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THE NEED FOR GPS STANDARDIZATION

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Abstract

A desirable and necessary step for improvement of the accuracy of GPS time comparisons is the establishment of common GPS standards. For this reason, the CCDS proposed the creation of a special group of experts with the objective of recommending procedures and models for operational time transfer by GPS common-view method.

Since the announcement of the implementation of Selective Availability at the end of last spring, action has become much more urgent and this CCDS Group on GPS Time Transfer Standards has now been set up. It operates under the auspices of the permanent CCDS Working Group on TAI and works in close cooperation with the Sub-Committee on Time of the CGSIC.

Taking as an example the implementation of SA during the first week of July 1991, this paper illustrates the need to develop urgently at least two standardized procedures in GPS receiver software: monitoring GPS tracks with a common time scale and retaining broadcast ephemeris parameters throughout the duration of a track. Other matters requiring action are the adoption of common models for atmospheric delay, a common approach to hardware design and agreement about short-term data processing. Several examples of such deficiencies of standardization are presented.

INTRODUCTION

In recent years the operational GPS worldwide time transfer by C/A code receivers in common-view mode [1] has seen significant progress in both precision and accuracy [2]. The accuracy of GPS time links within continents now approaches two nanoseconds on an operational basis. Between continents, the accuracy of operational links is between 10 and 20 nanoseconds. Some recent studies, however, have shown that, when using an accurate homogeneous reference frame for antenna coordinates, ionospheric measurements and post-processed precise satellite ephemerides, these long-distance time comparisons can be achieved with an accuracy of a few nanoseconds [3].

But when approaching such a level of accuracy other problems arise. These are mainly due to the lack of standardization in the software and hardware of commercial receivers which, for example, process raw data differently or treat the input signal to the antenna in different ways. There is, in addition, a need to remove the effects of SA degradation of GPS signals.

The first section of this paper presents an analysis of the effects of SA with the example of its implementation during the beginning of July 1991. We show here the absolute necessity of strict common views and of data post-processing with precise satellite ephemerides to overcome SA effects. There is a consequent need for unified procedures in the design of GPS time receivers.

The second section deals with some other deficiencies of GPS time transfer which could be reduced in the framework of an international standardization. Several examples are given and are illustrated by the diversity of GPS time receiver types now in operation at the BIPM and national centers.

The third section of this paper briefly reports on the roles of the formal bodies concerned with GPS standardization: the CGSIC Subcommittee on Time and the CCDS Group on GPS Time Transfer Standards.

IMPLEMENTATION OF SA, JULY 1-4 1991

The GPS system was designed with an optional facility to degrade the GPS signals available to non- cleared users. The degradation is called 'Selective Availability' (SA). In addition to SA, there is also Anti-Spoofing (AS).

The activation of SA and AS makes the GPS Precise Positioning Service (PPS), which contains the full accuracy of GPS, inaccessible to those without encryption keys (authorized users). However, the Clear Access (C/A) 1.023 MHz code on L1 frequency remains available for all users and provides the GPS Standard Positioning Service (SPS). In case of SA, the SPS has a stated 95% accuracy in two dimensions of 100 meters in position and 167 ns in time [4].

According to the information available to the civil community, the degradation brought about by SA concerns only Block II satellites and consists of a phase jitter in the satellite clock and a changeable bias in the broadcast ephemerides. For the civil users, SA causes peak-to-peak inaccuracies of several hundreds of nanoseconds in the direct extraction of GPS time from Block II satellites [5].

This was observed for four consecutive days at the beginning of July 1991. Figure 1 shows an example of raw GPS data taken at Paris Observatory (Paris, France): a time modulation as high as 200ns is added to the usual noise affecting the GPS data.

Use of post-processed precise ephemerides

The effect of a changeable bias in the broadcast ephemerides can be overcome if precise post-processed ephemerides are available. Such precise ephemerides are produced by the Defense Mapping Agency (DMA) and the National Geodetic Survey (NGS) [6]. They are received on a regular basis at the BIPM, the delay before access being several weeks. Their estimated accuracy is of order 3m.

In practice, computations with precise ephemerides require knowledge of the broadcast ephemerides used by the receiver software in order to apply differential corrections [7], so it is necessary to collect regularly GPS broadcast ephemerides, at least at some sites in the world. Another difficulty is the possible change of ephemeris parameters during the usual 13-minute tracking period. This makes it necessary to modify the software of current GPS receivers in order to retain a single set of ephemeris parameters for the full duration of the track.

