TWO-WAY SATELLITE TIME TRANSFER USING INTELSAT 706 ON A REGULAR BASIS: STATUS AND DATA EVALUATION

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Abstract

TWSTT (Two-Way Satellite Time Transfer) observations in Europe and between Europe and the United States resumed on 20 January 1997, using the INTELSAT 706 satellite on a regular basis. Six European and two US stations observe regularly. Two other European stations are about to become operational. The paper first describes the activities of the CCTF (Consultative Committee for Time and Frequency) Working Group on TWSTT. The use of INTELSAT 706 satellite and status of participating stations is then discussed together with related data. Evaluation of the TWSTT data reported in this paper includes its comparison with GPS common-view time transfer data for selected continental and intercontinental links over a period of one-and-a-half years.

INTRODUCTION

TWSTT (Two-Way Satellite Time Transfer) observations in Europe and between Europe and the United States resumed on 20 January 1997 (MJD = 50468) using the INTELSAT 706 satellite on a regular basis. Three one-hour observation windows, on Monday, Wednesday and Friday, have been purchased from INTELSAT. Within these windows two-minute TWSTT measurements are performed between participating stations according to a schedule. Six

European and two US stations observe regularly. Two other European stations are about to become operational. No significant problems concerning the satellite have been encountered. An ITU standard format is used for the exchange of data. The exchange and storage of dataareeasy, as the files are small. Data are available within two days.

First, a résumé is given of the activities of the CCTF (Consultative Committee for Time and Frequency) Working Group on TWSTT. The use of INTELSAT 706 satellite is then described, as well as the status of participating stations and related data. Evaluation of the TWSTT data reported in this paper includes its comparison with GPS common-view time transfer data for selected continental and intercontinental links over a period of one-and-a-half years. The goal of this study is to compare the stability of GPS common-view and TWSTT techniques, not accuracy.

CCTF WORKING GROUP ON TWSTT

The 11th CCDS (now CCTF) meeting of 1989 issued a declaration 1989/1 encouraging the use of TWSTT and suggesting the creation by the BIPM of an *ad hoc* Working Group on TWSTT. The *ad hoc* Group met twice in 1989 and 1992. Following the decision of the 12th CCDS meeting in 1993, the *ad hoc* Group was converted into a permanent CCDS Working Group with the task of helping the BIPM to elaborate the TWSTT technique for its possible use in the construction of TAI [1]. Since 1993 there has usually been one annual meeting of the full WG and two technical annual meetings of the participating stations. The main achievements of the WG are: development of a standard format; organization of TWSTT time links (choice of modems, schedule of observations, duration of observation, data exchange, ...); negotiation of the best conditions for the use of INTELSAT satellite; and the evaluation of TWSTT links by comparison with other available time transfer techniques.

USE OF INTELSAT 706 ON A REGULAR BASIS

As mentioned in the introduction, the TWSTT system has access to three one-hour observation periods from INTELSAT. In each window, beginning at 14 h UTC, 30 minutes are dedicated to links within Europe, and another 30 minutes to links between the United States and Europe. Within each 30-minute window, sessions are scheduled to last for 2 minutes with a 1-minute break to switch the codes [2].

The participating stations, namely the DTAG, NIST, NPL, PTB, TUG, USNO, and VSL, continue to perform observations on a regular basis, and the data from the present project are currently under evaluation. At the OCA, TWSTT equipment is presently undergoing tests before going into regular operation.

Each session between stations A and B consists of two-minute periods during which second-to-second measurements are carried out simultaneously at both stations. The time transfer measurement for each station is then obtained from a quadratic fit over the 1-second measurement interval. A specific data format has been developed to allow the exchange of two-minute tracks between partner stations. A provisional description of this format is given in the Report of the 3rd Meeting of the CCTF Working Group on TWSTT, held in Braunschweig (Germany) on 28-29 September 1995 [3]. A draft revision of Recommendation ITU-R TF.1153, recommending the use of this format, is presently under study.

Table 1. Availability of TWSTT data.

Laboratory	Continuous observations since ...
TUG	20 January 1997
USNO	22 January 1997
VSL	22 January 1997
DTAG	7 February 1997
PTB	17 February 1997
NIST	21 February 1997
NPL	20 April 1998
OCA	Temporarily interrupted

It is of considerable interest to note that all TWSTT data files listed above use the ITU-R format. This greatly simplifies the computation of time links. It should be emphasized that TWSTT dataareavailable quickly, usually one or two days after a session and, in the case of TUG, one hour after.

