Status report on TAI

E.Felicitas Arias

7th Meeting of representatives of laboratories contributing to TAI

BIPM, Sèvres, 12 – 13 September 2006

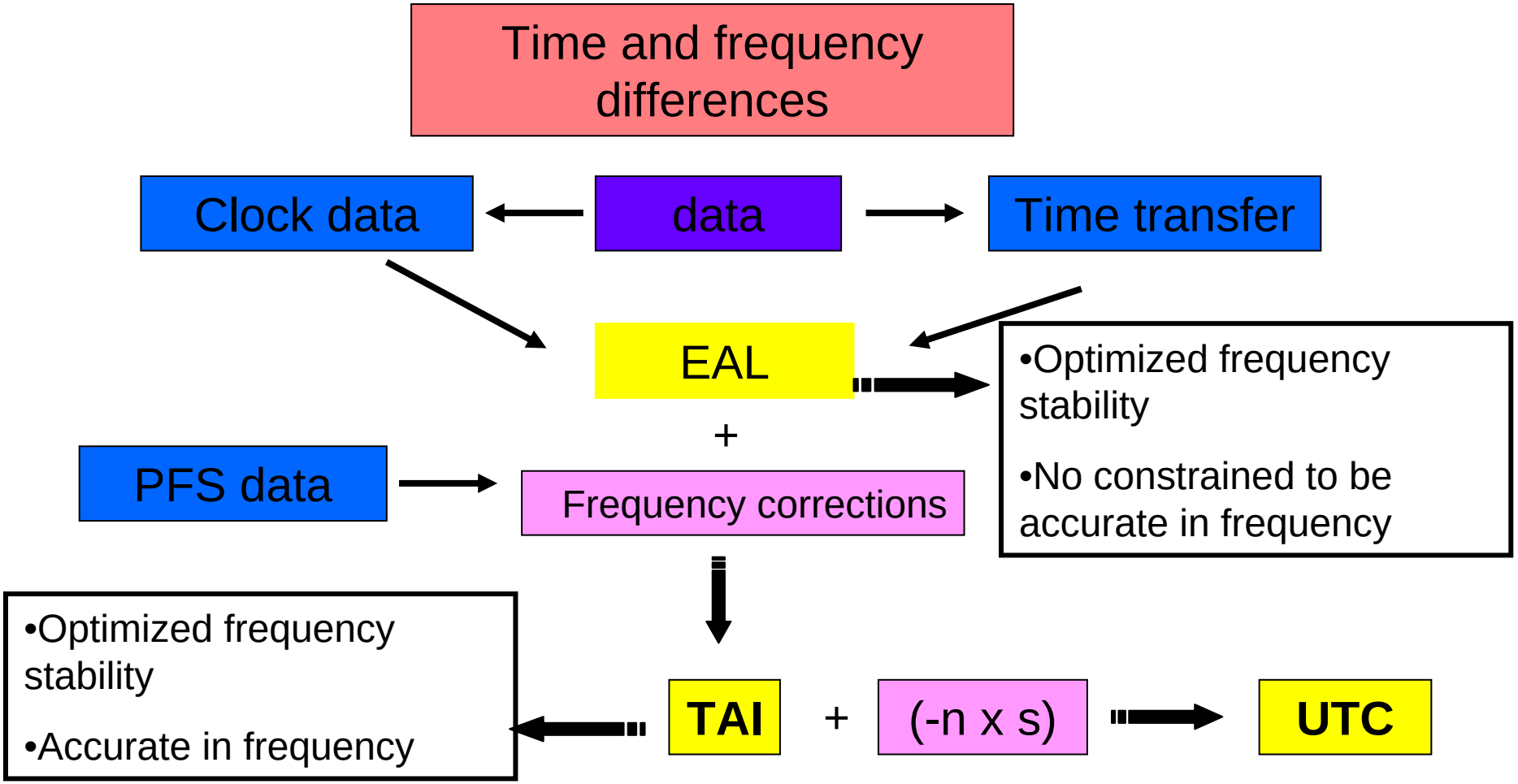
General organization
Time, frequency and gravimetry section since 1 January 2006

- Staff
  - E. Felicitas Arias (Head)
  - Wlodzdimierz Lewandowski
  - Raymond Felder
  - Zhiehng Jiang
  - Hawaï Konaté
  - Jacques Labot
  - Gérard Petit
  - Lennart Robertsson
  - Laurent Tisserand
  - Leonid Vitushkin
  - Peter Wolf

Characteristics and metrologic quality of TAI/UTC

- ✓ Atomic time scales
- ✓ TAI is continuous; UTC has 1-second discontinuities (leap seconds),
    - IERS monitors the Earth rotation and announces the dates of application of leap seconds
- ✓ Calculated in post-real time (~10 days after the last date of data)
- ✓ Frequency stability (4×10^{-16} @40 days)
- ✓ Unit: SI second
- ✓ Frequency accuracy ($\sim 10^{-15}$)
- ✓ UTC has local approximations UTC(k), disseminated by time signals
- ✓ UTC is the basis of legal times
- ✓ TAI is a frequency reference

Process of calculation



Contributors to TAI

- 58 time laboratories in NMIs and observatories
- 38 countries
  - 34 member states of the Metre Convention
  - 4 associates to the CGPM
- Laboratories maintain local realizations of UTC, named UTC(k)
  - UTC(k) represented by a clock
  - UTC(k) derived from a clock ensemble

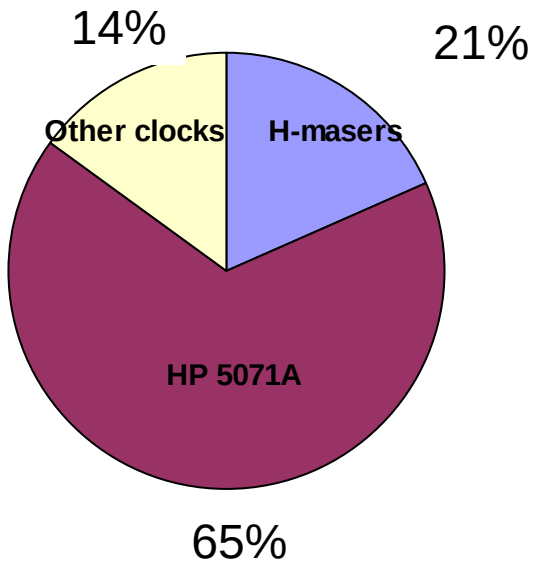
Clocks in TAI

- Participating clocks
  - ~ 300
  - 10% of clocks does not participate
  - in a month
- Type of clocks

	Stability	Accuracy
Cs standard (st. tube)	5×10^{-14} @ 5 days	1×10^{-12}
Cs standard (high perf.)	1×10^{-14} @ 5 days	5×10^{-13}
H- maser (active)	$< 2 \times 10^{-16}$ @ 1 day	

Clocks (cont.)

