GNSS and UTC

W. Lewandowski

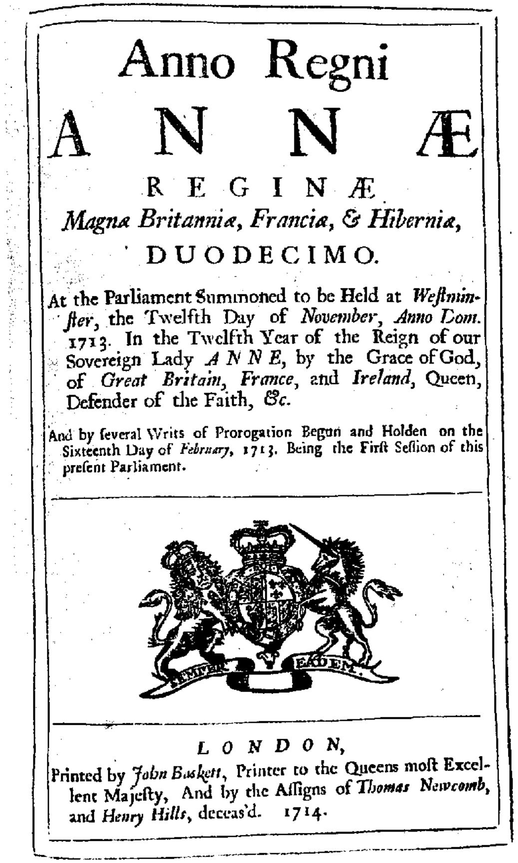
ITU-BIPM Workshop "Future of International Time Scale"
Geneve, 19-20 September 2013

Outline of presentation

- A historical note
  - Time scales
  - Navigation on seas
- Global Navigation Satellite Systems – GNSS
- Relation between UTC and GNSS time scales
  - GPS time
  - Glonass time
  - Galileo system time
  - GPS/Galileo Time/Offset (GGTO)
  - BeiDou system time
- Rapid UTCr to accomodate GNSS

If you want to know where you are,
get an accurate clock.

Accurately
knowing where we are on Earth
has been worth a big investment.



Anno Regni

A N N Æ

R E G I N Æ

Magnæ Britanniæ, Franciæ, & Hiberniæ,

DUODECIMO.

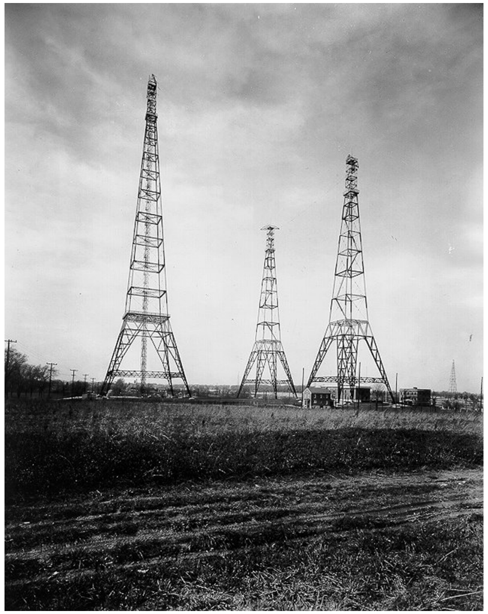
At the Parliament Summoned to be Held at *Weſtminſter*, the Twelfth Day of *November*, *Anno Dom.* 1713. In the Twelfth Year of the Reign of our Sovereign Lady *A N N E*, by the Grace of God, of *Great Britain*, *France*, and *Ireland*, Queen, Defender of the Faith, &c.

And by ſeveral Writs of Prorogation Begun and Holden on the Sixteenth Day of *February*, 1713. Being the Firſt Seſſion of this preſent Parliament.

L O N D O N,

Printed by *John Baskett*, Printer to the Queens moſt Excellent Majeſty, And by the Aſſigns of *Thomas Newcomb*, and *Henry Hills*, deceas'd. 1714.

