TWSTFT DATA TREATMENT FOR UTC TIME TRANSFER

Z. Jiang, W. Lewandowski, and H. Konaté

Bureau International des Poids et Mesures (BIPM)
Pavillon de Breteuil F-92312 Sèvres Cedex, France
E-mail: *zjiang@bipm.org*

Abstract

TWSTFT (TW) is the primary technique of time and frequency transfers used at BIPM for the UTC/TAI generations. At present, some 19 laboratories operate a TW facility and 12 of them are officially used in practice. The latter contribute more than two-thirds of the atomic clocks and almost all the primary frequency standards to UTC and TAI.

In addition to its major role, as a precise and an independent technique to GNSS, TW is used to evaluate the new GNSS techniques. In fact, all the recent GNSS techniques finally used in UTC/TAI transfers have been approved by the comparisons with TW, such as GPS P3, GPS All in View, GPS PPP, etc. A pilot study on the GLONASS time transfer is undertaking at BIPM and again TW is an indispensable tool.

Unlike the earlier publications discussing the technical details in TW, this paper focuses rather on the data treatment performed at BIPM: raw data collection, detection of outliers in the raw data, the calibration, the interpolation methods, and the link comparison with other techniques, as well as the availability of the raw and treated data sets on the Web. The authors would like the transparency of BIPM work to be helpful to the whole timing communication.

It is pointed in the end that TW and GPS PPP are each complementary and the combination of the two techniques will further improve the quality of the UTC time transfer.

1. INTRODUCTION

TW as an accurate time transfer technique became operational in 1998 and was officially introduced in UTC computation in 2000. Since then, a standard data processing procedure and a software package (Tsoft) have been gradually developed at BIPM and used for the production of the Circular T. This procedure is composed of 3 steps: 1) raw data collection; 2) link calibration, computation, and comparison; 3) related services through the BIPM Web site as well as the documentation.

Because the Circular T is one of the BIPM metrological Key Comparisons, this procedure is strictly controlled by the Quality System (QS): an internal audit per year by the BIPM QS inspector and an external audit every 2 years by an expert from the timing metrology community.

In this paper, we first present the situation of the current worldwide TW time and frequency transfer network and its role in UTC and TAI generations. Then we present the complete procedure of the TW data treatment at BIPM: data collection, time link computation, interpolation onto the standard MJD, uncertainty estimation, time link comparison, and the publication of the results through the Internet. Finally, we discuss the combination of TW and GPS PPP time as an accurate time transfer method.

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2. STATUS OF THE WORLDWIDE TW NETWORK AND ITS CONTRIBUTION TO UTC/TAI

Figure 2.1 demonstrates the current TW network comprised of nine Asia-Pacific laboratories and 10 Europe-American laboratories. The 19 laboratories operating the TW facility take 19% of the totally 68 UTC laboratories. They contribute to the UTC/TAI generations with 253 atomic clocks or 71% of the total clocks and 88% of the total clock weight, i.e. they have high-quality clocks. In addition, they transfer 11 of all the 12 Primary Frequency Standards for steering the free atomic time scale. TW plays a major role in the Circular T production.

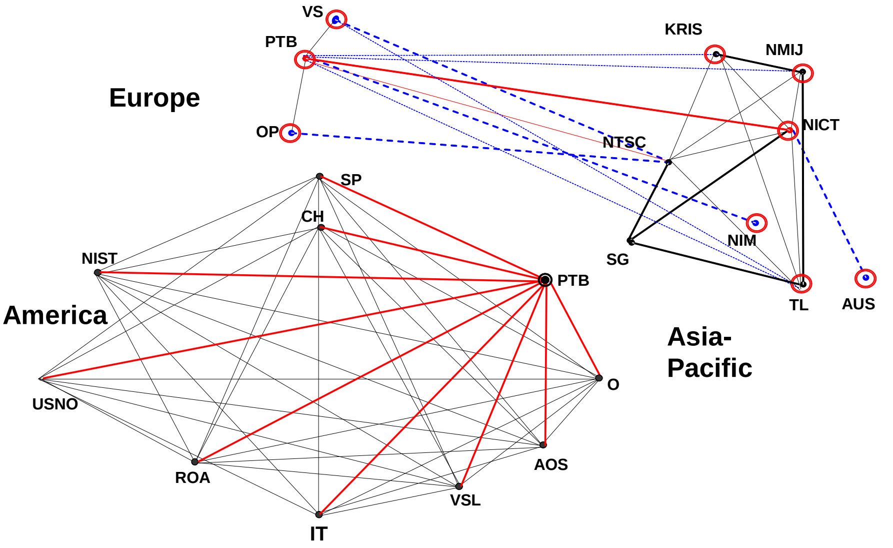


Fig. 2.1. The Europe-America-Asia TW network.

3. RAW DATA COLLECTION

TWSTFT data are collected on a daily basis by uploading the ITU data file **[1]** to the BIPM ftp server. It is possible to modify or reload and replace the data already submitted to BIPM, but any operations should be completed before the 4th of each month for the computation of UTC/TAI. The ftp connection parameters using the host name or the IP address are the following:

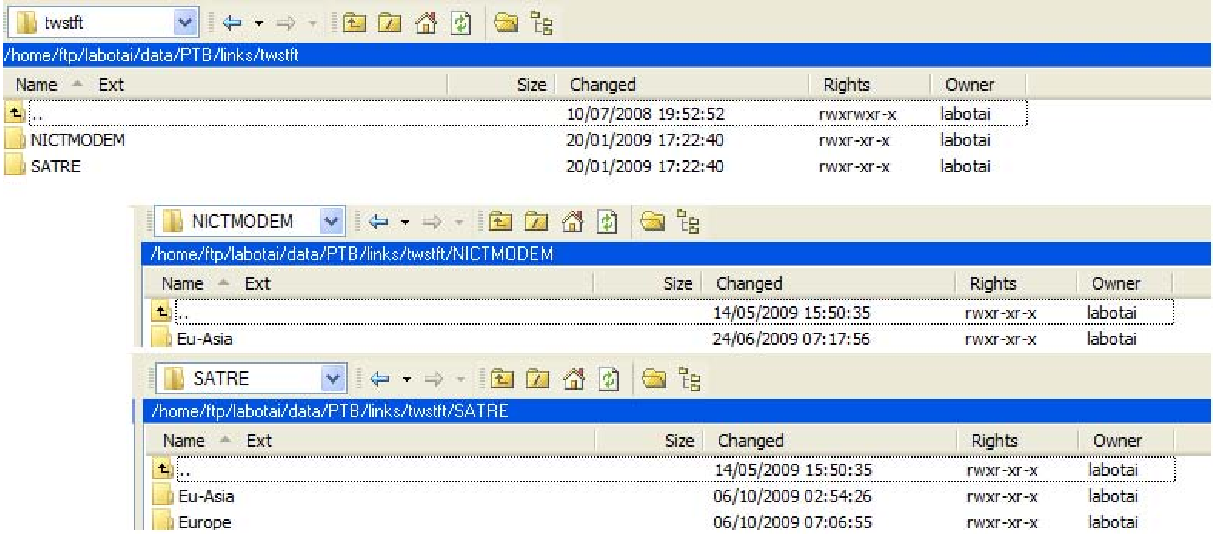
URL address or Host name: tai.bipm.org
IP address: 62.161.69.131
FTP:
Port: 21
Username: _______ (new username ruler will be applied starting 2010)
Password: _______

A specific directory for data of each laboratory was created in the remote directory “/data/lab”, where “lab” is the BIPM acronym of the laboratory, as in Section 1 of the Circular T. Then change to directory “/links/twstft” and upload your files to the right place by modem type (NICTMODEM, SATRE), then by regions (ASIA, EUROPE, USA).

Typical problems that may occur in data collection:

- *Data may be missing (for information a mail should be sent to* ***tai@bipm.org****)*

- *Existing data may be updated by the laboratory without warning the BIPM (risk of using wrong data)*
- *Failure to follow the procedure can lead to a mixture of data if wrong directory is used*
- *During the Satellite change, lots of messages on the TW stations and their operations are exchanged between the laboratories. In order to prevent the loss of specific information necessary to the calculation of Circular T, make sure to send a separate e-mail with the information for Circular T to* ***tai@bipm.org***
- *Daily data uploading is strongly recommended, as it allows to carry out scientific studies outside of the period of Circular T computation and also to have enough data to perform certain link calibrations when needed. Daily uploading is an important step towards speeding up the UTC/TAI computation and new products*
- *To safely keep the data on the BIPM ftp server, a new access policy to the server will be set up and you will be notify of the change for the username and password.*



/home/ftp/labotai/data/PTB/links/twstft

Name	Ext	Size	Changed	Rights	Owner
..			10/07/2008 19:52:52	rwxrwxr-x	labotai
NICTMODEM			20/01/2009 17:22:40	rwxr-xr-x	labotai
SATRE			20/01/2009 17:22:40	rwxr-xr-x	labotai

/home/ftp/labotai/data/PTB/links/twstft/NICTMODEM

Name	Ext	Size	Changed	Rights	Owner
..			14/05/2009 15:50:35	rwxr-xr-x	labotai
Eu-Asia			24/06/2009 07:17:56	rwxr-xr-x	labotai

/home/ftp/labotai/data/PTB/links/twstft/SATRE

Name	Ext	Size	Changed	Rights	Owner
..			14/05/2009 15:50:35	rwxr-xr-x	labotai
Eu-Asia			06/10/2009 02:54:26	rwxr-xr-x	labotai
Europe			06/10/2009 07:06:55	rwxr-xr-x	labotai

Fig. 5.1. The BIPM ftp TW site for uploading daily ITU data file.

4. TW LINK COMPUTATION

Before the link computation, the calibration and the raw data status are the first to check. Special sub-programs in Tsoft are developed for this purpose. Unusual data missing or any ambiguity of the calibration should be reported to the related laboratory.

4.1 Raw Data Checking

First, we check the number of the measured points per day. In normal case, there are 12 measured points per day or a point every 2 hours in the Europe-America network and 24 measured points per day or a point every hour in the Asia-Asia and Asia-Europe network, cf. Fig. 2.1. Table 4.1.1 is an example of this checking.

Calibration and offset or internal delay of the TW equipment is essential for UTC time transfer. The calibration is represented by the values of CALR and ESDVAR. Table 4.1.2 gives these values for TW 0907 MJD 55007-55041 in the raw ITU data files. There is a relation: CALR1 = −CALR2. The check of CALR and ESDVAR is especially important during or after a campaign of calibration or calibration-restoration. Any doubt about calibration is to be confirmed with the related TW lab and written in the monthly Circular T computation report for the metrological traceability.

Table 4.1.1. Number of the measurement points per day in ITU data files (partial).

No	**Lab1**	**Lab2**	**55011**	**12**	**13**	**14/**	**15**	**16**	**17**	**18**	**19/**	**20**
1	AOS	CH	129	23	14	9	1	___	8	21	21	18
2	AOS	USNO	126	22	14	9	1	___	10	19	19	17
3	AOS	NIST	130	22	15	11	2	___	10	20	18	18
…	…											
13	CH	USNO	333	12	11	12	12	12	12	12	12	12
14	CH	NIST	335	12	12	12	12	12	12	12	12	12
15	CH	ROA	291	11	9	10	12	12	11	11	11	9
16	CH	IT	307	11	12	11	12	11	10	12	11	10
…	…											
33	KRIS	NICT	631	23	20	19	22	22	23	21	23	21
34	KRIS	TL	628	24	21	18	21	22	21	22	23	21
35	KRIS	NTSC	465	20	8	___	___	14	22	17	23	18
36	NICT	KRIS	631	23	20	19	22	22	23	21	23	21
37	NICT	TL	686	24	22	20	23	23	22	23	24	24
…	…											
43	NIST	SP	351	12	12	11	12	12	12	12	12	12
44	NIST	OP	355	12	12	12	12	12	12	12	12	12
45	NIST	VSL	339	12	12	12	12	12	12	12	12	12
46	NIST	ROA	353	12	11	12	12	12	12	12	12	12
47	NIST	PTB	352	8	12	12	12	12	12	12	12	12

Then a first raw data filtering is made to pick up the absurd data records due to, for example, system overflows. These numbers are usually << 1% of the total data, but disturb the normal computations, statistics, and plots and, therefore, must be rejected beforehand. In some special cases, there are more absurd data; for example, during the satellite change from IS-3R to T-11N in July 2009, 1220 over 58135 (2%) record lines were rejected.