Participating clocks 2006



Relative weights

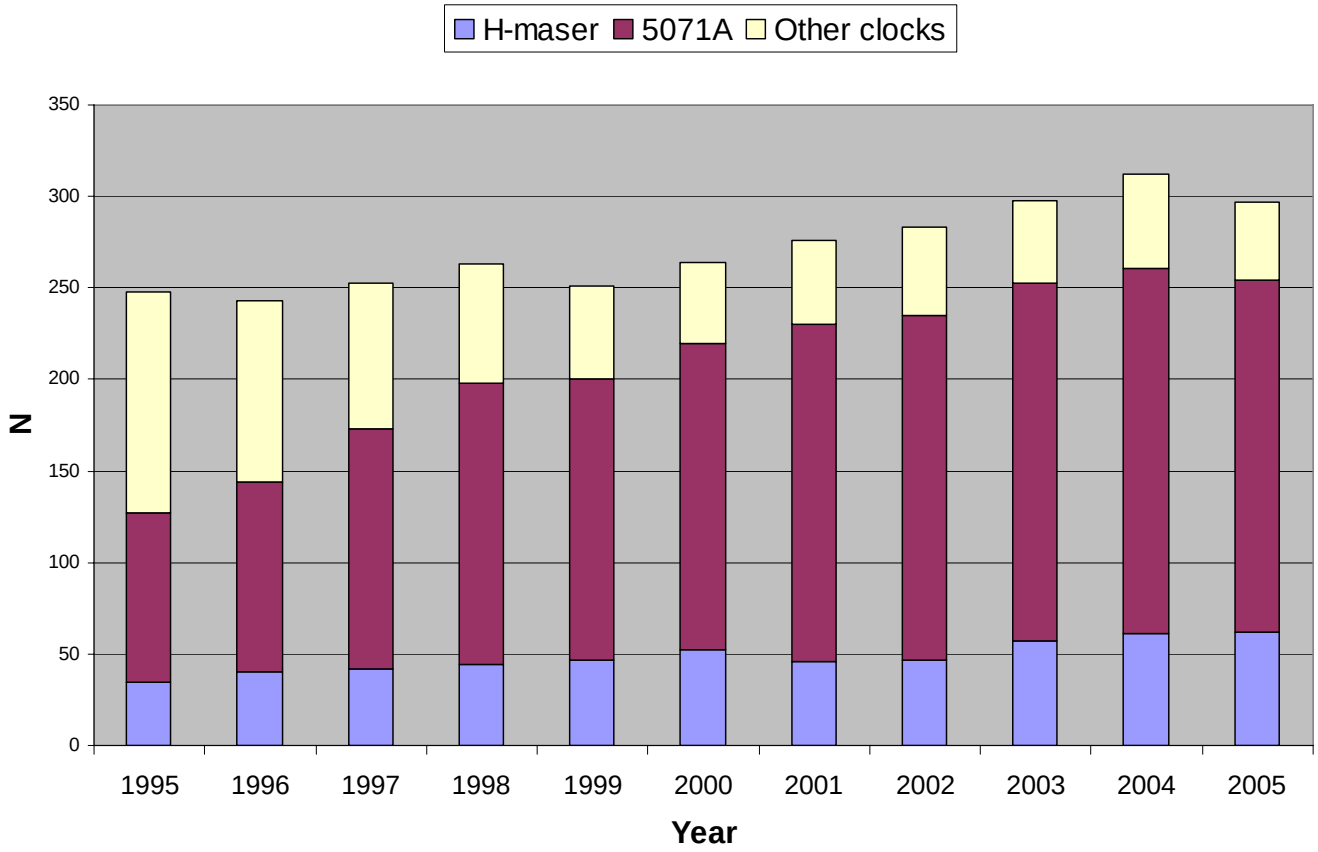
$\omega_{max} = 2.5 / N$

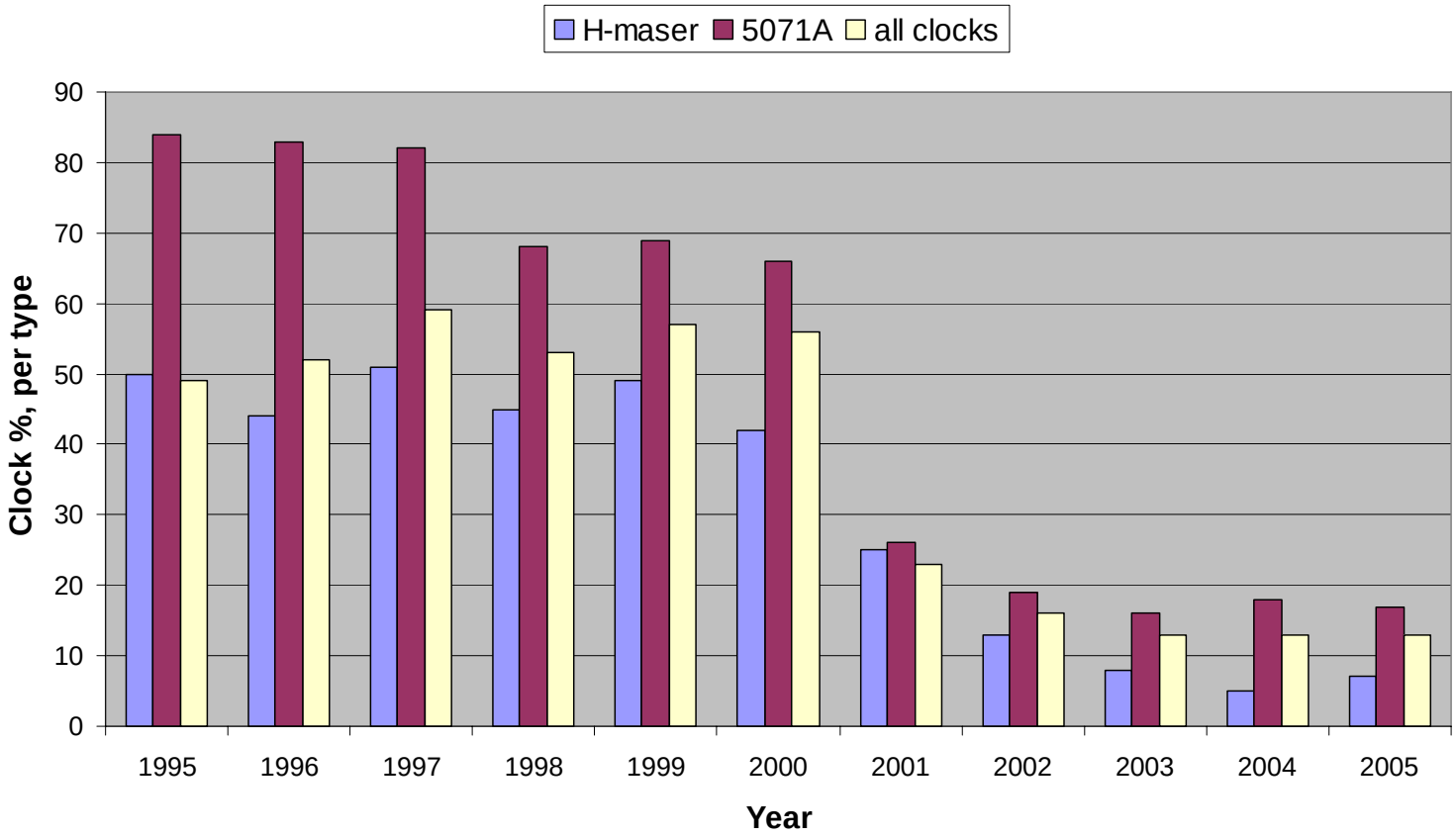
13% of clocks

17% of HP5071A

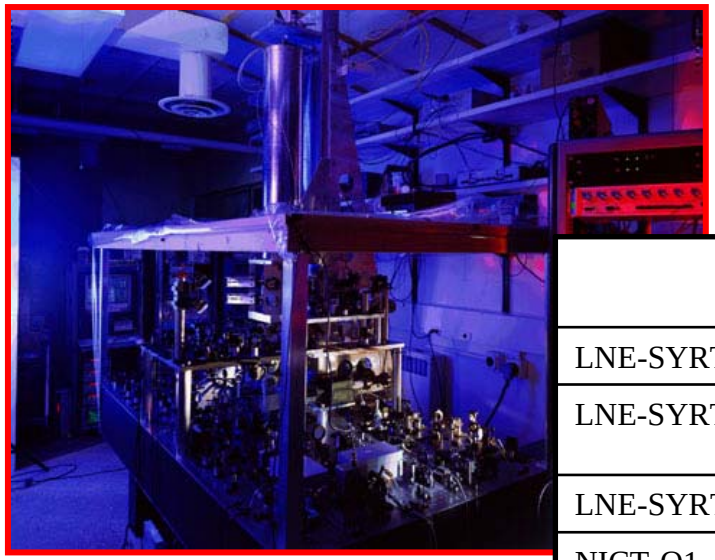
7% of H-masers

$\sigma_{min} = 6 \times 10^{-15}$


H-maser
5071A
Other clocks
350
300
250
200
150
100
50
0
N
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
Year

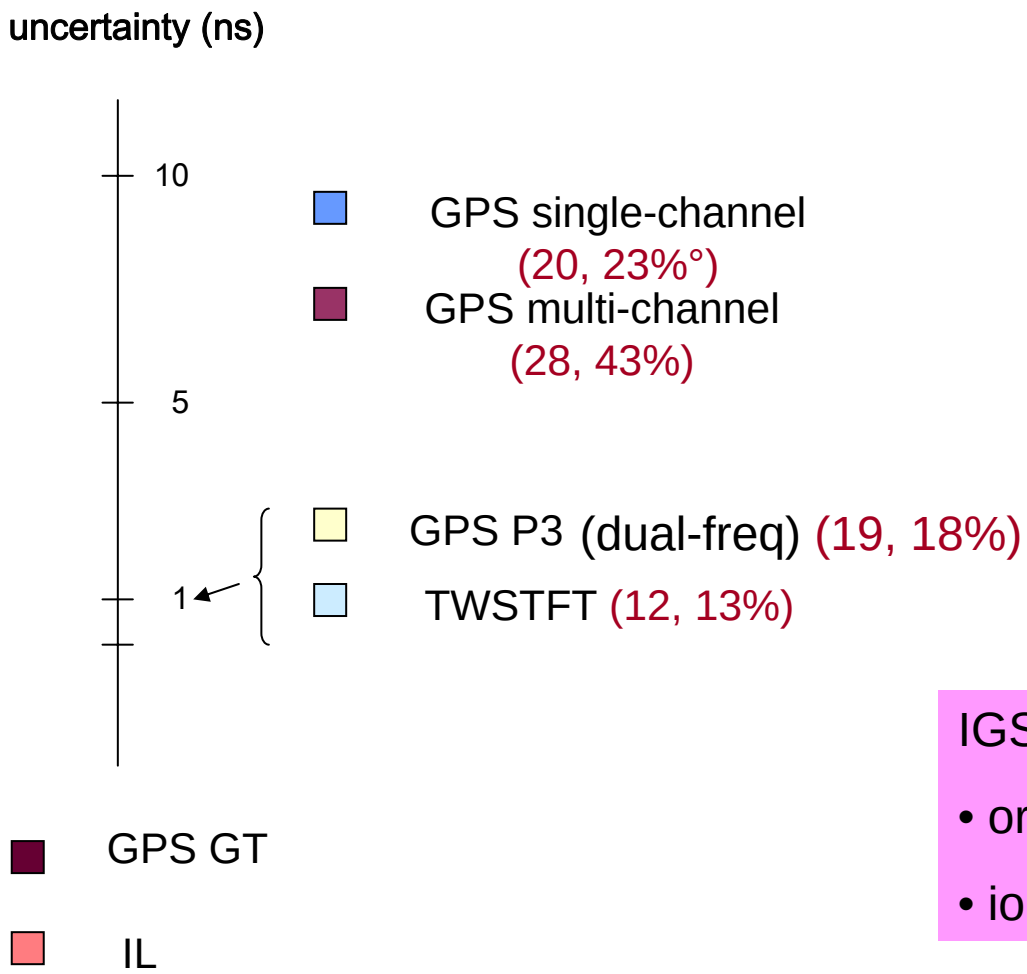

H-maser
5071A
all clocks
Clock %, per type
90
80
70
60
50
40
30
20
10
0
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
Year

