COMPARISON OF GLONASS AND GPS TIME TRANSFERS BETWEEN TWO WEST EUROPEAN TIME LABORATORIES AND VNIIFTRI

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Abstract

The University of Leeds built a GPS/GLONASS receiver about five years ago and since then has provided continuous information about GLONASS time and its comparison with GPS time. For the last two years VNIIFTRI and some other Soviet time laboratories have used Soviet-built GLONASS navigation receivers for time comparisons. Since June 1991, VNIIFTRI has been operating a GPS time receiver on loan from the BIPM. This offered, for the first time, an opportunity for direct comparison of time transfers using GPS and GLONASS. This experiment shows that even with relatively imprecise data recording and processing, in terms of time metrology, GLONASS can provide continental time transfer at a level of several tens of nanoseconds.

INTRODUCTION

Two global space navigation systems, the American GPS and the Soviet GLONASS, are at the about same stage in the development of their space segments, but they are unequally used for international time comparisons. GPS, with a large range of time-specialized receivers, has for many years been exploited worldwide for accurate time transfer [1], while GLONASS is still used on an experimental basis by only a few laboratories [2]. Although at present GPS time transfer fully satisfies the needs of time metrology, it is the sole method which is operationally effective and the lack of redundancy is felt. There is also a growing concern about GPS degradation by Selective Availability. In this context GLONASS is of increasing interest as an excellent additional source.

For about five years the University of Leeds (Leeds, UK) has operated a GPS/GLONASS timing receiver built in-house, and provided continuous information about GLONASS time and its comparison with GPS time. For the last two years VNIIFTRI (Mendeleevo, Moscow Region, USSR) and some other Soviet time laboratories have used Soviet-built GLONASS navigation receivers for time comparisons. Since June 1991, VNIIFTRI has been operating a commercial GPS time receiver on loan from the BIPM. This offers, for the first time, an opportunity for direct comparison of time transfers by GPS and GLONASS between laboratories of West Europe and USSR. Values of UTC(LDS)–UTC(SU) and UTC(OP)–UTC(SU), as provided by GPS and by GLONASS, are reported together with estimates of the errors involved.

This experiment covers the period from July 4 to September 8, 1991. The GPS Block II satellites have been deleted from GPS common-view treatment when they were affected by Selective Availability (beginning of July [3]).

GLONASS AND GPS OBSERVATIONS AT THE UNIVERSITY OF LEEDS

The time laboratory of the University of Leeds is equipped with the three following time receivers:

- **TRIMBLE 5000A**

  This receiver is programmed with the BIPM international common view schedule and refers to UTC(LDS).

- **TRIMBLE 4000A**

  This receiver generates a 1 PPS synchronised on UTC(USNO) as broadcast by GPS satellites with an uncertainty of 100ns [1]. This signal is the external reference of the Leeds University GPS/GLONASS receiver.

- **Leeds University GPS/GLONASS receiver**

  This receiver performs the measurements of UTC(USNO)–GPS time and UTC(USNO)–GLONASS time.

The three receivers are connected to the one omni-directional antenna and use the same set of coordinates expressed in the WGS 84 reference frame with an uncertainty of 3 m.

In the past GLONASS observations by GPS/GLONASS Leeds University receiver provided a series of navigational solutions expressed in the Soviet reference frame (SGS 85) used by GLONASS satellites. These results agreed with WGS 84 coordinates within 5 meters.

The delays of the receivers are known approximately within 20ns. The schema of the whole installation is illustrated in Figure 1.

The GPS/GLONASS receiver performs the measurements almost continuously, observing all available GLONASS satellites and a selection of GPS satellites (all Block I and 2 Block II satellites). For a given satellite, the receiver starts measurements of UTC(USNO)- satellite time and does this once a second for 180s. This data is stored, filtered to remove outliers and averaged. The typical standard deviation for 180s averages is 50ns. During one day the receiver performs roughly 340 tracks of 180s, 75% of them corresponding to GLONASS satellites. Daily averages of tracks have a standard deviation around 50ns for both GPS and GLONASS data. These results are not corrected for ionospheric or tropospheric delays.

