COMPARISON OF GPS AND GLONASS COMMON–VIEW TIME TRANSFERS

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Abstract

It has already been shown than even with a simple daily averaging of GLONASS data at each site, continental GLONASS time transfer can be achieved at a level of several tens of nanoseconds. A further step is to carry out observations of GLONASS satellites by the common–view method. This paper reports a comparison of GPS and GLONASS common–view time transfers between Russia and Western Europe. At each site, a GPS receiver and a GLONASS receiver are connected to the same atomic clock. Both GPS receivers are of NBS type and the GLONASS receivers are of type A–724. As GPS common–view time transfer between Sèvres and Mendeleevo is accomplished at a level of a few nanoseconds in precision, it gives an excellent reference with which to evaluate the performance of GLONASS common–view time transfer.

INTRODUCTION

Two global space navigation systems, the US GPS and the Russian 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 [2,3]. Although at present GPS time transfer fully satisfies the needs of time metrology, it is the sole operationally effective method and the lack of redundancy is felt. There is also a growing concern about GPS degradation by Selective Availability and Anti–Spoofing. In this context GLONASS is of increasing interest as an excellent additional source.

For the past three years VNIIFTRI (Mendeleevo, Moscow Region, Russian Federation) and some other Russian time laboratories have used Russian–built GLONASS navigation receivers for time comparisons. Since June 1991, VNIIFTRI has operated a commercial GPS time receiver on loan from the BIPM. Since February 1992, the BIPM has operated Russian GLONASS receiver on loan from the VNIIFTRI. This provides, for the first time, an opportunity for direct comparison of GLONASS common–view with GPS common–view time transfers.

THE EXPERIMENT

Two remote atomic clocks separated by about 2800 km have been compared by independent space links, GPS common–view and GLONASS common–view (Fig.1) in an experiment covering the period from April 2 to June 23, 1992.

On each site a GPS receiver and a GLONASS receiver are connected to a single clock, an Hydrogen–maser at Mendeleevo and a caesium standard at Sèvres. On both sites the receivers for each satellite system are of the same type, – AOA TTR6 at Mendeleevo and AOA TTR5 at Sèvres for GPS, and A-724 at both locations for GLONASS.

In common-view time transfer, two remote stations receive the signals from the same satellite at the same time and exchange the data to compare their clocks (Fig. 2). The main advantage of this method, introduced in 1980 for GPS [4], is that satellite clock error contributes nothing (satellite time disappears in the difference). Also over distances of up to a few thousands of kilometers the impact of other errors, such as poor estimation of ionospheric delay or broadcast ephemerides, is diminished. By using the same type of receiver, as in our case, the consistency of the comparison is improved as possible software errors are removed by the common-view approach.

GPS COMMON-VIEW LINK

The GPS time receivers correct observations for atmospheric refraction. Tropospheric delay is computed by a model which is a function of the elevation of the GPS satellite and of the altitude of the observation site. Ionospheric delay is estimated from a model using broadcast parameters.

The coordinates of the GPS antennas are expressed in the ITRF88 reference frame and were provided by the BIPM method of differential positioning [5,6] with respect to the closest ITRF sites. The estimated uncertainty of coordinates at Mendeleevo, obtained through a link with the ITRF laser site in Graz (Austria), is 70 cm, and that at Sèvres is 30 cm (link with the ITRF laser site in Grasse, France). The uncertainties of the GPS ground antenna coordinates can have an impact on the accuracy of this GPS common–view link of up to a few nanoseconds.

The GPS receivers used are not differentially calibrated, however, according to the available data, the uncertainty of the difference of their internal delays is 10 ns.

A standard GPS track for common-view observations has a duration of 13 minutes. The choice of this length is imposed by the 12.5 minute interval at which are broadcast the ionospheric parameters. A typical GPS track is shown by figure 3. The receiver processes short–term measurements, smoothing them over a period of 15 seconds through use of a second degree fit [1,7]. A linear fit of the 15 second points is used to deduce the time difference between the satellite and laboratory clocks for the mid–point of the 13 minute track. The slope of the linear fit for Block I satellites is usually no bigger than several ps/s and the corresponding standard deviation ranges from 3 to 20 ns depending on the multipath effects.

