USE OF GEODETIC RECEIVERS FOR TAI

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Abstract

The classical time transfer method used to realize the TAI (International Atomic Time) is based on the common-view technique, with GPS observations collected by C/A code receivers. The resulting clock offsets between the laboratory clock and GPS time are obtained from a fixed procedure defined by the CCTF (Consultative Committee for Time and Frequency). A similar procedure can be applied on the RINEX observation files produced by geodetic receivers driven by a stable external frequency. We propose here to modify the CCTF procedure for the links between geodetic receivers, in order to take advantage of the P codes available on L1 and L2. This new procedure forms the ionosphere-free combination of the P1 and P2 codes as given by the 30-second RINEX observations files, the standard of the International GPS Service (IGS), and uses the satellite positions as deduced from the IGS rapid orbits. The procedure is tested using the Ashtech Z-XII3T geodetic receivers and the results are compared to those obtained with the classical CCTF procedure based on the C/A code. For short baselines, the Allan deviations up to 10 days are equivalent, while there is an improvement of a factor 2 for the transatlantic time link.

INTRODUCTION

In order to compare remote clocks for the computation of TAI, the Bureau International des Poids et Mesures (BIPM) uses the common view method [1] based on GPS C/A code observations from time receivers installed in the time laboratories. These time receivers are connected to the 1 pps (pulse per second) signal delivered by UTC (k), the local realization of UTC at time lab 'k'. An internal software computes, following a given procedure as recommended by the Consultative Committee for Time and Frequency (CCTF), the clock offsets between UTC (k) and GPS time as realized by each satellite for conventional 13-minute tracks appearing in the international BIPM tracking schedules [2]. These clock offsets are collected in a well-determined format, called CGGTTF (Common GPS GLONASS Time Transfer Standard [3]. The CCTF procedure is based on broadcast satellite orbit and clock parameters and uses the broadcast Klobuchar model for the ionospheric corrections. For the computation of TAI, the BIPM then improves the CGGTTS results using the IGS rapid orbits, and replacing the ionospheric corrections computed by the time receiver from the broadcast Klobuchar model, with the value computed from IGS ionex maps.

We recently developed software providing CGGTTS files for geodetic receivers driven by a stable external frequency [4]. This software applies the CCTF procedure to the code pseudoranges collected in the RINEX observation files. The method was validated by collocation of time and geodetic receivers [5]. Geodetic GPS receivers have the advantage of providing additionally the P-code observations, with a noise level smaller than the noise on the C/A code. However, most of these receivers do not allow a direct link between their internal clock signal and the external clock used to steer the receiver frequency. In fact, these receivers resynchronize their internal clock on GPS time after each tracking interruption, and this with an uncertainty of 1 microsecond. This induces a clock discontinuity at each tracking interruption. For this reason, some geodetic receivers have been especially designed to be also suitable for time transfer, like the Ashtech Z-XII3T. This receiver does not phase-lock to the external oscillator, but instead uses that oscillator directly. The 1pps input signal is used to define the 1-second points of the input frequency, so that the receiver internal clock is directly a mirror of the external clock, which can be chosen as UTC (k). In this way, there are no clock discontinuities associated with tracking interruptions, as is the case with classical geodetic receivers. Introducing CGGTTS files from RINEX observations files gathered by geodetic receivers such as the Ashtech Z-XII3T into the realization of TAI fits one of the main goals of the IGS-BIPM pilot project [6], which is to establish a link between the IGS clock combinations, i.e. satellite and receiver clock offsets [7], as well as the IGS time scale [8] and TAI.

The original CCTF procedure is based on the pseudoranges collected on the C/A code observations and at a 1-second sampling rate. We propose here to adapt this procedure for the links between geodetic receivers, in order to take advantage of the P codes available on L1 and L2. This new procedure uses the 30-second RINEX observations files, the standard of the International GPS Service (IGS), and processes the ionosphere-free combination of the codes P1 and P2; the satellite positions are deduced from the IGS rapid orbits, available after 2 days.

