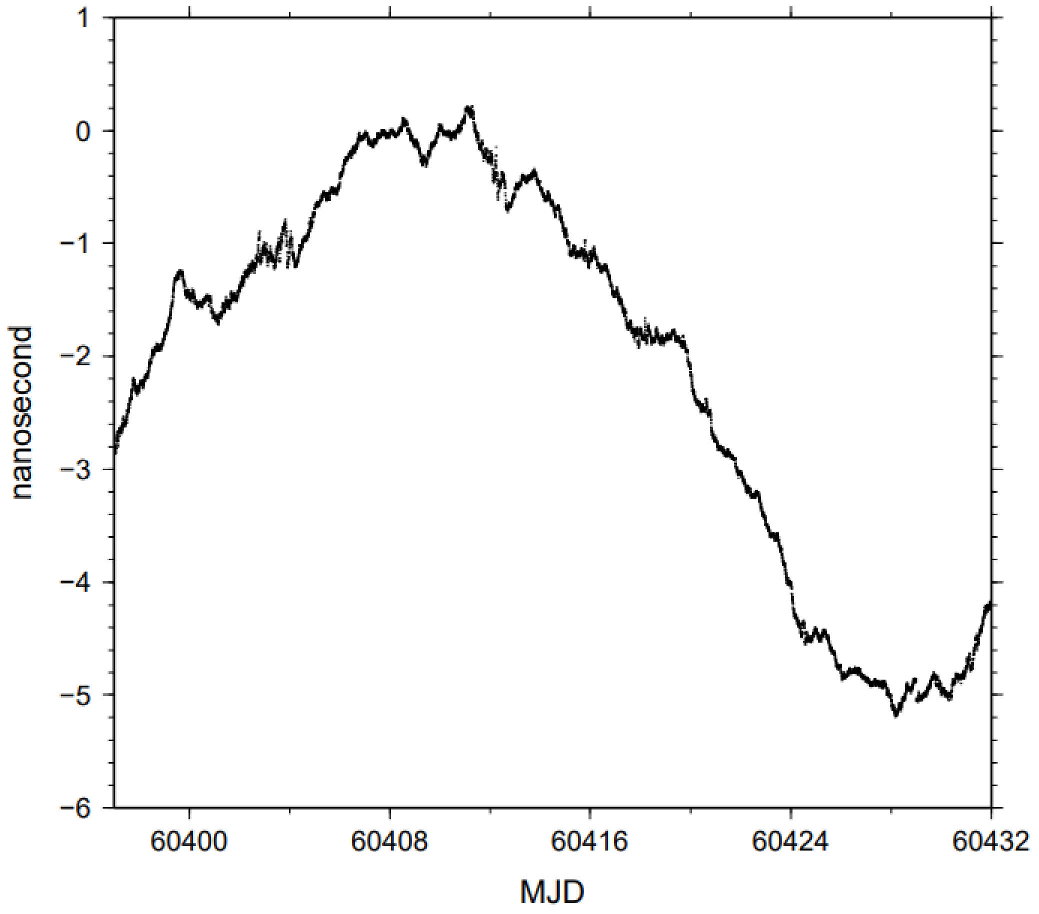
Where are IGS product used in UTC



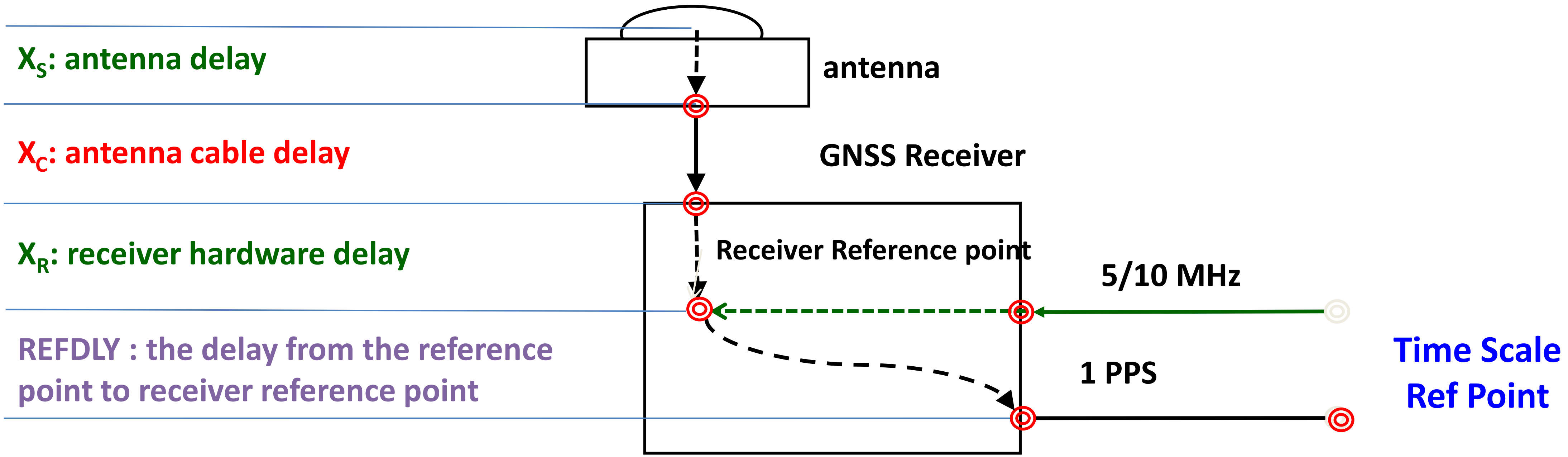
PPP current solution

- Based on GPS PPP from NRCan. (Open source)
- Use GPS rapid IGS ephemerids.
- Solutions of 35 days with forward and backward KF.
- Float ambiguities