Primary frequency standards in TAI



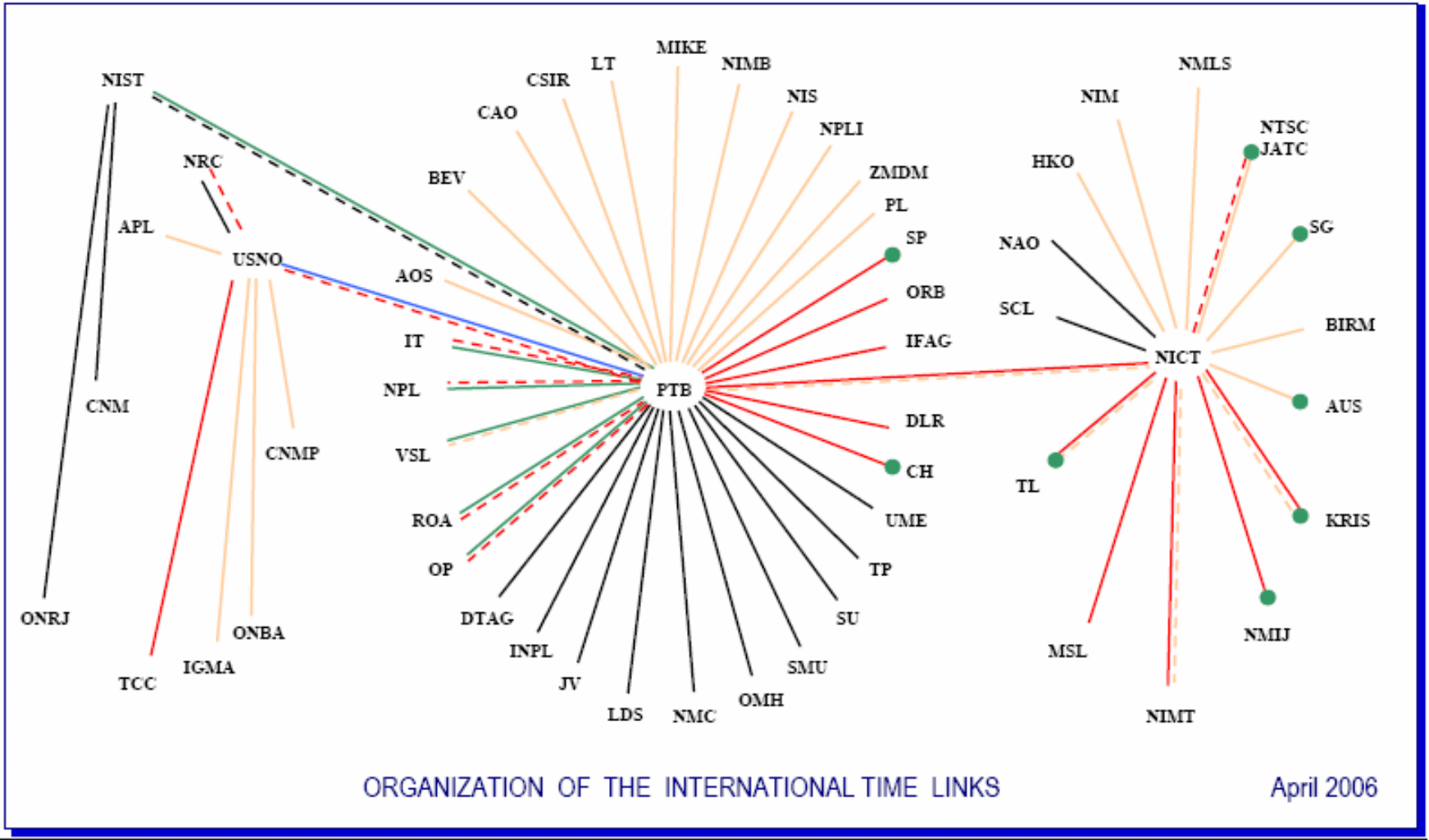
PFS	Type	$u_B \times 10^{15}$
LNE-SYRTE-FO2	Cs/Rb double fountain	0.7
LNE-SYRTE-FOM	Cs fountain	1.1
LNE-SYRTE-JPO	Optically pumped Cs beam	6.4
NICT-O1	Optically pumped Cs beam	5.5
IEN-CSF1	Cs fountain	1.0
NIST-F1	Cs fountain	0.4
PTB-CS1	Magnetically defl. Cs beam	8.
PTB-CS2	Magnetically defl. Cs beam	12.
PTB-CSF1	Cs fountain	2.6
NPL-CSF1	Cs fountain	1.0
NMIJ-F1	Cs fountain	4.0