MODIFICATIONS TO THE CCTF PROCEDURE

The values given in the CGGTTS files result from a well-defined analysis procedure [2], which can be summarized as follows. For each individual GPS satellite track, the time receiver uses raw 1-second C/A-code pseudorange data collected during 13 minutes (leading to 780 data points). These pseudorange data are measurements of the clock offset between the receiver and the satellite, resulting from an integration of the received signal over a time interval of maximum 1 second. Note that in this clock offset determination, the station coordinates are fixed and the satellite position is determined using the broadcast ephemerides. Simultaneously during the track, an internal TIC determines the clock offset between the receiver 1pps and the laboratory reference UTC (k) 1pps signal input in the receiver. The difference between the two quantities so obtained gives access to the clock offset between UTC (k) and the satellite clock. The 780 pseudorange data points are then separated into 52 blocks of 15 data points. In each of the blocks the 1-second data are smoothed using a quadratic polynomial. The following of the procedure is applied on the 52 points corresponding to the values of the quadratic fits at the midpoints of the blocks. These 52 points are then corrected for: geometric delay (computed with antenna coordinates and broadcast ephemerides), ionospheric delay (computed with broadcast Klobuchar model), tropospheric delay (computed with Hopfield's model with standard atmosphere values), the Sagnac effect, periodic relativistic effect associated with the satellite orbit, L1-L2 group delay (from broadcast parameter TGD), receiver delay, and antenna and local clock cable delays.

The final CCTF results for this satellite track are obtained after performing two linear fits. A first one is applied on the 52 corrected data points, and the value of this fit at the midpoint of the track is given as 'UTC (k) – Tsat' (column REFSV in the CGGTTS files). A second linear fit is applied on the 52 points additionally corrected for the satellite clock offset using the broadcast polynomial parameters. The final result of the track for 'UTC (k) - GPS time' (column REFGPS in the CGGTTS files) is the value of this second linear fit at the midpoint of the track.

In the classical CCTF procedure described here above, the values of 'UTC (k)-GPS time' given in the CGGTTS files are computed from the raw GPS C/A-code data taken at a 1-second sampling rate. However, within the IGS, the standard sampling interval is 30 second. We, therefore, proposed the following modifications in order to use directly the 30-second RINEX files **[5]**. First, we chose to apply directly a linear fit on the 26 points corresponding to the 13-minute track (after having corrected for the effects mentioned above and given in the CCTF conventions). The difference between the pseudo-CCTF results so obtained and those obtained from the 1-second RINEX files following strictly the CCTF conventions is smaller than 0.1 ns, well below the precision of the time transfer by common view with the C/A code, which is about 4 ns **[9]**. Note that because the BIPM tracking schedules are dated in UTC and the RINEX files are dated in GPS time, we have to take this difference into account to choose the 26 data points which are inside the 13-minute tracks.

The second modification consists of using the ionosphere-free combination P3 instead of the C/A code as used by classical time receivers. This requires the knowledge of the receiver hardware delays on both P1 and P2, presently determined by a calibration campaign for Ashtech Z-XII3T receivers **[10]**. Furthermore, rather than using the broadcast orbit parameters, we propose to use the IGS rapid orbits, available after 2 days. In order to test this modification, two time links have been investigated, one on a short baseline (about 500 km) and the other one on a transatlantic baseline. The stations used are NPLD (Teddington, UK), WSRT (Westerbork, the Netherlands), and USNO (Washington DC, USA). The receivers used in these stations, as well as the external frequencies used to drive the receiver, are given in Table 1. Only one of these stations (NPLD) is equipped with a receiver Ashtech Z-XII3T; the two other stations use a classical geodetic receiver with resynchronization of the internal clock within 1 microsecond of the GPS time after each tracking interruption. For this reason, we had to correct for two clock jumps in the data of WSRT (MJD 52172.0 : 930.0 ns, MJD 52183.0: 245.0 ns) and for one clock jump in the data of USNO (MJD 52179.6 : 529.2 ns). These jumps have been determined from the data collected in the CGGTTS files, but computed with P3 and rapid orbits. Furthermore, because these receivers are not calibrated, there is no access to the absolute offset between the remote clocks compared; only the frequency comparison is performed here.

Figure 1 shows the time links obtained for the short baseline using either the classical CCTF procedure, with C/A code, broadcast orbits, and the Klobuchar ionosphere model, or with the modified procedure explained here above, using the ionosphere-free combination P3 and rapid orbits. Also shown are the results as modified by the BIPM for orbits (from broadcast to IGS rapid orbits) and for the ionospheric corrections (from Klobuchar model as used in the CGGTTS files to ionex maps). The corresponding Allan deviations are given in Figure 2. It appears clearly that the use of the ionosphere-free combination P3 gives equivalent results as the use of C/A code or P1 code with the IGS ionex maps. This is explained by the proximity of the stations. Indeed, the ionosphere-free combination eliminates both the short and long wavelength behaviors of the ionosphere as well as short- and long-term variations, while the ionex maps only allow the correction for the long-wavelength and long-term variations (above 2 hours). Close stations observe a similar ionosphere, with the same variations, so that the ionospheric delays cancel out in the time transfer. Therefore, there is no improvement when using the measured ionospheric delay as with P3. Note that the noise level on the observable P3 is about 3 times larger than the noise level on the observable P1, due to the combination of the two codes P1 and P2. However, this does not appear in Figure 1, where the noise levels of the time link obtained either with P3 or with P1 are equivalent. This is because the time transfer data presented in Figure 1 are not obtained from the raw observables P1 and P3 of both stations, but rather from the results of the linear fits applied on either P3 or P1 corrected with ionex maps.

