TAI TIME LINKS WITH GEODETIC RECEIVERS: A PROGRESS REPORT

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Abstract

In April 2002, a pilot experiment (TAIP3) was proposed by the BIPM to laboratories participating to TAI in order to study the use of GPS P3 code measurements obtained with calibrated receivers of the type Ashtech Z12-T or equivalent to compute time links. First data were submitted in June 2002 and, by the end of 2002, close to ten laboratories routinely submitted such data. This paper presents the results of several time links computed with this data set and compares them to those obtained by other time transfer techniques. The achieved stability shows improvements with respect to other techniques presently used for TAI links and the achieved accuracy is consistent with that expected from uncertainty in calibration.

INTRODUCTION: THE TAIP3 PILOT EXPERIMENT

In past years, most time links used for International Atomic Time TAI have been based on C/A code (single-frequency) GPS receivers using simultaneous measurements of the same satellites **[1,2]**. Following the introduction of some geodetic (dual-frequency) receivers, like the Ashtech Z12-T, which are steered by an external clock frequency and synchronize their internal clock on the 1pps signal provided by the same clock, a number of studies have been carried out to use these receivers for TAI time links. On the one hand, a procedure has been developed to obtain data in a format compatible with the one defined by the CGGTTS, the working group of the Consultative Committee for Time and Frequency dealing with time transfer standards **[3]**. On the other hand, methods to calibrate these receivers have been set up and put into operation **[4,5]**. Based on these results and on the availability of such receivers in a significant number of laboratories participating in TAI, the BIPM initiated in April 2002 a pilot experiment to study the use of these receivers for time link computation, with the aim of introducing them for the computation of TAI at a later stage. This experiment, named TAIP3, involves about a dozen laboratories, a large fraction of them regularly sending data to the BIPM. In the following sections, results of time link computations are presented and studied in terms of the achieved stability and accuracy.

The time link results presented in this paper are obtained with the following procedure: the data obtained from the receivers are the differences between the station reference and GPS time, here named REFGPS. All data are corrected using GPS precise ephemerides from the IGS with the standard TAI procedure. Data obtained from single-frequency receivers are corrected for the ionospheric delay by using ionosphere maps obtained from the IGS processing center CODE (see *http://www.aiub.unibe.ch/ionosphere.html*). For the dual-frequency receivers, the ionosphere-free linear combination (P3) is used to compute the REFGPS values. The REFGPS measurements taken in strict common view from two receivers are differenced and a Vondrak smoothing is applied following the standard TAI procedure. The smoothed data are interpolated to obtain the link values at the standard TAI dates, which are indicated on some of the figures, and are used to compare the accuracy of the different techniques.

LINK STABILITY: RESULTS AND COMPARISON WITH OTHER TECHNIQUES

Several time links have been computed and compared with up to three different techniques currently used for TAI link computations: GPS single-channel C/A time receivers, GPS multi-channel C/A time receivers, and Ku-band two-way satellite time transfer. In the following, some comparisons with each technique are presented and analyzed.

COMPARISON WITH SINGLE-CHANNEL C/A TIME RECEIVER

All the links studied, whether at short distance, e.g. OP-PTB, or at long distance, e.g. CRL-PTB, show a typical five-fold improvement in stability for short-term averaging times (hours) when using P3. This is of course mostly due to the number of available measurements, and it is difficult to infer from this some information on the relative advantages of using P3 rather than using C/A + Ionex maps. For longer averaging times (2-3 days and above), because none of the links that are available for comparison connects two H-masers, all time transfer techniques reveal the instability of the clocks, even though instability values for 2-3 days averaging times are slightly lower for P3 links. This situation is similar to the short baseline multi-channel link shown below.

COMPARISON WITH MULTI-CHANNEL C/A TIME RECEIVER

For multi-channel C/A time links, the number of measurements is similar to P3, so that more meaningful comparisons may be performed. Results are presented for a transatlantic baseline (USNO-NPL) and a shorter baseline (IEN-NPL, about 1000 km).