The GPS observations produced by the GPS TRIMBLE 5000A receiver are used in this study for common-view time transfer with VNIIFTRI. Previous analysis of common-view time transfer between the University of Leeds and the Paris Observatory showed that the TRIMBLE 5000A data is affected by a noise which limits the uncertainty of such a time transfer to 10- 15ns. This noise is partly due to uncertainty in the coordinates. Several attempts have been made to improve the Leeds antenna coordinates by the BIPM method [4]. All of them produced the coordinates with uncertainties of several meters which indicates other than geometrical error sources. The TRIMBLE 5000A receiver was programmed during this experiment with the 37 13-minute tracks of the BIPM international tracking schedule no 17 including all Block I and Block II satellites. About 25 tracks were available each day for this experiment.

GLONASS AND GPS OBSERVATIONS AT THE VNIIFTRI

The USSR State Time & Frequency Service (VNIIFTRI) is located in Mendeleevo, near Moscow. This organization is responsible for the maintenance of the Soviet national time reference UTC(SU). An ensemble of high-quality atomic clocks, mostly hydrogen masers, is operated.

GLONASS time observations at VNIIFTRI have been carried out, since 1989, using a Soviet-built commercially available receiver A-724 designed for aircraft navigation. The receiver is supplied with 1 PPS and 5 MHz provided by the VNIIFTRI master clock. The readings of the master clock are corrected "a posteriori", to transform them into UTC(SU). The receiver uses a fixed model of the ionospheric delay and does not correct observations for tropospheric delay. The antenna coordinates are expressed in the Soviet Geodetic System 85 (SGS 85) with estimated uncertainty of order 5m provided by a series of navigational solutions.

There are three to five observations per day of UTC(SU)–GLONASS time. All of them are performed at low elevations in the direction of East. With the limited model of ionosphere and the lack of tropospheric correction this particular configuration of observations can produce a bias.

As an estimated uncertainty for the daily averages of UTC(SU)–GLONASS time, we adopted the value of 50ns as already deduced for the observations at the University of Leeds.

Since June 1991 VNIIFTRI has operated a commercial GPS time receiver on loan from the BIPM referred to SU master clock. The delay of the GPS receiver was determined by the comparison with the Paris "on line" GPS receiver [5]. The coordinates of its antenna were determined by the BIPM method [4] and expressed in the ITRF reference frame [6] with an uncertainty of 1m. The receiver is programmed with 37 daily tracks according to the BIPM tracking schedule no 17. About 35 tracks were available each day for this study. The GPS installation at the VNIIFTRI allows the comparison of the UTC(SU) in common view mode to the West European time laboratories with an accuracy of a few ns.

GLONASS TIME TRANSFER BETWEEN MENDELEEVO AND WESTERN EUROPE

To realize time transfer between Leeds and Mendeleevo via GLONASS we use the measurements of UTC(SU)–GLONASS time, UTC(LDS)–GPS time, and GLONASS time–GPS time. Combination of these three values gives UTC(SU)–UTC(LDS).

VNIIFTRI provides the daily values of UTC(SU)–GLONASS time with uncertainty of 50ns and Leeds provides the measurements of UTC(LDS)–GPS time realized by the TRIMBLE 5000A receiver. The 25 or so available daily measurements of UTC(LDS)-GPS time are smoothed at the BIPM to provide daily values at 0h UTC with an uncertainty of 15ns.

To obtain the values of GLONASS time–GPS time we use the daily averages of UTC(USNO)–GLONASS time and UTC(USNO)–GPS time provided by Leeds with uncertainties of 50ns. We believe that these two measurements are affected partly by the same systematic biases (uncertainty of the UTC(USNO) as locally reconstituted, ionospheric delay, coordinates,...). For this reason when we remove UTC(USNO) by differencing the above measurements to obtain the daily values of GLONASS time–GPS time, we adopt the uncertainty of 50ns for this difference.