Table 1. Description of the IGS stations used

station	*receiver*	*External frequency*
NPLD	Ashtech Z-XII3T	Sigma Tau H-maser = UTC(NPL)
WSRT	AOA SNR-12 ACT	Sigma Tau H-maser
USNO	AOA SNR-12 ACT	Sigma Tau H-maser MC3 steered to UTC(USNO)

The corresponding quantities for the transatlantic time link (NPLD-USNO) are presented in Figure 3 (after removing a linear drift of 4.6 ns/day) and the Allan deviation is shown in Figure 4. In that case, the improvement associated with the use of the ionosphere-free combination P3 is clear. The Allan deviations up to 10 days obtained using P3 are a factor 2 better than using the classical method used by BIPM for TAI (with ionex maps). Note that the RINEX observation files of USNO do not give the C/A code observations, so that we only tested with the P1 code for the classical CCTF procedure.

LINK BETWEEN THE IGS TIME SCALE AND TAI

One of the main goals of the IGS-BIPM Pilot project is to get an improved availability of accurate time and frequency comparisons. On the one hand, the TAI has a very good long-term stability, but is available only after several weeks. On the other hand, the IGS provides with a 2-day delay a time scale with a very good short-term stability **[8]**. The IGS time scale will be steered to TAI in order to ensure the long-term stability. It is realized from the IGS clock combinations, i.e. satellite and receiver clock offsets **[7,8]**, based on time transfer between IGS receiver and/or satellite clocks, and it is computed from the combination of code and phase observations. In order to establish the link between the two time scales (IGS and TAI), we need collocated IGS stations and Time Laboratories, where the same clocks are contributing to both the IGS time scale and TAI. In addition, the IGS receivers need to be calibrated, as is presently done for the Ashtech Z-XII3T receivers **[10]**. Furthermore, if the same receiver is involved within both IGS and TAI, we have access to its clock offset with respect to the IGS clock products and with respect to TAI. In the case of the Ashtech Z-XII3T receiver, we have therefore simultaneously the clock offset of the external clock with respect to the IGS clock products and with respect to TAI. If we apply this setup in several stations we will finally be able to determine, with a very high precision, the link between the IGS clock products and the TAI. This is illustrated schematically in Figure 5.

CONCLUSIONS

To allow including IGS stations in TAI, we need a time link between IGS stations and time laboratories. This link requires that at the IGS stations the clock offsets between UTC (k) and GPS time are computed following a procedure similar as used at the time laboratories. In this paper, we proposed the following procedure to include the time links between IGS receiver: using the standard 30-second RINEX files (with 26 observations inside the 13-minute tracks), the ionosphere-free code P3, and the IGS rapid orbits. With respect to the classical procedure used at BIPM for time transfer within the TAI realization, i.e. C/A code with rapid orbits and ionex maps, this new procedure brings no improvement for short baselines, while for a transatlantic baseline, the improvement reaches a factor 2 on the Allan deviation up to τ=10 days.

A practical implementation is proposed, with the creation of CGGTTS files from geodetic receivers (Ashtech Z-XII3T) fully compatible for the participation to TAI: the CGGTTS files would then contain

- calibration data: internal + antenna delays on P1 and P2,
- a given code for the use of rapid orbits in the column devoted to index of ephemerides (900 is proposed), and
- the same value for the computed and measured ionospheric delay **[11]**.

The procedure at time labs using geodetic receivers would then consist of automatic daily ftp connections in order to collect the RINEX observation files and the IGS rapid orbits, and daily run of the code in order to generate the file in the CGGTTS format from RINEX files. This will be a first step for getting the link between IGS time scale and UTC, presently realized from the data of UTC - GPS time (Circular T).