Table 4.1.2. CALR and ESDVAR values presented in the ITU data file for the UTC links.

LAB1	**LAB2**	**MJD1**	**MJD2**	**CALR1**	**CALR2**	**ESDVAR1**	**ESDVAR2**
AOS01	PTB04	55007	55021	-183.320	183.320	-8.000	-0.180
CH01	PTB04	55007	55041	-205.600	205.600	999999999	0.000
IT02	PTB04	55007	55042	-316.200	316.200	999999999	0.000
NICT01	NTSC01	55007	55044	99999.999	99999.999	99999.999	99999.999
NICT14	PTB13	55007	55044	214.500	-214.5	99999.999	99999.999
NIST01	PTB04	55007	55042	-30.100	30.100	-00000.72	-0.180
NPL01	PTB04	55007	55042	498.2	-498.200	0.000	0.000
NTSC02	PTB13	55007	55045	999999999	999999999	-3597.8	999999999
OP01	PTB04	55007	55041	-7315.900	7315.900	0.000	0.000
PTB04	ROA01	55007	55041	288.400	-288.400	-0.180	+242.000
PTB04	VSL01	55007	55040	298.300	-298.300	-0.180	+228.850
PTB04	SP01	55007	55042	188.800	-188.800	-0.180	2.000
PTB04	USNO01	55007	55043	-218.800	218.800	-0.180	-379.910

4.2 Link Computation

Calibration is so important for the metrology computation that, in addition to the CALR and ESDVAR value checking in the one-way raw data, the two-way checking is performed for every calculated link (cf. Table 4.2.1).

Table 4.2.1. Link computation and the corrections added: L2U, CALR, and ESDVAR.

```
 Tw Links Collected/MjdAveraged for CH-PTB
     MJD  hhmmss      Tw      Tw+L2U        CalR2     CalR1   EsdVar2   EsdVar1 S2/1
  1 55009 003700 -37.007 L2U -37.007     -205.600   205.600 999999999     0.000  1 1
 96 55013 223700 -37.204 L2U -37.204     -205.600   205.600 999999999     0.000  1 1
195 55018 023700 -38.965 L2U -38.965     -205.600   205.600 999999999     0.000  1 1
295 55022 063700 -45.914 L2U -45.914     -205.600   205.600 999999999     0.000  1 1
349 55026 103700 -40.183 L2U -40.183     -205.600   205.600 999999999     0.000  1 1
399 55030 143700 -39.190 L2U -39.190     -205.600   205.600 999999999     0.000  1 1
449 55034 183700 -34.623 L2U -34.623     -205.600   205.600 999999999     0.000  1 1
513 55040 103700 -20.572 L2U -20.572     -205.600   205.600 999999999     0.000  1 1
524 55041 193700 -30.027 L2U -30.027 _? 999999999 999999999 999999999 999999999  9 9
543 55043 233700 179.146 L2U 179.146    999999999 999999999 999999999 999999999  9 9
```

Sometimes, the CALR changes in the middle of a UTC month in one or several labs due to, e.g., change of the satellites, etc. Hence, the correction should be added before or after a link computation. There are several ways. Two of them are: 1) to make a L2U (link to UTC) and 2) to make an alignment to a calibrated link. The upper and lower tables in Table 4.2.2 illustrate two cases. The differences of the two corrections are: the first is to be added to all the measuring epochs and, therefore, can be seen in the link comparison (see below), while the second is only to be added to the standard MJD for Circular T computation and, in consequence, the corrections cannot be seen in the link comparison result. This is why, if we use the Circular T to reestablish the time link, we may find a constant difference from what was issued in the link or link comparison results through the Web (cf. Section 5).

Table 4.2.2. Insert a time jump at different levels during or after the link computation.

```
Link to UTC, add a jump due to the Satellite change:

55000.00 0.0
55054.00 0.0
55054.01 194.4        ! jump added from MJD 55054.01 and all the rest
56000.00 194.4
END -SP-PTB for SATELLITE CHANGE


Aligning to a calibrated link by a constant:
   -9.8  0.0 NICTPTB.TTTT_.lkT   ! WL/HK 08/10 to align Tw to GPS P3
   +5.2  0.0 NMIJPTB.PPPA_.lkG   ! GP/AH 08/11 P3 aligned to GPS MC
    4.3  0.0 DTG_PTB_.MMMA_.lkG  ! WL/HK 08/10 to align K1 GPS MC to K2 GPS MC
… …
END 0811 GP/AH

The lower corrections will not be seen in the link comparison
```

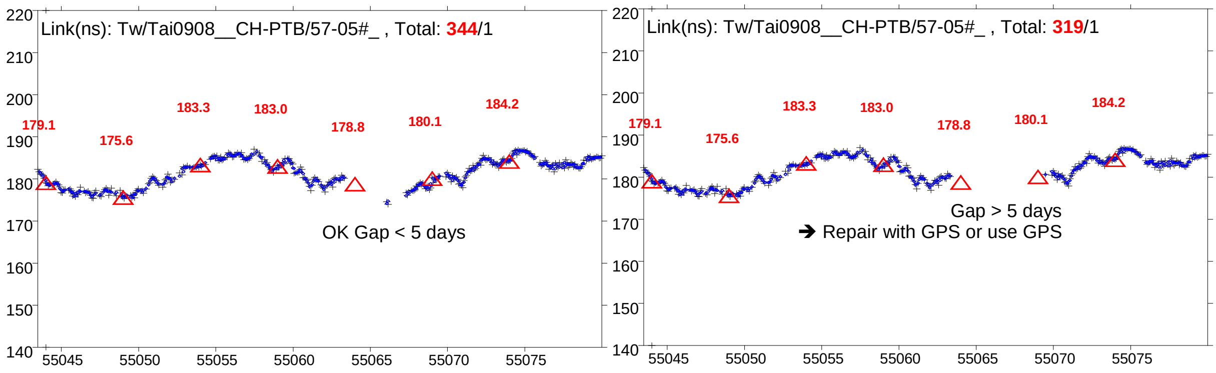


Fig. 4.2.1. Tolerance of the data gap should be less than 5 days in the usual case.