The GPS common–view time transfer was realized from the about 35 tracks of Block I and Block II satellites available daily (Fig.5). During this experiment the Block II satellites were subject to Selective Availability, so that strict common views were required [8]. A Vondrak smoothing [9], which acts as a low–pass filter with a cut–off period of about 0.5 day, is performed on the raw common-view values. For this experiment, the smoothed values are interpolated for the times of occurrence of GLONASS common views. The precision of this GPS link, estimated from the residuals of the smoothed values, is about 4 ns.

GLONASS COMMON–VIEW LINK

The organization of the GLONASS common–view link is determined by manual operation of the A–724 navigation receiver. This receiver does not have an interface to allow the connection of an external micro–computer for automatic control and data recording. Therefore two operators, one at Mendeleevo and one at Sèvres, have to read the receiver screens simultaneously and write the observations on a paper sheet. This limits the length of track to 3 minutes and the number of common–view observations to about 5 per day.

The choice of the 3 minutes track is also influenced by the 2.5 minute GLONASS navigation message length. The short–term manual observations are realized every 15 seconds. A typical GLONASS track is given in figure 4. A linear fit of the short–term data is used in post–processing to deduce the time difference between the satellite and laboratory clocks for the middle of the 3–minute track. The slopes of the linear fit do not usually exceed a few tens of ps/s and the corresponding standard deviations are of order a few ns. These particularly small standard deviations can possibly be explained by the fact that the observations displayed on the screen are not raw ones, but come from a smoothing done by the receiver. No information is available on the nature of this smoothing.

The A–724 GLONASS navigation receiver does not correct its observations for tropospheric delay. The ionospheric delay is estimated by a fixed model which does not depend on external parameters.

The coordinates of the GLONASS antennas are expressed in the SGS 85 reference frame with an estimated uncertainty of 5 m. They were obtained at each site by averaging a series of navigation solutions. The uncertainties of GLONASS ground antenna coordinates can have an impact on the accuracy of GLONASS common–view link of a few tens of nanoseconds.

The GLONASS receivers were compared side by side for several days before one was shipped to the BIPM. Their differential delays should be known to within a few nanoseconds.

The GLONASS common views are presented on figure 6. The numerous gaps in the data, due to interruption of observations during weekends and vacations, preclude any sophisticated statistical analysis and smoothing.

COMPARISON OF GLONASS AND GPS COMMON–VIEW TIME TRANSFERS

As the GPS common–view link between Mendeleevo and Sèvres is realized with a precision of a few nanoseconds it serves as an excellent reference for estimation of the precision of the GLONASS common–view link. GLONASS raw common–view values are compared to the GPS smoothed and interpolated values in figure 7. Note that the GPS and GLONASS results differ by a fairly constant bias with peak-to-peak discrepancy of about 40 ns. The mean of these differences over the duration of the experiment is 43 ns. The root mean square of the residuals to the mean, which is taken as an estimation of the confidence of the mean, is equal to 13 ns.

The bias of 43 ns between the GLONASS common views and the GPS common-views is partially due to an approximate calibration of the GLONASS and GPS equipment and partially due to the large error in GLONASS ground antenna coordinates. The noise affecting the GLONASS common views is also partially due to coordinate error, to the absence of a tropospheric correction and to an imprecise estimate of ionospheric correction. Table I shows comparison of typical GLONASS raw data with GPS smoothed data. In the last column the 43 ns bias has been removed. If we compare the last column of Table I with the differences between GPS raw data and GPS smoothed data, given in Table II, we find that the noise affecting raw GLONASS common views is not much greater than that affecting raw GPS common views.

To illustrate this, consider figures 8 and 9 which present, respectively, comparisons of GPS smoothed common views with GPS raw common views, and GPS smoothed common views with GPS common views affected by a coordinate error of 14 m artificially introduced. A constant bias and noise similar to that affecting raw GLONASS common views can be seen.

CONCLUSION

This study demonstrates that even with GLONASS navigation receivers not designed specifically for timing purposes, the common-view time transfer can be realized with precision close to that found in the early stages of GPS common-view time comparisons.

More accurate determinations of GLONASS antenna coordinates in the SGS 85 reference frame would significantly improve GLONASS common-view time transfer.

Manual mode of operation of the GLONASS receivers was possible only during short period of this experiment. The development of automatic GLONASS receivers dedicated especially for time transfer is an urgent challenge.