At the BIPM the software of one commercial GPS receiver has been modified to permit a 13-minute freezing of ephemeris parameters and the recording of broadcast ones. We are thus in position to

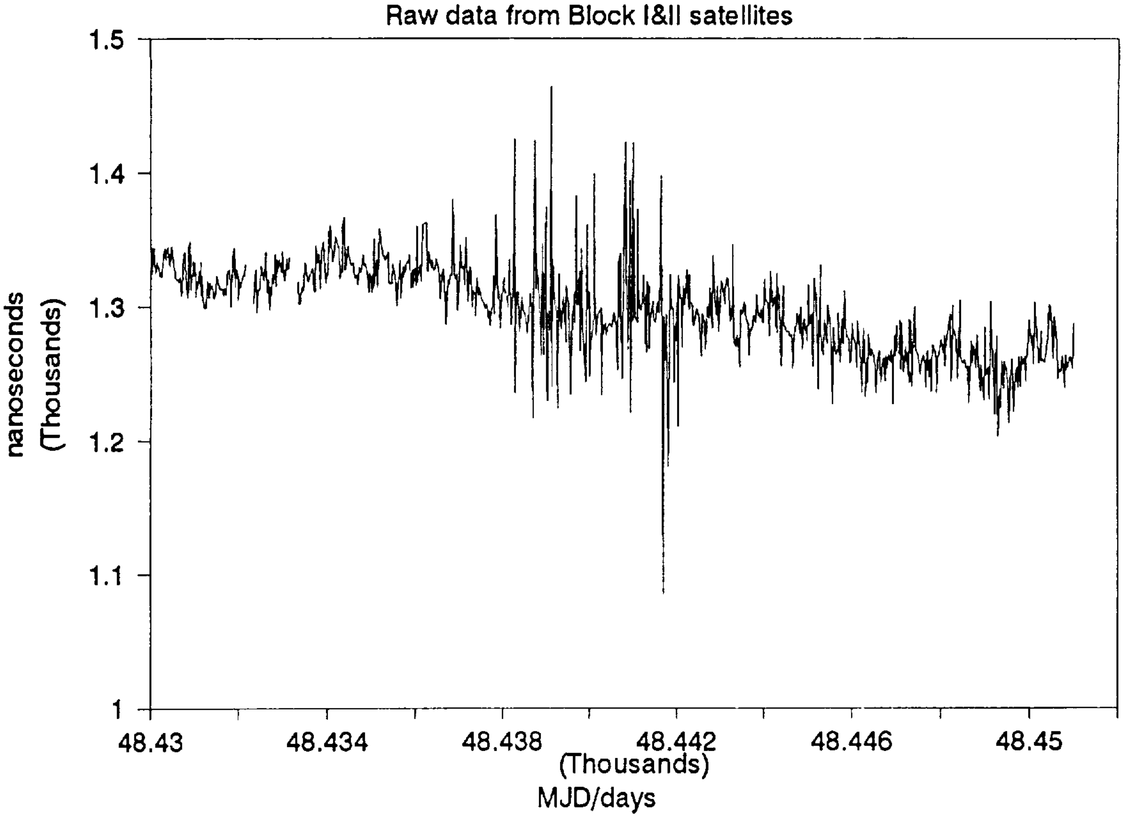
Figure 1. [UTC(OP) - GPS time]

correct raw GPS data for precise satellite ephemerides [8].

The raw data taken at Paris Observatory at the beginning of July 1991 are repeated in Figure 2-a for Block I satellites and in Figure 2-b for a selection of Block II satellites, those for which we can effectively process an ephemeris correction. The results of this correction process are shown in Figures 3-a and 3-b, together with the smoothed values [UTC(OP) - GPS time] obtained from Block I satellites only, through a Vondrak smoothing with a cut-off period of about 3 days [9].

The use of precise ephemerides improves the precision of time extraction from Block I satellites, and removes major errors from Block II satellites. For the 4– day period (1-4 July 1991) the root mean square of the residuals to the smoothed values [UTC(OP) - GPS time] is equal to 15.4ns for Block I satellites and to 29.9ns for Block II satellites. Such a high value for the Block II satellites implies that the specific implementation of SA used in this period consists not only in the degradation of satellite ephemerides but also in the activation of on-board clock jitter.

It is interesting to make a quantitative evaluation of the amount of noise brought about by SA during these four days:

- The degradation of ephemerides can be estimated from the root mean square of the differential time corrections between broadcast and precise ephemerides. From the values computed at the BIPM for the period 1-4 July 1991, we obtain about 39ns. However, this value is probably an under-estimate as the differential corrections for satellite 21, one of those most affected by SA, is unavailable (no recording of its broadcast ephemerides at that time).

- The noise observed for Block II satellites corrected for precise ephemerides (Fig. 3-b) comes both from clock jitter brought about by SA and from the usual noise of time extraction. This latter can be estimated from data taken from Block I satellites (Fig. 3-a). Thus this gives a rough estimation of the root mean square of the clock-jitter deviation of about 26ns.

Computation of strict common views

It is possible to eliminate on-board clock jitter in the comparison of remote clocks on the Earth. This supposes that strict common-view observations are available [1,5], that is observations having:

- same track length (780s),
- same start time (within 1s).