Longitude Act of 1714



U. S. Navy radio towers, Arlington, Virginia, about 1914

Launch of the 50th GPS satellite, 2004

Courtesy of Smithonian Institution

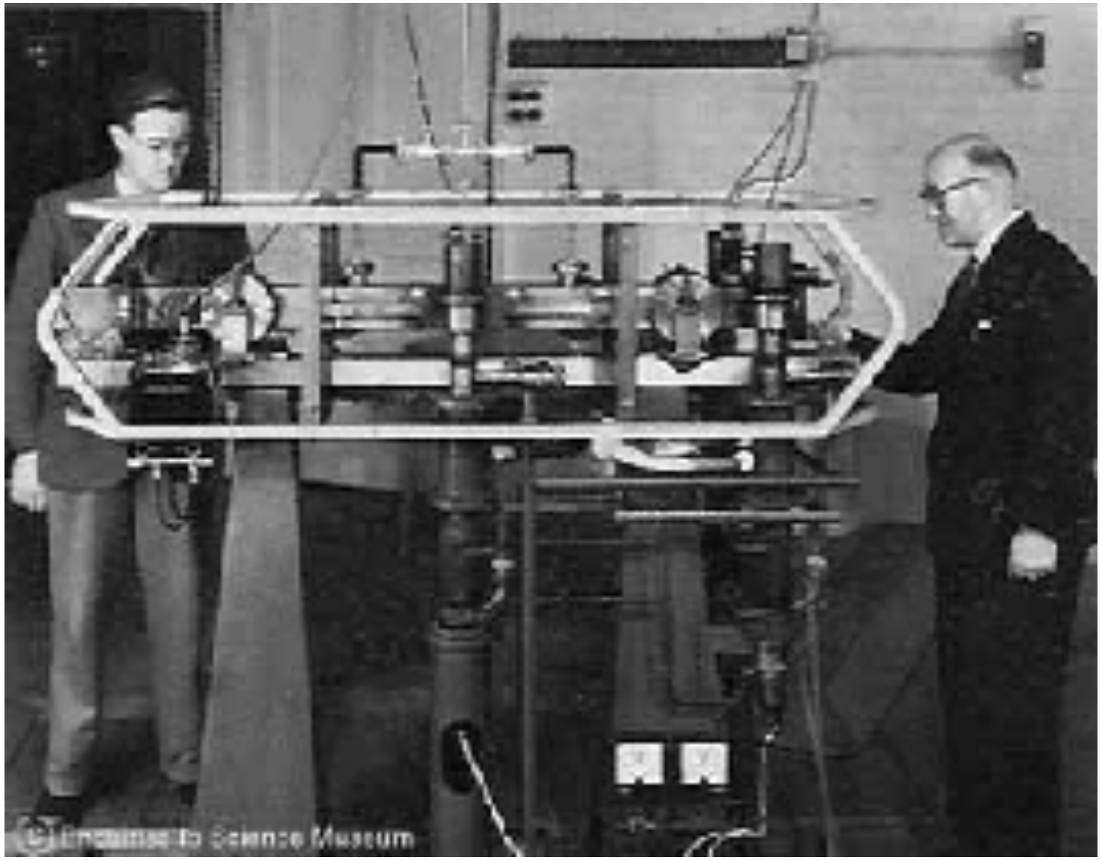
John Harrison

Harrison's fourth marine timekeeper

Working model of Harrison's second marine timekeeper

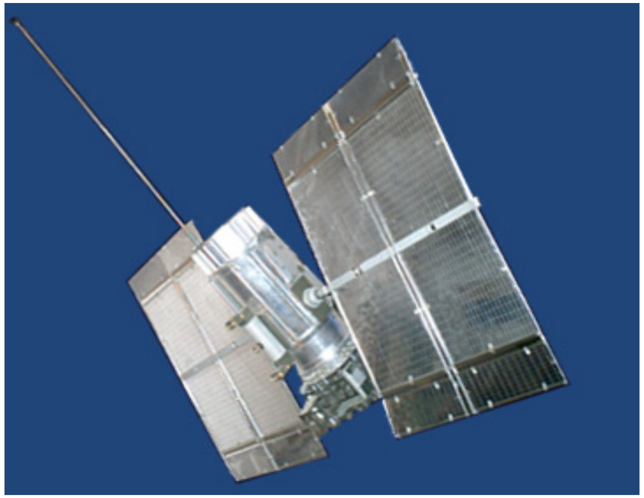
Courtesy of Smithonian Institution

GNSS are based on atomic clocks

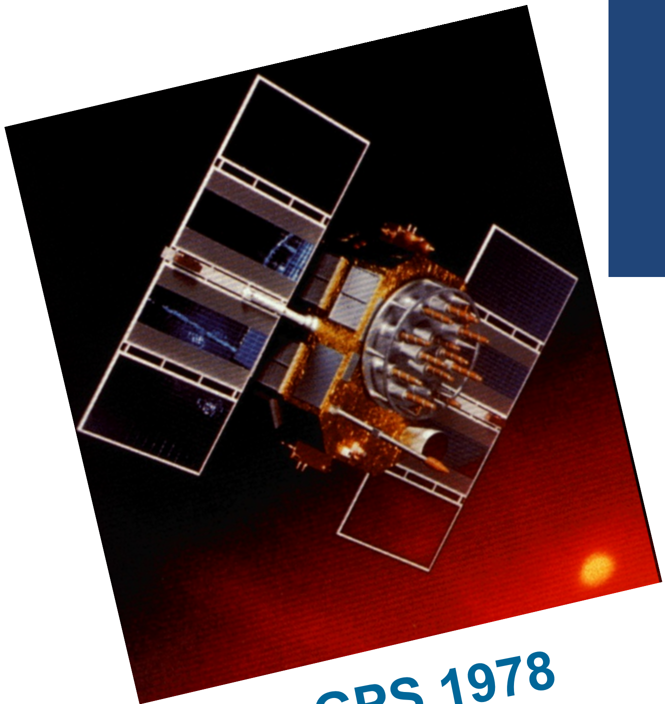


First atomic clock
UK, 1955

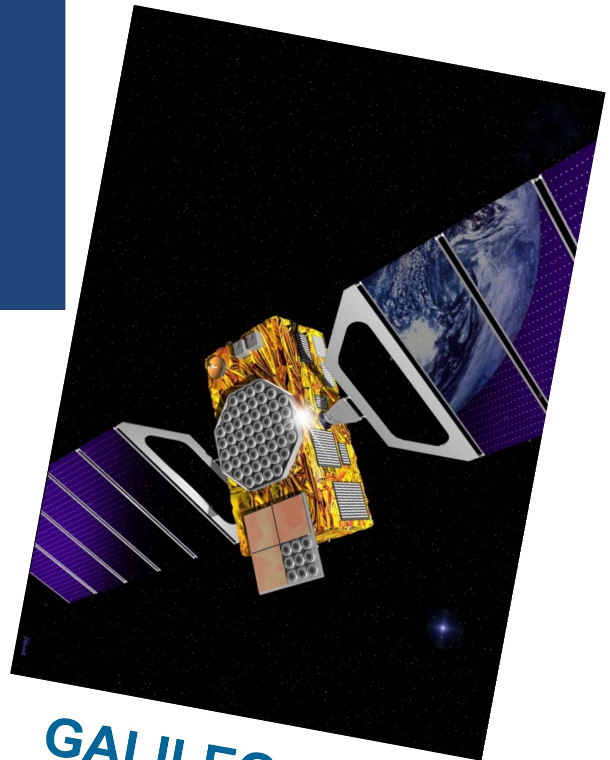
First GNSS satellites



GLONASS 1982



GPS 1978



GALILEO 2011

GNSS Navigation solution based on time measurement

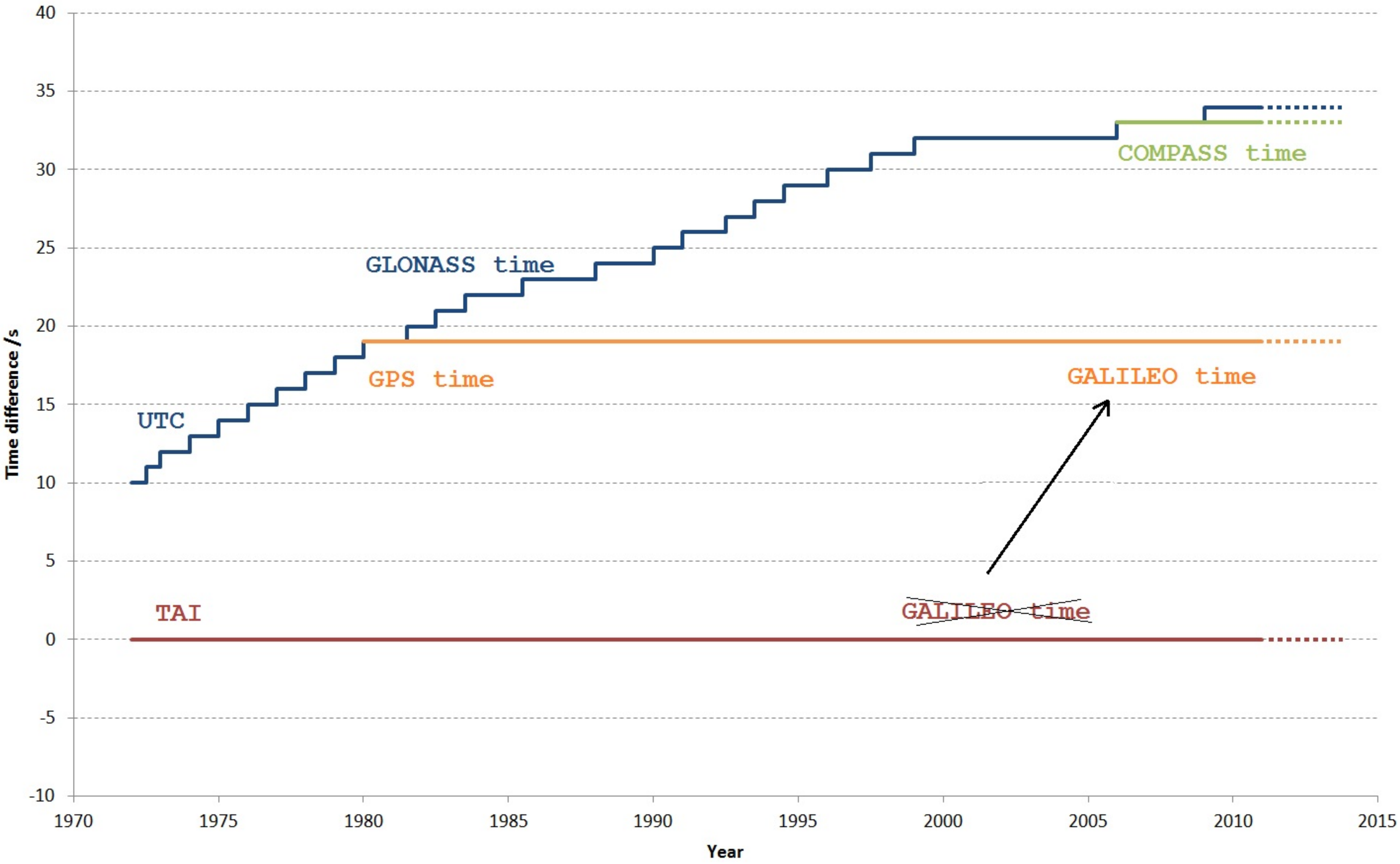
- A common reference time scale is required