COMPARISON OF GPS AND TWSTT MEASUREMENTS

The goal of this study is to compare the stability of GPS common-view and TWSTT techniques, not accuracy. However, some indications on the constant biases between these two techniques are provided. A detailed study of the accuracy of the two techniques is provided elsewhere in these Proceedings in "Calibration of Three European TWSTFT Stations Using A Portable Stations and Comparison of TWSTFT and GPS Common-View Measurement Result" by D. Kirchner et al.

Aside from other differences, the TWSTT and GPS common-view data differ in their density: TWSTT measurements are performed every two or three days during 120 s intervals; GPS measurements are performed every day and there are about thirty 780 s tracks per day, which corresponds to 23400 s GPS observations per day.

It will be shown that very short interval TWSTT data give comparable or sometimes better results when compared with GPS. For the needs of the present comparison a choice was made to smooth and interpolate GPS data to the midpoints of the TWSTT sessions. As a result we obtained differences between the two techniques at intervals of two or three days. This comparison was performed for two types of time link:

- short-distance time link, over 700 km, between the PTB and the TUG,
- long-distance time link, over 8000 km, between the PTB, and the NIST.

The Figure 1 shows the differences between UTC(TUG) and UTC(PTB) obtained by TWSTT and GPS common-view for a period of about fourteen months. One can observe an apparent agreement between the two methods with a shift of several nanoseconds. We observe also a large drift between the two time scales, which complicates somewhat the statistical analysis. Figure 2 indicates the differences between the two methods at the times of the TWSTT observations, as well as the outside temperature at the TUG. The scatter of the differences between the TWSTT and GPS data for this short-baseline is about 12 ns. These differences exhibit an apparent systematic variation correlated with the external temperature. The seasonal effect has always been attributed to the environmental sensitivity of the GPS time equipment [4]. The stronger seasonal effect in 1997 stems from a problem with the power supply to the GPS time receiver at the TUG, which has amplified the temperature dependence of TUG GPS equipment. One should note that clocks are not entirely removed in these differences because of the different nature of the TWSTT and GPS data already mentioned: for GPS we have over 20000 s of observations per day, while for TWSTT we have 120 s of observations every two or three days. Concerning the bias of several nanoseconds between the two methods it should be pointed out that a differential correction issued from a TWSTT equipment calibration was applied to the TWSTT data considered here, but GPS data were not corrected for calibration during this study. Once GPS calibration corrections provided by a series of GPS calibration trips [5] are applied, the observed shift between the two methods disappears (see D. Kirchner et al. in these Proceedings).

Figure 3 shows the time deviation of [*UTC(TUG) – UTC(PTB)*] for the TWSTT and GPS common-view data. We see the same behavior for the two methods. The small differences are not significant. In fact from the beginning we see the behavior of the two clocks used in the comparison. The plot is not a property of the time transfer measurement, but an indication of the performance of the two cesium clocks. A comparison involving two masers would produce a different curve.

The long-distance comparison over 8000 km was performed between UTC(PTB) and UTC(NIST) for a period of about fourteen months (see Figure 4). We also observe for this long-baseline an apparent agreement between the two methods with a shift of several nanoseconds. The scatter of the differences between the TWSTT and GPS data reported on Figure 5 is about 20 ns. If we remove two outliers, this scatter reduces to about 12 ns. No seasonal effect is noticeable. The bias of several nanoseconds observed between the two methods is due to the way in which the TWSTT data were calibrated. As no independent TWSTT calibration was available for this link, the TWSTT link was calibrated using a GPS link provided by the BIPM Circular T. All transatlantic GPS links in Circular T are corrected for precise satellite ephemerides and ionospheric measurements. No such corrections were applied to the GPS link computed for this study. The GPS link was computed with broadcast ephemerides and modelled ionospheric delay. This is because no reliable ionospheric measurements were available. Differences between the measured and modelled ionospheric delays for the period covered by this study are roughly equal to –10 ns. So the bias we observe here arises from the differences in the computation of GPS links, and not from the differences between the two methods. As was mentioned earlier, this study is not about the comparison of accuracy between TWSTT and GPS methods,but about their stability. To realize a comparison of the accuracy of the two methods an independent calibration of TWSTT and GPS equipment should be organized.