Example UTC(USNO) via using – IGS Time Rapid



GNSS link – Hardware calibration - Intro



$CABDLY = X_C$

$INTDLY = X_S + X_R$

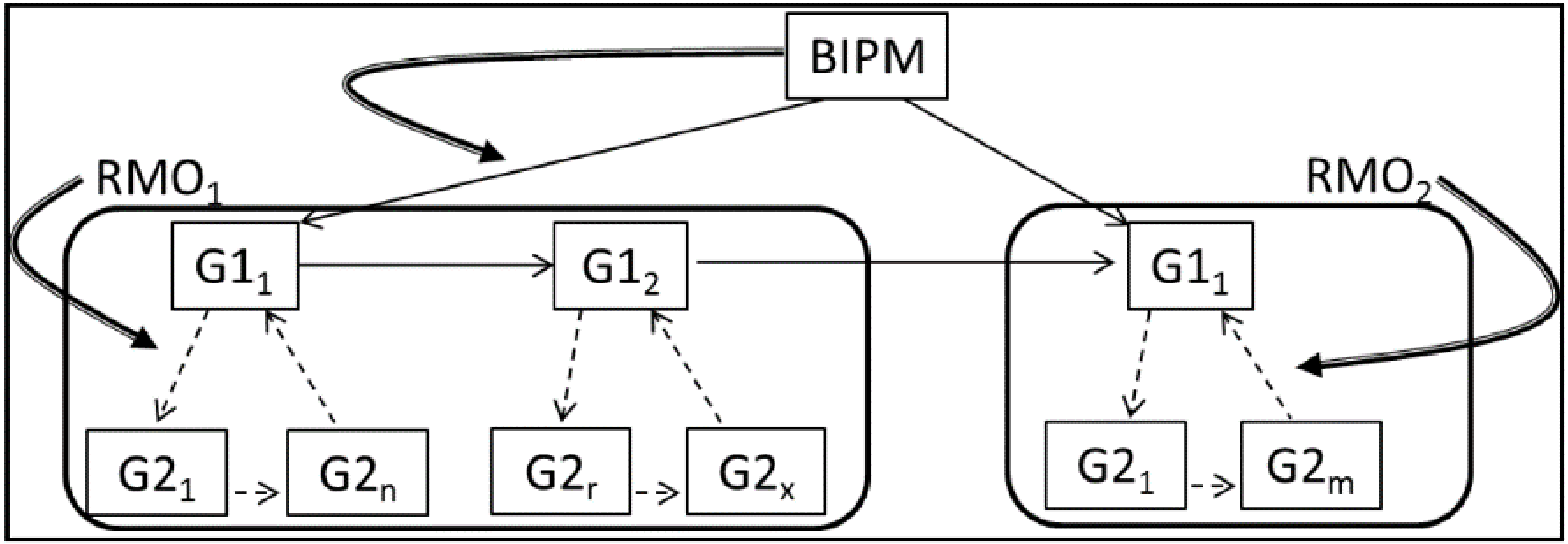
$REFDLY = X_O + X_P$

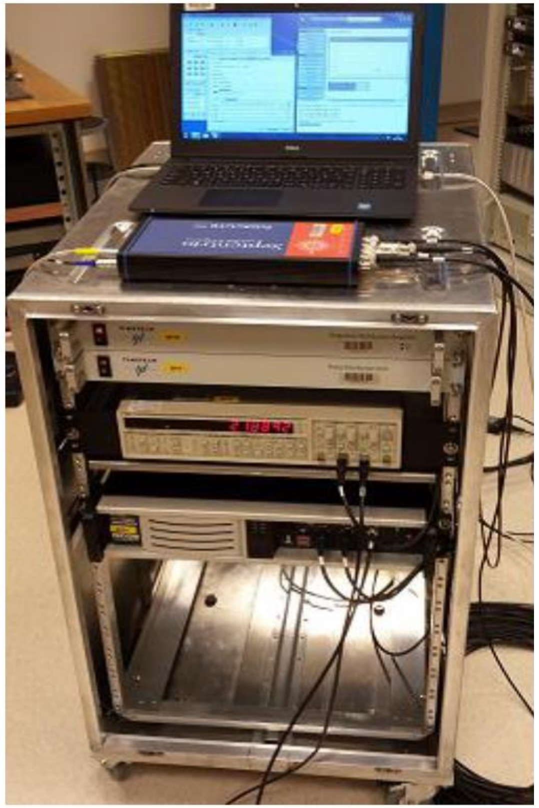