  - ideally a common clock
- GNSS satellites equipped with atomic clocks
- *For example*: GPS time is realized across GPS constellation with an uncertainty of about 10 ns

System times

- **GNSS times**
  - ✓ **System times (pseudo-time scales)**
  - ✓ **Constructed from a clock ensemble**
  - ✓ **Used for internal system synchronization**
  - ✓ **Continue (desirable)**
  - ✓ **Metrological quality (?)**
  - ✓ **Steered to a reference time scale**

- **GPS time**
- **GLONASS time**
- **Galileo time**
- **BeiDou time**


40
35
30
25
20
15
10
5
0
-5
-10
Time difference /s
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
Year
UTC
GLONASS time
GPS time
COMPASS time
GALILEO time
TAI
GALILEO time

GNSS system times (cont.)

GPS time: steered to UTC(USNO) modulo 1s

- ✓ [TAI – GPS time] = 19 s + C_0
- ✓ [UTC – GPS time] = -16 s + C_0
- ✓ Tolerance is 1 μs

GLONASS time: steered to UTC(SU) with leap second

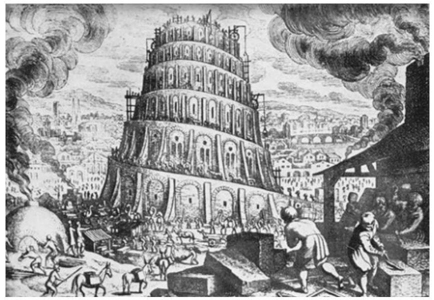
- ✓ [TAI – GLONASS time] = 35 s + C_1
- ✓ [UTC – GLONASS time] = C_1
- ✓ Tolerance is 1 ms

Galileo time: steered to a set of EU UTC(k); using GPS time seconds, GGTO

- ✓ [TAI – Galileo time] = 19 s + C_2
- ✓ [UTC – Galileo time] = -16 s + C_2
- ✓ Tolerance is 50 ns

BeiDou time: will be steered to set of Chinese UTC(k)

- ✓ [TAI – BeiDou time] = 33 s + C_3
- ✓ [UTC – BeiDou time] = -2 s + C_3
- ✓ Tolerance is 100 ns



Babel Tower

Multiple GNSS use

- Users need:
  - Interoperability
  - Interchangability
- Common geodetic and time references are necessary
- A number of recommendations by:
  - ICG
  - CCTF
  - CIPM
  - CGPM

International Committee on Global Navigation Satellite Systems (ICG)

ICG is meeting annually:

- last time in November 2012 in Beijing
- next time in November 2013 in Dubai

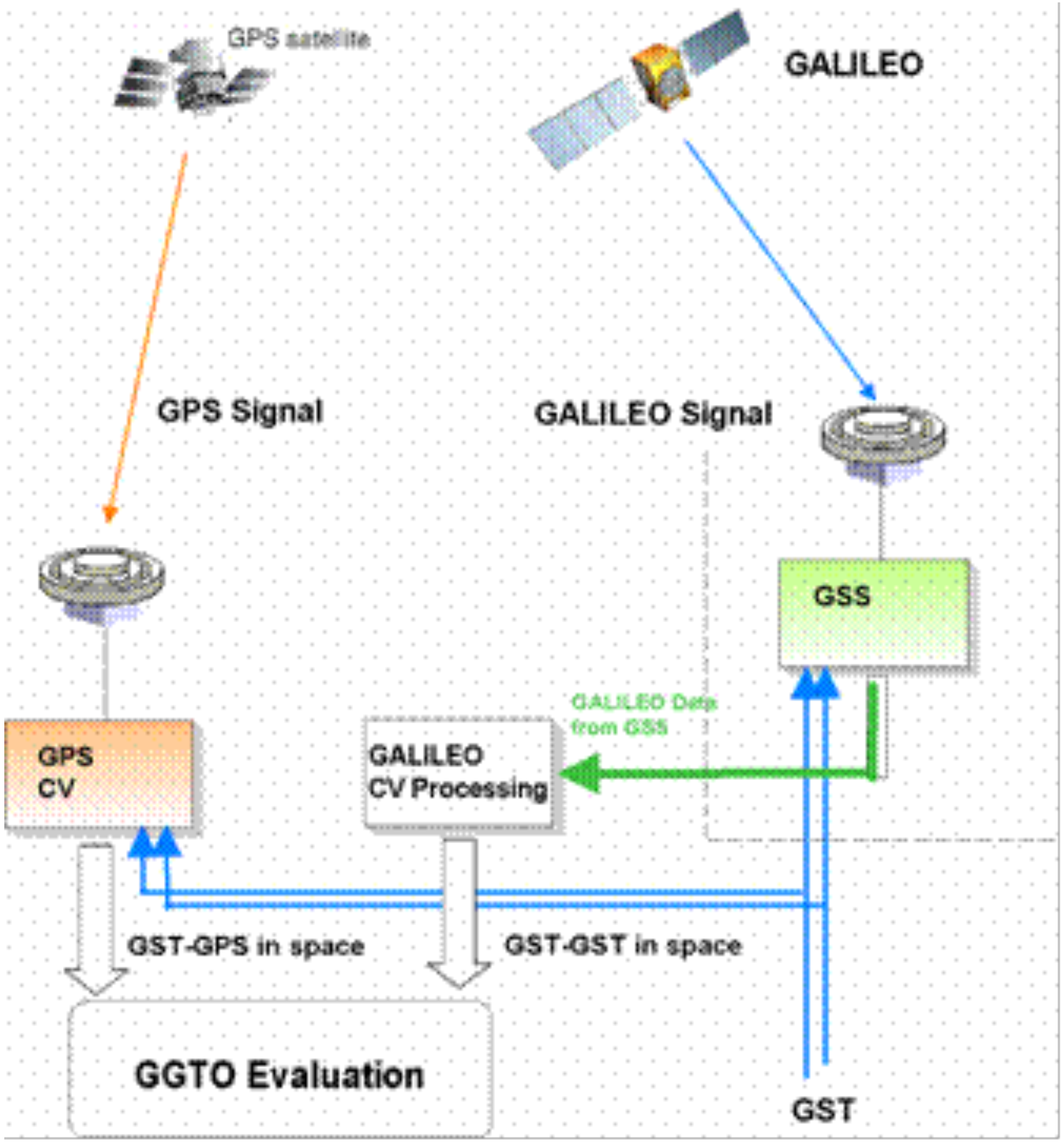
GPS/GALILEO Time Offset (GGTO)

Five different ways of the determination of GGTO:

1. **Using a GPS receiver at PTF and GST realized at PTF.**
2. **Using a single GPS/Galileo receiver.**
3. **Using two separate GPS and Galileo receivers.**
4. **Using a GPS receiver at USNO, a Galileo receiver at PTF, and TWSTFT link between USNO and PTF.**
5. **Using a GPS receiver at USNO, a Galileo receiver at PTF, and GPS P3 CV link between USNO and PTF.**