Clock comparison



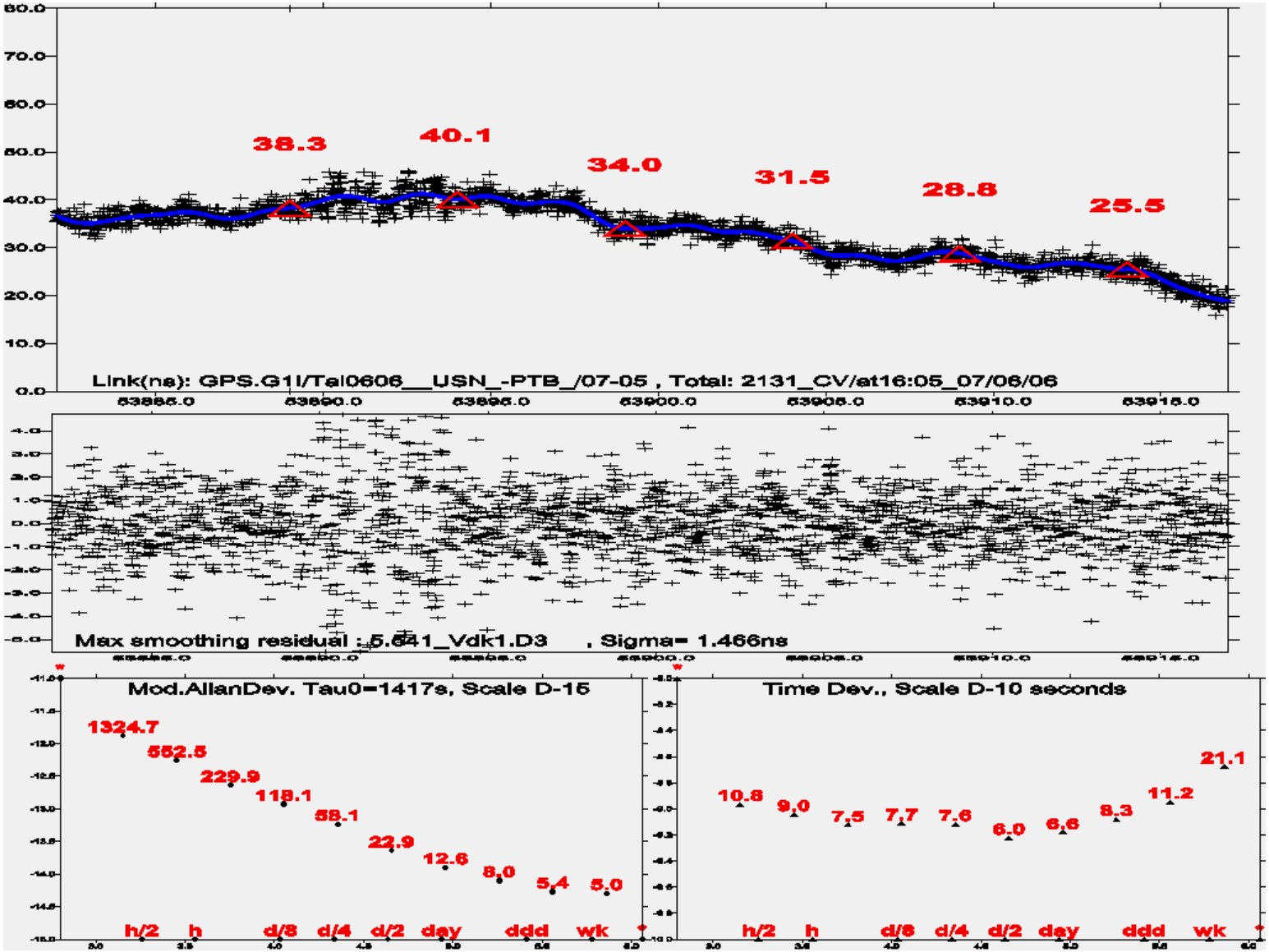
IGS products

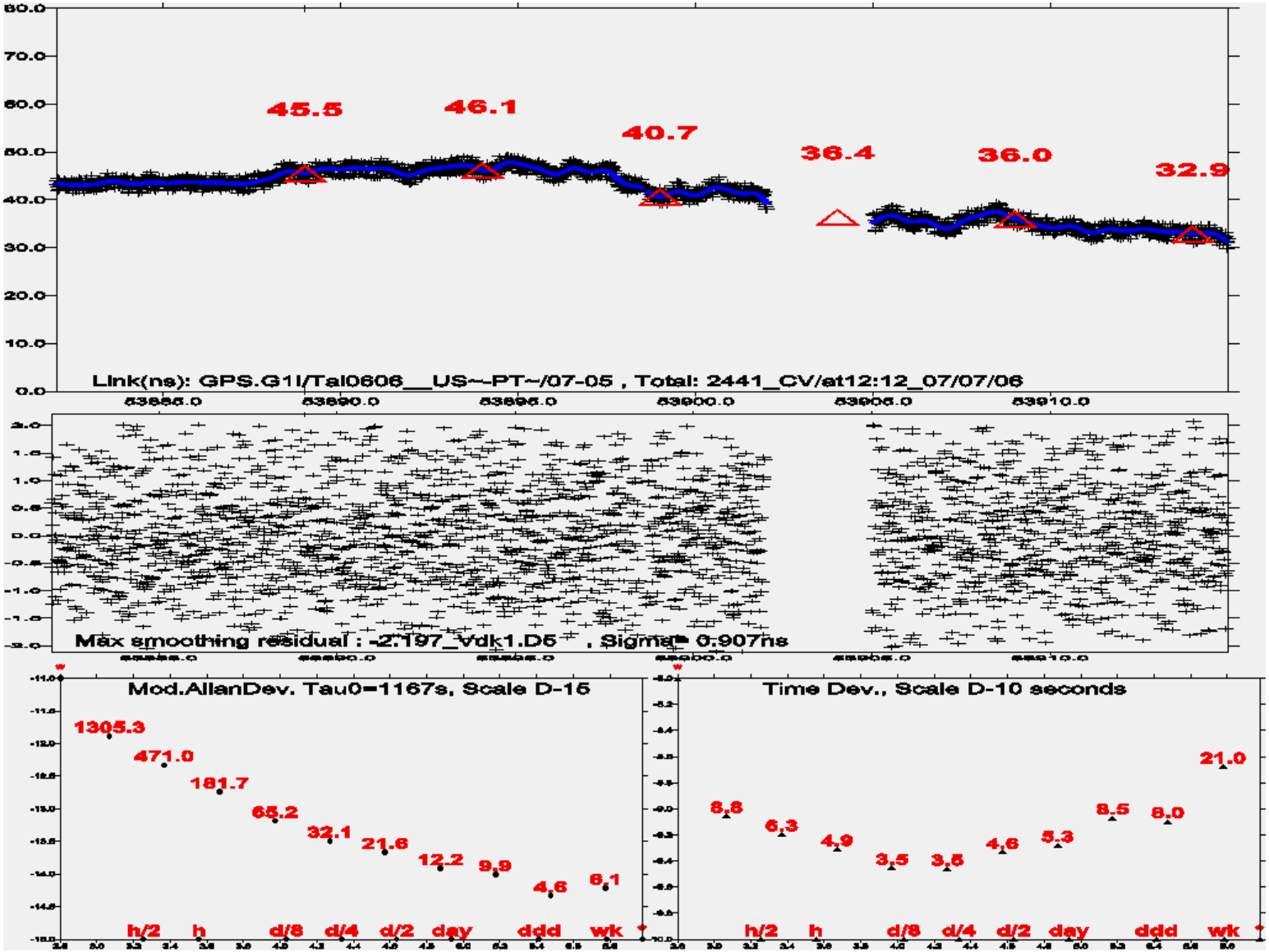
- orbits
- ionosphere

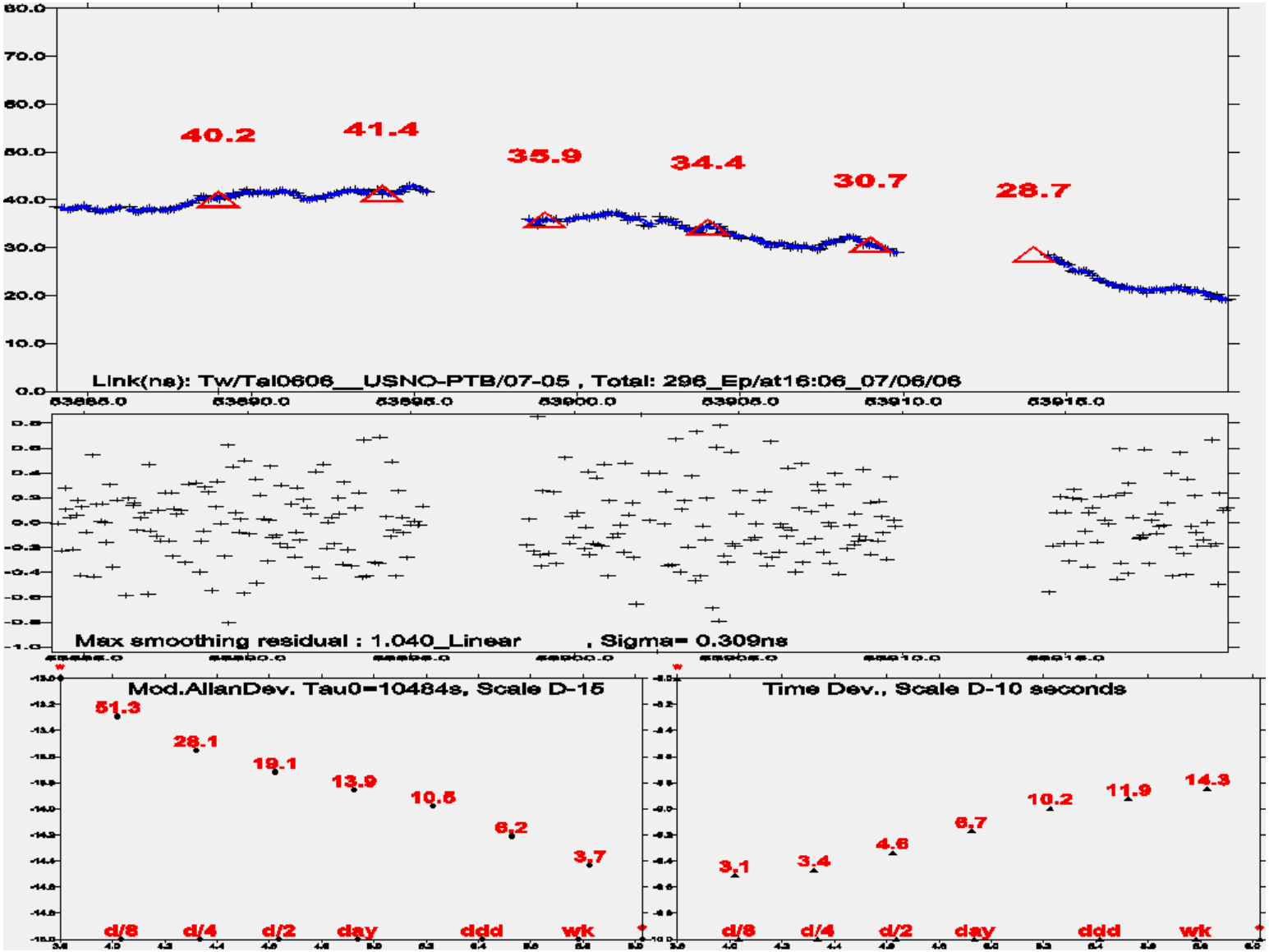

NIST
NRC
APL
USNO
CNM
ONRJ
TCC
IGMA
ONBA
CNMP
MIKE
LT
CSIR
NIMB
CAO
NIS
NPLI
BEV
ZMDM
PL
SP
AOS
ORB
IT
IFAG
NPL
PTB
VSL
DLR
CH
ROA
UME
OP
TP
DTAG
SU
INPL
SMU
JV
OMH
LDS
NMC
NMLS
NIM
NTSC
JATC
HKO
SG
NAO
SCL
BIRM
NICT
AUS
TL
KRIS
NMIJ
MSL
NIMT
ORGANIZATION OF THE INTERNATIONAL TIME LINKS
April 2006
Laboratory equipped with TWSTFT (not yet used)
TWSTFT by Ku band with X band back-up
TWSTFT link
GPS CV single-channel link
GPS CV single-channel back-up link
GPS CV multi-channel link
GPS CV multi-channel back-up link
GPS CV dual frequency link
GPS CV dual frequency back-up link
BIPM

