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BUREAU INTERNATIONAL DES POIDS ET MESURES

DETERMINATION OF THE DIFFERENTIAL TIME CORRECTION BETWEEN GPS TIME EQUIPMENT LOCATED AT THE OBSERVATOIRE DE PARIS, PARIS, FRANCE, AND THE ASTRONOMICAL LATITUDE OBSERVATORY, BOROWIEC, POLAND

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Abstract

The method of clock comparisons using GPS satellites can now reach an accuracy of several nanoseconds. Poor calibration of GPS time receiving equipment is one of the limiting factors to this accuracy. One method which permits removal of calibration errors is the comparison of remote GPS equipment by transporting a portable receiver from one location to another. We reported here the results of a comparison of the GPS equipment located at the Paris Observatory, Paris, France, and at the Astronomical Latitude Observatory, Borowiec, Poland. This comparison was effected by means of a portable AOA-TTR6 GPS time receiver.

Resumé

La méthode de comparaison des horloges en utilisant les satellites du GPS peut, à ce jour, atteindre une exactitude de quelques nanosecondes. Un mauvais étalonnage des équipements du temps du GPS constitue l'un des facteurs limitant cette exactitude. Une méthode qui permet d'éliminer les erreurs d'étalonnage consiste à comparer des équipements GPS distants par transport d'un récepteur GPS portable. Nous rapportons ici les résultats d'un étalonnage des équipements GPS situés à l'Observatoire de Paris, Paris, France et à l'Observatoire Astronomique de Latitude, Borowiec, Pologne. Cet étalonnage a été effectué à l'aide d'un récepteur de temps du GPS portable modèle AOA-TTR6.

INTRODUCTION

The method of time transfer between remote locations using GPS satellites in common view has now achieved an accuracy of several nanoseconds [1]. Calibration errors in GPS time equipment (for example, receiver and antenna delays, cable delays, 1 pps distribution) limit this accuracy. One method which permits the removal of calibration errors is the comparison of remote GPS time equipment using a portable GPS time receiving equipment. Such calibrations were initiated in 1984 by the Naval Research Laboratory (NRL) with the support of the USNO [2]. Since then a number of comparisons of remote GPS time receivers have taken place [3, 4]. Careful calibration of local hardware, such as cables, is also required [5].

The reproducibility of the comparisons from such exercises is a few nanoseconds, but our experience with the long-term stability of GPS time receiving equipment is still limited; drifts or steps of several tens of nanoseconds can occur without being noticed. Some types of GPS time receivers have been shown to be sensitive to external temperature [6, 7]. For these reasons, frequent comparisons of GPS equipment are required.

We report here the results of a calibration exercise organized under the auspices of the BIPM. Comparison of the receivers located at the Observatoire de Paris (OP), Paris, France and the Astronomical Latitude Observatory (Astronomiczne Obserwatorium Szerokościowe - AOS), Borowiec, Poland, was effected by the means of a portable GPS time receiver BIPM3 belonging to the BIPM. This was organized as a round-trip, the portable receiver coming back to the OP after visit to the AOS.

EQUIPMENT

All three receivers involved in this comparison are single-channel, C/A code receivers. Their principal characteristics are:

Portable receiver: BIPM3	Maker: Allen Osborne Associates, Type: NBS/TTR6, Ser. No: 277.
OP:	Maker: Allen Osborne Associates, Type: NBS/TTR5, Ser. No: 051.

AOS: Maker: NAVI & AOS,
Type: NAVI,
Ser. No: 21.

The OP receiver serves as reference for many international comparisons of GPS time equipment. It has been compared 9 times in the last 12 years with the NIST 'on line', absolutely calibrated, GPS time receiver. The differences between two receivers have always been within a few nanoseconds.

Comparisons at short distances allow cancellation of a number of errors. If the software of the receivers compared is identical, no error should arise from satellite broadcast ephemerides, antenna coordinates or imperfect modelling of the ionosphere and troposphere. This is the case for this comparison, where all involved receivers are of the NBS type.

Unfortunately, differences have been found in the software receivers of different type [1, 8]. The *Group on GPS Time Transfer Standards*, operating under the auspices of the permanent CCDS Working Group on TAI, has recently issued standards to be adopted by receiver designers and users concerned with the use of GPS time receivers for common-view time transfer [9]. These standards will soon be implemented on most GPS time receivers.

CONDITIONS OF COMPARISON

For the present comparison, the portable equipment took the form of the receiver, its antenna and a calibrated antenna cable. The laboratories visited supplied a) a 5 MHz reference signal, b) a series of 1 s pulses from the local reference, UTC(k), via a cable of known delay. In each laboratory the portable receiver was connected to the same clock as the local receiver and the antenna of the portable receiver was placed close to the local antenna. The differential coordinates of the antenna phase centres were known at each site with uncertainties of a few centimetres.