TOTDLY = CABDLY + INTDLY – REFDLY

SYSDLY = CABDLY + INTDLY

GNSS link – Hardware calibration – The Calibration scheme

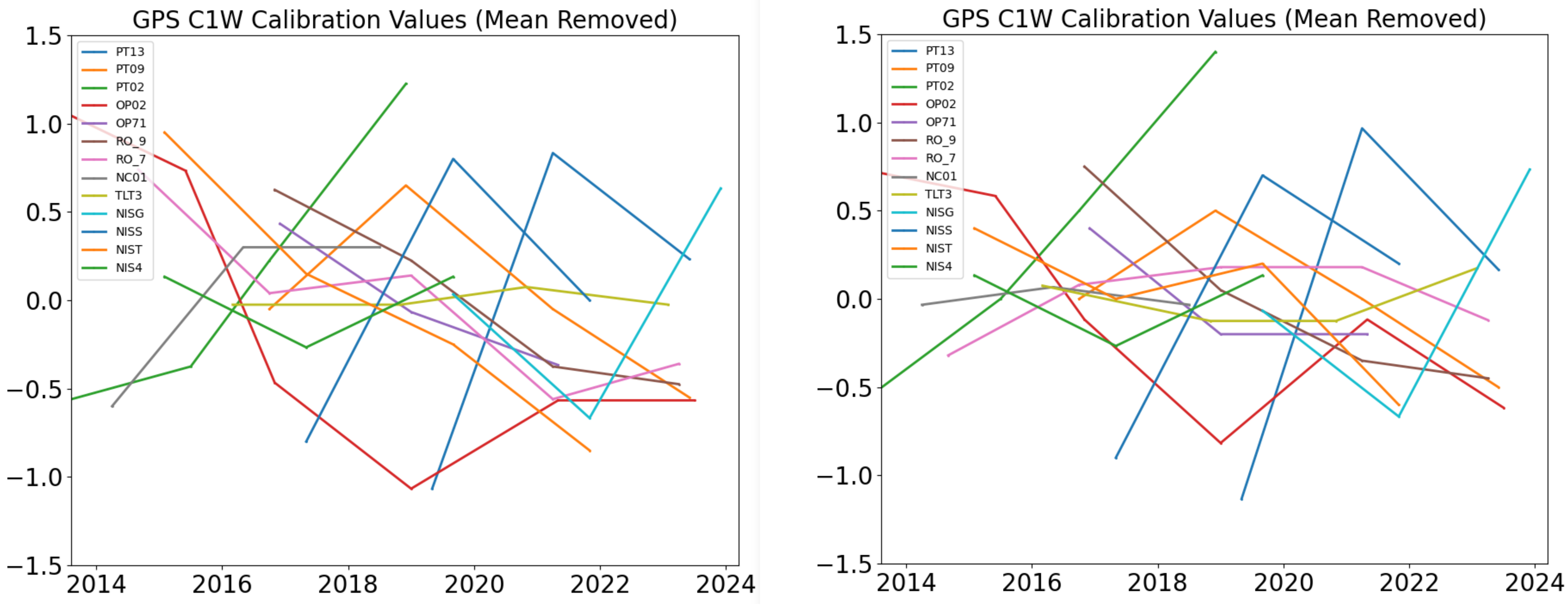
The BIPM coordinates a pyramidal relative calibration scheme of GNSS equipment.