Figure 6 shows the time deviation of [*UTC(PTB) – UTC(NIST)*] for TWSTT and GPS common-view data. For averaging times up to 10 days, the TWSTT link seems to be more stable than the GPS link. This GPS behavior is probably linked to the poor quality of broadcast ephemerides and modelled ionospheric delay which were used for this study.

CONCLUSIONS

• The CCTF WG on TWSTT has been very active for the past five years and has successfully moved the TWSTT method to an operational phase.

• Presently there are six operational and two pre-operational TWSTT stations in Europe and two operational stations in the USA using the INTELSAT 706 satellite. Preparations are also under way to operate several other TWSTT stations in the Asia-Pacific region. They are using INTELSAT 702 and JCSAT-3 satellites. Future connection between Asia-Pacific and Europe-North America TWSTT networks is already under consideration (see M. Imae et al. in these Proceedings).

• The INTELSAT 706 satellite was used for the past twenty-two months on a commercial basis. For this period we observed smooth, uninterrupted, routine operations of a network of TWSTT stations.

• Comparison of the stability of TWSTT and GPS common-view methods during this study can be summarized roughly as follows:

- for the short-baseline comparison a seasonal effect correlated with outside temperature was observed; difference in the stability of the two methods could not be determined, as their performance from the beginning is covered by the noise of the two cesium clocks being compared;

- for the long-baseline comparison the TWSTT method is more stable than GPS for up to 10 days (GPS was not corrected for precise ephemerides and ionospheric measurements);

- the performance of TWSTT appears to be at least as good as the performance of GPS common view.

• The progress accomplished until now allows us already to look toward possible consideration of the TWSTT method for TAI needs.

REFERENCES

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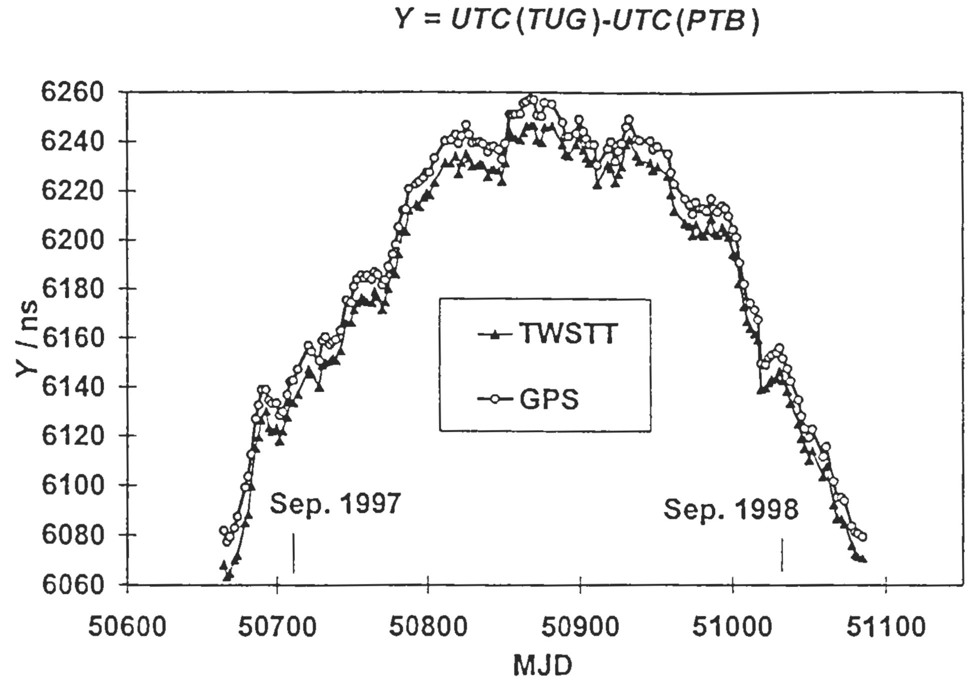

Figure 1. Differences between UTC(TUG) and UTC(PTB) obtained by TWSTT and GPS common-view for a period of about fourteen months (after slope removal).