The maximum tolerance of a data gap is 5 days (Fig. 4.2.1), so that an interpolation can be made to determine the link value onto the standard MJD using the measured data. For more than 5 days, we have to use the GPS link to repair the missed data or use the backup GPS link. Conventionally, an uncompleted link implies that the ensemble of the clocks of the laboratory in question will be removed from the EAL/TAI/UTC computation and can come back at least 4 months later in the best case. Therefore, we always try to repair the gaps so as to save the clocks involved.

Outlier rejection is also an important operation. The general criteria are: 1) do not reject the measurements due to the diurnal disturbances; 2) reject absurd errors by a moving window of ± 10 ns; 3) reject those whose residual $> 4 \times$ uA (or $4 \times 0.5 = 2$ ns). The residual is obtained by both the predictions of phase and frequency; 4) total rejected points < 3% of the total measurements. A special iteration procedure is developed for this purpose. Fig. 4.2.2 is an example. Here, two iterations were made and, in total, 652 – 578 = 74 points were rejected. However, most of them are absurd, not measurement errors, and only five among them were rejected statistically by the phase-frequency predictions, i.e. only 0.8%. The standard deviation of the residuals reduced from 3.52 ns to 0.15 ns.

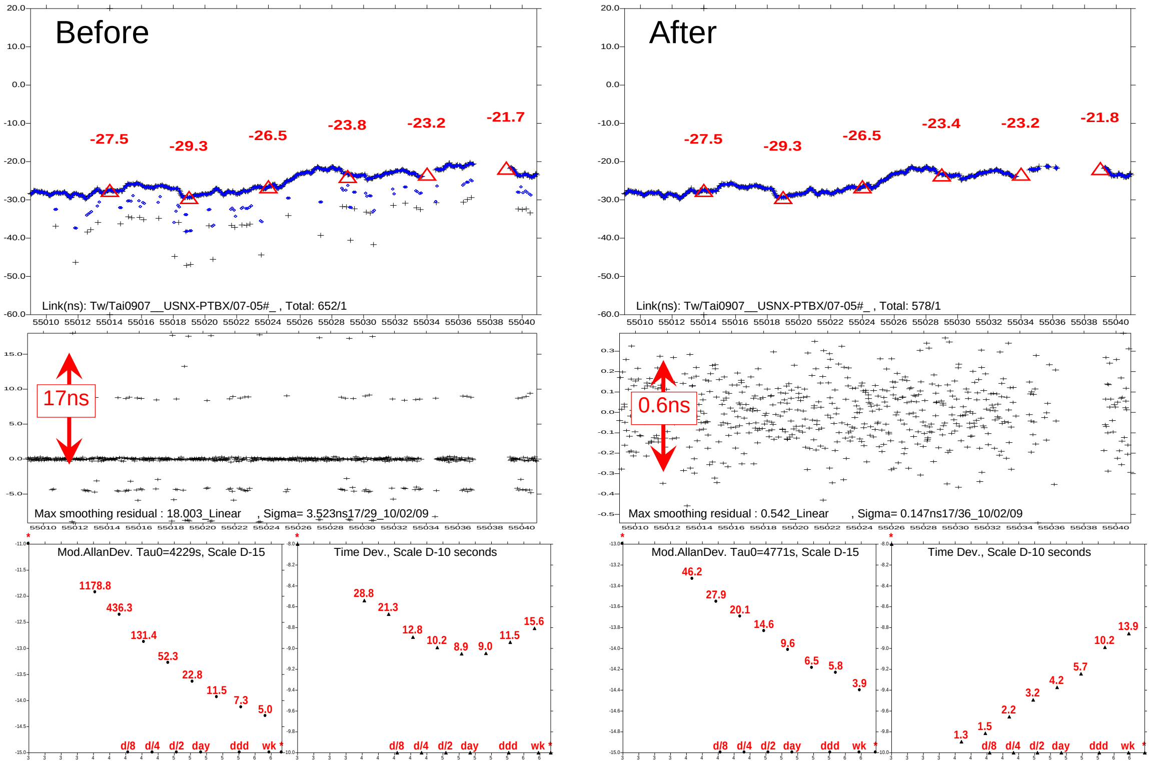


Fig. 4.2.2. TW0907 USNO-PTB X band links before and after cleaning outliers.

A result of the TW link computation is the measuring epochs. We have to use an interpolation method to obtain the values on the 0 hour of the standard MJDs. The traditional method is linear interpolation, where there are only two adjacent points, one just before the midnight and the other just after. As 12-24 points are measured per day, the linear interpolation implies that the other 12-22 measured points do not contribute anything to UTC/TAI computations. Experience tells that the redundant measurements will decrease the influence of the measurement noises and increase the precision of the interpolation. Jiang **[2]** studied the gain of using the high-order interpolations by comparing to the GPS PPP as a reference. Thanks to the high short-term stability of the latter, we can judge that a solution which is closer to the PPP is better (cf. Fig. 4.2.3). It concludes that a high-order interpolation method is better for the simple linear interpolation and the Vondrak smoothing interpolation with a filtering power of 10^5 to 10^6 is suitable. Fig. 4.2.3 is a comparison between the linear and Vondrak 10^5 interpolations. The σ of the differences from GPS PPP is reduced from 0.714 ns to 0.555 ns. Other studies, such as the TW triangle closures, give the similar result that the suitable power designed Vondrak smoothing-interpolation gives better output.