GNSS link – Hardware calibration – Repeatability

GPS P1 and P2 code are calibrated. For Galileo E1 and E5a, For BDS3 B1C B2a. Repeatability typically in the order of 400 ps (STDEV).



GNSS link – Hardware calibration – The BIPM DB

More than 500 equipment calibrations (GPS, Galileo and BDS) has been performed in the past, the values are feely accessible at:

https://webtai.bipm.org/database/calib.html

Also, we collect absolute calibrations of UTC receivers by different labs at:

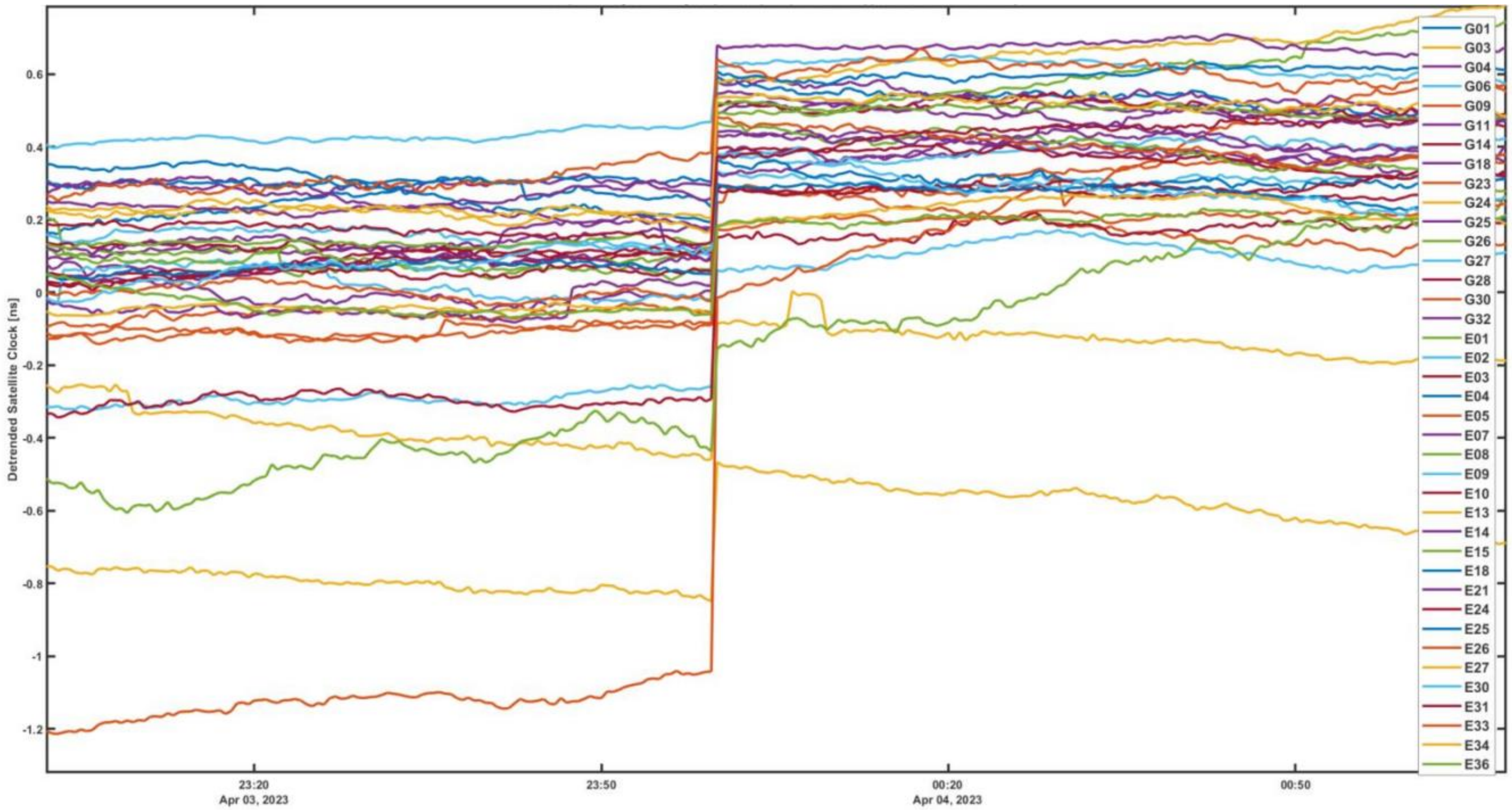
https://webtai.bipm.org/ftp/pub/tai/publication/gnss-calibration/absolute/