REFERENCES

[1] W. Lewandowski, C. Thomas, *"GPS time transfer,"* in Proc. of the IEEE, Special Issue on Time and Frequency, pp. 991-1000, July 1991.

[2] P. Daly, G. T. Cherenkov, N. B. Koshelyaevsky, S. Pushkin, *"Satellite time transfer between UTC(USNO) and UTC(SU) using Navstar GPS and GLONASS,"* in Proc. 4th Institute of Navigation Technical Meeting, pp. 199–206, September 1991.

[3] P. Daly, N.B. Koshelyaevsky, W. Lewandowski, G. Petit and C. Thomas, *"Comparison of GLONASS and GPS time transfers between two West European time laboratories and VNIIFTRI,"* in Proc. 23rd PTTI meeting, pp. 341–350, 1991.

[4] D.W. Allan and M.A. Weiss, *"Accurate time and frequency transfer during common-view of a GPS satellite,"* in Proc. 34th Ann. Symp. on Frequency Control, pp. 334–346, May 1980.

[5] B. Guinot, W. Lewandowski, *"Improvement of the GPS Time Comparisons by Simulta-*

neous Relative Positioning of the Receiver Antennas," in Bulletin Géodésique, 63, pp. 371–386, 1989.

[6] 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.

[7] W. Lewandowski, G. Petit, C. Thomas, *"The Need for GPS Standardization,"* in Proc. 23rd PTTI meeting, pp. 1–9, 1991.

[8] D.W. Allan, M. Granveaud, W.J. Klepczynski and W. Lewandowski, *"GPS time transfer with implementation of Selective Availability,"* in Proc. 22nd PTTI meeting, pp. 145–156, 1990.

[9] J. Vondrak, *"A Contribution to the Problem of Smoothing Observational Data,"* in Bull. Astron. Inst. Czechoslovakia, 20, pp. 349–355, 1969.

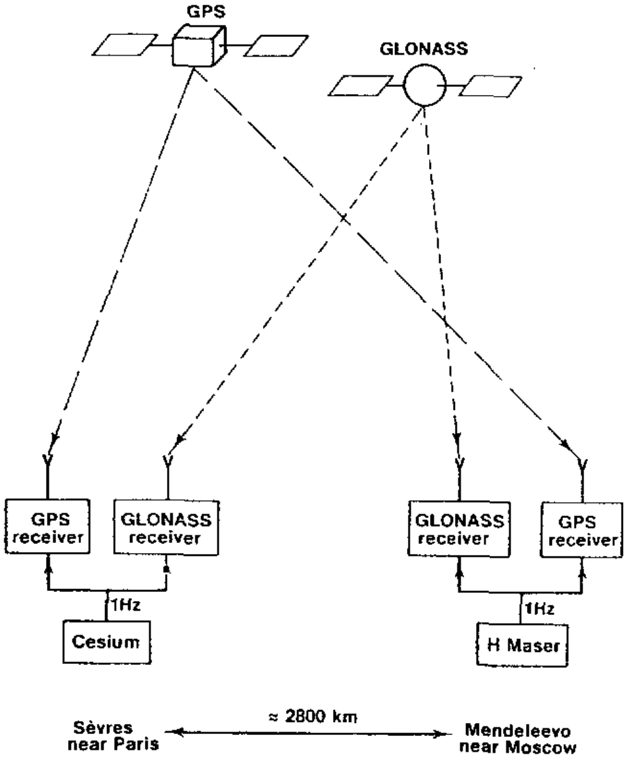

FIGURE 1. *The experiment configuration.*

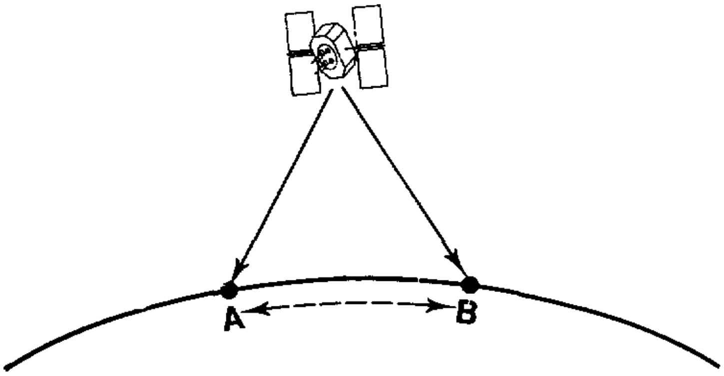

FIGURE 2. *Common-view time transfer: Clock A - Clock B = [Clock A - satellite time] - [Clock B - satellite time].*