Figure 1 shows the link [UTC (IEN) – UTC (NPL)] for September 2002 (P3 link in Figure 1a, C/A + Ionex link in Figure 1b). Comparison of the Modified Allan deviation obtained from the data show a factor of 2 improvement in stability up to an averaging time close to half a day, after which the P3 link just reveals the stability of the clocks, while the C/A link takes some 2-day averaging before clearly revealing the clock behavior. However in this region, the instability of the P3 link is still some 30% lower than the C/A link.

Figure 2 shows the link [UTC (USNO) – UTC (NPL)] for July-August 2002 (P3 link in Figure 2a, C/A + Ionex link in Figure 2b). Comparison of the stability (Modified Allan deviation in Figure 3) shows a factor of 2 improvement at all averaging times. For this link the clock stability is indeed very good, as indicated by the level reached by the P3 link at averaging time of 3 days and above, while the C/A link suffers some additional instability for such averaging times.

COMPARISON WITH KU-BAND TWO-WAY SATELLITE TIME TRANSFER

The Ku-band two-way (TW) data presently used for TAI links consist of three 2-minute measurements per week. This comparison is therefore best performed by first estimating the value of the GPS P3 link at the epochs of the two-way measurements. For this purpose the P3 values are Vondrak-smoothed and interpolated. Due to the smoothing parameter used in this study, this procedure results in estimating the

GPS value at the time of TW observation by averaging a few hours of adjacent GPS data. Therefore, it does not make full use of all available GPS data, but this could be achieved if needed by changing the value of the smoothing parameter. Figure 4a presents the results of this comparison for the link [UTC (USNO) – UTC (NPL)] over July-August 2002 (21 TW measurements). The rms of the 21 differences P3-TW (triangles on Figure 4a) is 1.0 ns. Figure 4b presents the Modified Allan deviation computed for the three series of Figure 4a. It can be seen that the P3 and TW link have a comparable level of instability. It can also be noted that both techniques display some level of measurement noise at a 3-day averaging time. This is visible because the instability of the difference (P3-TW) is higher than the value obtained for each link for this averaging time. But, as noted above, the instability of the P3 link for a 3-day averaging time is lower when the link is computed using all data (Figure 3) than the value in Figure 4b.

LINK ACCURACY: RESULTS AND COMPARISON WITH CIRCULAR T

It is possible to compare directly the values [UTC (k) – GPS Time] obtained at laboratory k from a calibrated P3 receiver to the values obtained from a calibrated time receiver. However, the interpretation of such comparison is not straightforward because different types of measurements are used (P1 code vs. C/A code) and, when using ionosphere-corrected results, different ionosphere corrections are used (P3 measurements vs. ionosphere maps). Such differences yield biases in [UTC (k) – GPS Time] between the two techniques which typically depend on the satellite being observed and on the receiver being used. These biases may be determined (see, e.g., *http://www.aiub.unibe.ch/ionosphere.html*), but generally only to within a global (unknown) offset. However, the satellite biases have no significant effect on the results of a time link that is computed with strict common view, and the receiver biases are supposedly determined through calibration. Therefore, it is more meaningful to compare time links [UTC (k) – UTC (l)] rather than [UTC (k) – GPS Time].

Comparisons of [UTC (k) – UTC (l)] as obtained for Circular T (i.e., mostly from GPS time receivers corrected with IGS precise ephemerides and ionosphere maps) and from P3 data corrected with IGS precise ephemerides have been carried out over October 2002 and are presented in Table 1. Such comparisons require a lot of care because each link present specific characteristics that have to be taken into account (see the notes to Table 1). Nevertheless, they indicate that two completely independent calibration schemes yield results which are consistent with the estimated uncertainty of the link calibration, which is of order of 3 ns for each technique.

Table 1: Comparison of calibrated P3 time links with time links used in BIPM Circular T.