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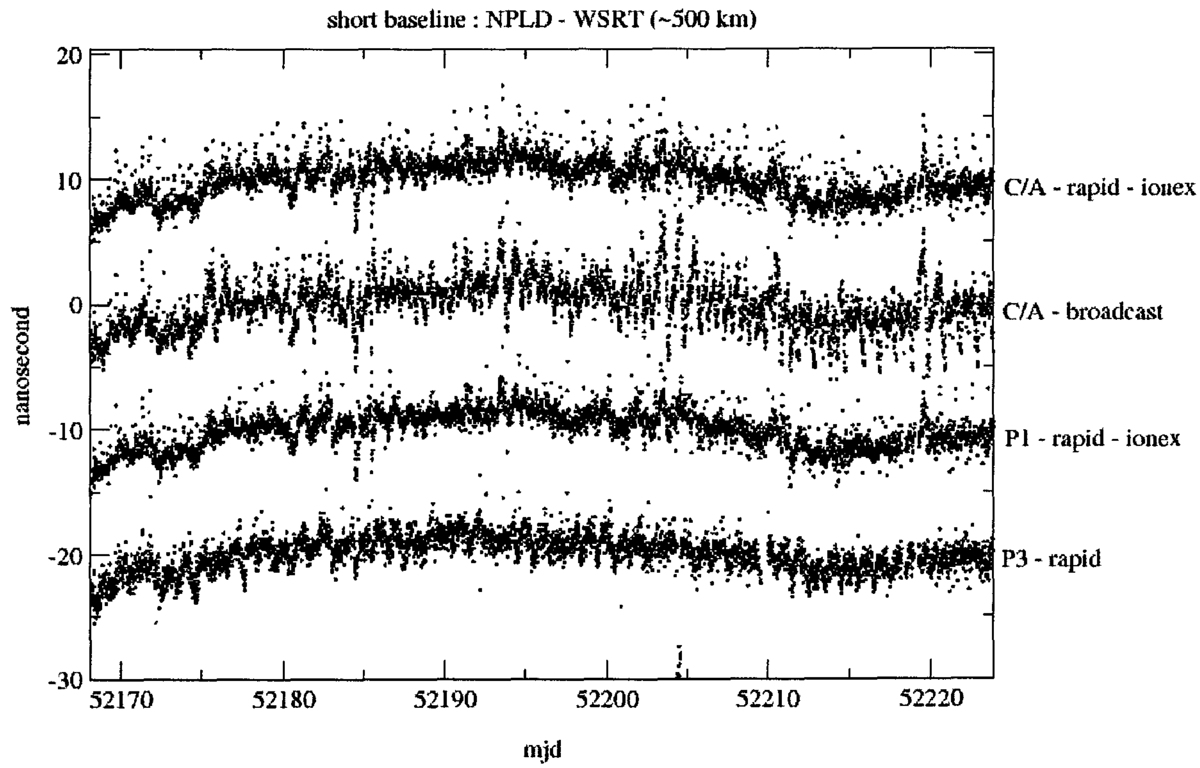

Figure 1. Time transfer between NPL and WSRT (short baseline) using different procedures.