For the final values of UTC(LDS)–UTC(SU) obtained from this process we adopt an uncertainty of 70ns, which is derived from the quadratic combination of the involved uncertainties.

We have also realized the comparison of UTC(SU) with the Paris Observatory time scale UTC(OP) using both systems GLONASS and GPS. Paris Observatory operates a commercial GPS time receiver connected to UTC(OP). The comparison of UTC(SU) with UTC(OP) via GLONASS was realized in a similar way to that described above, the values UTC(LDS)–GPS time replaced by UTC(OP)–GPS time. The 35 or so available daily measurements of UTC(OP)–GPS time are smoothed at the BIPM to provide daily values at 0h UTC with an uncertainty of 7ns. The final values of UTC(OP)–UTC(SU) via GLONASS are provided with an estimated uncertainty of 70ns.

GPS COMMON-VIEW TIME TRANSFER BETWEEN MENDELEEVO AND WESTERN EUROPE

The common-view time transfer between Mendeleevo and Leeds was realised with about 25 tracks available, and between Mendeleevo and Paris with about 35 daily tracks available. In both cases a Vondrak smoothing [7], which acts as a low-pass filter with a cut-off period of about 3 days, was performed on the common-view values. For this experiment, the smoothed values are interpolated for 0h UTC of each day. The precision of both time links is estimated from the residuals of the smoothed values. Over the period of this study, the residuals ranged from 12 to 15ns for the UTC(LDS)–UTC(SU) and 3 to 4 ns for the UTC(OP)–UTC(SU).

COMPARISON OF GLONASS AND GPS

Time transfer via GLONASS between Mendeleevo and two West European laboratories was realized with an estimated uncertainty of 70ns. The GPS common-view time transfer provided a time link between Mendeleevo and Leeds with an uncertainty of about 15ns and between Mendeleevo and Paris with an uncertainty of about 4ns. Accordingly the comparison of GLONASS with GPS for the Leeds–Mendeleevo link has an estimated uncertainty of 80ns and for Mendeleevo–Paris, 70ns.

The daily differences between the two methods are presented in figures 2 and 3. Use of the modified Allan variance (Figures 4 and 5) allows us to characterize the noise affecting the values of comparison for each of the two links. For both links the data exhibit white phase noise up to an averaging time of about 4 days. This justifies computation of mean values for periods of duration up to 4 days and corresponding standard deviations of the mean. For a 4-day averaging period the results are as follows:

Period MJD	Mean values of GPS-GLONASS for UTC(OP)-UTC(SU) (ns)	Stand. dev. (ns)	Mean values of GPS–GLONASS for UTC(LDS)-UTC(SU) (ns)	Stand. dev. (ns)
48440–48443	-64	2	-91	2
48444–48447	-44	5	-55	13
48448–48451	-54	2	-70	6
48452–48455	-48	2	-44	10
48456–48459	-45	5	-44	5
48460–48463	-40	2		
48464–48467	-43	9		
48468–48471	-43	10	-52	10
48472–48475	-42	6	-42	7
48476–48479	-48	9	-57	12
48480–48483	-44	4	-27	10
48484–48487	-44	9	-43	8
48488–49491	-12	5	-28	17
48492–48495	-2	2	-5	2
48496–48499	12	3	18	4
48500–48503	-3	8	2	15
48504–48507	-3	4	-10	14

This table shows a fairly constant bias of about −45ns between the two techniques for the first period of the experiment (MJD period: 48440–48487) and for the two links. A sharp change then occurs, reducing the bias to roughly 0ns. As we do not know the differential delays between GLONASS equipments, the bias does not have meaning, and this comparison relates only to precision. The sharp change in the bias could be explained by the low elevation of the observations and their orientation in only one direction (far East) at Mendeleevo. In the absence of good estimates of ionospheric delay the changes in solar activity should have a significant effect on the measurements. Also frequent changes in the hour of observations at Mendeleevo could introduce a bias into measurements caused by ionospheric delay. The ionospheric conditions change dramatically between day and night.