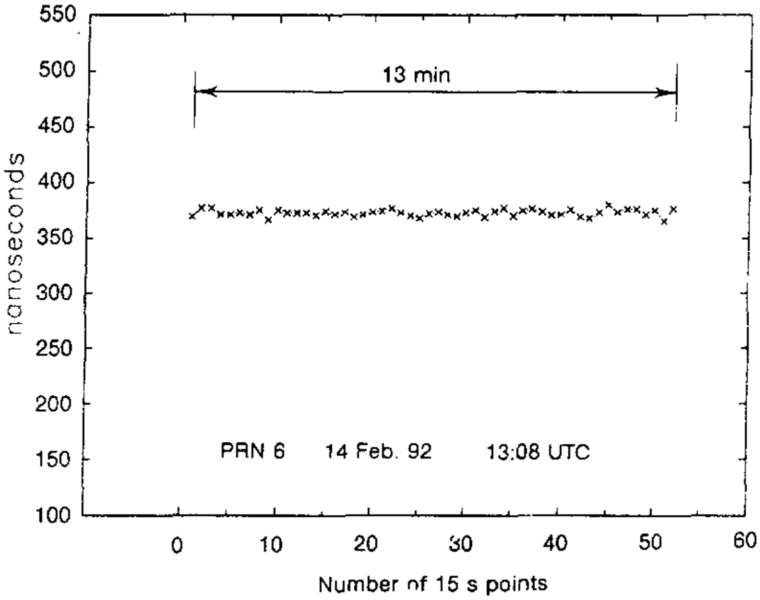

FIGURE 3. *A typical GPS track of a Block I satellite. Short-term GPS data [Local Cs Clock - GPS time] taken every 15 seconds at the BIPM, for a 13-minute track of PRN 6 on 14 February 1992.*

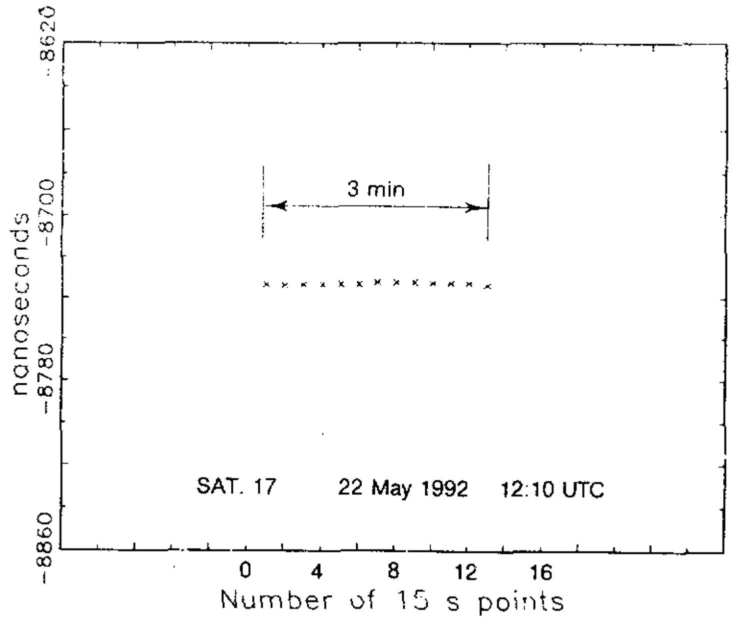

FIGURE 4. *A typical GLONASS track. Short-term GLONASS observations [Local Cs Clock - GLONASS time] taken manually every 15 seconds at the BIPM, for a 3-minute track of Sat. 17 on 22 May 1992.*