Data Sets under Comparison	Offset and Standard Uncertainty
$[UTC(OP)-UTC(PTB)]_{P3}$ - $[UTC(OP)-UTC(PTB)]_{CirT}$	+3 ± 2 ns (1)
$[UTC(IEN)-UTC(PTB)]_{P3}$ - $[UTC(IEN)-UTC(PTB)]_{CirT}$	+5 ± 1 ns (2)
$[UTC(ORB)-UTC(PTB)]_{P3}$ - $[UTC(ORB)-UTC(PTB)]_{CirT}$	+4 ± 1 ns (3)

Notes to Table 1:

(1) The CirT link is with GPS C/A one-channel time receivers. The result in Table 1 accounts for the most recent differential calibration of these receivers (Lewandowski and Moussay, 2002 **[6]**).

(2) The CirT link is with two-way satellite time transfer that has been aligned on a GPS C/A one-channel time link. The result in Table 1 accounts for the most recent differential calibration of these receivers (Lewandowski and Moussay, 2002 **[6]**).

(3) The CirT link is with GPS C/A, with ORB data taken from the Z12-T receiver and PTB data from a one-channel time receiver.

CONCLUSIONS

It is clear that geodetic-type GPS receivers, which are able to maintain the continuity of their reference through power cycles, may be used for time comparisons. Time links may be computed using the P3 ionosphere-free measurements, corrected for precise satellite ephemerides following standard procedures of the BIPM for TAI computation.

Such P3 time links provide superior stability at all averaging times when compared to single-channel C/A time links: The five-fold gain at short term (averaging time of hours) is mostly due to the use of multi-channel data, but the gain is still significant at a 2-3 day averaging time. When compared to multi-channel C/A time links, the gain is also very significant (up to a factor of 2 at all averaging times) for long baselines and may still be significant for shorter baselines. When compared to Ku-band two-way links, the two techniques are found to be of similar stability for averaging duration of 3 days and above, with P3 data providing better access to clock behavior due to its continuous measurements. The accuracy obtained from independent calibration of P3 links is comparable to that obtained from classical GPS time links: the stated uncertainties as well as the observed differences are at a level of a few nanoseconds.

It is expected that the continuation of the TAIP3 experiment for some months will provide more insight on the long-term stability of the different techniques and that it will be thereafter proposed to introduce a set of P3 links in the computation of TAI.

ACKNOWLEDGMENTS

At the time of this writing (November 2002), the TAIP3 experiment involves more than ten laboratories, and this number is expanding. We thank all people involved in the participating laboratories a list including, but not limited to, P. Defraigne (ORB), P. Uhrich (BNM-SYRTE), T. Gotoh (CRL), A. Moudrak (DLR), V. Pettiti (IEN), U. Hessels (BKG), L-G. Bernier (METAS), J. Clarke (NPL), D. Piester (PTB), K. Jaldehag (SP), and D. N. Matsakis (USNO).