From PPP to IPPP, from GPS to Multi Constellation

- Past works based on a collaboration between the BIPM and CNES showed the great impact of fixing ambiguities in time transfer.
- GPS, GAL and BDS integer products are now routinely produced by different IGS Analysis Center.
- Time transfer technique are now a limiting factor for the stability and frequency accuracy of UTC.

An operational multi-constellation IPPP solution will significantly improve the quality of UTC.

Ephemerids Continuity



Possible Discontinuities:

- Jumps in the Time Scale

- Jump in the Inter system bias

- Narrow Lane steps

Any effort to produce clock continuous IGS products is very appreciated by the BIPM.

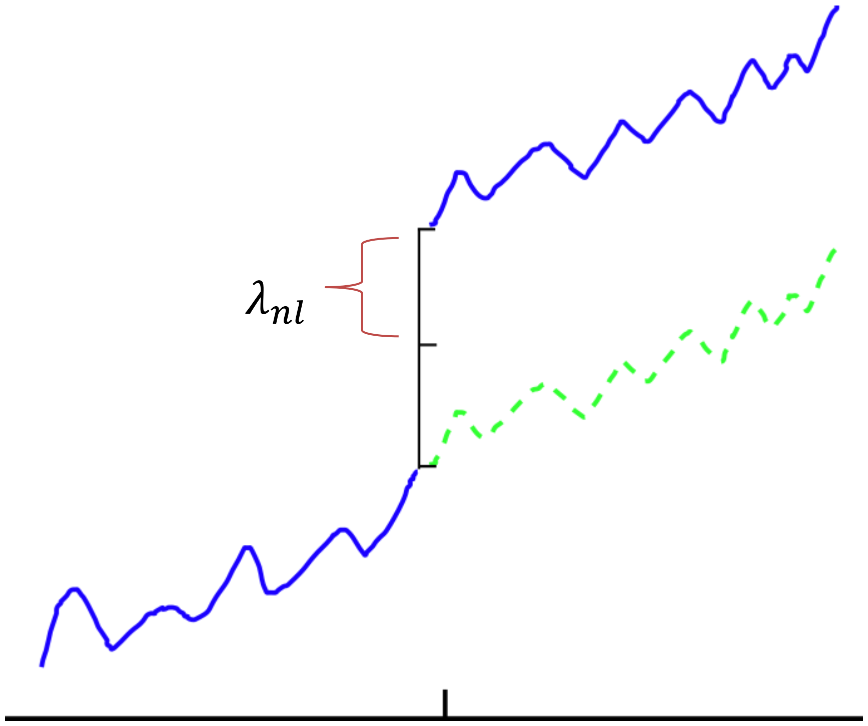
IPPP link computation strategy

Some clock are stable enough that this NL step can be estimated and removed. (H-Maser, GPS new RAFS -> yes, Cesium beam -> no).