These conditions on timing express the need for a common reference time scale for monitoring tracks. This is not always the case at present: the BIPM international schedule refer to UTC time but some commercial receivers refer to GPS time or even mix UTC time and GPS time.

To complete the example of SA described here, we have computed the long-distance time comparisons [UTC(OP) - UTC(NIST)] for 21 consecutive days covering the period 1-4 July 1991. The residuals to smoothed values (Vondrak smoothing with a 3-day cut-off period [9]) are shown in Figure 4-a from strict common views. They show that on- board clock jitter noise is canceled, but ephemerides degradation is still present. After applying corrections for precise ephemerides (Fig. 4-b) the effect of SA become indiscernible: the root mean square of the residuals to smoothed values drops to 5.2ns for the 21- day period. Figure 4-c, where correction for measured ionospheric delay on both branches of the link is applied [8], is yet more striking: the precision of the time transfer (root mean square of the residuals) is a remarkable 2.7ns.

Conclusions

The particular example of SA chosen here does not correspond to the full specification of SA given in official documents [4]. The civil community must be then prepared to face even more serious problems. At least we know how to overcome SA in a post-processed mode: we use precise satellite ephemerides and strict common-view observations.

The impact on the need for GPS Standardization is now very clear: local GPS time receivers should, at least, use the same reference time for monitoring track start time and retain ephemeris parameters over the 13- minute duration of a track. It may also be wise to follow, strictly, the international schedule for common- view time transfer issued by the BIPM.

EXAMPLES OF DEFICIENCIES IN GPS TIME-TRANSFER CAUSED BY A LACK OF STANDARDIZATION

In this section we give some examples of deficiencies in GPS time transfer caused by a lack of standardization. We report briefly on recent progress and underline residual difficulties. Some of these points have already been discussed in **[10]** so we have chosen here to focus on topics pointed out more recently.

Homogenization of antenna coordinates

At one time, errors in antenna coordinates contributed one of the largest terms to the global error budgets of GPS time links **[2]**. These errors were first reduced for continental links **[11,12]**, then, in 1990, a global homogenization of coordinates was realized in one of the most accurate reference frames, the ITRF (IERS Terrestrial Reference Frame) **[13]**. The BIPM continues this effort of homogenization by providing accurate coordinates in ITRF (uncertainties range from 10cm to 1m) to new laboratories equipped with GPS time receivers and contributing to TAI. The last GPS antenna position determined by the BIPM is installed near Moscow in the VNIIFTRI: it is the first ITRF point in USSR, the uncertainty of the determination is 1m **[14]**.

Receiver hardware

A recent study **[15]** has shown one particular GPS time receiver type to be sensitive to external temperature. This sensitivity has been shown to depend on the length of antenna cables. With a 100m antenna cable the peak-to-peak deviations can reach 20ns.

Recently a sensitivity to signal power has been discovered at the NIST (National Institute of Standards and Technology, Boulder, Colorado) **[16]**: when a 10dB pad is added to the antenna, the measured receiver delay is modified. Generally this change is of order 1ns, but for one receiver tested at the NIST the change was much higher.

At present time, the reasons for such discrepancies are not completely understood but it is already clear that a standardization in hardware design may be necessary.

Receiver software

A typical example

Colleagues from the Laboratoire Primaire du Temps et des Fréquences (LPTF, Paris, France), responsible for the production of TA(F) and UTC(OP), have recently drawn the attention of the BIPM to an example of non-uniformity in the treatment of GPS signals by different GPS receivers operating in France.

Figures 5-a, 5-b and 5-c summarize the situation. The LPTF operates on site three receivers from different manufacturers A, B and C. Raw GPS data [UTC(OP) - GPS time] obtained by receivers A and B are in good agreement except for satellite 19 (Fig. 5-a) which provides raw values with a spread of about 15ns. Raw GPS data obtained by receivers C and B are in good agreement even for satellite 19 (Fig. 5-b).

The CNES (Centre National d'Etudes Spaciales, Toulouse, France) operates one receiver of type A. When computing the time link [UTC(CNES) - UTC(OP)] with receiver A in CNES and B in LPTF, values given from observing satellite 19 are too small by about 15ns (Fig. 5-c).

It may be that receivers of type A perform an incorrect treatment of data from satellite 19 for some reason at present unknown, while receivers of types B and C handle it correctly. But there is an alternative: satellite 19 data may be treated correctly by receiver of type A, while all other values are wrong.

Sampling of short-term GPS data

For most of GPS time receivers, short-term data are taken every 15s. For others short-term data are taken every 6s but offer an option which allows the choice of 6s or 15s for basic observations. Another receiver, recently put in operation at the BIPM, uses 1s intervals short-term measurement. In addition short-term raw data are not treated identically. This could make it difficult to define the actual start times of tracks when strict common views are necessary.

Sampling of short-term measurement is one important element of receiver software which is not standardized, but other points are questionable, among them the models which are used for estimation of the ionospheric and tropospheric delays of GPS signals, and also the regular updates of constants used in receiver software.