GGTO will be broadcast by GALILEO

Determination of GGTO at Galileo PTF



GGTO determined using separate GPS and Galileo receivers at PTF

Uncertainty budget

Source of uncertainty	Real-time (broadcast orbits) smoothing 24h back	Real-time (ultra-rapid predicted) smoothing 24h back
Smoothed GPS P3	3.0 ns	2.0 ns
Smoothed Galileo P3	3.0 ns	2.0 ns
GPS rec. calib.	2.5 ns	2.5 ns
Galileo rec. calib.	2.5 ns	2.5 ns
Total uncert.	5.5 ns	4.5 ns

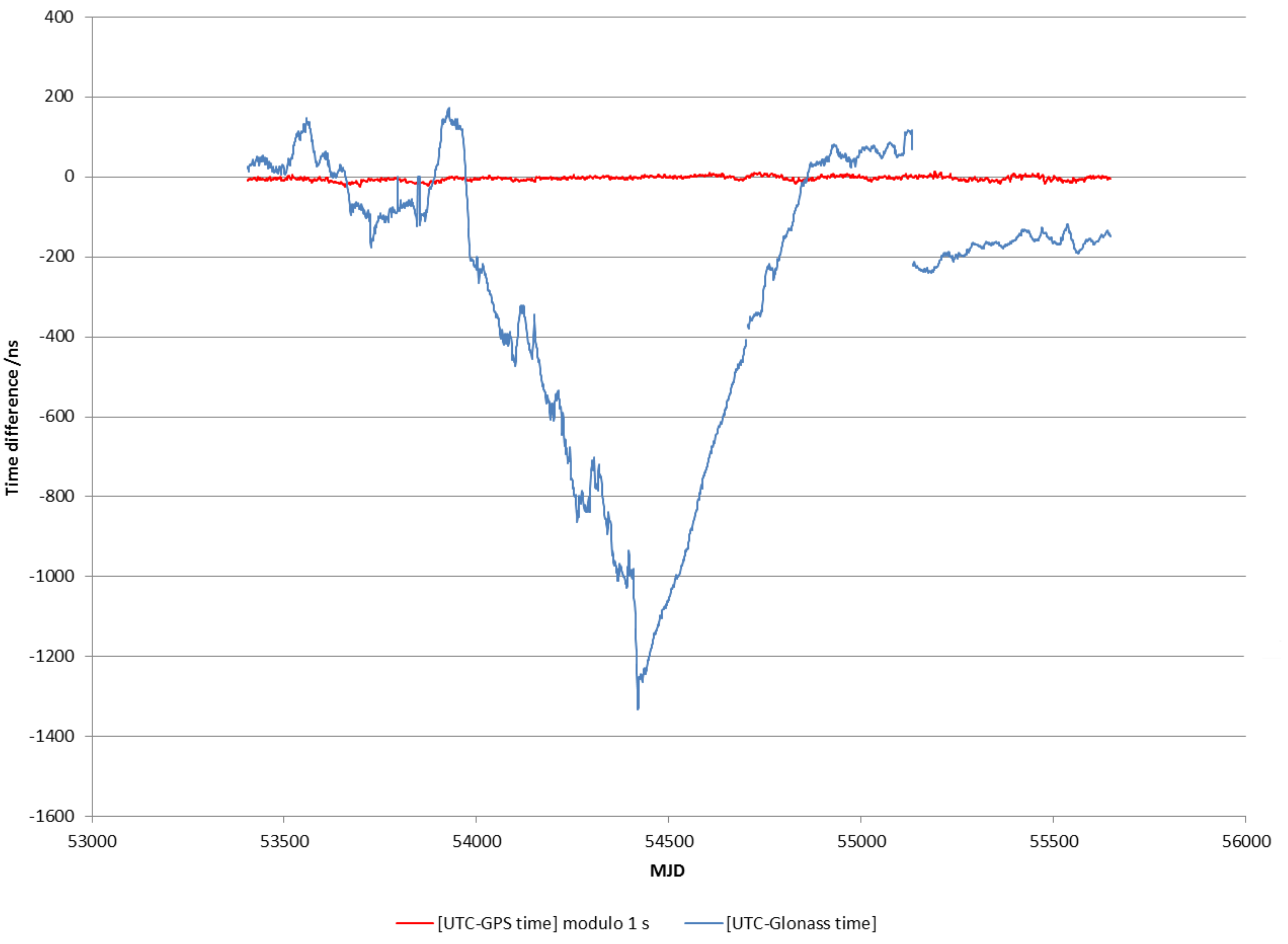
GNSS time dissemination

GNSS broadcast :

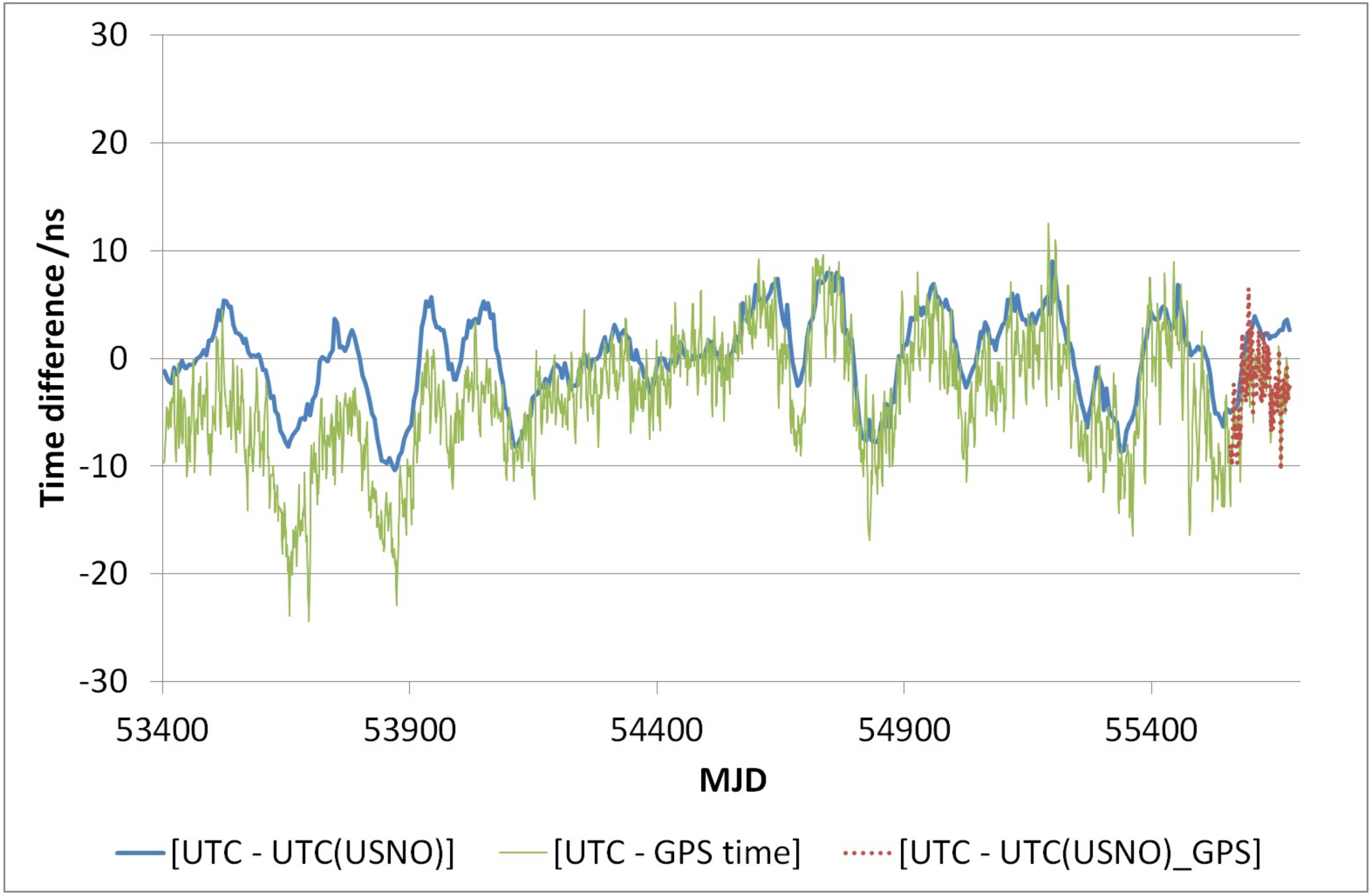
- System time
- Prediction of UTC(k) through broadcasting related correction to system time