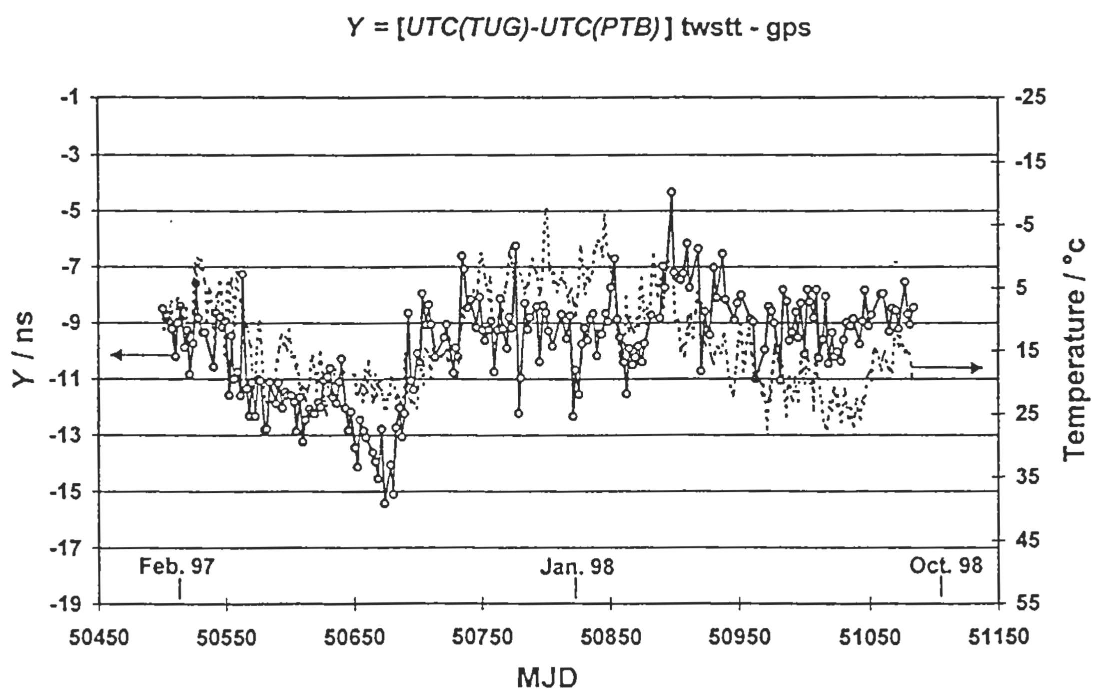

Figure 2. Differences between TWSTT and GPS common-view methods at the times of TWSTT observations, and the outside temperature at the TUG.

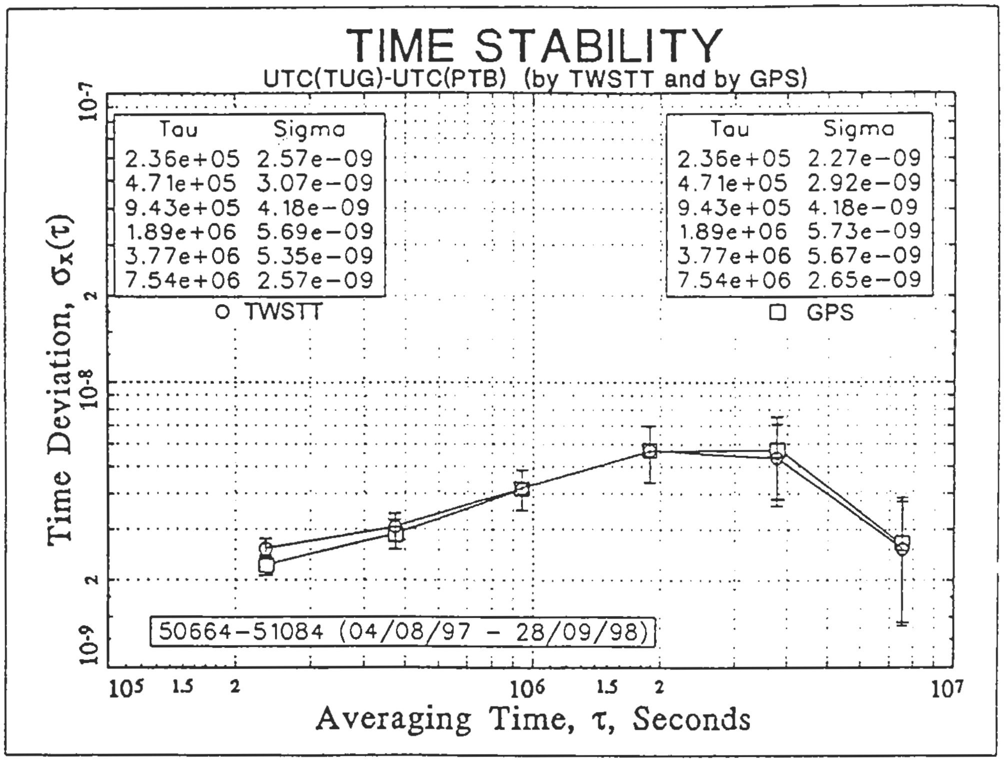

Figure 3. Time deviation of [*UTC(TUG) – UTC(PTB)*] for TWSTT and GPS common-view.