GPS data format

At present time most GPS receivers use the so-called 'NBS format' initially developed for 'NBS type' receivers in 1983.

Until early 1990, this standard format has fully played its role. The problem of defining a new format for GPS data files arose when ionospheric measurement systems began to operate in tandem with current time receivers. The automatic correction of GPS data by ionospheric measurements raised several questions, in particular the need to provide additional data columns for ionospheric measurements and the corresponding statistical parameters. The values of the tropospheric model should also be present in the output files.

In addition to these new questions, there is an incoherence in the usual data format: the quantities issued are not referenced to the same instant of the track. 'START TIME' is given for the beginning of the track while 'ELEVATION' and 'AZIMUTH' of the satellite refer to its position at the end of the track. The useful data 'REF-GPS' is referenced to any of the beginning, the mid-point or the end of the track, among which, statistically, the mid-point value is the most reliable. In fact all the values given in GPS data files should be referenced to the mid-point of the track.

The choice of unit is also questionable. It has become necessary to specify time values in tenths of nanoseconds rather than in nanoseconds. The elevation and azimuth of the satellite should also be given in tenths of degrees.

Finally, it must be remembered that the arrangement of the columns is only the visible part of the work. It is also necessary to agree on and to distribute the corresponding software. Setting up a new format also means that users need to be informed about its meaning for the best use of data.

Most discussion about the GPS data format is now opened. Receiver manufacturers and the staff of the national time laboratories are invited to give their opinions and suggestions. Agreement on the format may constitute the first concrete output of the official bodies set up to deal with the problem of GPS standardization.

FORMAL BODIES FOR GPS STANDARDIZATION

Two formal bodies are concerned with GPS coordination and standardization, they are the CGSIC Subcommittee on Time and the CCDS Group on GPS Time Transfer Standards **[11]**.

The Subcommittee on Time of the Civil GPS Service Interface Committee (CGSIC) is mainly a forum for the exchange of information between military and civilian elements. It cannot undertake formal decisions. On the one hand, the Subcommittee provides up to date information to the civil timing community , as presently reports on progress in the computation of precise satellite ephemerides and their availability. On the other hand, it promotes the needs of the civil community, especially about SA, during general meetings of the CGSIC.

The CCDS Group on GPS Time Transfer Standards (CGGTTS) operates under the auspices of the permanent Working Group on TAI of the Comité Consultatif pour la Définition de la Seconde (CCDS). This Group can initiate formal procedures as the CCDS could choose to submit its recommendations and standards to the approbation of the Comité International des Poids et Mesures (CIPM) and then to the Conférence Générale des Poids et Mesures (CGPM). The Group on GPS Time Transfer Standards was set up during the summer of 1991. Its first formal meeting was held on 2 December 1991 during the 23rd PTTI meeting in Pasadena, California.

The CGSIC Subcommitee on Time and the CCDS Group on GPS Time Transfer Standards are indispensable and are complementary.

CONCLUSIONS

Accuracy of a few nanoseconds in GPS time transfer is now possible even for long-distance links using post- processed corrections. Further improvements are feasible through international coordination and standardization of receiver hardware and software. Joint action is required to overcome the SA degradation of GPS signals. Two complementary formal bodies are concerned with these matters, the CGSIC Subcommitee on Time and the CCDS Group on GPS Time Transfer Standards. At the end of 1991, the prime activities of these two committees are, respectively, providing information on SA to the civil timing community and initiating a widespread debate on GPS data format.