One can also observe a lower noise level for the link between Paris and Mendeleevo than that between Leeds and Mendeleevo. This can be explained mainly by more accurate coordinates at Paris.

We have computed the mean values of the differences GPS–GLONASS for each of two links for the 68 days of this experiment. As the noise is not white for this period we adopt the root mean square of the residuals to the mean as an estimation of the confidence of the mean. The mean value for the link Paris–Mendeleevo is −33ns with estimated confidence 24ns and for the link Leeds–Mendeleevo respectively −38ns and 32ns. Both estimates of confidence for the period of this study are significantly lower that for our estimation of the uncertainties of the involved measurements (70ns and 80ns). This indicates that our estimates are too conservative. However, a longer period of comparison is required to obtain more precise specification of the uncertainty of this comparison.

CONCLUSION

This study shows that even with relatively imprecise data recording and processing, in terms of time metrology, GLONASS can provide continental time transfer at a level of several tens of nanoseconds. By introducing common-views, this performance should be significantly improved. Further possible improvements are the, at least partial, removal of ionospheric and tropospheric delays. More precise determination of GLONASS antenna coordinates in the SGS 85 reference frame is another task. The development of automatic GLONASS receivers dedicated especially for time transfer would be a most significant breakthrough.

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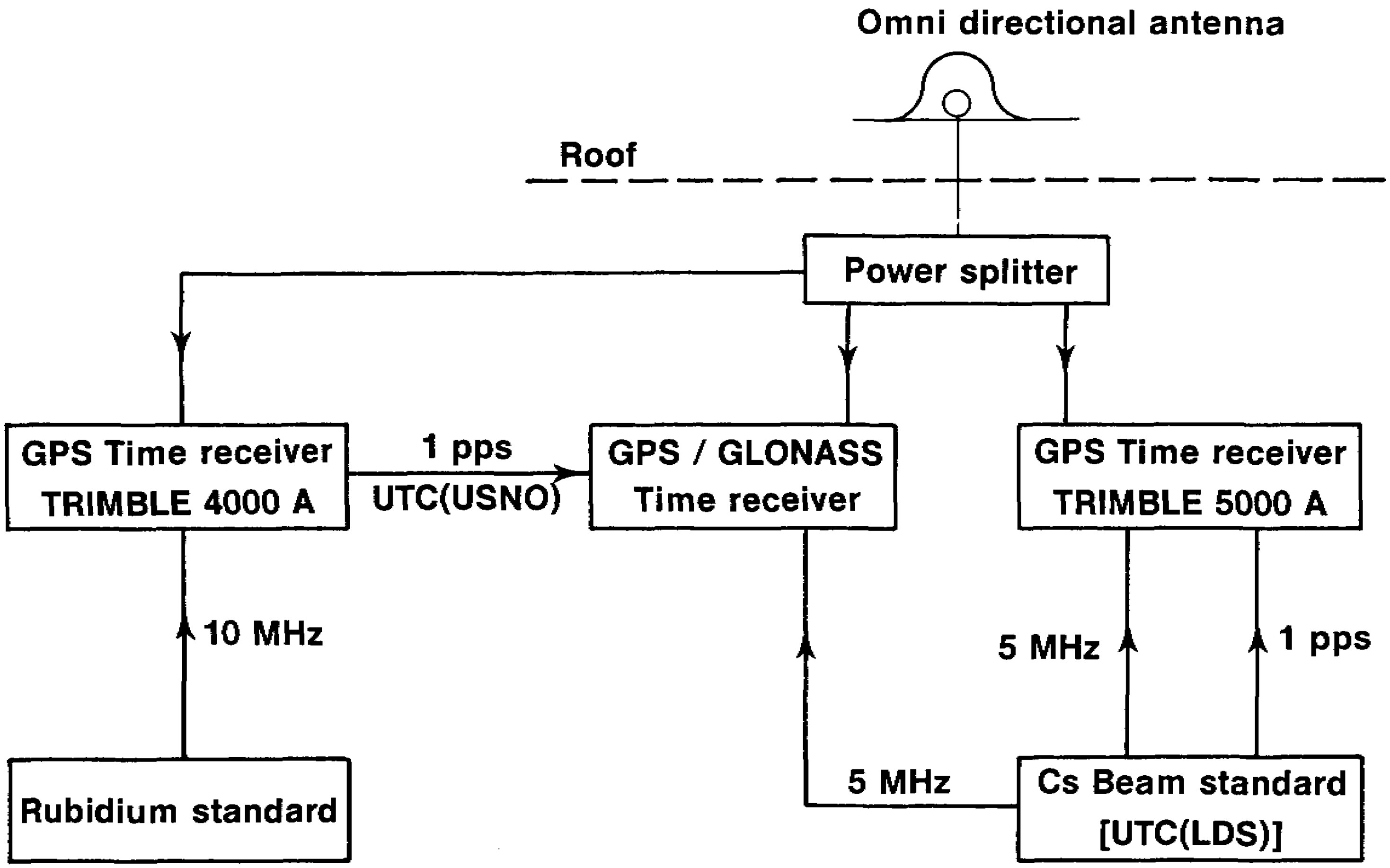
ACRONYMS