Every computed link has a plot consisting of four figures: 1) the link; 2) the differences between the measured value and the related prediction; 2) Modified Allan variance and 4) Time deviation. The caption of these figures gives the most important information concerning the computed link: baseline names, technique used, the number of total points, statistics, time of the computation, etc. This one-page plot (cf. Fig. 4.2.2) should be printed, viewed, and signed by two persons who are responsible for the Circular T computation in question, the so-called double verifications. All the link computation, data and results, should be monthly archived. A monthly report should be edited to record all the problems met in the link computation and what to do for the next month.

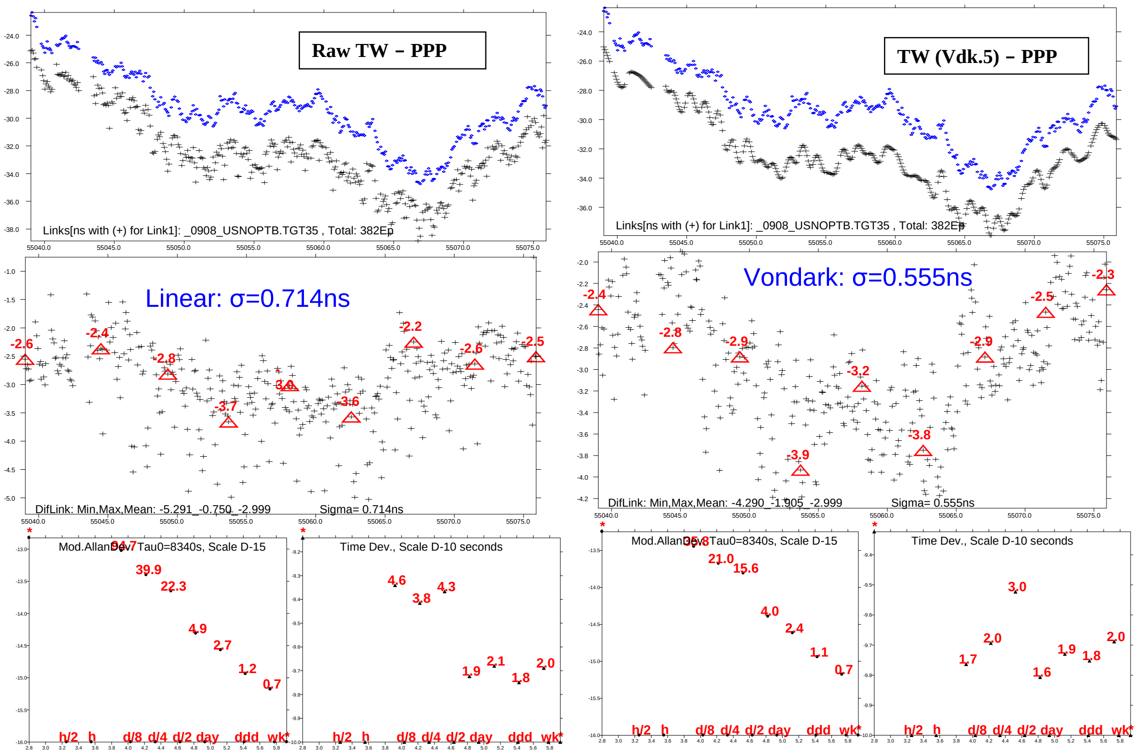


Fig. 4.2.3. Comparison between the linear and Vondrak 10^5 interpolations.

4.3 Uncertainty of UTC – UTC (k)

The total uncertainty (cf. Table 4.3.1a) estimation of the UTC−UTC (k) is based on the method given by **[3]**. The uncertainty of the time link contributes the most to the budget of the total uncertainty in UTC − UTC (k). Fig. 4.3.1 illustrates the evolution of the time link uncertainties type A (uA) and type B (uB) of different techniques. We see that the uncertainty uB of TW is at the nanosecond level **[4,5]**, while that of GPS, whether C/A code or PPP, is at the 5-nanosecond level, cf. Table 4.3.1a. This explains why the uncertainty of TW linked laboratory k has a much lower uncertainty in UTC – UTC (k), cf. Table 4.3.1b. This demonstrates an advantage of TW vs. GPS.

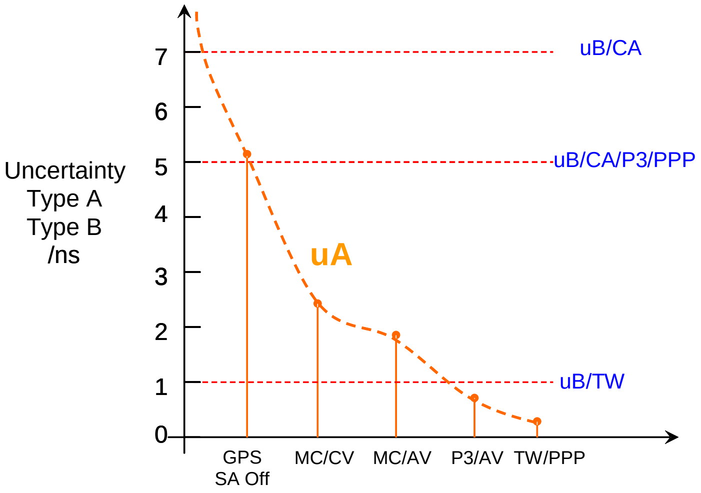
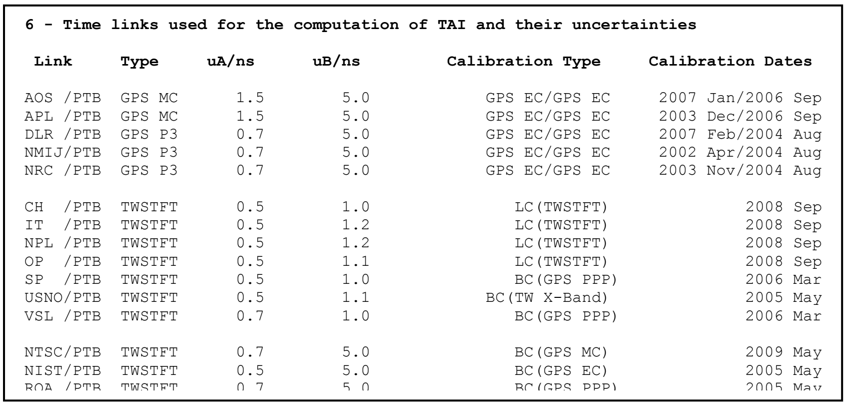