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References

1. D. W. Allan and M. A. Weiss, *"Accurate Time and Frequency Transfer during Common-View of a GPS Satellite"*, Proc. 34th Annual Symposium on Frequency Control, pp. 334-346, 1980.
2. W. Lewandowski and C. Thomas, *"GPS Time Transfer"*, IEEE Special Issue on Time and Frequency, 79, pp. 991-1000, 1991.
3. W. Lewandowski, G. Petit and C. Thomas, *"Accuracy of GPS Time Transfer Verified by Closure around the World"*, accepted in Proc. 23rd Annual Precise Time and Time Interval (PTTI) Applications and Planning Meeting, 1991.
4. NATO Standardization Agreement (STANAG) 4294 (1 August 1990), Arinc Research Corporation, 2551 Riva Road, Annapolis, MD 21401, United States, Publication 3659-01- 01-4296.
5. D. W. Allan, M. Granveaud, W. J. Klepczynski and W. Lewandowski, *"GPS Time Transfer with Implementation of Selective Availability"*, in Proc. 22nd Annual Precise Time and Time Interval (PTTI) Applications and Planning Meeting, pp. 145-156, 1990.
6. W. Lewandowski, G. Petit and C. Thomas, *"Precise GPS Ephemerides from DMA and NGS Tested by Time Transfer"*, accepted in Proc. 23rd Annual Precise Time and Time Interval (PTTI) Applications and Planning Meeting, 1991.
7. W. Lewandowski and M. A. Weiss, *"The Use of Precise Ephemerides for GPS Time Transfer"*, in Proc. 21st Annual Precise Time and Time Interval (PTTI) Applications and Planning Meeting, pp. 95-106, 1989.
8. W. Lewandowski, G. Petit, C. Thomas and M. A. Weiss, *"The Use of Precise Ephemerides, Ionospheric Data and Corrected Antenna Coordinates in a long-distance GPS Time Transfer"*, in Proc. 22nd Annual Precise Time and Time Interval (PTTI) Applications and Planning Meeting, pp. 547-558, 1990.
9. J. Vondrak, *"A Contribution to the Problem of Smoothing Observational Data"*, Bull. Astron. Inst. Czechoslovakia, 20, pp. 349-355, 1969.
10. W. Lewandowski, C. Thomas and D. W. Allan, *"CGSIC Subcommittee on Time and CCDS Group of Experts on GPS Standardization"'*, in Proc. ION GPS-91 4th International Technical Meeting, in press, 1991.
11. B. Guinot and W. Lewandowski, *"Improvement of the GPS Time Comparisons by Simultaneous Relative Positioning of the Receiver Antennas"*, in Bulletin Géodésique, 63 pp. 371-386, 1989.
12. W. Lewandowski, R. J. Douglas, W. J. Klepczynski, W. Strange, J. Suter and M. A. Weiss, *"Positioning of GPS Antennas in Time-Keeping Laboratories of North America"*, in Proc. 43rd Annual Symposium on Frequency Control, pp. 218-224, 1989.
13. W. Lewandowski, *"High Accuracy Ground-Antenna Coordinates for GPS Time Transfer"*, in Proc. IAG Symposium G2-Permanent Satellite Tracking Networks for Geodesy and Geodynamics, Vienna, August 1991, in press.

14. W. Lewandowski, G. Petit and C. Thomas, *"Comparison of GLONASS and GPS Time Transfers between University of Leeds and VNIIFTRI"*, accepted in Proc. 23rd Annual Precise Time and Time Interval (PTTI) Applications and Planning Meeting, 1991.

15. W. Lewandowski and R. Tourde, *"Sensitivity to the External Temperature of some GPS Time Receivers"*, in Proc. 22nd Annual Precise Time and Time Interval (PTTI) Applications and Planning Meeting, pp. 307-316, 1990.