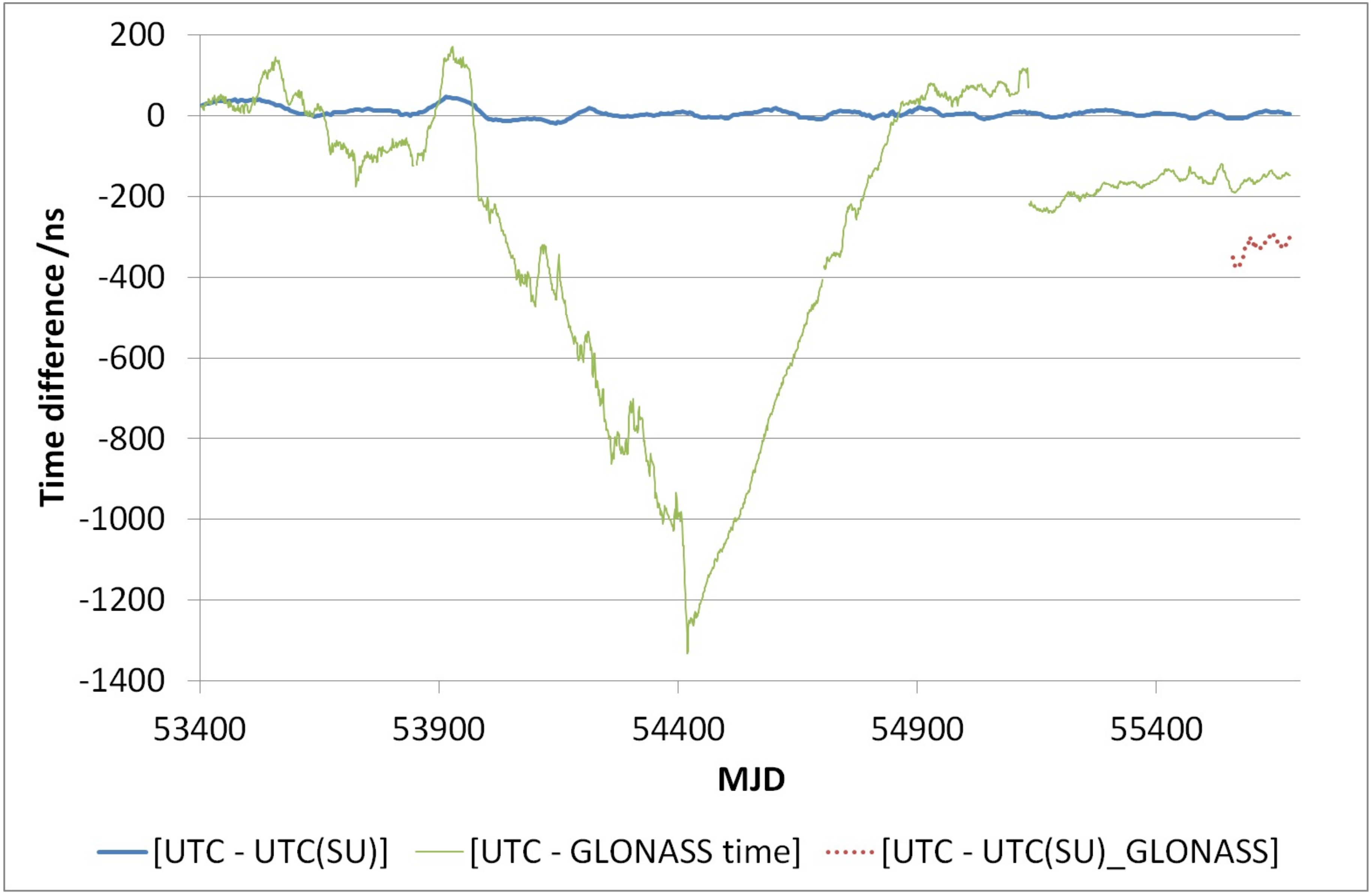
UTC- ....

2013	GPS time +15 s /ns	**UTC(USNO) by GPS** /ns	GLONASS time /ns	**UTC(SU) by GLONASS** /ns
AUG 1	-0.3	-0.2	-173.4	-362.5
AUG 2	-0.1	-2.3	-171.8	-361.0
AUG 3	-0.2	-2.2	-173.1	-363.0
AUG 4	-0.2	-0.2	-172.1	-362.9
AUG 5	0.0	-2.0	-169.3	-361.2
AUG 6	-0.4	-1.4	-170.2	-362.7
AUG 7	-1.1	-0.6	-169.7	-362.2
AUG 8	-1.2	-2.2	-168.1	-360.7
AUG 9	-2.4	-2.5	-168.4	-360.2
AUG 10	-2.1	-1.6	-170.7	-361.7
AUG 11	-1.8	-0.5	-171.7	-362.3
AUG 12	-2.2	-1.8	-169.7	-359.9
AUG 13	-2.1	-0.5	-168.2	-358.1
AUG 14	-3.8	-3.1	-169.9	-359.1
AUG 15	-3.6	-2.0	-174.1	-362.3
Stand. dev.	**1.1**	**1.2**	**6.3**	**6.3**
Uncert. uB	**10.0**	**10.0**	**500.0**	**500.0**