Fig. 4.3.1. Ten years' evolution in uncertainties type A and B (uA/uB).

Table 4.3.1a. Time link technique and uncertainty in Section 6 of the Circular T.



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

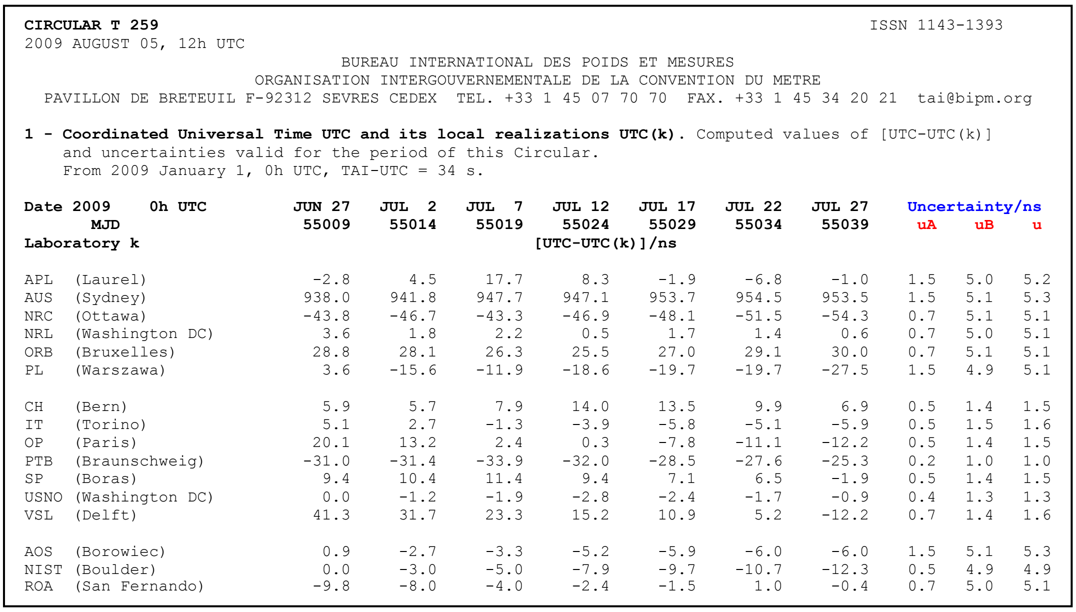
 Link      Type      uA/ns       uB/ns          Calibration Type     Calibration Dates

AOS /PTB  GPS MC      1.5         5.0              GPS EC/GPS EC      2007 Jan/2006 Sep
APL /PTB  GPS MC      1.5         5.0              GPS EC/GPS EC      2003 Dec/2006 Sep
DLR /PTB  GPS P3      0.7         5.0              GPS EC/GPS EC      2007 Feb/2004 Aug
NMIJ/PTB  GPS P3      0.7         5.0              GPS EC/GPS EC      2002 Apr/2004 Aug
NRC /PTB  GPS P3      0.7         5.0              GPS EC/GPS EC      2003 Nov/2004 Aug

CH  /PTB  TWSTFT      0.5         1.0                 LC(TWSTFT)               2008 Sep
IT  /PTB  TWSTFT      0.5         1.2                 LC(TWSTFT)               2008 Sep
NPL /PTB  TWSTFT      0.5         1.2                 LC(TWSTFT)               2008 Sep
OP  /PTB  TWSTFT      0.5         1.1                 LC(TWSTFT)               2008 Sep
SP  /PTB  TWSTFT      0.5         1.0                 BC(GPS PPP)              2006 Mar
USNO/PTB  TWSTFT      0.5         1.1              BC(TW X-Band)               2005 May
VSL /PTB  TWSTFT      0.7         1.0                 BC(GPS PPP)              2006 Mar