16. D. Davis, NIST, Boulder, Colorado, USA, personal communication.

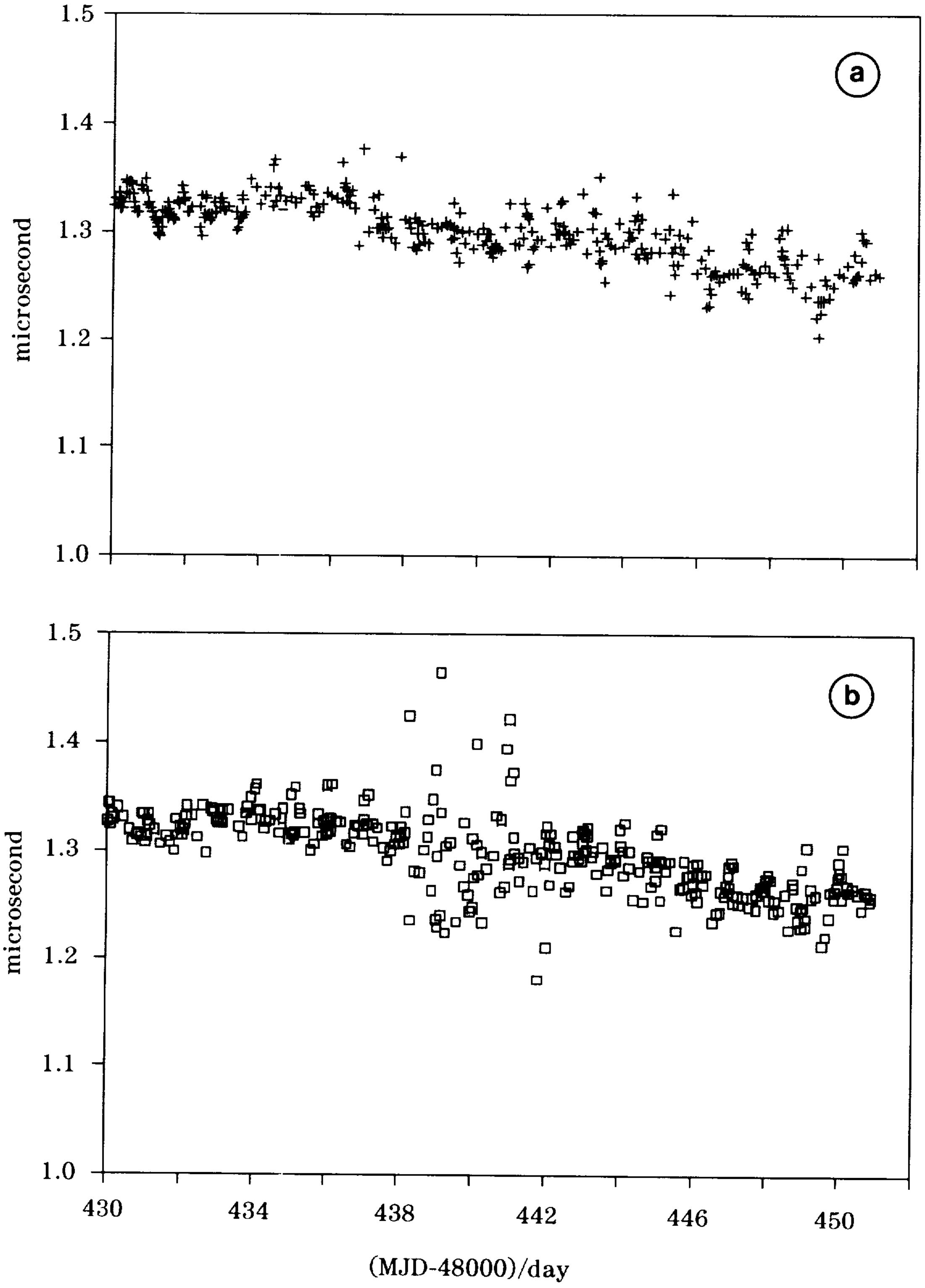

FIGURE 2. *Raw GPS data [UTC(OP) - GPS time] taken at Paris Observatory from 23 June to 14 July 1991,*

2-a. from Block I satellites only,

2-b. from a selection of Block II satellites.