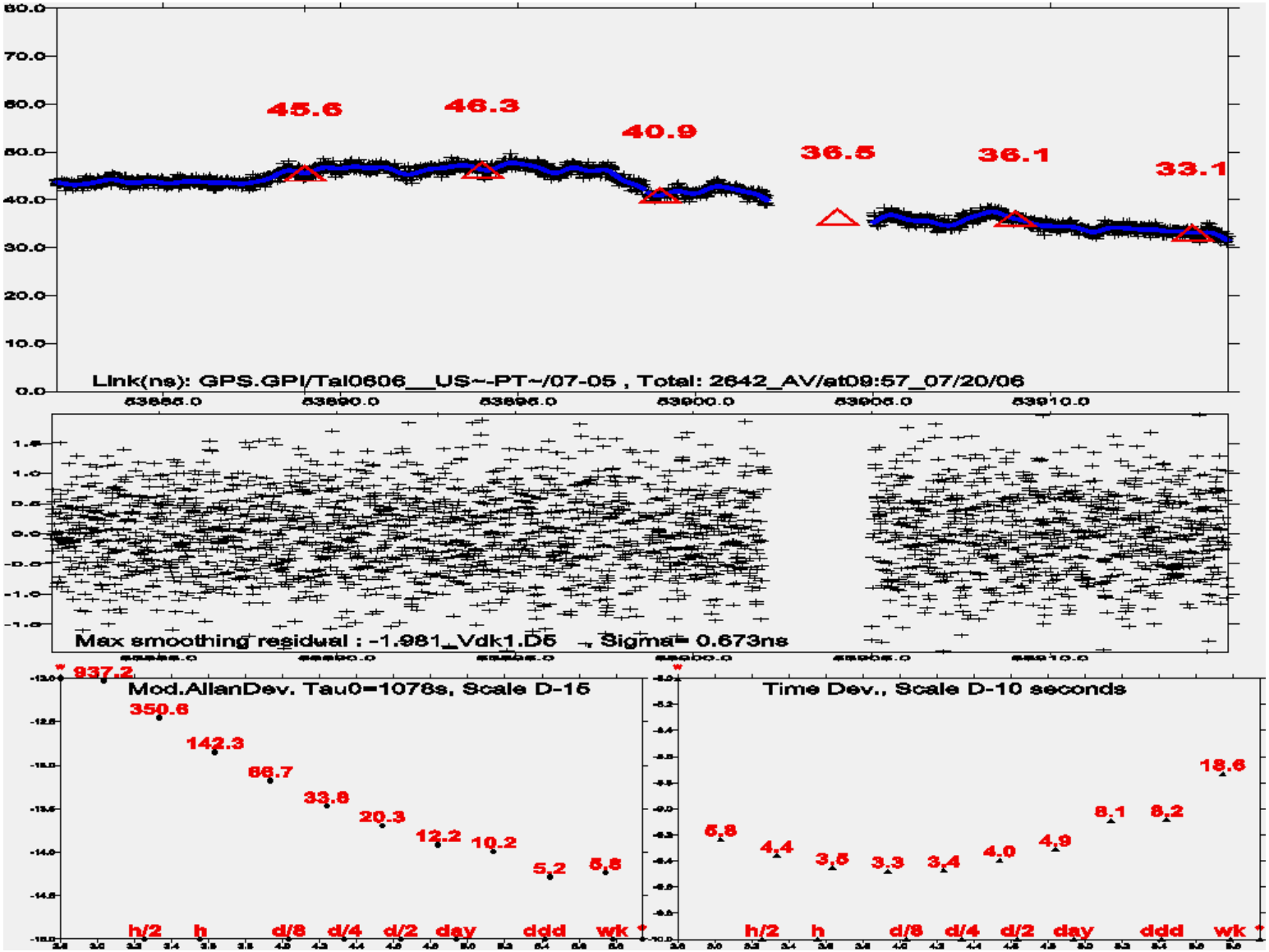
Progress in the period 2004-2006

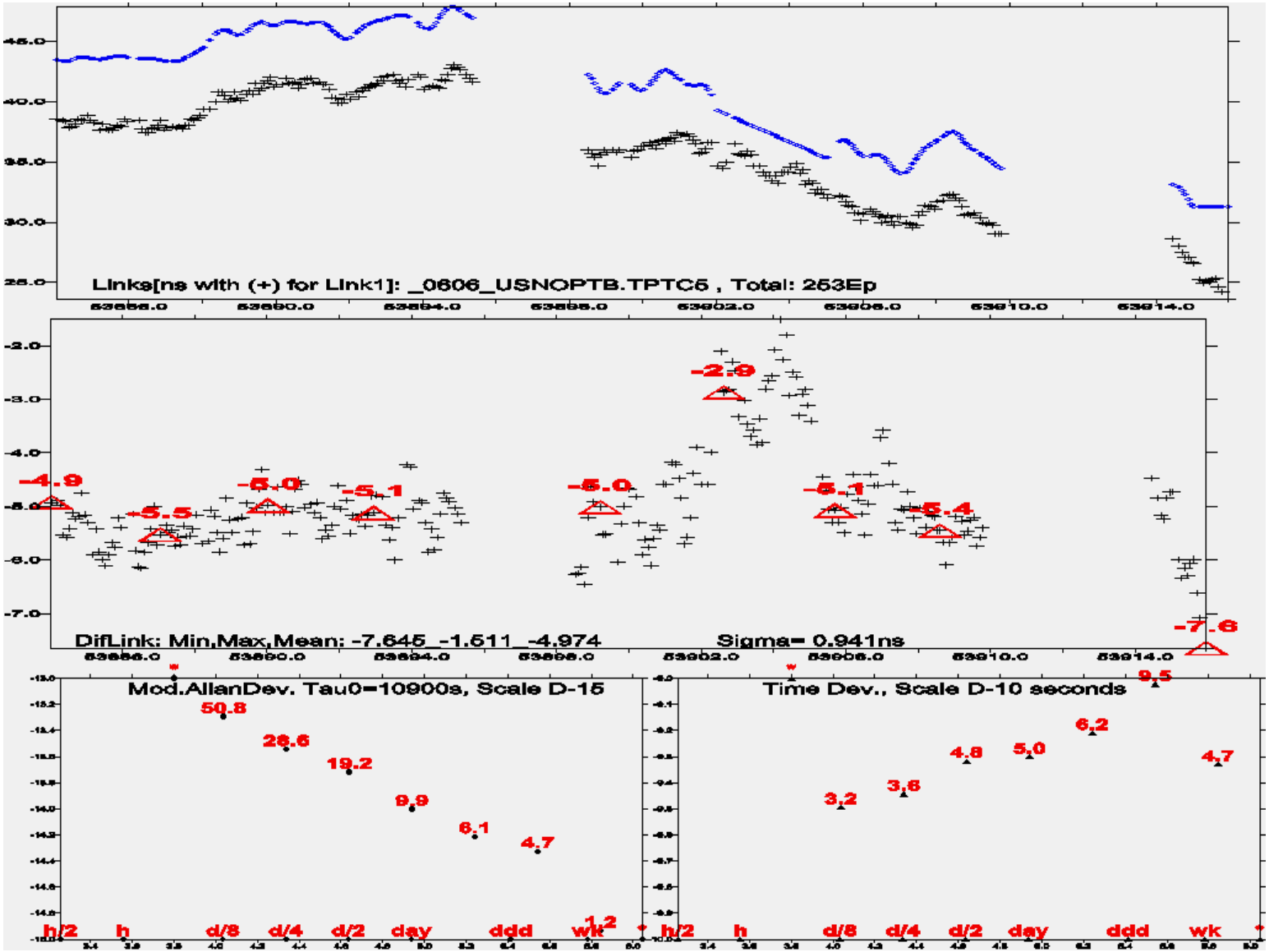
- Techniques and methods of time transfer
  - GPS single-frequency
  - GPS dual-frequency
  - TWSTFT
  - GPS satellites common-views / GPS all-in-view
  - Baselines with multiple techniques
  - Comparison of techniques / methods
  - GPS equipment calibration (single and dual-frequency)
  - Publication of link comparison results on ftp


38.3
40.1
34.0
31.5
28.8
25.5
Link(ns): GPS.G1I/Tai0606__USN_-PTB_/07-05 , Total: 2131_CV/at16:05_07/06/06
Max smoothing residual : 5.641_Vdk1.D3 , Sigma= 1.466ns
Mod.AllanDev. Tau0=1417s, Scale D-15
1324.7
552.5
229.9
118.1
58.1
22.9
12.6
8.0
5.4
5.0
h/2
h
d/8
d/4
d/2
day
ddd
wk
Time Dev., Scale D-10 seconds
10.8
9.0
7.5
7.7
7.6
6.0
6.6
8.3
11.2
21.1
h/2
h
d/8
d/4
d/2
day
ddd
wk


45.5
46.1
40.7
36.4
36.0
32.9
Link(ns): GPS.G1I/Tai0606__US~-PT~/07-05 , Total: 2441_CV/at12:12_07/07/06
Max smoothing residual : -2.197_Vdk1.D5 , Sigma= 0.907ns
Mod.AllanDev. Tau0=1167s, Scale D-16
1305.3
471.0
181.7
65.2
32.1
21.6
12.2
9.9
4.6
6.1
h/2
h
d/8
d/4
d/2
day
ddd
wk
Time Dev., Scale D-10 seconds
8.8
6.3
4.9
3.5
3.5
4.6
5.3
8.5
8.0
21.0
h/2
h
d/8
d/4
d/2
day
ddd
wk


40.2
41.4
35.9
34.4
30.7
28.7
Link(ns): Tw/Tai0606___USNO-PTB/07-05 , Total: 296_Ep/at16:06_07/06/06
Max smoothing residual : 1.040_Linear , Sigma= 0.309ns
Mod.AllanDev. Tau0=10484s, Scale D-15
51.3
28.1
19.1
13.9
10.5
6.2
3.7
d/8
d/4
d/2
day
ddd
wk
Time Dev., Scale D-10 seconds
3.1
3.4
4.6
6.7
10.2
11.9
14.3
d/8
d/4
d/2
day
ddd
wk


45.6
46.3
40.9
36.5
36.1
33.1
Link(ns): GPS.GPI/Tal0606__US~-PT~/07-05 , Total: 2642_AV/at09:57_07/20/06
Max smoothing residual : -1.981_Vdk1.D5 , Sigma= 0.673ns
937.2
Mod.AllanDev. Tau0=1078s, Scale D-16
350.6
142.3
66.7
33.8
20.3
12.2
10.2
5.2
5.8
h/2
h
d/8
d/4
d/2
day
ddd
wk
Time Dev., Scale D-10 seconds
6.8
4.4
3.5
3.3
3.4
4.0
4.9
8.1
8.2
18.6
h/2
h
d/8
d/4
d/2
day
ddd
wk


Links[ns with (+) for Link1]: _0606_USNOPTB.TPTC5 , Total: 263Ep
DifLink: Min,Max,Mean; -7.645 -1.511 -4.974
Sigma= 0.941ns
Mod.AllanDev. Tau0=10900s, Scale D-15
50.8
28.6
19.2
9.9
6.1
4.7
h/2
h
d/8
d/4
d/2
day
ddd
wk
Time Dev., Scale D-10 seconds
3.2
3.6
4.8
5.0
6.2
4.7
9.5

Progress in the triennium 2003-2006

- Uncertainties
  - Time links (published in *BIPM Circular T*)
  - [*UTC*-*UTC*(*k*)
  - Key comparison in Time (published in the BIPM Key Comparison Data Base, KCDB)

CIRCULAR T 223 ISSN 1143-1393
2006 AUGUST 10, 14h UTC

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1 - Coordinated Universal Time UTC and its local realizations UTC(k). Computed values of [*UTC-UTC(k)*] and uncertainties valid for the period of this Circular. From 2006 January 1, 0h UTC, *TAI-UTC* = 33 s.