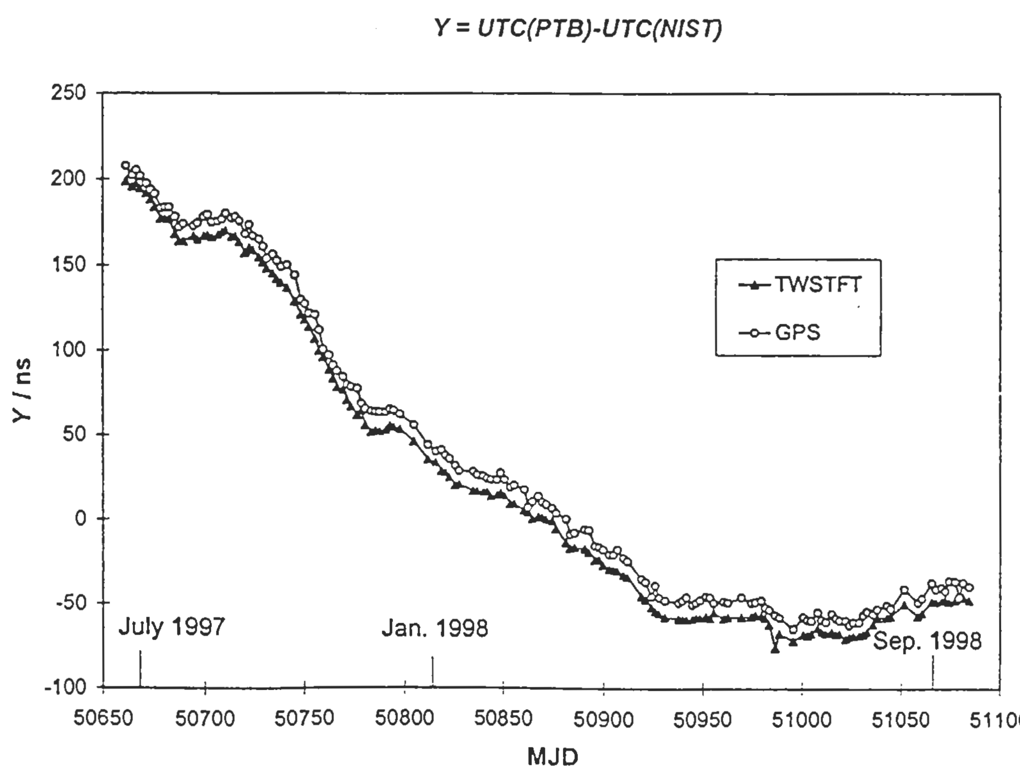

Figure 4. Differences between UTC(PTB) and UTC(NIST) obtained by TWSTT and GPS common-view for a period of about fourteen months.