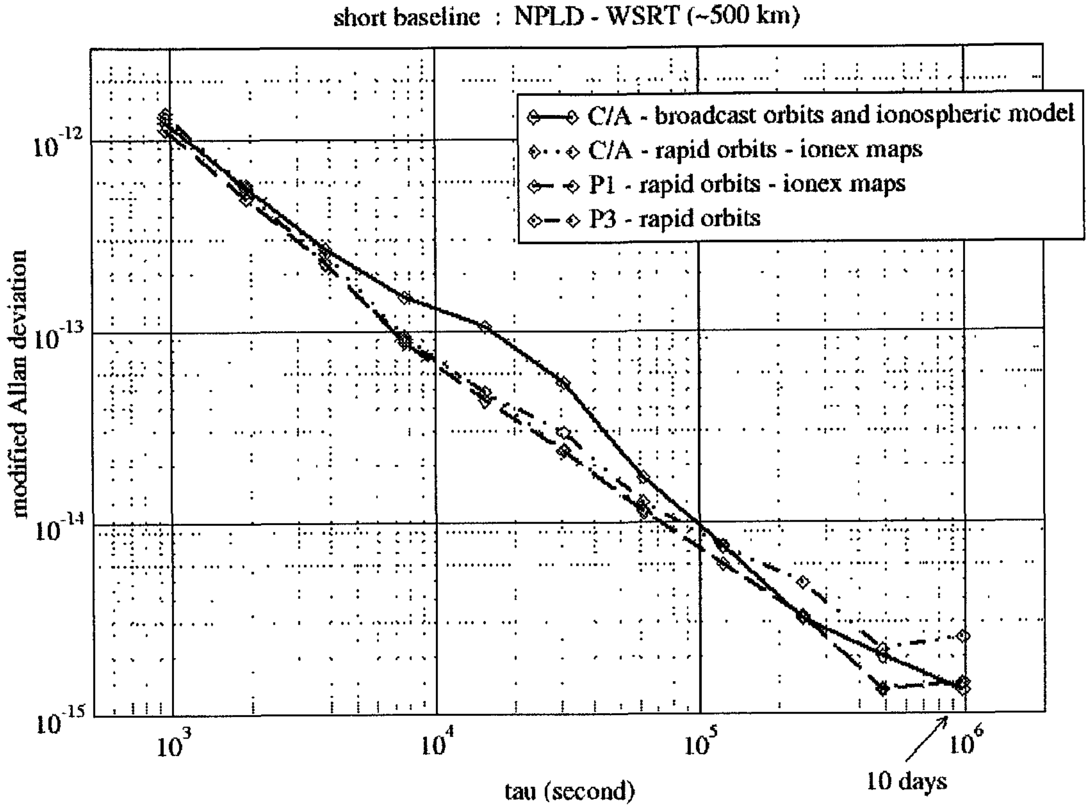

Figure 2. Frequency stability corresponding to Figure 1.

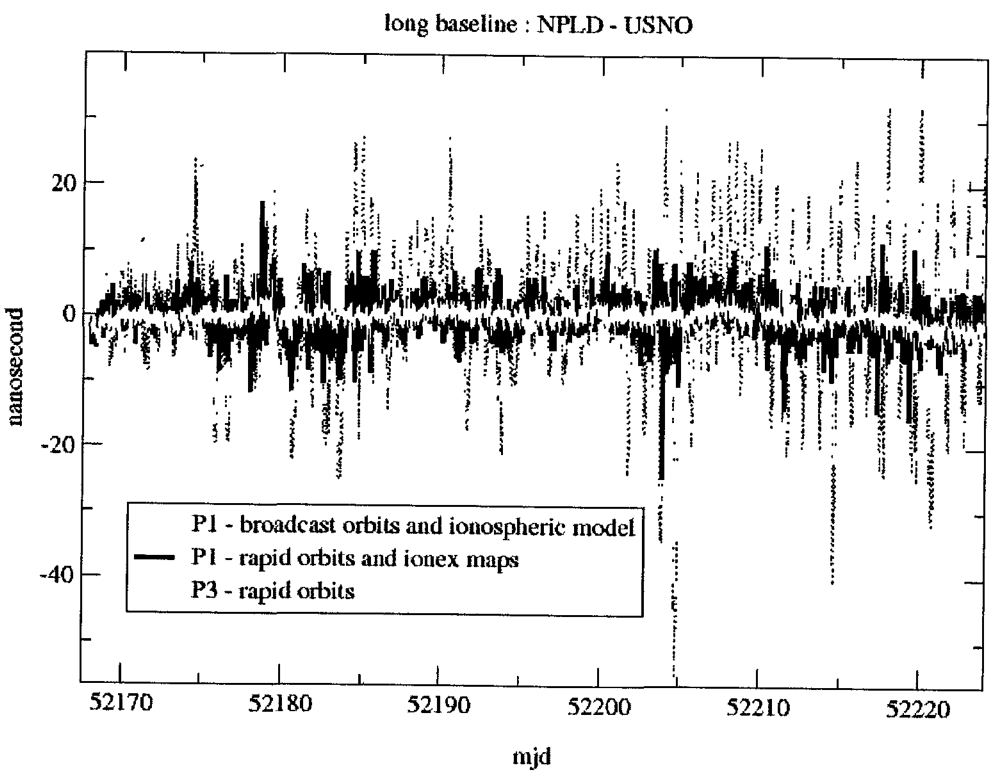

Figure 3. Time transfer between NPL and USNO (long baseline) using different procedures.