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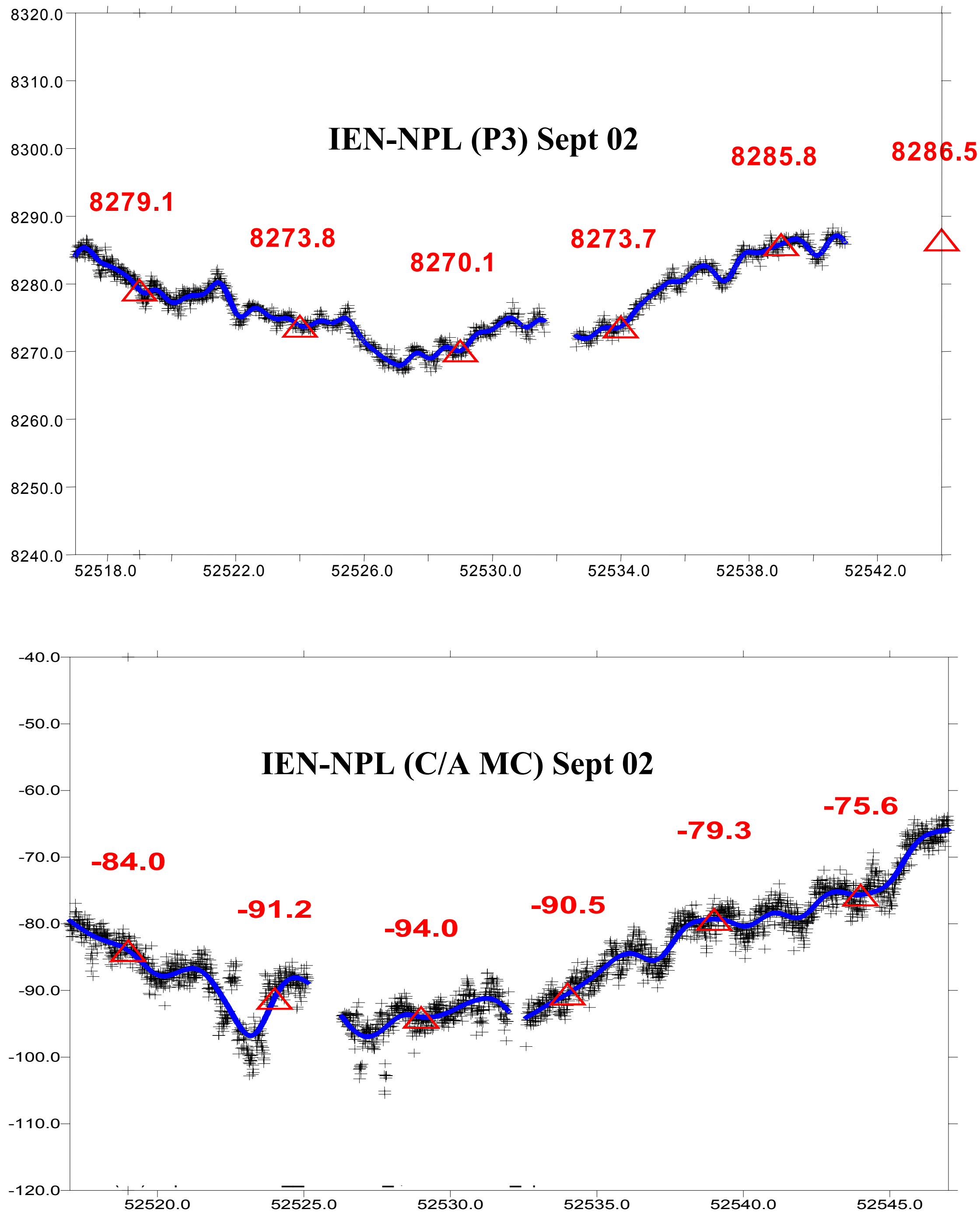


Figure 1. Time link [UTC (IEN) – UTC (NPL)]/ns for September 2002 computed with P3 data (1a, above) and with C/A + Ionex data (1b, below). Note that the P3 link has an arbitrary shift.