BIPM	Bureau International des Poids et Mesures
GLONASS	Global Navigation Satellite System
GPS	Global Positioning System
IERS	International Earth Rotation Service
ITRF	IERS Terrestrial Reference Frame
LDS	University of Leeds, Leeds, United Kingdom
OP	Paris Observatory, Paris, France
SA	Selective Availability of GPS
SGS	Soviet Geodetic System
TAI	International Atomic Time
USNO	US Naval Observatory, Washington D.C.
UTC	Coordinated Universal Time
UTC(LDS)	Coordinated Universal Time realized by the University of Leeds
UTC(OP)	Coordinated Universal Time realized by the Paris Observatory
UTC(SU)	Coordinated Universal Time realized by the VNIIFTRI
VNIIFTRI	Vsiesoiuznyi Naouchno Issliedovatielskii Institut Fiziko Tieknichieskih i Radiotieknichieskih Izmierienii (All Union Institute for Physical, Technical & Radiotechnical Measurements).
WGS	World Geodetic System



University of Leeds

FIGURE 1. *Schema of installation of time receivers at the University of Leeds.*

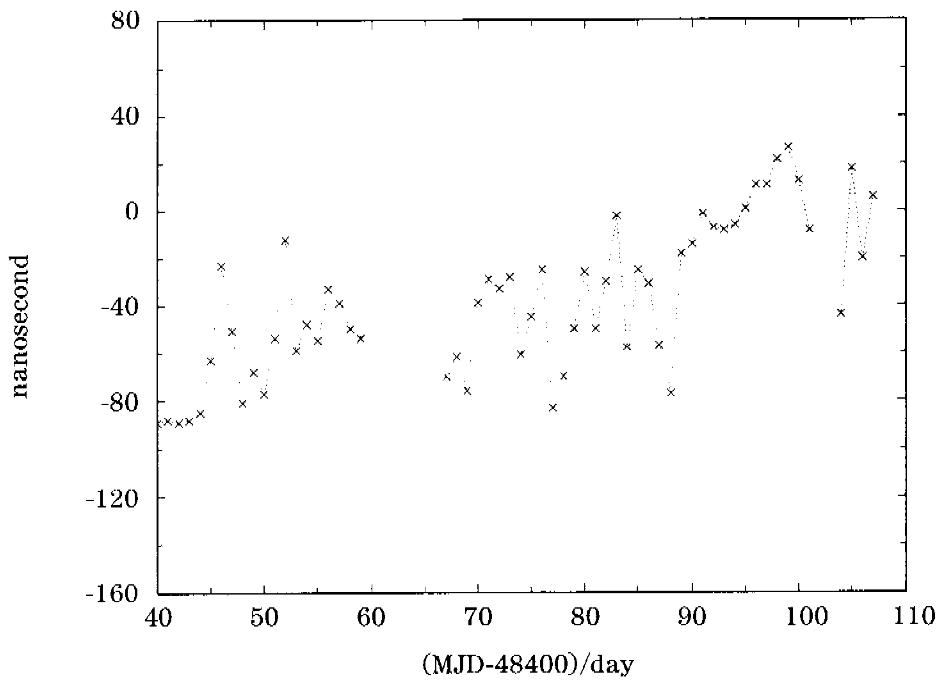


Figure 2. *UTC(LDS)-UTC(SU) as obtained by GPS minus UTC(LDS)-UTC(SU) as obtained by GLONASS+GPS. Daily values interpolated for 0h UTC.*

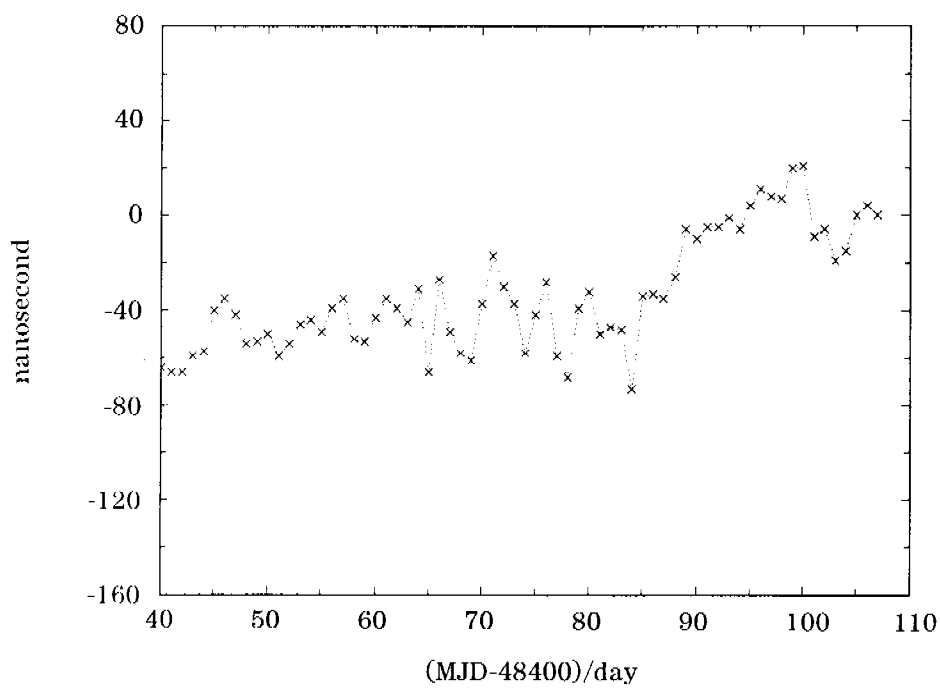


Figure 3. *UTC(OP)-UTC(SU) as obtained by GPS minus UTC(OP)-UTC(SU) as obtained by GLONASS+GPS. Daily values interpolated for 0h UTC.*