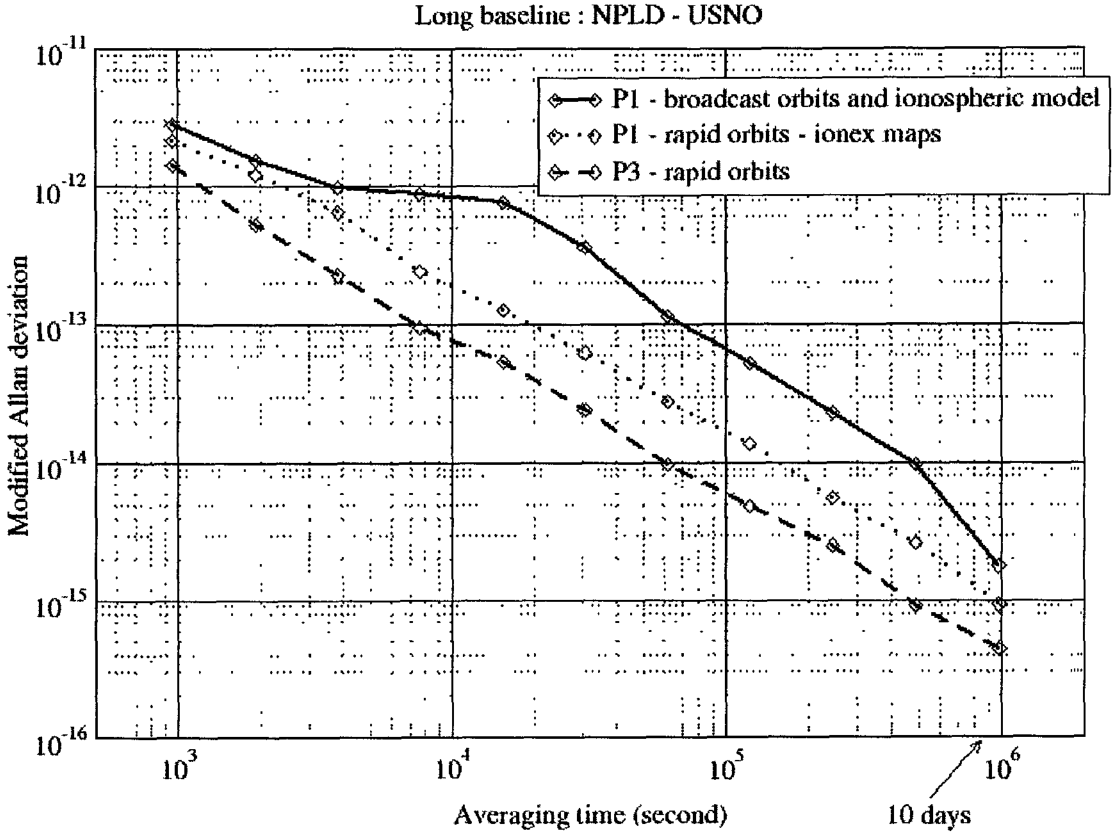

Figure 4. Frequency stability corresponding to Figure 3.

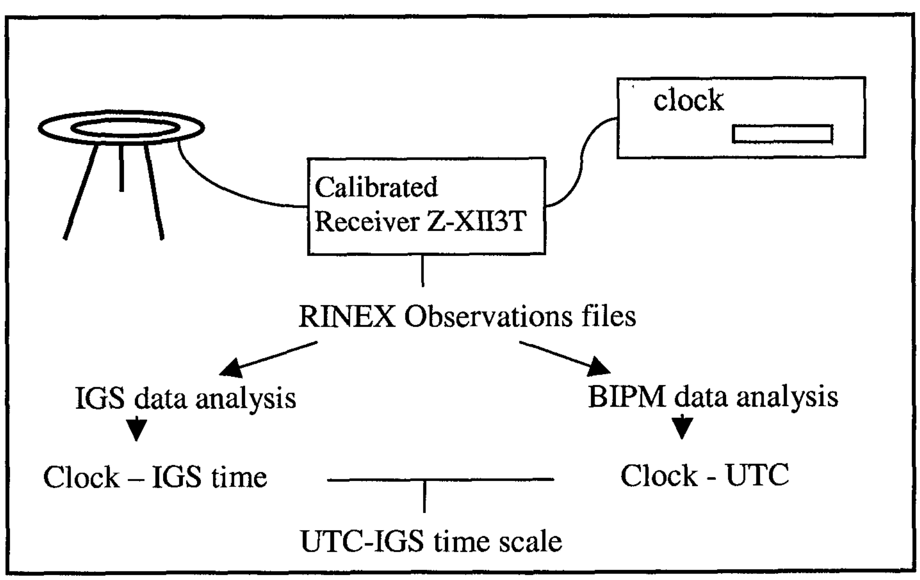

Figure 5. Best configuration to make the link between TAI and IGS time scale.