Date 2006 0h UTC	JUN 28	JUL 3	JUL 8	JUL 13	JUL 18	JUL 23	JUL 28	Uncertainty/ns			Notes
MJD	53914	53919	53924	53929	53934	53939	53944	u_A	u_B	u	
Laboratory *k*				[*UTC-UTC(k)*]/ns							
AOS (Borowiec)	5.2	9.3	3.3	6.2	10.6	7.1	9.9	1.6	5.3	5.5	
APL (Laurel)	0.8	4.6	-0.7	-3.4	-4.3	3.7	15.4	1.6	5.2	5.4	
AUS (Sydney)	-529.0	-498.6	-490.1	-489.2	-475.2	-445.1	-437.4	3.2	6.3	7.1	
BEV (Wien)	97.9	100.7	102.9	105.2	111.6	110.5	112.1	1.6	5.2	5.4	
BIRM (Beijing)	-1874.4	-1893.8	-1898.2	-1913.1	-1930.8	-1946.6	-1964.5	2.8	20.4	20.6	
CAO (Cagliari)	-1311.8	-1311.0	-1277.8	-1245.6	-1246.1	-1222.6	-	1.6	7.2	7.4	
CH (Bern)	30.9	31.3	36.1	32.2	29.9	25.1	21.5	0.8	5.2	5.3	
CNM (Queretaro)	-13.5	-9.4	-8.4	-4.0	-5.7	-4.0	-3.3	5.0	20.4	21.0	
CNMP (Panama)	-5216.4	-5254.9	-5275.9	-5297.4	-5324.9	-5352.0	-5371.2	4.0	7.2	8.2	
CSIR (Pretoria)	65.9	1.0	-57.2	-125.3	-192.5	-263.5	-354.8	3.0	20.1	20.3	
DLR (Oberpfaffenhofen)	.	.	.	.	.	.	.				
DTAG (Darmstadt)	-70.8	-77.8	-79.2	-75.4	-92.5	-90.7	-88.4	3.0	10.1	10.5	
HKO (Hong Kong)	133.5	125.4	128.1	126.1	116.2	112.6	105.6	3.2	6.3	7.1	
IFAG (Wettzell)	-27.0	-5.9	-502.8	-503.1	-500.0	-491.1	-473.8	2.5	5.2	5.8	(1)
IGMA (Buenos Aires)	.	.	.	.	.	.	.				
INPL (Jerusalem)	154.9	161.2	182.4	182.8	183.8	185.0	190.6	4.0	10.1	10.9	
IT (Torino)	-5.0	-5.2	-3.4	-4.6	-3.6	-2.8	-1.1	0.7	2.2	2.3	
JATC (Lintong)	-3.3	-8.3	-6.4	-6.2	-6.4	-10.2	-14.3	2.6	20.9	21.1	
JV (Kjeller)	-3696.8	-3646.7	-3596.5	-3555.1	-3479.9	-3420.4	-3374.6	5.0	20.0	20.6	
KRIS (Daejeon)	-14.6	-5.4	-4.0	-8.2	-1.6	2.2	-0.3	1.4	6.3	6.5	
LDS (Leeds)	5331.2	5348.0	5377.0	5418.9	5451.3	5491.8	5524.4	3.0	20.0	20.2	
LT (Vilnius)	147.0	153.3	145.7	138.2	149.2	161.1	143.2	1.6	5.3	5.5	
MIKE (Espoo)	-109.1	-111.9	-127.6	-143.2	-163.6	-182.5	-141.6	5.0	19.9	20.5	
MSL (Lower Hutt)	35.7	37.5	9.6	26.6	34.4	26.5	30.3	2.3	20.3	20.5	
NAO (Mizusawa)	214.0	218.4	210.4	207.7	213.4	218.2	223.1	3.1	19.8	20.0	
NICT (Tokyo)	-8.1	-11.4	-7.6	-8.1	-5.8	-5.2	-0.7	1.2	3.9	4.1	
NIM (Beijing)	-53.7	-50.0	-49.9	-48.6	-49.0	-48.0	-45.4	3.2	20.2	20.4	
NIMB (Bucharest)	-875.1	-885.2	-886.6	-897.3	-892.8	-899.6	-904.7	2.5	20.0	20.1	
NIMT (Bangkok)	-1149.6	-1146.4	-1143.6	-1146.8	-1144.0	-1142.3	-1147.8	1.5	20.4	20.4	
NIS (Cairo)	-2.4	-3.9	-2.7	-6.4	-7.7	-8.7	-12.4	1.6	7.2	7.4	

6 - Time links used for the computation of TAI and their uncertainties.

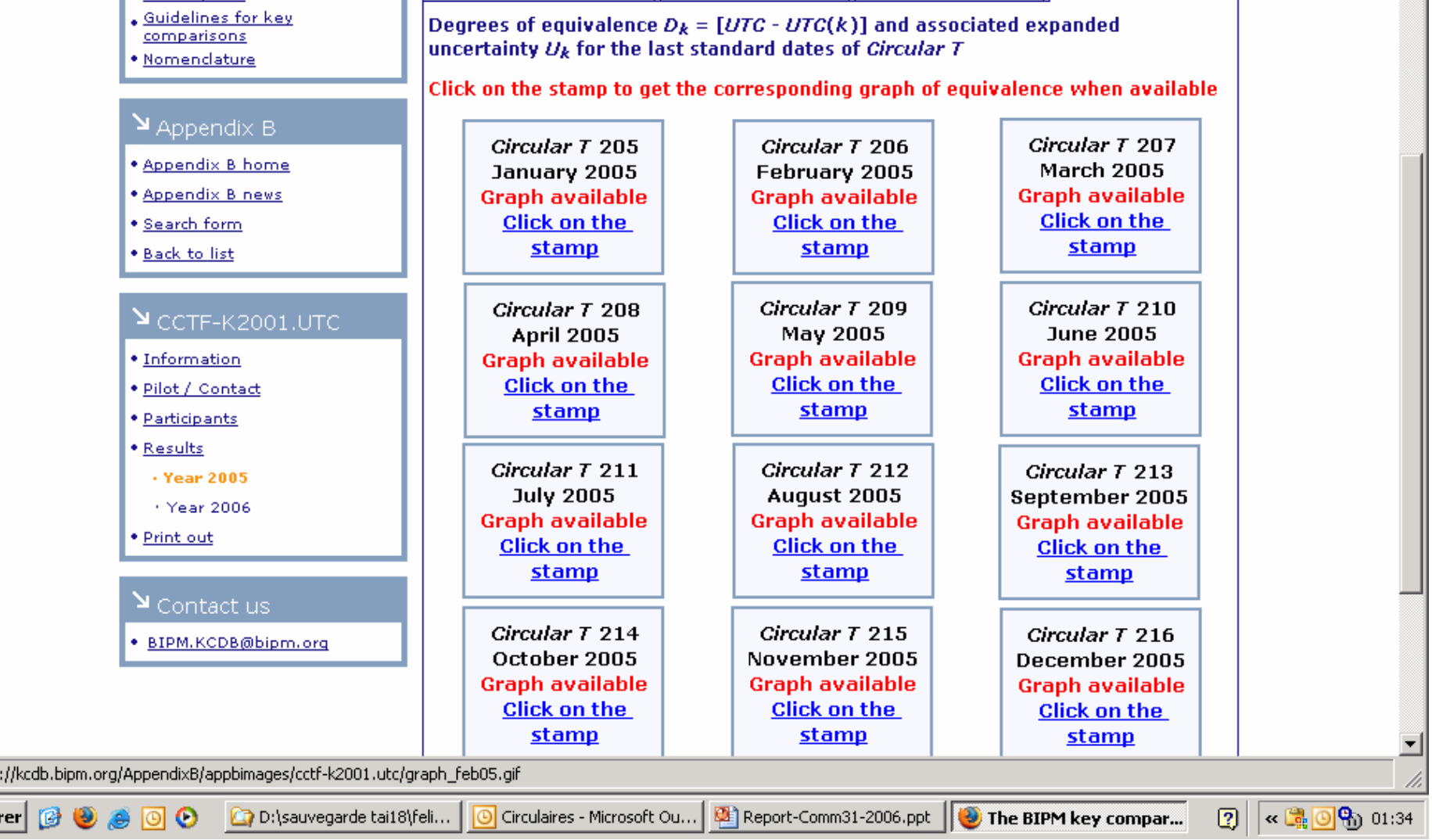
The time links used in the elaboration of this Circular T are listed in this section. The technique for the link is indicated as follows: GPS SC for GPS common-view single-channel C/A data; GPS MC for GPS common-view multi-channel C/A data; GPS P3 for GPS common-view multi-channel dual-frequency P code data; GPS GT for 'GPS time' observations; INT LK for internal cable link and TWSTFT for two-way satellite time and frequency transfer data.

For each link, the following uncertainties are provided: u_A is the statistical uncertainty evaluated by taking into account the level of phase noise in the raw data, the interpolation interval between data points and the effects with typical duration between 5 and 30 days. u_B is the estimated uncertainty on the calibration.

The calibration type of the link is indicated as: GPS EC for GPS equipment calibration; TW EC for two-way equipment calibration; LC (technique) for a link calibrated using 'technique'; BC (technique) for a link calibrated using 'technique' to transfer a past equipment calibration through a discontinuity of link operation.