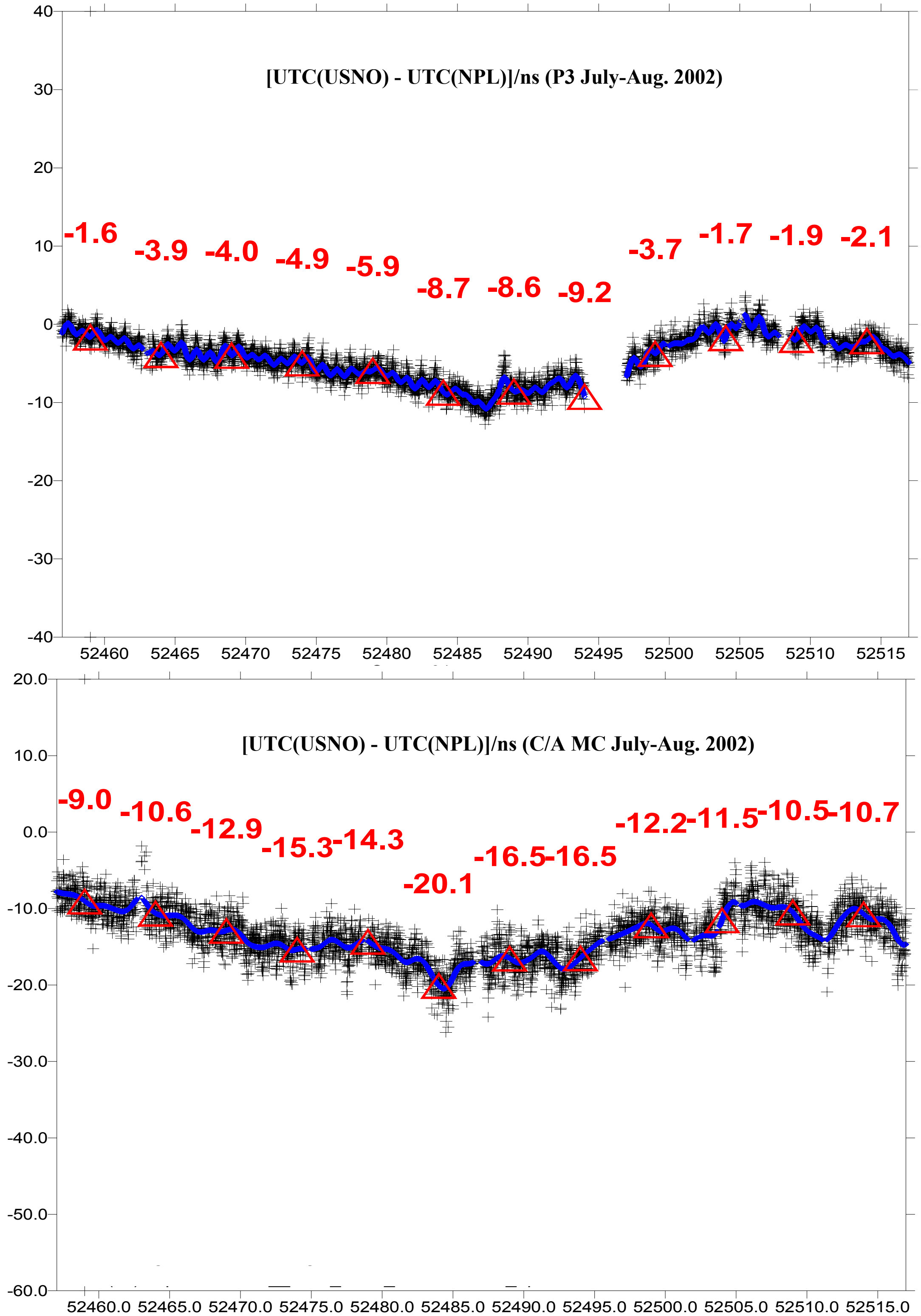


Figure 2. Time link [UTC (USNO) – UTC (NPL)]/ns for July-August 2002: computed with P3 data (2a, above) and with C/A + Ionex data (2b, below). Note that the P3 link has an arbitrary shift.