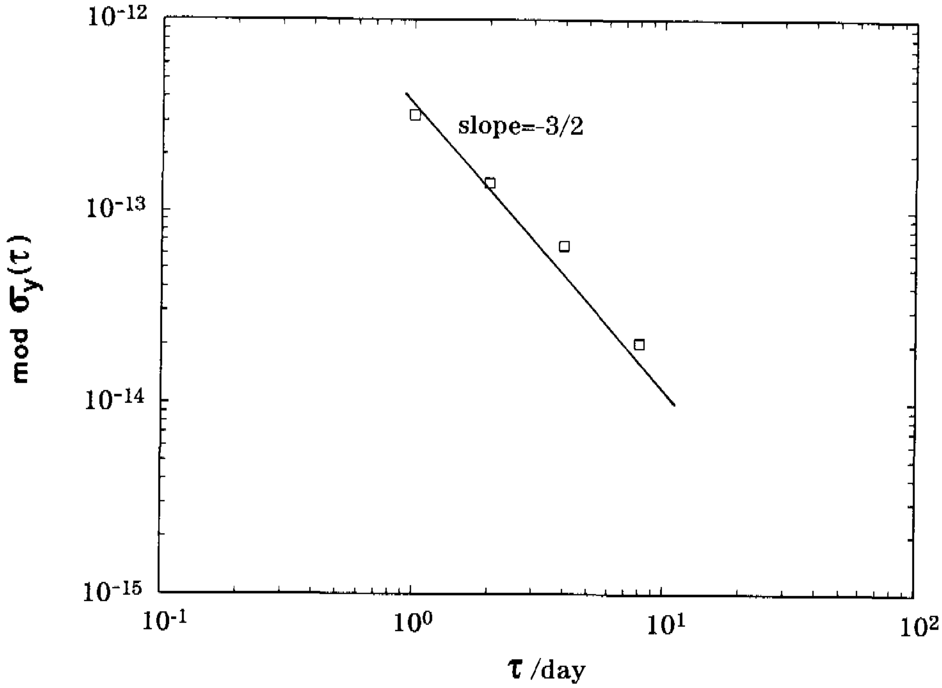


Figure 4. *Square root of the modified Allan variance of the differences presented in Figure 2.*

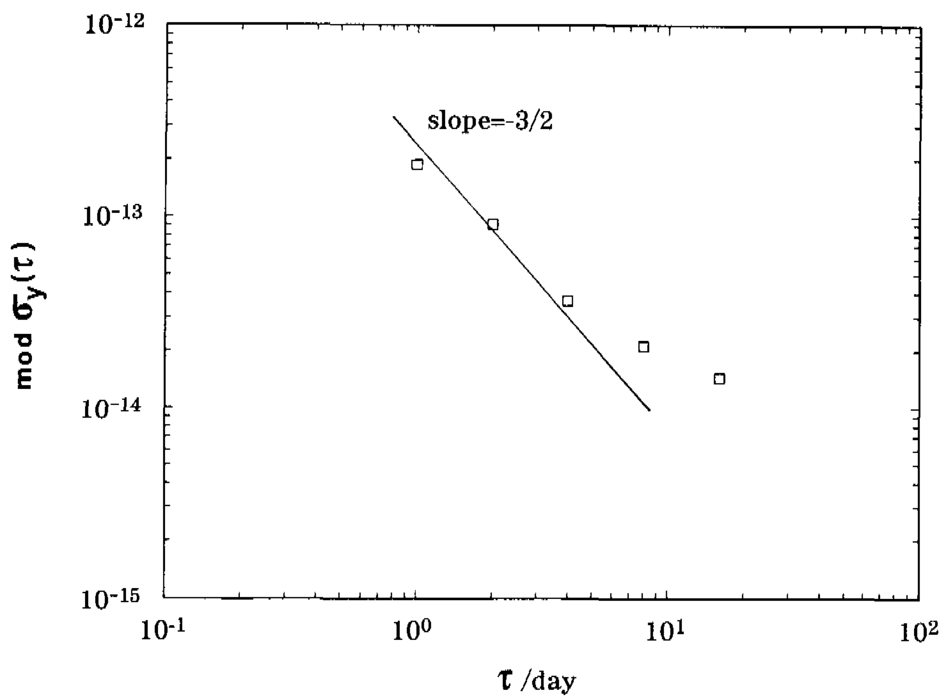


Figure 5. *Square root of the modified Allan variance of the differences presented in Figure 3.*