The calibration dates indicate: the most recent calibration results for the two laboratories in the case of EC and
the most recent calibration of the link in the case of LC and BC,
NA stands for not available, in this case estimated values are provided

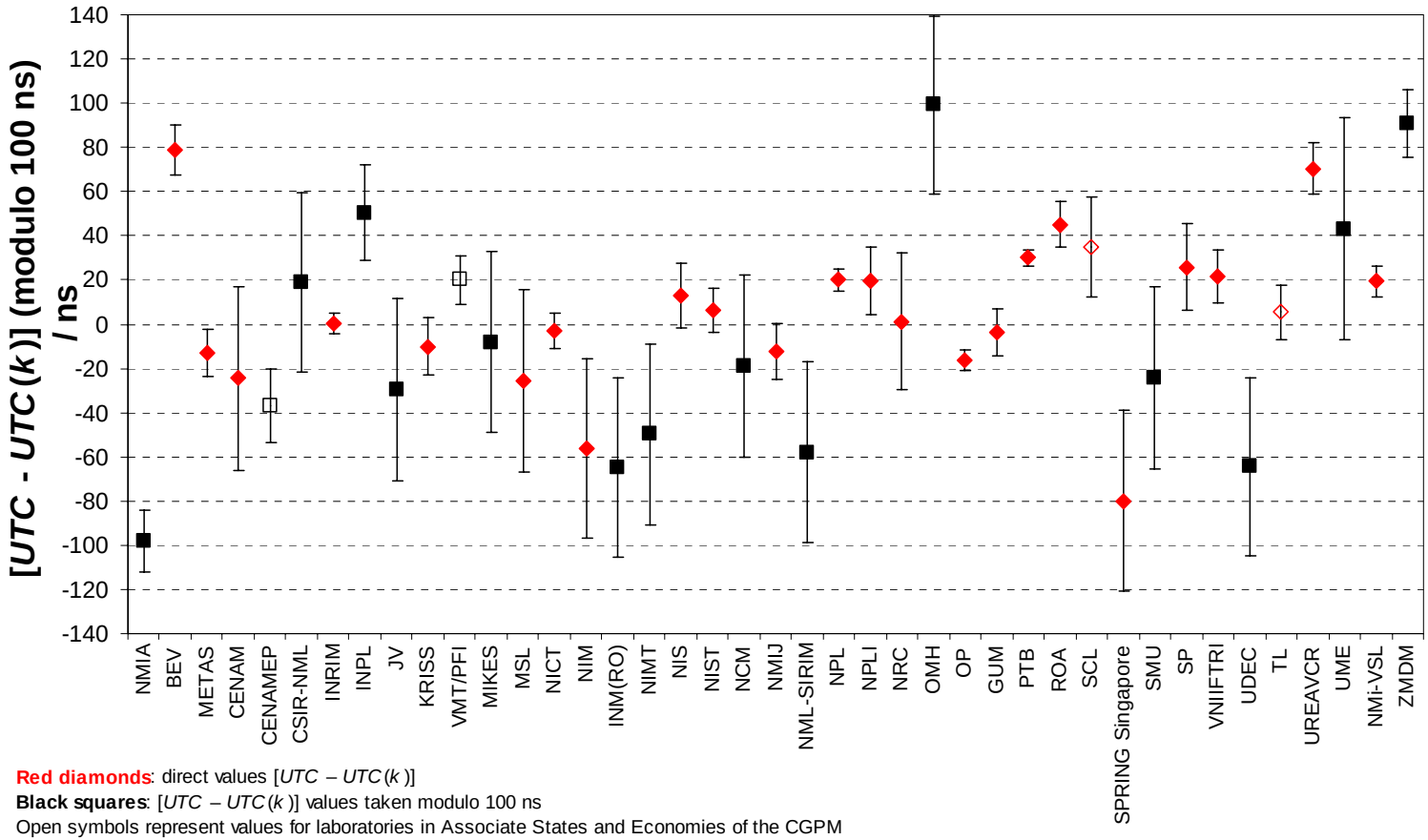
Link	Type	u_A/ns	u_B/ns	Calibration Type	Calibration Dates
AOS /PTB	GPS MC	1.5	5.0	GPS EC /GPS EC	2003 Sep/2003 Aug
APL /USNO	GPS MC	1.5	5.0	GPS EC /GPS EC	2003 Dec/2003 Dec
AUS /NICT	GPS MC	3.0	5.0	GPS EC/GPS EC	2002 Sep/2003 Nov
BEV /PTB	GPS MC	1.5	5.0	GPS EC/GPS EC	2001 Dec/2003 Aug
BIRM/NICT	GPS MC	2.5	20.0	NA /GPS EC	NA /2003 Nov
CAO /PTB	GPS MC	1.5	7.0	GPS EC/GPS EC	2004 Nov/2003 Aug
CH /PTB	GPS P3	0.7	5.0	GPS EC/GPS EC	2004 Nov/2004 Aug
CNM /NIST	GPS SC	5.0	20.0	NA /GPS EC	NA /2003 Dec
CNMP/USNO	GPS MC	4.0	7.0	GPS EC/GPS EC	2002 Oct/2003 Dec
CSIR/PTB	GPS MC	3.0	20.0	NA /GPS EC	NA /2003 Aug
DLR /PTB	NA				
DTAG/PTB	GPS SC	3.0	10.0	GPS EC/GPS EC	1998 May/2003 Aug
HKO /NICT	GPS MC	3.0	5.0	GPS EC/GPS EC	2004 Apr/2003 Nov
IFAG/PTB	GPS SC	2.5	5.0	GPS EC/GPS EC	2003 Jun/2003 Aug
IGMA/USNO	NA				
INPL/PTB	GPS SC	4.0	10.0	GPS EC/GPS EC	1987 Jun/2003 Jun
IT /PTB	TWSTFT	0.5	1.5	BC (TWSTFT)	2005 May
JATC/NTSC	INT LK	0.2	20.0	NA	NA
JV /PTB	GPS GT	5.0	20.0	NA /GPS EC	NA /2003 Aug
KRIS/NICT	GPS P3	0.7	5.0	GPS EC/GPS EC	2005 Aug/2005 Jun


Guidelines for key comparisons
Nomenclature
Appendix B
Appendix B home
Appendix B news
Search form
Back to list
CCTF-K2001.UTC
Information
Pilot / Contact
Participants
Results
Year 2005
Year 2006
Print out
Contact us
BIPM.KCDB@bipm.org
Degrees of equivalence D_k = [UTC - UTC(k)] and associated expanded uncertainty U_k for the last standard dates of Circular T
Click on the stamp to get the corresponding graph of equivalence when available
Circular T 205 January 2005 Graph available Click on the stamp
Circular T 206 February 2005 Graph available Click on the stamp
Circular T 207 March 2005 Graph available Click on the stamp
Circular T 208 April 2005 Graph available Click on the stamp
Circular T 209 May 2005 Graph available Click on the stamp
Circular T 210 June 2005 Graph available Click on the stamp
Circular T 211 July 2005 Graph available Click on the stamp
Circular T 212 August 2005 Graph available Click on the stamp
Circular T 213 September 2005 Graph available Click on the stamp
Circular T 214 October 2005 Graph available Click on the stamp
Circular T 215 November 2005 Graph available Click on the stamp
Circular T 216 December 2005 Graph available Click on the stamp
://kcdb.bipm.org/AppendixB/appbimages/cctf-k2001.utc/graph_feb05.gif
D:\sauvegarde tai18\feli...
Circulaires - Microsoft Ou...
Report-Comm31-2006.ppt
The BIPM key compar...
01:34

CCTF-K2001.UTC Calculation of UTC

Degrees of equivalence: [*UTC* - *UTC*(*k*)] and its expanded uncertainty ($U_k = 2u_k$)

Computed values for 29 May 2006 at 0h UTC, MJD = 53884



Red diamonds: direct values [*UTC* – *UTC*(*k*)]

Black squares: [*UTC* – *UTC*(*k*)] values taken modulo 100 ns

Open symbols represent values for laboratories in Associate States and Economies of the CGPM

Progress in the triennium 2003-2006

- TAI accuracy
  - 11 primary frequency standards contributing
  - 7 caesium fountains
  - Reports of measurements with more frequency
  - New frequency steering strategy to pilot the frequency of TAI
  - Secondary representations of the second
    - Micro-wave (Rb) - recommended
    - Optical (Sr^+, Hg^+, Yb^+, neutral Sr) – to be submitted to the CCTF