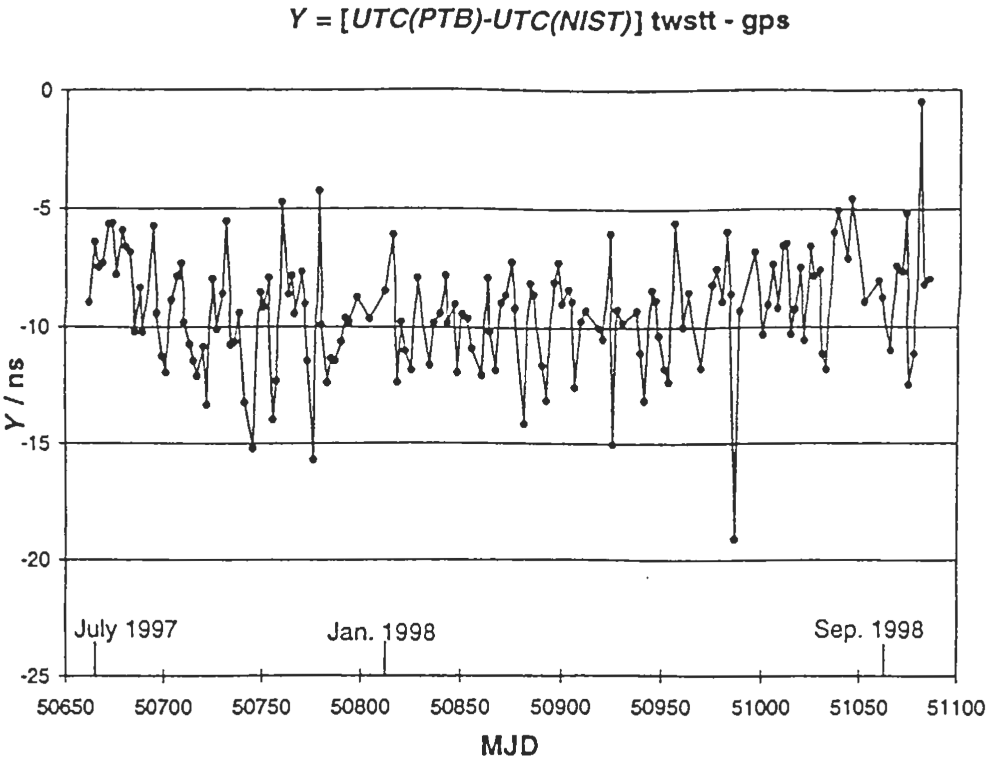

Figure 5. Differences between TWSTT and GPS common-view methods at the times of TWSTT observations.

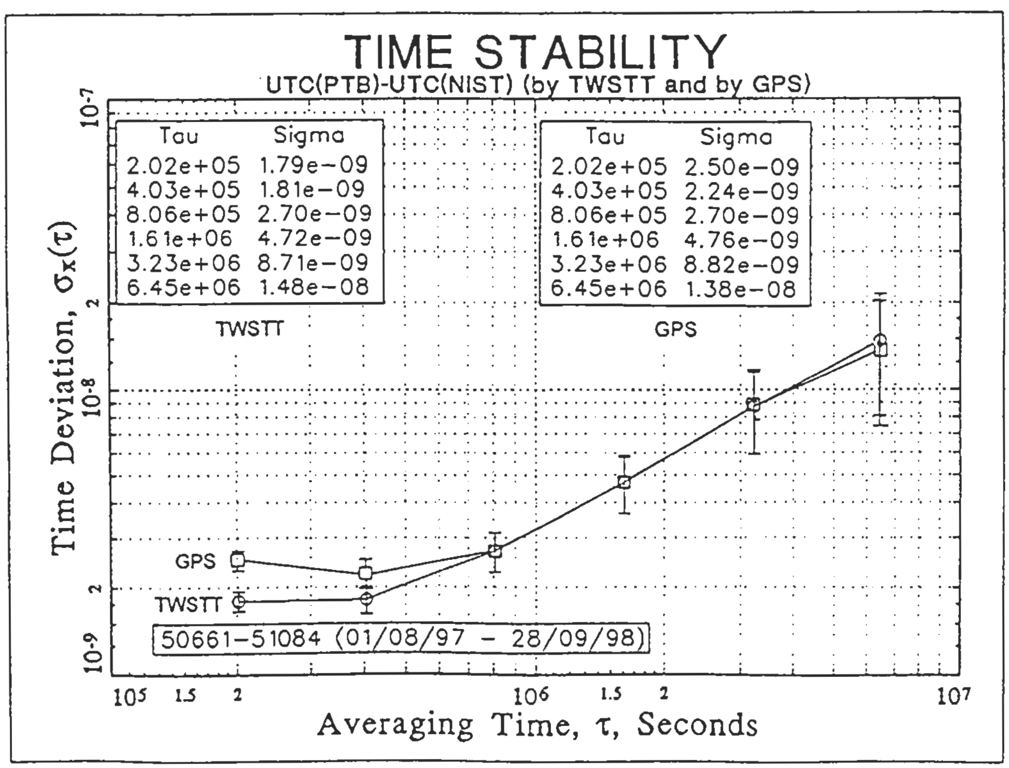

Figure 6. Time deviation of [*UTC(PTB) – UTC(NIST)*] for TWSTT and GPS common-view.