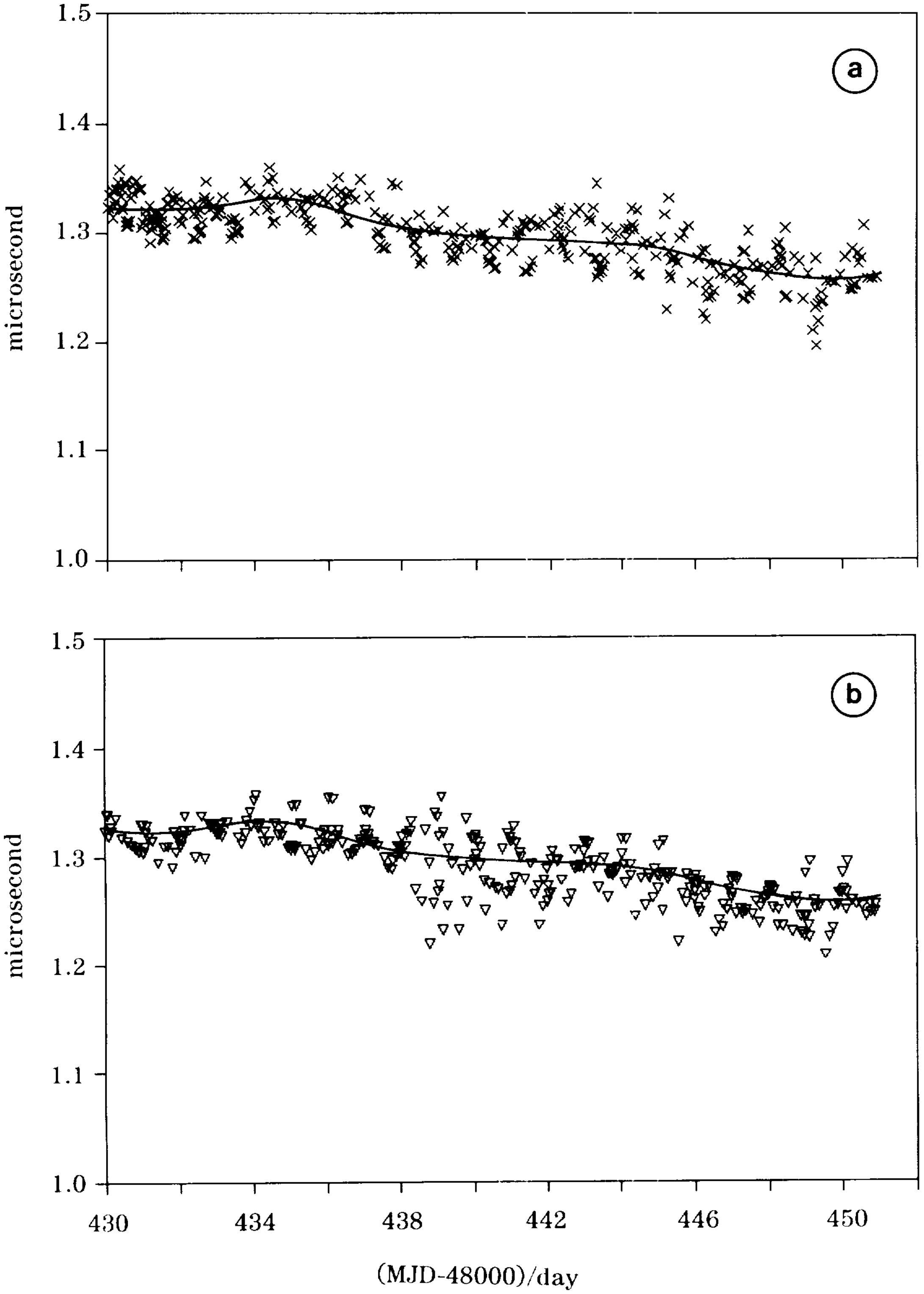

FIGURE 3. *GPS data [UTC(OP) - GPS time] taken at Paris Observatory from 23 June to 14 July 1991, after correction for precise ephemerides,*
3-a. from Block I satellites only,
3-b. from a selection of Block II satellites.
The continuous line represents the smoothed values [UTC(OP) - GPS time] obtained from Block I satellites only.

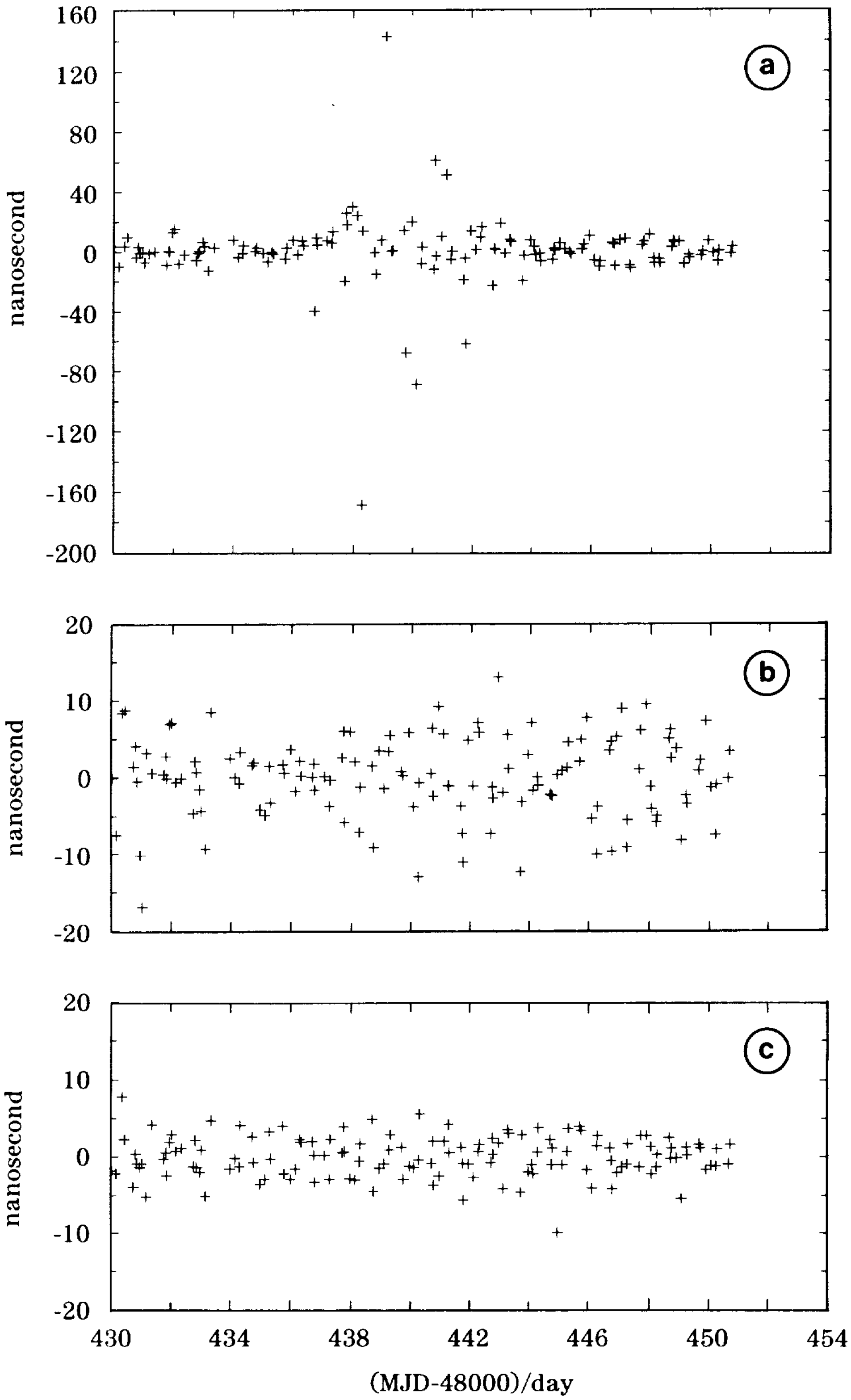

FIGURE 4. *Time link [UTC(OP) - UTC(NIST)] computed from strict common views,*
4-a. with raw GPS data,
4-b. with GPS data corrected for precise ephemerides,
4-c. with GPS data corrected for precise ephemerides and ionospheric measurements.