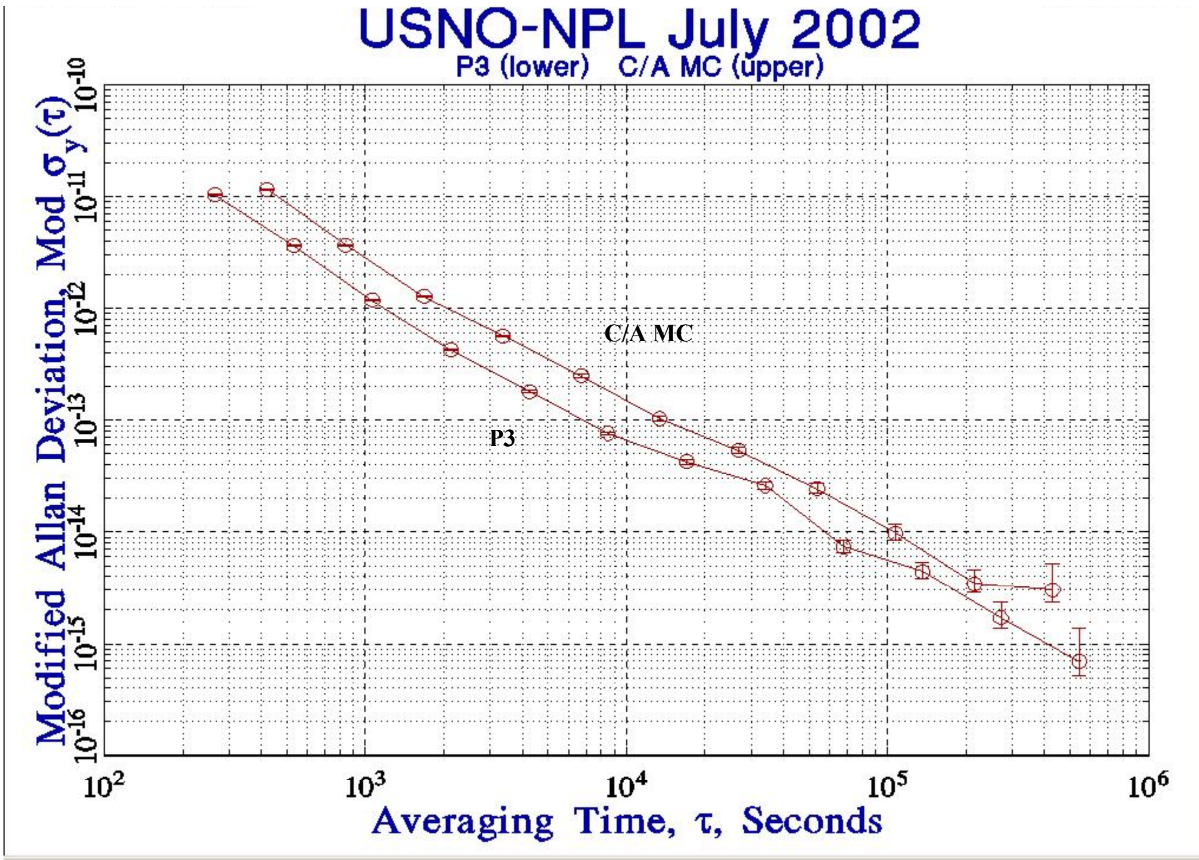
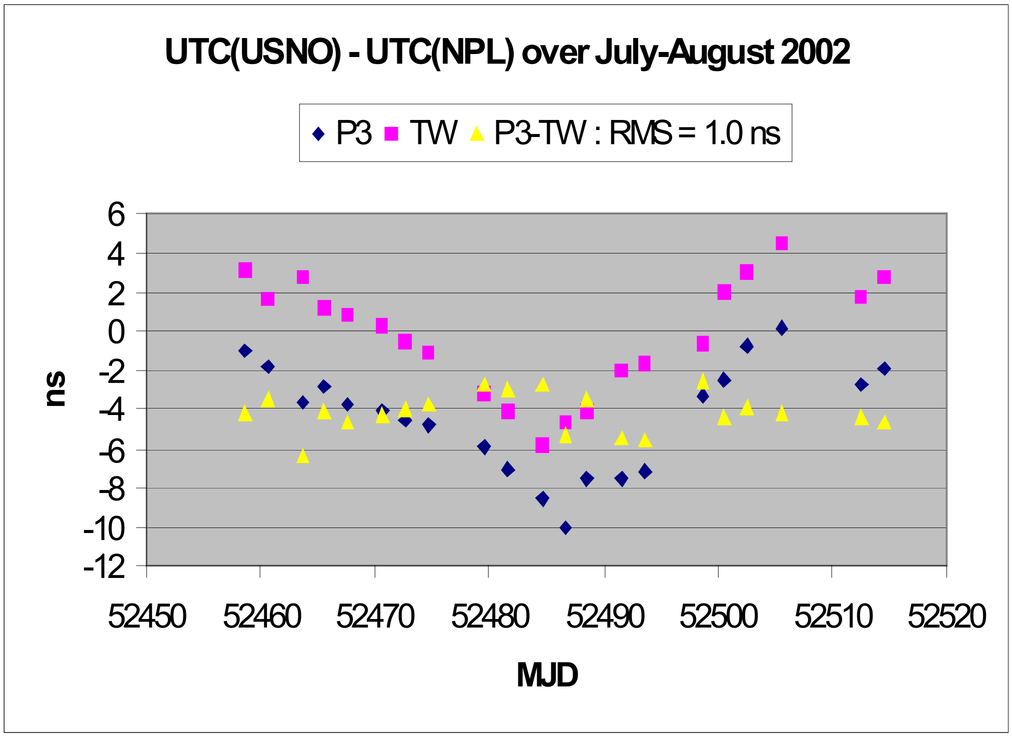