NTSC/PTB  TWSTFT      0.7         5.0                 BC(GPS MC)               2009 May
NIST/PTB  TWSTFT      0.5         5.0                 BC(GPS EC)               2005 May
ROA /PTB  TWSTFT      0.7         5.0                 BC(GPS PPP)              2005 May
```

Table 4.3.1b. Uncertainty of UTC – UTC (k) in Section 1 of the Circular T.



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CIRCULAR T 259                                                                     ISSN 1143-1393
2009 AUGUST 05, 12h UTC
                                  BUREAU INTERNATIONAL DES POIDS ET MESURES
                           ORGANISATION INTERGOUVERNEMENTALE DE LA CONVENTION DU METRE
  PAVILLON DE BRETEUIL F-92312 SEVRES CEDEX  TEL. +33 1 45 07 70 70  FAX. +33 1 45 34 20 21  tai@bipm.org

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 2009 January 1, 0h UTC, TAI-UTC = 34 s.

Date 2009    0h UTC           JUN 27   JUL  2   JUL  7   JUL 12   JUL 17   JUL 22   JUL 27    Uncertainty/ns
       MJD                     55009    55014    55019    55024    55029    55034    55039     uA    uB    u
Laboratory k                                             [UTC-UTC(k)]/ns

APL  (Laurel)                   -2.8      4.5     17.7      8.3     -1.9     -6.8     -1.0    1.5   5.0   5.2
AUS  (Sydney)                  938.0    941.8    947.7    947.1    953.7    954.5    953.5    1.5   5.1   5.3
NRC  (Ottawa)                  -43.8    -46.7    -43.3    -46.9    -48.1    -51.5    -54.3    0.7   5.1   5.1
NRL  (Washington DC)             3.6      1.8      2.2      0.5      1.7      1.4      0.6    0.7   5.0   5.1
ORB  (Bruxelles)                28.8     28.1     26.3     25.5     27.0     29.1     30.0    0.7   5.1   5.1
PL   (Warszawa)                  3.6    -15.6    -11.9    -18.6    -19.7    -19.7    -27.5    1.5   4.9   5.1

CH   (Bern)                      5.9      5.7      7.9     14.0     13.5      9.9      6.9    0.5   1.4   1.5
IT   (Torino)                    5.1      2.7     -1.3     -3.9     -5.8     -5.1     -5.9    0.5   1.5   1.6
OP   (Paris)                    20.1     13.2      2.4      0.3     -7.8    -11.1    -12.2    0.5   1.4   1.5
PTB  (Braunschweig)            -31.0    -31.4    -33.9    -32.0    -28.5    -27.6    -25.3    0.2   1.0   1.0
SP   (Boras)                     9.4     10.4     11.4      9.4      7.1      6.5     -1.9    0.5   1.4   1.5
USNO (Washington DC)             0.0     -1.2     -1.9     -2.8     -2.4     -1.7     -0.9    0.4   1.3   1.3
VSL  (Delft)                    41.3     31.7     23.3     15.2     10.9      5.2    -12.2    0.7   1.4   1.6

AOS  (Borowiec)                  0.9     -2.7     -3.3     -5.2     -5.9     -6.0     -6.0    1.5   5.1   5.3
NIST (Boulder)                   0.0     -3.0     -5.0     -7.9     -9.7    -10.7    -12.3    0.5   4.9   4.9
ROA  (San Fernando)             -9.8     -8.0     -4.0     -2.4     -1.5      1.0     -0.4    0.7   5.0   5.1
```
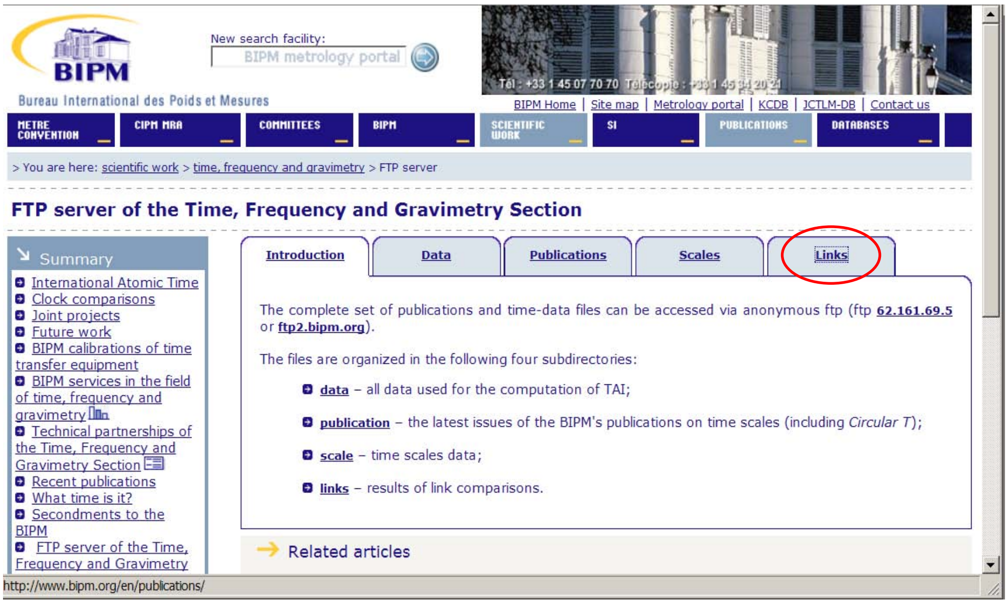

5. TIME LINK COMPARISON

The last step of the monthly computation is the time link comparison between TW and GNSS and among different solutions of GNSS. Since 2005 **[6]**, BIPM began to publish the link and link comparison results on its ftp site. The purposes of this work are 1) verification of the quality of different techniques, especially the link used in UTC/TAI transfer; 2) information communication between the BIPM and the time laboratories; 3) scientific studies in new time and frequency transfer techniques or new methods. For example, results comparing GPS P3, GPS All in View, GPS PPP, and certain TW links in the Asia-Pacific regions to the traditional methods have been published monthly on ftp for 1~2 years before finally being used in UTC/TAI.

The address of the BIPM ftp site is *ftp://tai.bipm.org/TimeLink/LkC/*. Fig. 5.1 illustrates the access of the link and link comparison through the BIPM Web page: *http://www.bipm.org/jsp/en/TimeFtp*.

jsp?TypePub=introduction. Fig 5.2 gives the directory tree and how the link and link comparison data are arranged in these directories. Detailed information can be found in the ReadMe file: *ftp://tai.bipm.org/TimeLink/LkC/ReadMe_LinkComparison_ftp_v8.doc*.



> You are here: scientific work > time, frequency and gravimetry > FTP server

FTP server of the Time, Frequency and Gravimetry Section

The complete set of publications and time-data files can be accessed via anonymous ftp (ftp **62.161.69.5** or **ftp2.bipm.org**).

The files are organized in the following four subdirectories:

- **data** – all data used for the computation of TAI;
- **publication** – the latest issues of the BIPM's publications on time scales (including *Circular T*);
- **scale** – time scales data;
- **links** – results of link comparisons.

http://www.bipm.org/en/publications/

Fig. 5.1. Access of the link and link comparison on the BIPM ftp server by a click on "Links."