During the comparisons the receivers were programmed with the *BIPM Common-View International Schedule No 24* for Europe.

During this exercise the Block II satellites were subjected to Selective Availability (SA), so strict common views were required. All common views retained for the comparison fulfilled the following conditions: 15 s common-view tolerance, 765 s minimum duration of the track, 25° minimum elevation angle for satellites. The 15 s tolerance for common views is necessitated by a fault in the AOA TTR receivers which begin observations 15 s later than scheduled. Values of the common views were computed for the midpoints of the tracks.

RESULTS

The processing of the comparison data obtained in laboratory k consists first of the computation, for each track i, of the time differences:

$$dt_{k,i}=[UTC(k)\text{-}GPS\ time]_{BIPM3,i}-[UTC(k)\text{-}GPS\ time]_{k,i}\ .$$

The noise exhibited by the time series $\mathbf{dt_k}$ is then analysed for each laboratory by use of the modified Allan variance. For the comparisons at the OP, at the AOS and again at the OP, the time series $\mathbf{dt_k}$ exhibit white phase noise up to an averaging interval of one day (Figures 1, 2, 3).

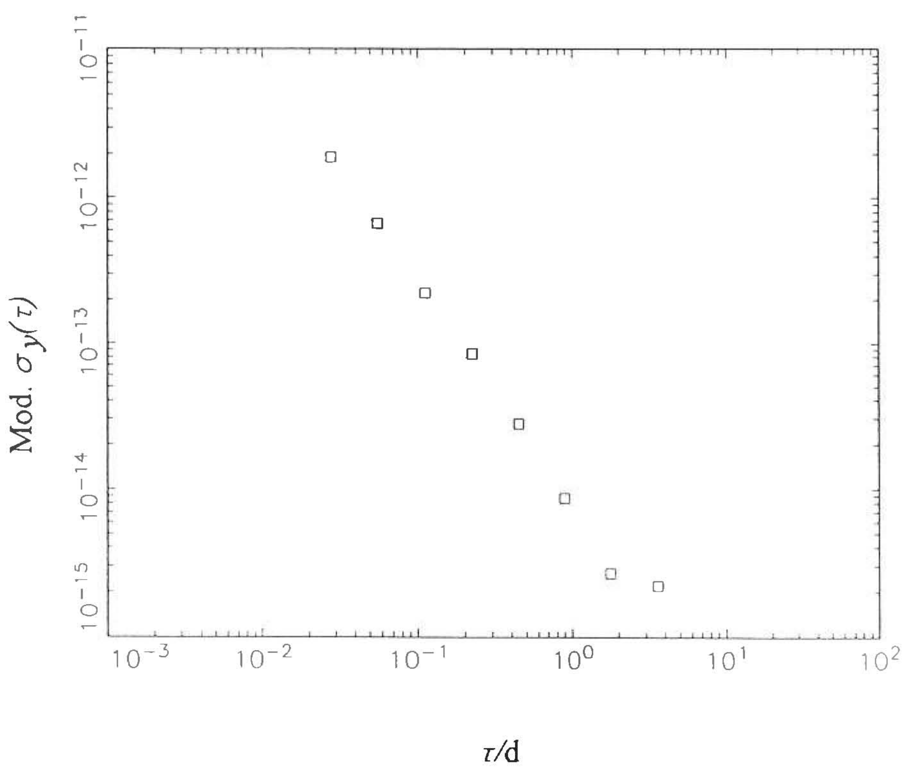

Figure 1. Square root of the modified Allan variance of the time series $\mathbf{dt_{OP}}$ for the period March 7-April 3, 1995.