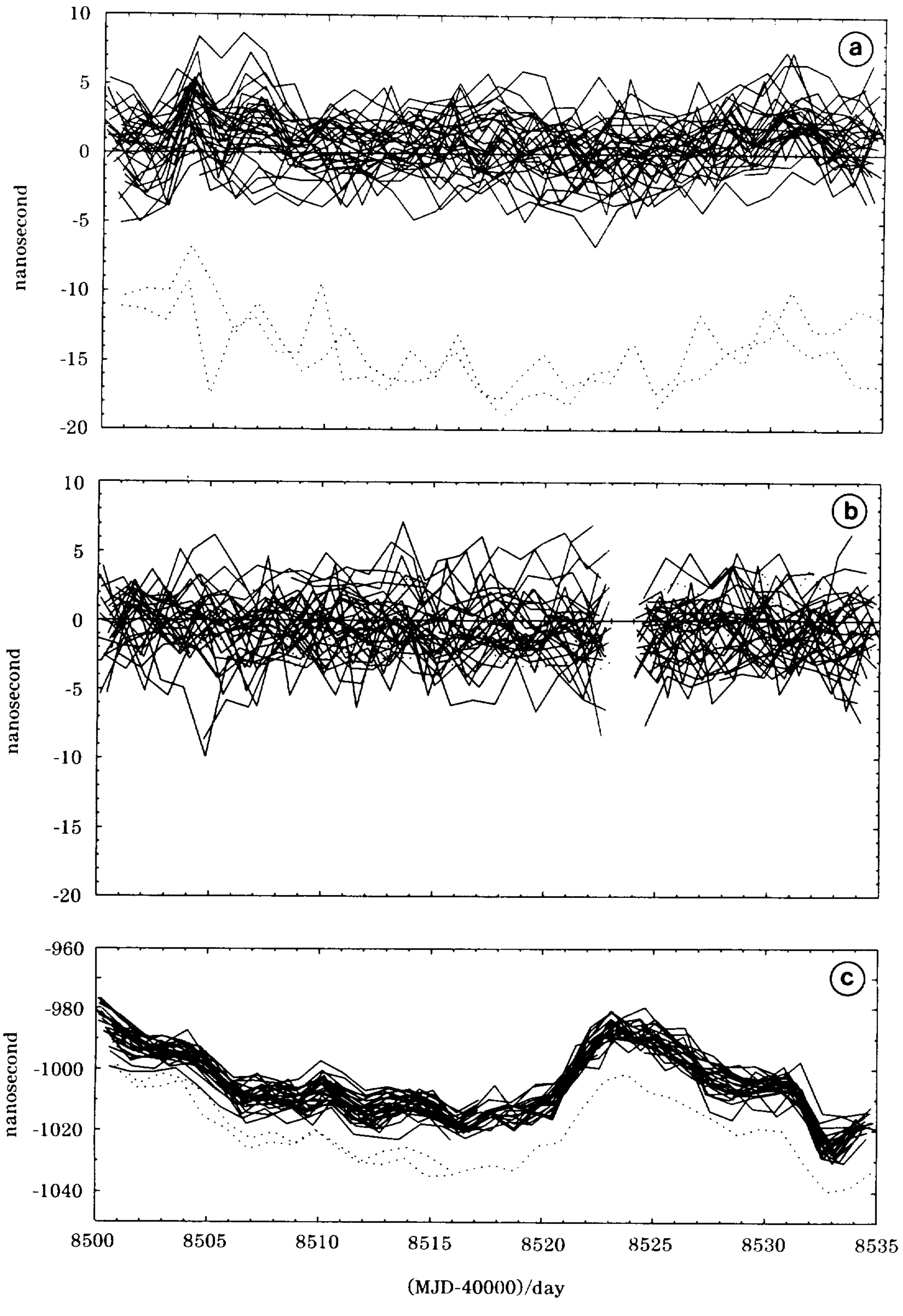

FIGURE 5. *GPS data taken by three different GPS time receivers (A-, B-, C-type) at two sites in France (Observatoire de Paris, Paris and Centre National d'Etudes Spatiales, Toulouse).*
Observations from satellite 19 are represented with a dash line.
5-a. [UTC(OP) - GPS time]$_A$ - [UTC(OP) - GPS time]$_B$,
5-b. [UTC(OP) - GPS time]$_C$ - [UTC(OP) - GPS time]$_B$,
5-c. [UTC(CNES) - GPS time]$_A$ - [UTC(OP) - GPS time]$_B$.