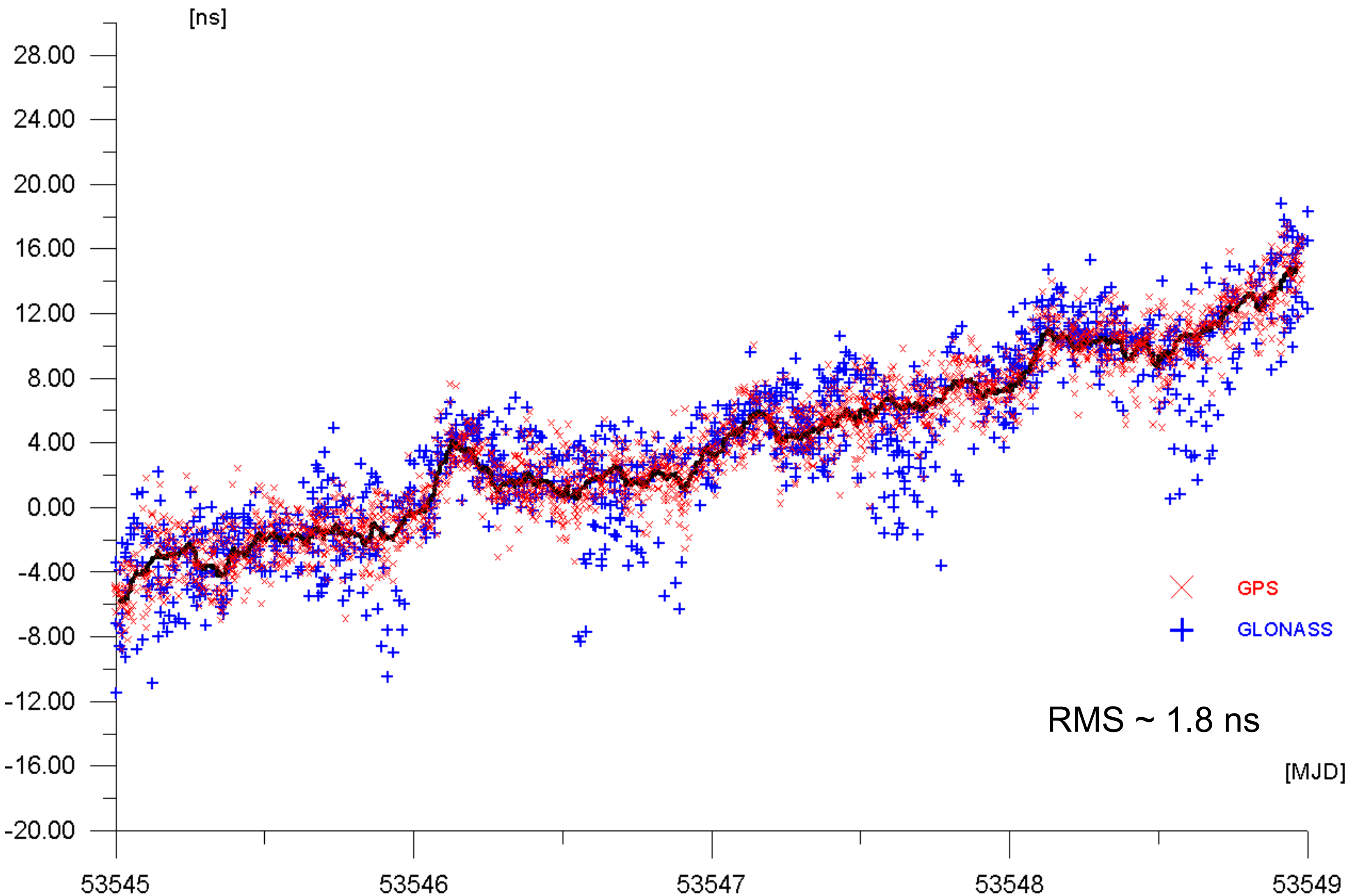
400
200
0
-200
-400
-600
-800
-1000
-1200
-1400
-1600
Time difference /ns
53000
53500
54000
54500
55000
55500
56000
MJD
[UTC-GPS time] modulo 1 s
[UTC-Glonass time]


30
20
10
0
-10
-20
-30
Time difference /ns
53400
53900
54400
54900
55400
MJD
[UTC - UTC(USNO)]
[UTC - GPS time]
[UTC - UTC(USNO)_GPS]



200
0
-200
-400
-600
-800
-1000
-1200
-1400
Time difference /ns
53400
53900
54400
54900
55400
MJD
[UTC - UTC(SU)]
[UTC - GLONASS time]
[UTC - UTC(SU)_GLONASS]

AOS/BIPM, GPS+GLONASS, P1 CODE



UTCr
A rapid realization of UTC
(following an ICG request)

Time department
Bureau International des Poids et Mesures
Sèvres

Characteristics of UTCr

- **Based on daily data reported (daily) by contributing laboratories**
- **Weekly access to daily values of [*UTCr*-*UTC*(*k*)]**
- **Automatically generated weekly solution over four weeks of data (sliding solution)**

Implementation of UTCr

September 2011: UTC contributing laboratories have been invited to participate on a voluntary basis to a pilot experiment.

January 2012: Pilot experiment started, with the target of reporting to the CCTF in September 2012;

July 2013: Official production of UTCr;

Impact of a rapid realization of UTC

On UTC contributing laboratories:

- **More frequent assessing of the UTC(k) steering, and consequently its better stability and accuracy.**
- **Traceability to UTC is enhanced.**

On users of UTC(K):

- **Access to a better "local" reference, and indirectly, better traceability to the UTC "global" reference.**

On GNSS:

- **Better synchronization of GNSS times to UTC, through improved UTC and UTC(k) predictions: case of UTC(USNO) for GPS, UTC(SU) for GLONASS, UTC(k) used in the generation of Galileo ST, BeiDou ST and Gagan ST.**

Publication

Every Wednesday before 18:00 UTC

on

ftp://tai.bipm.org/UTCr/Results/

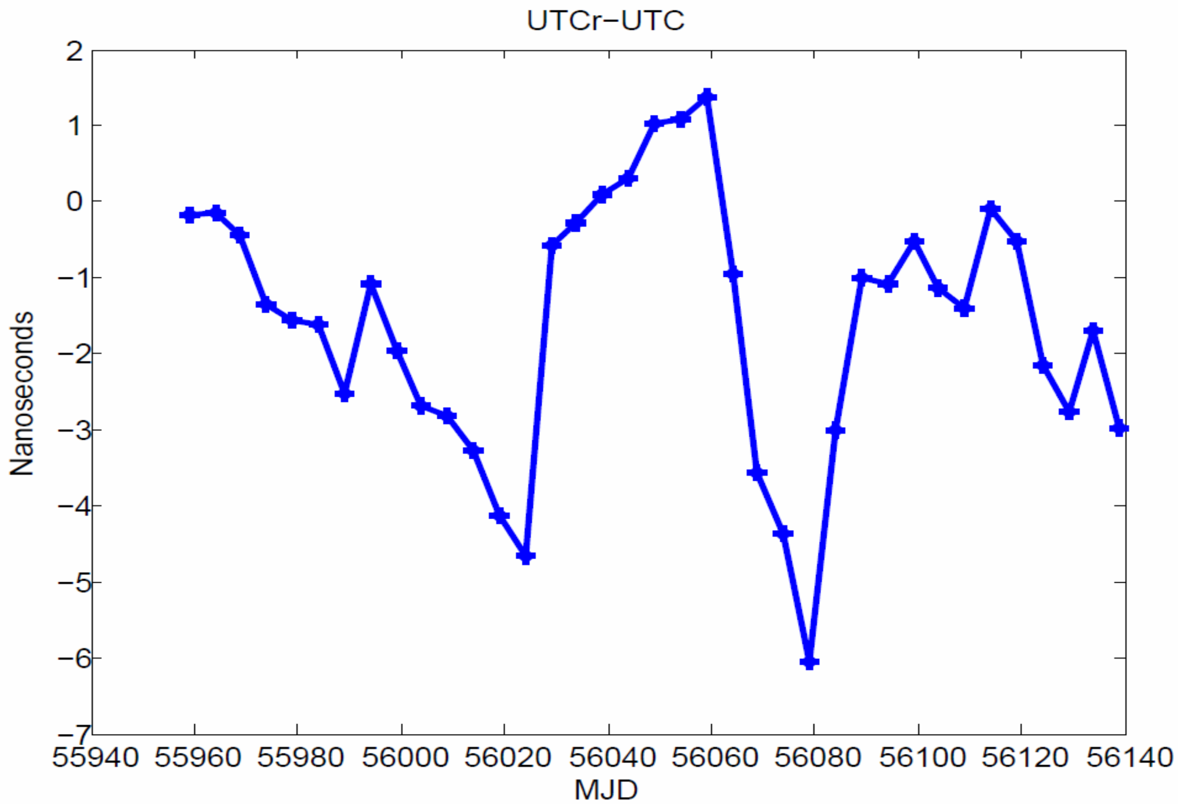
UTCr_1211
2012 MARCH 21, 13h UTC

The results in this page are established by the BIPM Time Department in the frame of the pilot experiment on a rapid UTC, UTCr. The computed values [UTCr-UTC(k)] are reported.