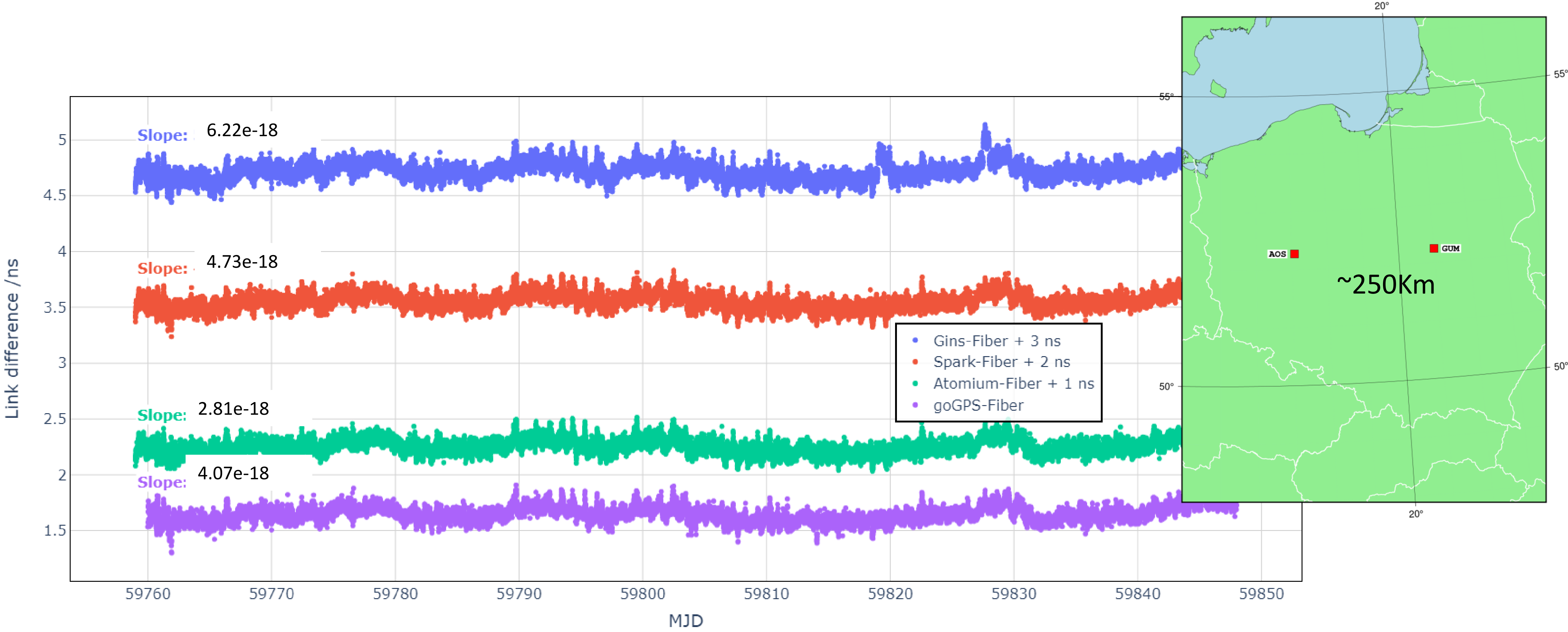
Such narrow lane steps can be repaired:

- on the UTC(k1) – UTC(k2) link (if UTC(k)s are maser based).

- Directly in the clock ephemerids (if clock stable enough)