Figure 3. Modified Allan deviation for the time link [UTC (USNO) – UTC (NPL)] for July 2002.



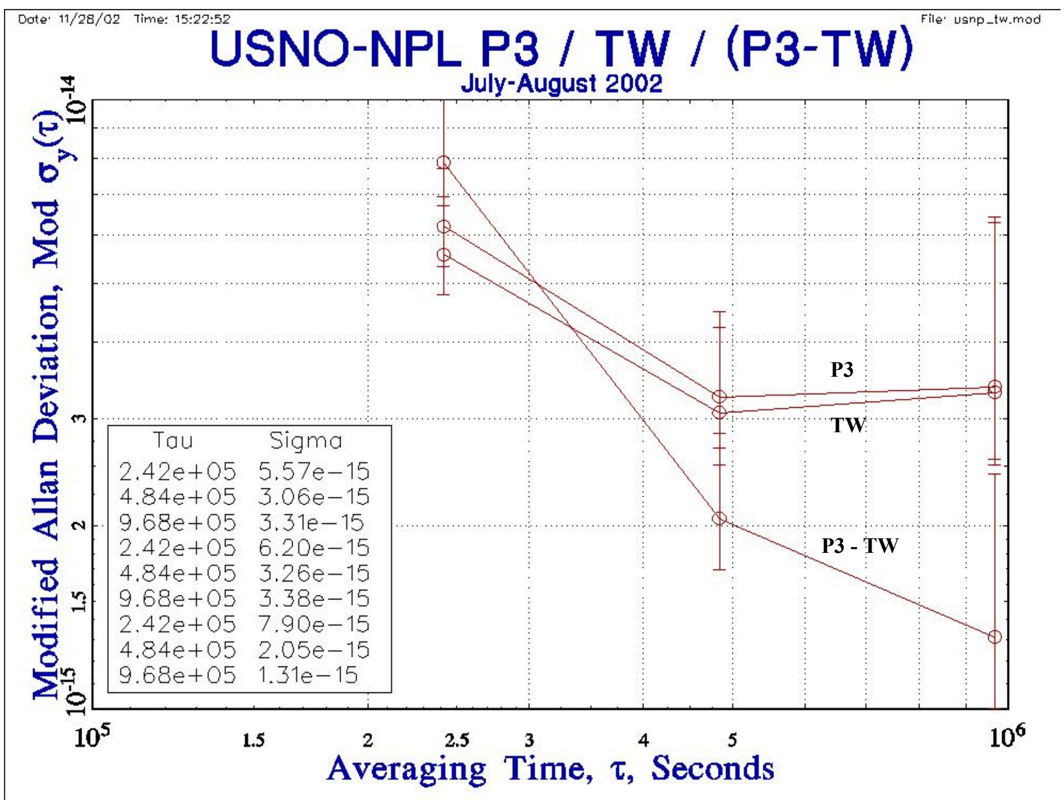


Figure 4. Time link [UTC (USNO) – UTC (NPL)] for July-August 2002: comparison of P3 and TW data (4a, above) and corresponding Modified Allan deviation (4b, below).

QUESTIONS AND ANSWERS

DEMETRIOS MATSAKIS (U.S. Naval Observatory): Gerard, a lot of the P-3 time links also have their data being reduced by IGS centers. And I wonder if you have made any comparison between those two sets of data reductions.

GERARD PETIT: No, we have not compared it with IGS production.