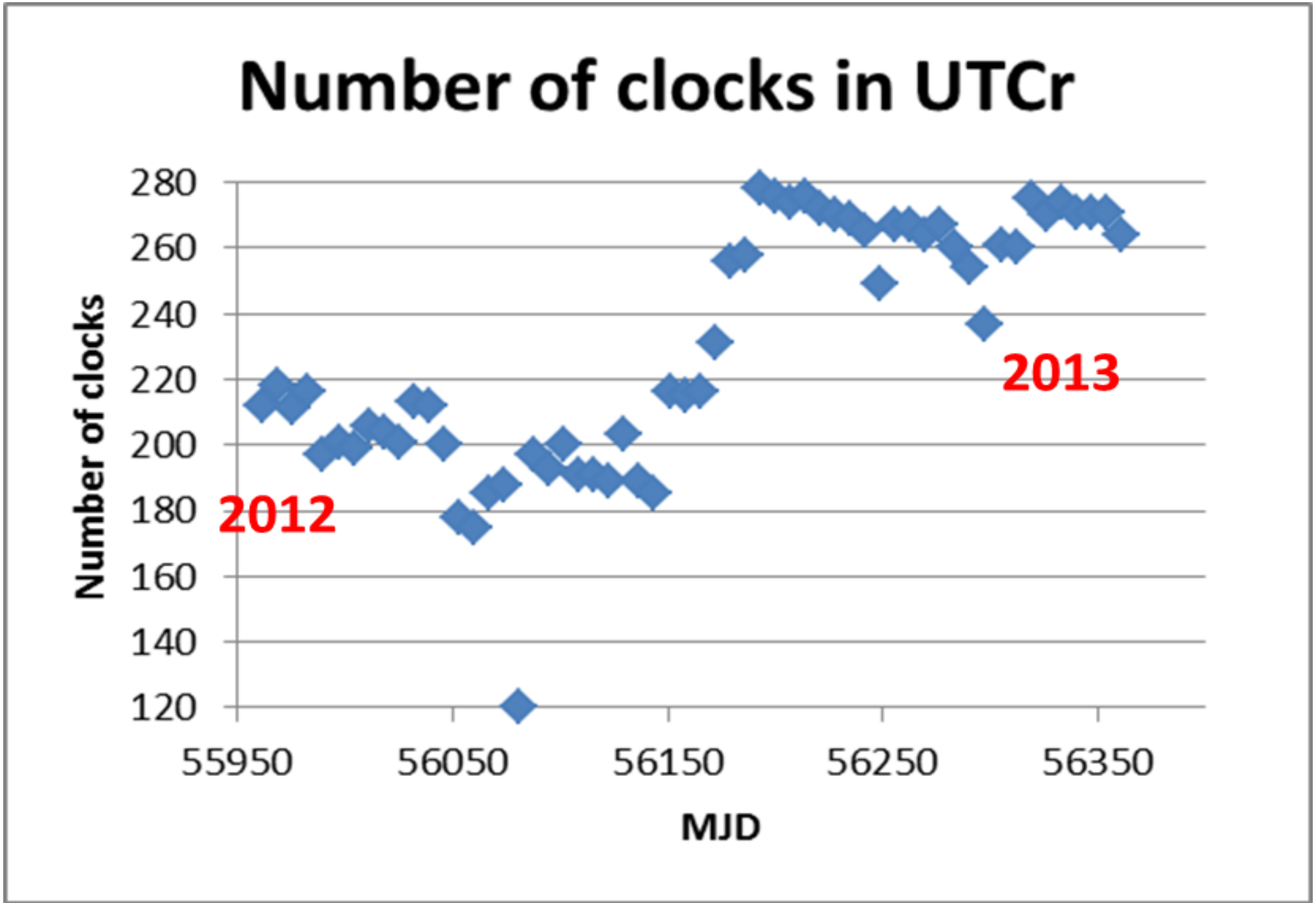
Date 2012 0h UTC	MAR 12	MAR 13	MAR 14	MAR 15	MAR 16	MAR 17	MAR 18
MJD	55998	55999	56000	56001	56002	56003	56004
Laboratory k			[UTCr-UTC(k)]/ns				
AOS (Borowiec)	-2.6	-2.4	-1.9	-1.3	-1.9	-1.9	-1.2
BEV (Wien)	11.9	11.3	10.3	6.5	0.4	-2.3	-5.7
CAO (Cagliari)	-6291.7	-6290.8	-6293.1	-6291.4	-6298.8	-6308.3	-6300.0
CH (Bern)	-12.5	-12.3	-12.0	-10.9	-9.8	-9.2	-9.3
CNM (Queretaro)	-13.8	-15.0	-15.5	-14.9	-17.3	-18.4	-17.1
CNMP (Panama)	75.8	81.4	85.5	83.1	83.8	83.0	88.0
DTAG (Frankfurt/M)	6.8	5.1	5.8	5.7	6.8	6.4	7.7
IFAG (Wettzell)	-620.2	-619.1	-623.8	-627.3	-627.8	-626.7	-627.4
IGNA (Buenos Aires)	6691.8	6700.6	6711.9	6724.6	6737.0	6747.7	6762.6
INTI (Buenos Aires)	-26.4	-32.2	-32.6	-32.7	-32.5	-31.6	-36.7
IPQ (Caparica)	-23.1	-29.1	-27.5	-24.7	-22.6	-16.5	-12.5
IT (Torino)	1.2	2.3	2.6	3.0	3.4	3.8	4.0
KRIS (Daejeon)	-8.3	-8.7	-9.4	-	-	-	-
LT (Vilnius)	42.4	39.1	32.9	35.0	30.1	37.5	43.8
MSL (Lower Hutt)	67.0	61.2	55.3	-	-	-	-
NAO (Mizusawa)	54.8	49.9	52.4	54.7	50.1	49.0	50.8
NICT (Tokyo)	2.5	2.7	2.6	3.1	3.4	3.2	3.2
NIM (Beijing)	-7.1	-7.5	-8.3	-8.9	-9.8	-9.8	-10.7
NIMT (Pathumthani)	987.6	1008.5	1026.4	1042.7	1058.3	1074.2	1090.9
NIS (Cairo)	-782.1	-784.0	-783.8	-786.8	-794.0	-797.0	-799.5
NIST (Boulder)	-4.1	-5.0	-4.2	-3.9	-6.6	-6.3	-5.2
NMIJ (Tsukuba)	-8.7	-8.4	-8.5	-8.2	-7.7	-8.0	-8.2
NMLS (Sepang)	-664.4	-665.1	-667.1	-667.0	-670.4	-672.4	-674.5
NRC (Ottawa)	-18.1	-14.2	-15.1	-13.9	-13.8	-14.0	-13.6
NTSC (Lintong)	0.8	2.2	2.1	5.0	4.3	4.5	3.8
ONRJ (Rio de Janeiro)	-12.3	-9.7	-6.9	-7.5	-7.8	-4.7	-1.9
OP (Paris)	-24.5	-22.8	-23.7	-21.8	-21.4	-21.8	-24.5
ORB (Bruxelles)	-0.4	-0.1	0.5	0.0	0.4	-0.5	-1.0
PL (Warszawa)	15.8	16.5	18.1	16.1	15.0	12.4	12.8
PTB (Braunschweig)	-3.2	-3.4	-3.6	-3.5	-4.0	-4.0	-4.6
ROA (San Fernando)	-2.8	-2.2	-2.7	-3.1	-3.5	-3.8	-4.4
SCL (Hong Kong)	13.8	11.5	5.2	5.5	2.8	-5.8	-2.0
SG (Singapore)	9.6	9.3	7.5	7.8	7.8	7.4	6.6
SP (Boras)	-15.7	-15.6	-15.5	-15.6	-15.5	-15.6	-16.0
SU (Moskva)	1.4	1.2	2.0	2.2	0.6	0.3	0.9
TL (Chung-Li)	6.4	6.5	5.5	4.9	4.2	2.7	1.3
UME (Gebze-Kocaeli)	103.3	100.2	104.3	109.5	107.7	105.3	107.1
USNO (Washington DC)	-0.7	-1.1	-1.2	-1.3	-1.5	-1.5	-1.5
VSL (Delft)	10.0	8.1	3.6	3.2	4.4	4.5	4.6