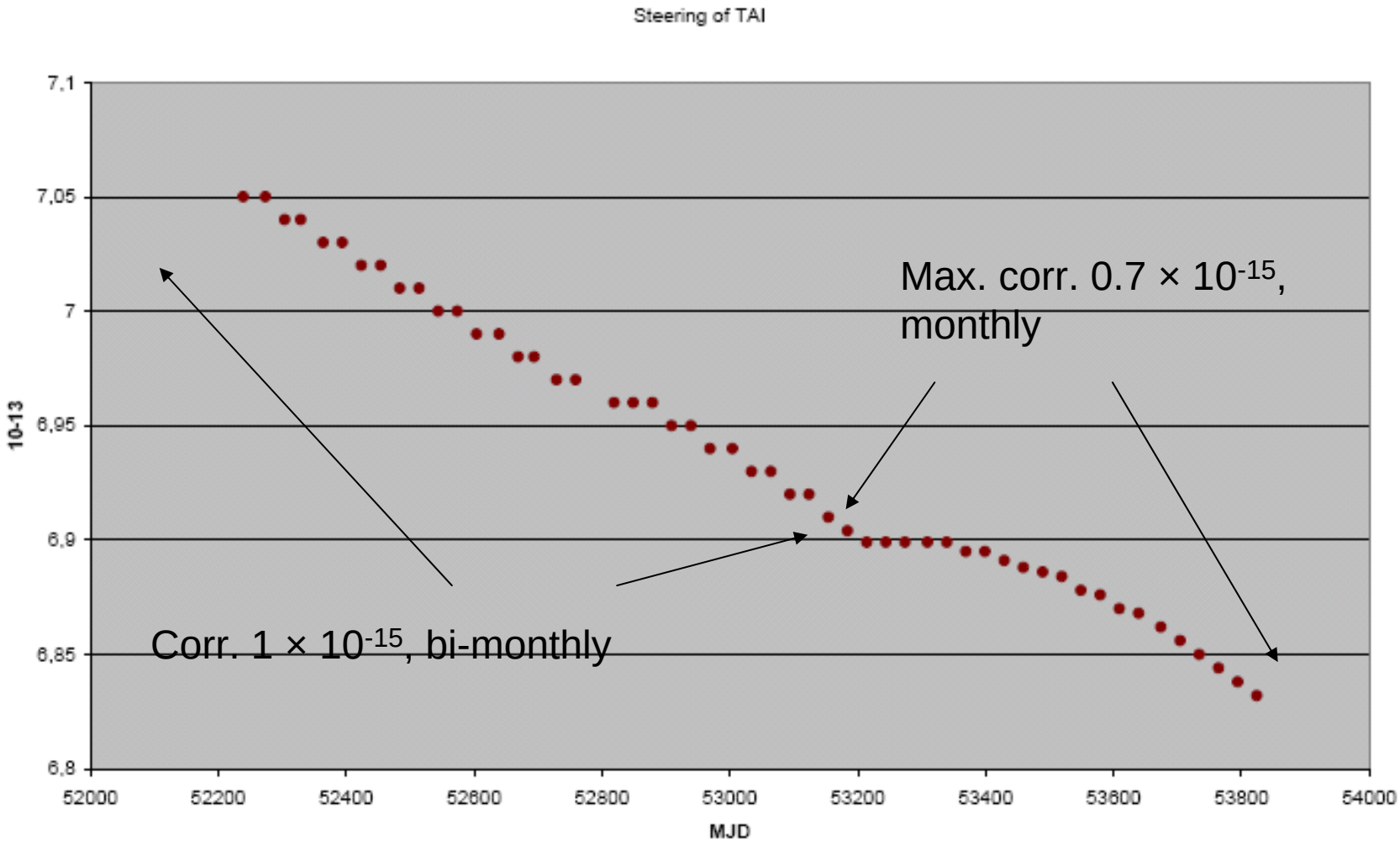
- **Frequency steering**

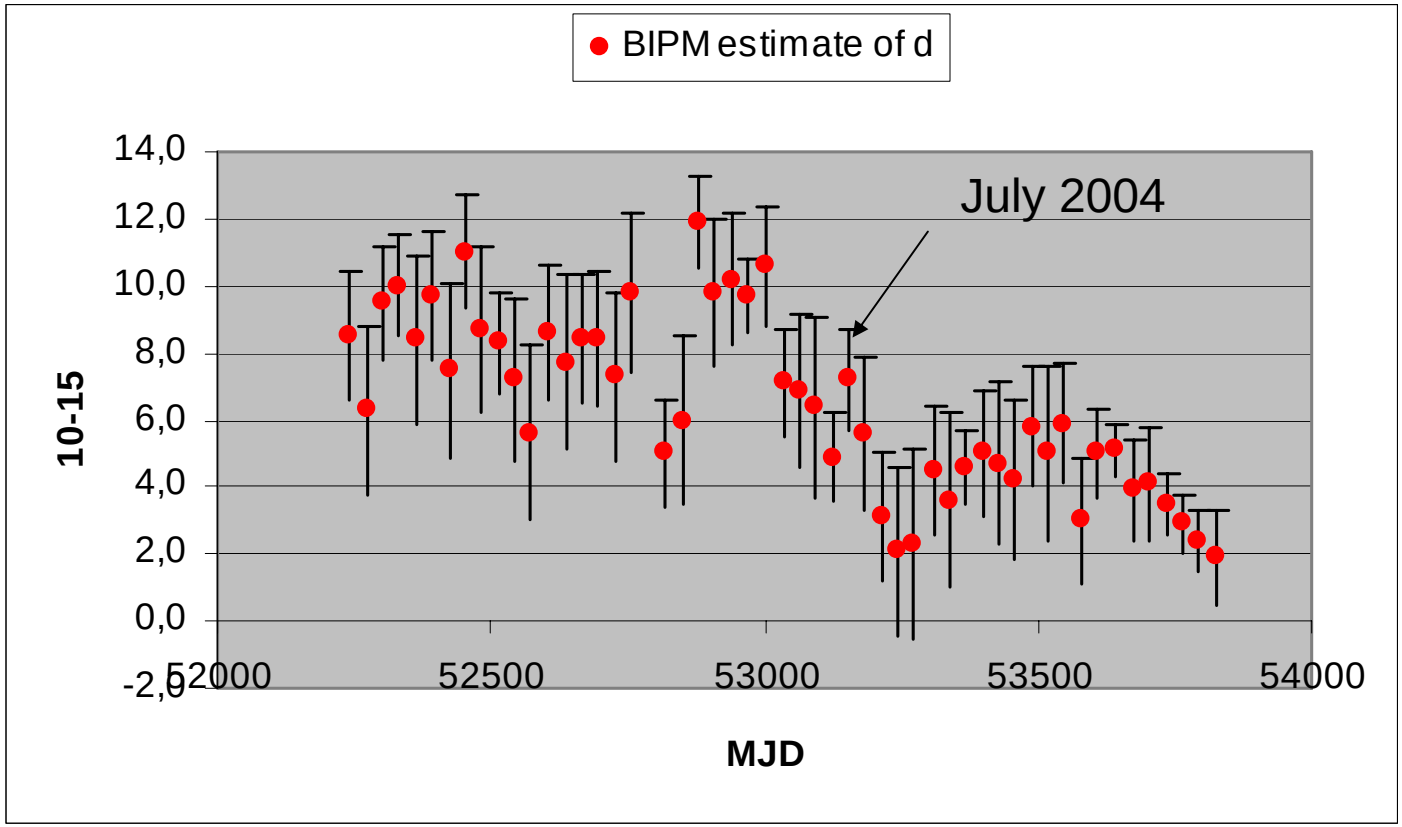
  Apply a frequency correction to assure the accuracy of the scale

  f(TAI) = f(EAL) + corr (steering, pilotage)

- since 1997 corr = -1×10^{-15} every two months

- since july 2004 $corr_{max} = -0.7 \times 10^{-15}$ monthly


Steering of TAI
7,1
7,05
7
6,95
6,9
6,85
6,8
10-13
52000
52200
52400
52600
52800
53000
53200
53400
53600
53800
54000
MJD
Max. corr. 0.7 × 10-15, monthly
Corr. 1 × 10-15, bi-monthly


BIPM estimate of d
July 2004
10-15
14,0
12,0
10,0
8,0
6,0
4,0
2,0
0,0
-2,0
52000
52500
53000
53500
54000
MJD

Regular publications

- BIPM Circular T, monthly
  - [*UTC* – *UTC*(*k*)] and their uncertainties
  - [*TAI*-*TA*(*k*)]
  - PFS contributions, individual values of *d*, BIPM estimation
  - [*UTC*-*GPS time*], [*UTC*-*GPS time*]
  - Type of time links, uncertainties, calibration information

- BIPM Time section Annual Report
  - Results for a year

Internet (web site / ftp)

http://www.bipm.org/jsp/en/TimeFtp.jsp

Data submission format

ftp://62.161.69.5/pub/tai/data/readme.pdf

ftp://62.161.69.5/pub/tai/data/cggtts_format_v1.pdf

ftp://62.161.69.5/pub/tai/data/cggtts_format_v2.pdf

Clock data format

- One file to be submitted on the 5th of the month,
  - clock data
  - clock step data

```
53949 10038 0020038 -757592.4 1403802 0012057.0 1403805 -259214.4
53949 10038 1403825 -756068.9 1403837 -710485.7 1403810 -245980.2
53954 10038 0020038 -757569.9 1403802 0012113.4 1403805 -258778.9
53954 10038 1403825 -755854.9 1403837 -710229.8 1403810 -245667.4
53959 10038 0020038 -757547.5 1403802 0012169.7 1403805 -258343.5
53959 10038 1403825 -755640.0 1403837 -709974.1 1403810 -245355.5
53964 10038 0020038 -757525.0 1403802 0012224.1 1403805 -257909.7
53964 10038 1403825 -755427.0 1403837 -709716.4 1403810 -245043.3
53969 10038 0020038 -757500.4 1403802 0012281.7 1403805 -257472.7
53969 10038 1403825 -755210.8 1403837 -709457.8 1403810 -244728.2
53974 10038 0020038 -757475.7 1403802 0012339.0 1403805 -257036.0
53974 10038 1403825 -754994.1 1403837 -709199.0 1403810 -244413.7
53957.21 1403822 -000005.9 00000.000    SU   10038
```

Any text should be in a separate file.

Time transfer data

- GPS files
  - CGGTTS standard format
  - Submitted weekly
- TWSTFT files
  - ITU standard format
  - Submitted with different frequency (daily, weekly,)
- Files sent by e-mail, posted on the lab's fpt, or posted at the time section ftp.
- Using ftp is strongly recommended.

Final comment

- To speed up the publication of *Circular T*, and to render the process more reliable, an automated software has been designed.

- This software is « user friendly », but in order to make a rational use if it, format respect is requested.

Wlodek Lewandoswki, 2002.