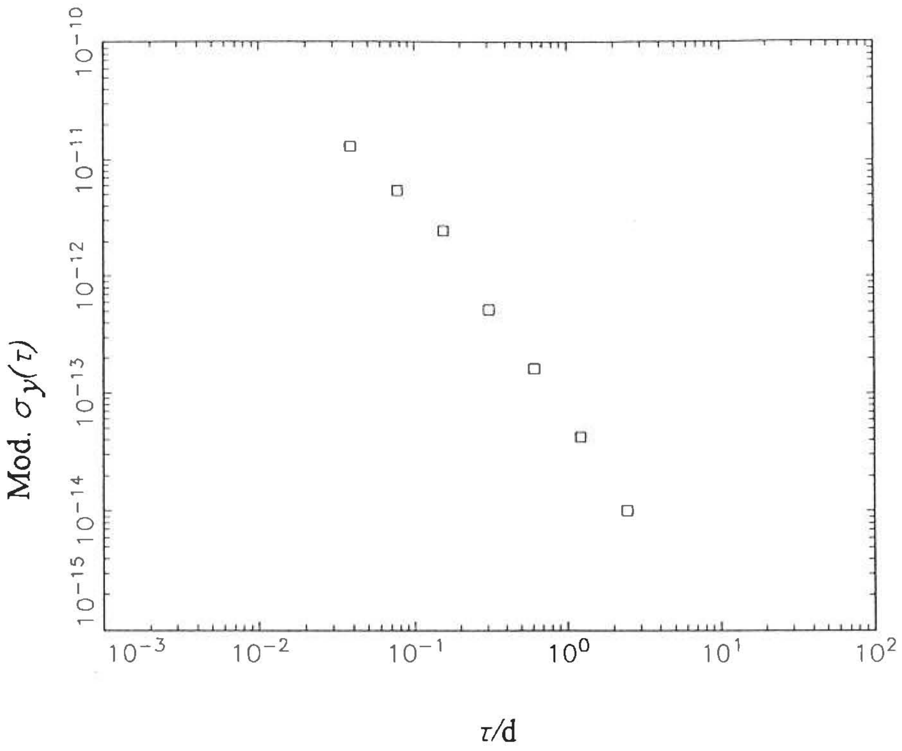

Figure 2. Square root of the modified Allan variance of the time series $\mathbf{dt_{AOS}}$ for the period April 5-17, 1995.

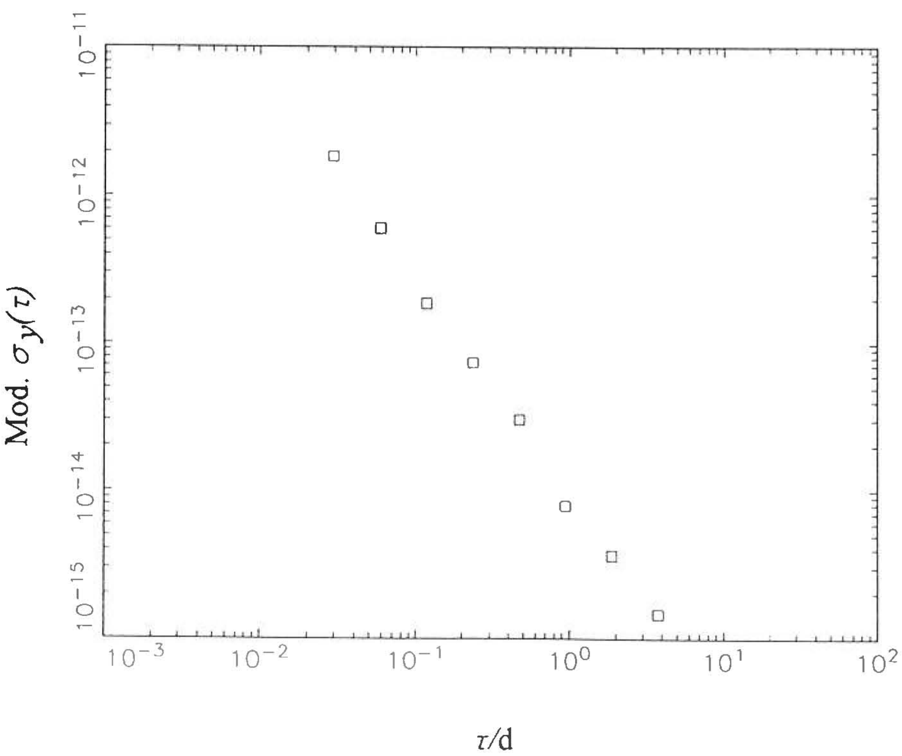

Figure 3. Square root of the modified Allan variance of the time series $\mathbf{dt_{OP}}$ for the period April 24-May 14, 1995.

This justifies computation of a mean offset for one-day periods and the use of the standard deviation of the mean as an expression of confidence in the mean. It should be noted that the standard deviation of the mean reflects only the physical conditions during the one-day period of the comparison and gives no indication of the day-to-day reproducibility of the measurements.

The daily results of the comparisons are as follows:

Lab	Date 1995	Number of individual common views	Mean offset /ns	Standard deviation of individual common view /ns	Standard deviation of the mean /ns
OP	Mar 7	17	-6,20	2,59	0,63
	Mar 8	38	-6,00	2,66	0,43
	Mar 9	38	-6,62	3,05	0,50
	Mar 10	38	-6,02	2,74	0,44
	Mar 11	39	-6,15	3,23	0,52
	Mar 12	39	-6,40	3,27	0,52
	Mar 13	39	-5,80	3,09	0,50
	Mar 14	39	-6,22	3,54	0,57
	Mar 15	36	-6,03	3,07	0,51
	Mar 16	39	-5,62	2,98	0,48
	Mar 17	34	-5,75	2,77	0,48
	Mar 18	37	-5,70	2,17	0,36
	Mar 19	39	-6,37	2,58	0,41
	Mar 20	36	-6,29	1,44	0,24
	Mar 21	37	-5,93	2,33	0,38
	Mar 22	38	-5,73	2,17	0,35
	Mar 23	36	-4,96	2,67	0,44
	Mar 24	37	-5,71	2,95	0,49
	Mar 25	37	-5,75	2,52	0,41
	Mar 26	35	-5,64	2,94	0,50
	Mar 27	28	-6,52	2,34	0,44
	Mar 28	37	-6,95	1,96	0,32
	Mar 29	38	-6,21	2,53	0,41
	Mar 30	35	-6,36	2,38	0,40
	Mar 31	36	-5,19	1,73	0,29
	Apr 1	36	-5,51	2,67	0,45
	Apr 2	35	-5,16	2,97	0,50
	Apr 3	37	-4,55	3,35	0,55

Lab	Date 1995	Number of individual common views	Mean offset /ns	Standard deviation of individual common view /ns	Standard deviation of the mean /ns
AOS	Apr 5	6	362,63	13,53	5,52
	Apr 6	26	362,58	27,45	5,38
	Apr 7	27	362,68	28,61	5,51
	Apr 8	27	363,75	29,10	5,60
	Apr 9	29	365,11	28,25	5,25
	Apr 10	28	363,07	27,99	5,29
	Apr 11	29	362,60	27,68	5,14
	Apr 12	27	367,16	26,71	5,14
	Apr 13	30	363,99	28,35	5,18
	Apr 14	26	364,66	29,18	5,72
	Apr 15	26	367,68	29,78	5,84
	Apr 16	26	366,06	27,52	5,40
	Apr 17	26	365,50	29,46	5,78
OP	Apr 24	15	-5,25	2,70	0,70
	Apr 25	36	-5,05	2,50	0,42
	Apr 26	35	-5,08	3,16	0,53
	Apr 27	35	-5,89	2,83	0,48
	Apr 28	35	-6,50	2,24	0,38
	Apr 29	33	-5,79	1,97	0,34
	Apr 30	35	-6,20	2,67	0,45
	May 1	34	-6,70	2,03	0,35
	May 2	34	-5,38	2,43	0,42
	May 3	34	-5,12	2,65	0,45
	May 4	32	-6,45	1,99	0,35
	May 5	34	-5,03	2,04	0,35
	May 6	33	-4,70	1,70	0,30
	May 7	25	-4,69	2,82	0,56
	May 8	34	-4,51	2,47	0,42
	May 9	30	-4,57	2,36	0,43
	May 10	35	-5,00	2,44	0,41
	May 11	34	-4,55	2,42	0,42
	May 12	33	-4,08	2,85	0,50
	May 13	33	-4,18	2,25	0,39
	May 14	35	-4,77	2,99	0,51

The following table gives averages, and corresponding standard deviations, of the daily mean offsets for the whole period of comparison at each location.

Lab	Period 1995	Total number of common views	Mean offset /ns	Estimated uncertainty /ns
OP	Mar 7-Apr 3	1010	-5,9	0,5
AOS	Apr 5-17	333	364,4	1,8
OP	Apr 24-May 14	684	-5,2	0,8

It is noticeable that the two measurements carried out at the OP, before and after the trip to the AOS, agree to within 1 ns.

The practical purpose of such a comparison is to estimate a differential correction to be applied to the pair of involved laboratories. The following differential correction should be added to the GPS comparison values between the time scales of the two visited laboratories:

$UTC(k_1)-UTC(k_2)$	Differential time correction to be added to $UTC(k_1)-UTC(k_2)$ /ns	Estimated uncertainty for the period of comparison /ns
UTC(AOS)-UTC(OP)	370	3 (1σ)

The above correction is derived from the mean offsets evaluated over the periods of comparisons. The given uncertainty is a conservative estimate appropriate to the particular conditions of observation at the AOS.

CONCLUSION

The differential time correction between the GPS time equipment located at the OP and at the AOS is large and corresponds to an offset of 370 ns. The origin of this is that the delay adopted for the AOS GPS time receiver matches the delays chosen for television method used previously at the AOS.

Large standard deviations of the daily means at the AOS are explained by the use of non-standardised procedures in the software of the AOS GPS time receiver, which remains in prototype form. This issue is now under study at the AOS. The noticeable fluctuation of the results at the AOS, peak to peak 5 ns during 14 days, is characteristic of the temperature dependence of the receivers [6], this also being the object of an investigation at the AOS.

To test the influence of ageing on time receivers, comparisons of this sort should be repeated from time to time. Environmental conditions such as temperature, humidity and multipath reflections should also be investigated.

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