These results should not be used as a prediction of UTC.
UTC remains available from the monthly Circular T at
(http://www.bipm.org/jsp/en/TimeFtp.jsp?TypePub=publication).
The BIPM retains full internationally protected copyright of these results.
The BIPM declines all liability in the event of improper use of these results.

Comparisons between UTCr and UTC (1): Results



Based on first six months (February to July 2012)

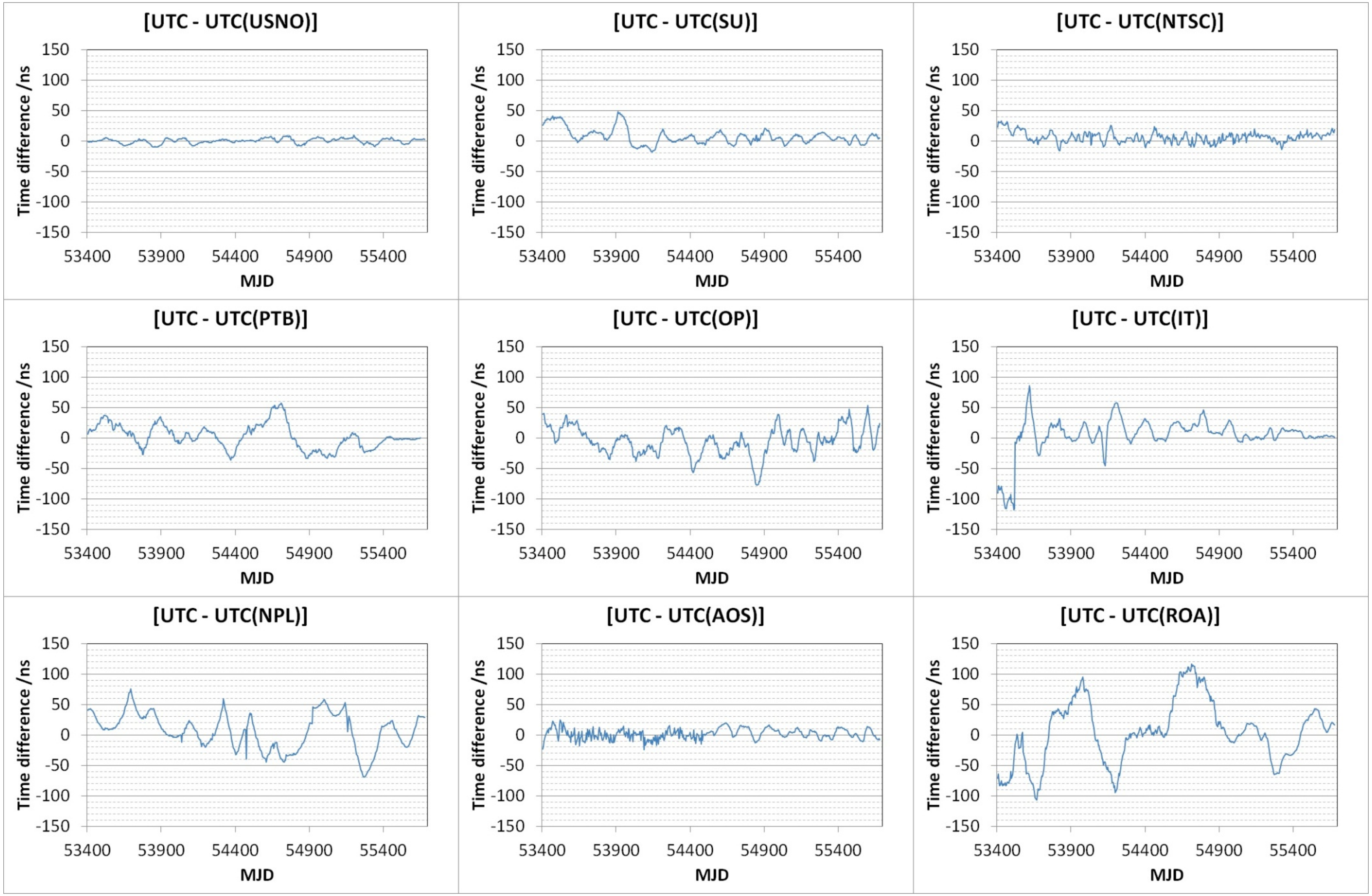


Number of clocks in UTCr
Number of clocks
280
260
240
220
200
180
160
140
120
2012
2013
55950
56050
56150
56250
56350
MJD

Accurately

knowing where we are on Earth

has been worth a big investment.



[UTC - UTC(USNO)]
[UTC - UTC(SU)]
[UTC - UTC(NTSC)]
[UTC - UTC(PTB)]
[UTC - UTC(OP)]
[UTC - UTC(IT)]
[UTC - UTC(NPL)]
[UTC - UTC(AOS)]
[UTC - UTC(ROA)]
Time difference /ns
150
100
50
0
-50
-100
-150
53400
53900
54400
54900
55400
MJD

Summary (1/2)

- GNSS providers choose most often flat system times for safety of life issues, because of weakness of stepping UTC.

- GNSS system times are not representations of UTC, and being broadcast they are not fulfilling requests of ITU, which is recommending only UTC to be broadcast, even if GNSS broadcast predictions of UTC(k).

- UTCr helps to coordinate GNSS system times.

Summary (2/2)

- GNSS system times shall be considered as internal technical parameters used only for internal system synchronization, but this is not the case.
- Flat system times are used for a number of apllications, contributing to proliferation of alternative time scale, and creating major source of confusion.
- Within GNSS might be a confusion by using system time and UTC for dating various system functions.
- Possible errors due to leap second when using MJD datation.
- GNSS users need interoperability or even interchangability of various systems. Multiplicity of reference time scales is not helping.

Louis Essen :

"…… In 1960s there was a suggestion that astronomical time should be used for sea navigation and domestic purposes, and atomic time for air navigation and scientific work. My experiences with time signals and standard frequency transmissions convinced me that this would cause endless confusion as well as involving duplication of equipment and I argued strongly that a method of combining all the information in one set of transmission must be found….."


THANK YOU!