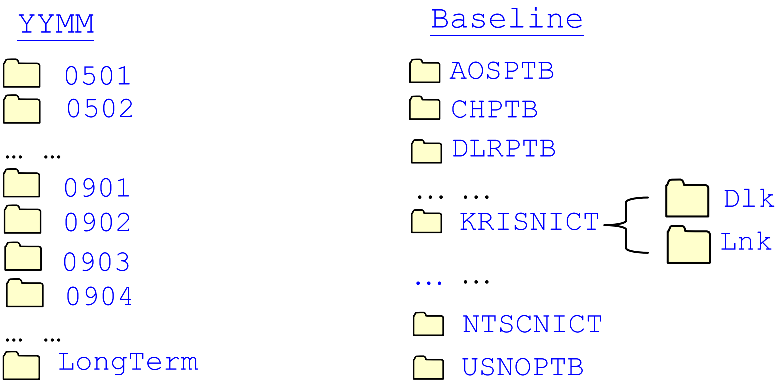


Fig. 5.2. Monthly link and link comparison results are arranged in the directory YYMM (left: *ftp://tai.bipm.org/TimeLink /LkC/YYMM*) and then the sub-directory of baseline (right: *ftp://tai.bipm.org/TimeLink/LkC/YYMM/Lab2Lab1*).

6. COMBINATION OF TW AND GNSS

Fig. 4.3.1 displays the evolution of the uncertainties type A (uA) and type B (uB) of the UTC time transfer techniques. The recently developed GPS PPP has its advantage that its uA is only 0.3 ns vs. 0.5 ns of TW **[7-9]**. According to the recommendation of CCTF 2009, PPP is used in UTC/TAI generation since Sept. 2009. TW is facing a challenge.

Tab. 6.1 compares the main characteristics of TW and GPSPPP. In terms of the geometry limit (baseline and distance), the diurnals, and the cost, the GPS PPP is more advantageous, while in terms of atmospheric effects and the simplicity in data processing and, especially, the calibration and its reproducibility, TW is more advantageous.

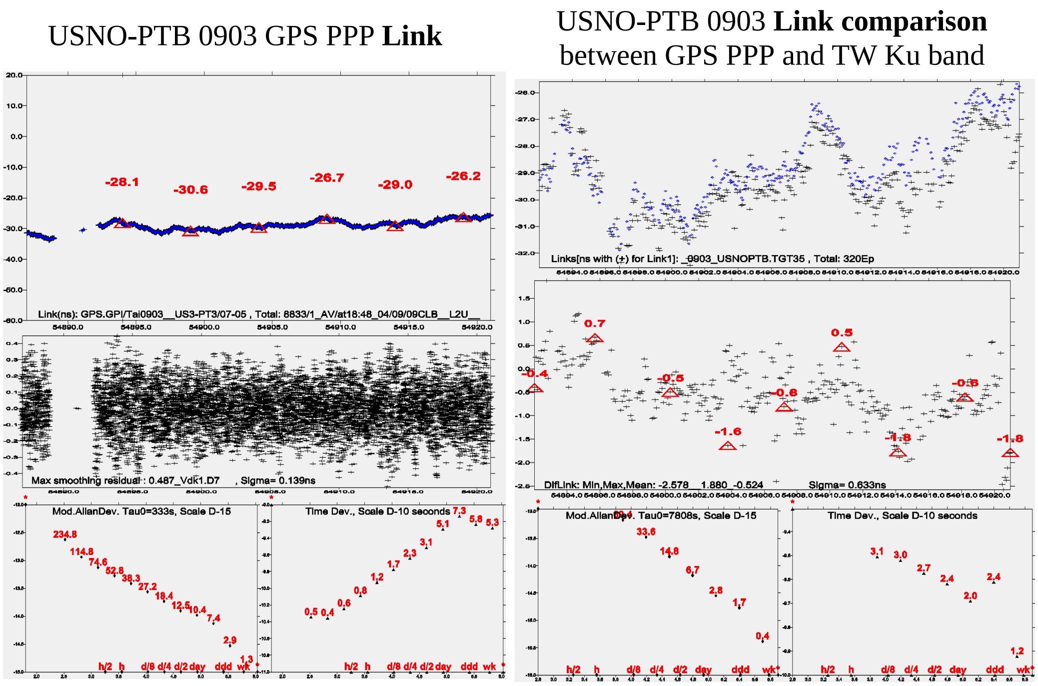


Fig. 5.3. Examples of the Link and link comparison available on the BIPM ftp site.

Table 6.1. Comparison of the main characteristics between TW and GPS PPP.

Terms	**TW**	**GPS PPP**
Calibration uB	1ns	5ns
Precision uA	0.5ns	0.3ns
Transfer limit	baseline	global
Distance	dependent	independent
Atmosphere effect	free	correction
Diurnals	yes	free
Data processing	simple/independ.	complex/depend.
Cost	expensive	less

Briefly, in view of uB, TW is superior to GPS PPP; however, in view of uA, it is the opposite. It is hard to still reduce the uA for a single TW baseline without hardware updating. Is there any way to improve the uA of TW? The answer is yes. Jiang **[10]** proposes the so-called TW network time transfer method to fully use the redundancy in the TW network. The study shows a gain of up to 20% may be achieved.

On the other hand, the TW and GPS PPP are backups for and, therefore, redundant to each other. As shown in Table 6.1, an advantage of one technique is in most cases the disadvantage of the other, such as uA and uB, etc. This implies that the combination of TW and GPS PPP will be a good solution. Jiang and Petit **[11]** prove this idea that the combination of TW and GPS PPP takes the advantages and reduces the disadvantages of the two techniques. The CCTF 2009 encouraged making further investigations in this direction.

7. SUMMARY

TW has a dominant role in the generation of UTC/TAI. We presented the routine work of how we deal with the TW data at the BIPM from the raw data collection to the computation of TW to the link comparison and the service through the BIPM Web site.

TW is facing the challenge of a new technique based on the precise GPS carrier-phase data. The solution is to fully use the redundant information supplied by TW network itself and by the GPS carrier phase.

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