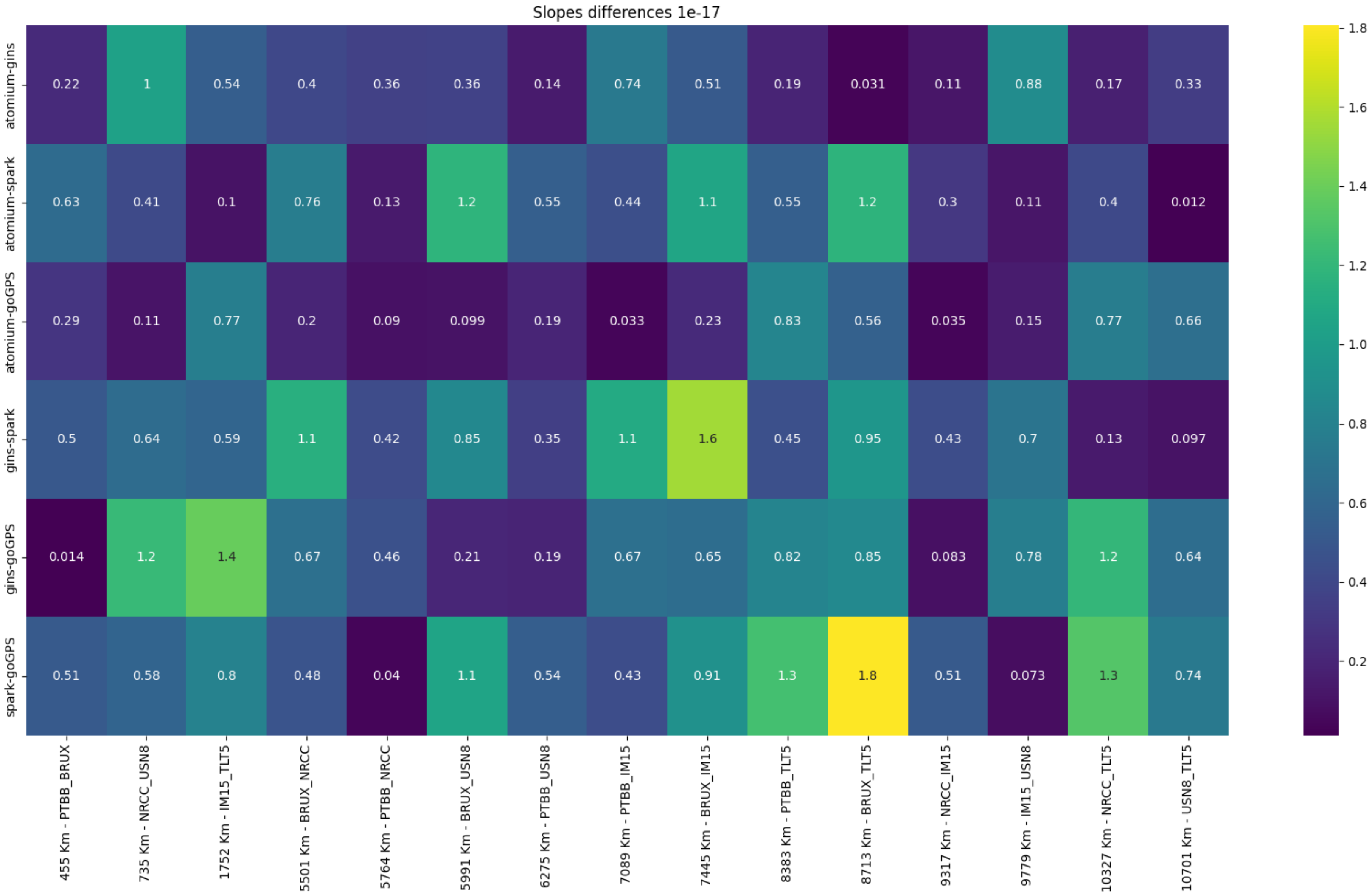


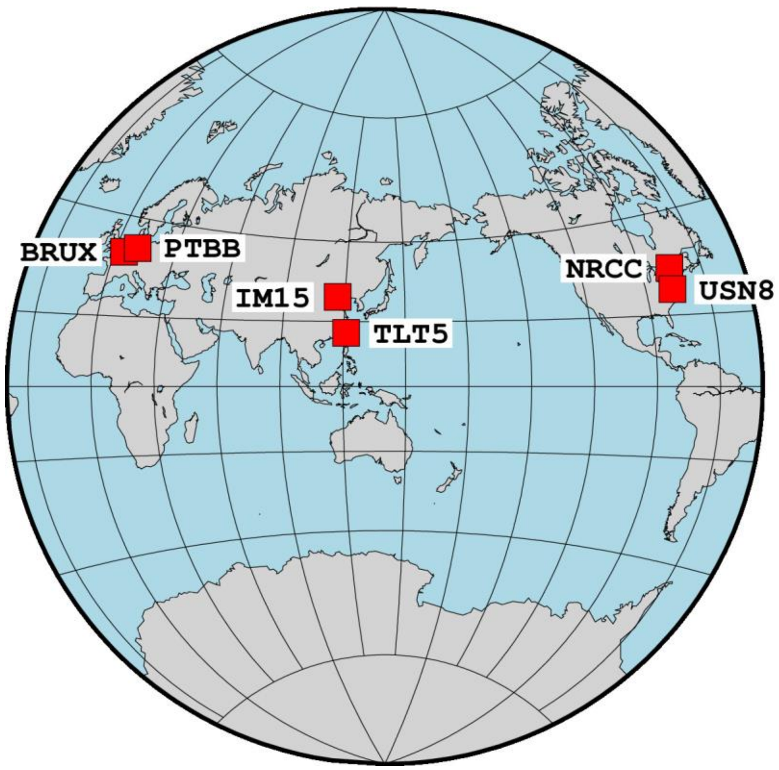
IPPP current test I



"A Comparison of IPPP GNSS Solutions for Time and Frequency Transfer", European Time and Frequency Forum, June 25-27, Neuchâtel

IPPP current test II





Conclusion

- The current UTC computation makes extensive use of IGS products.
- There is a push to go from a PPP float solution to a one with ambiguity resolution.
- A combined continuous IGS product would make this effort much easier.
- The BIPM maintain a DB of GNSS calibrations with potential applications beyond timing.