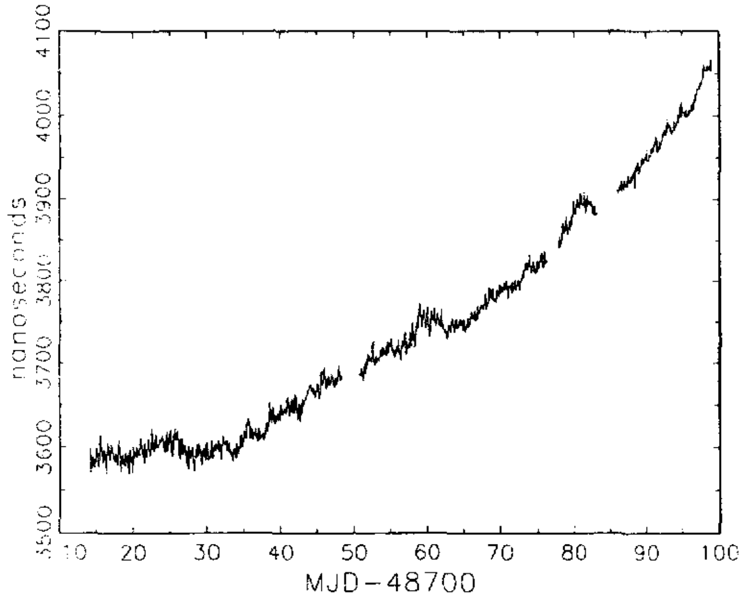

FIGURE 5. *[BIPM Cs Clock - VNIIFTRI H-maser] by GPS common-view.*

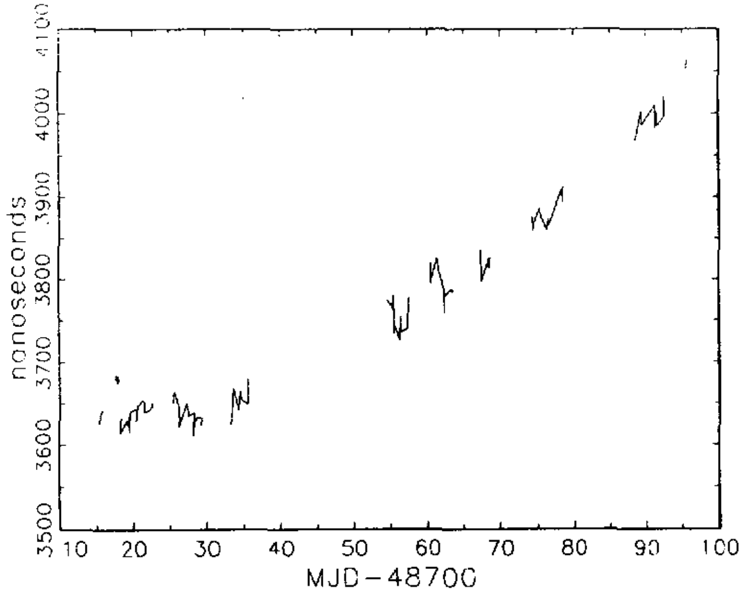

FIGURE 6. *[BIPM Cs Clock - VNIIFTRI H-maser] by GLONASS common-view.*

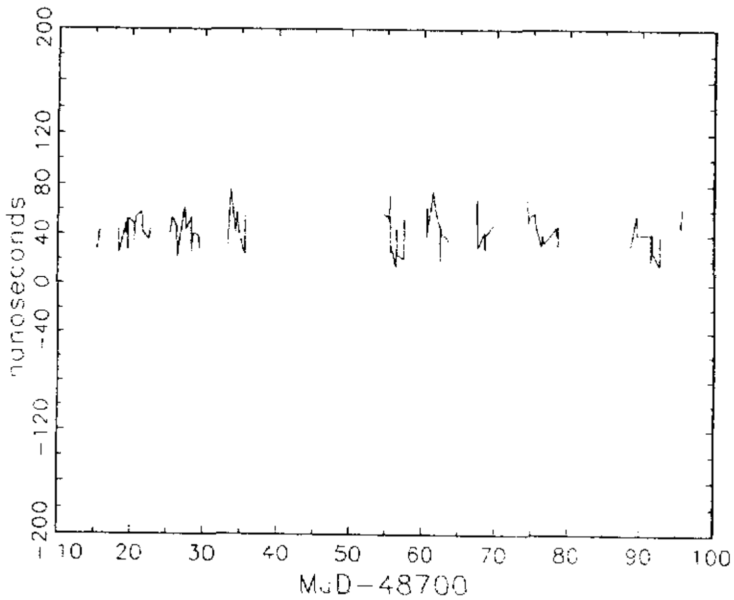

FIGURE 7. *[BIPM Cs Clock - VNIIFTRI H-maser] by raw GLONASS minus [BIPM Cs Clock - VNIIFTRI H-maser] by smoothed GPS.*

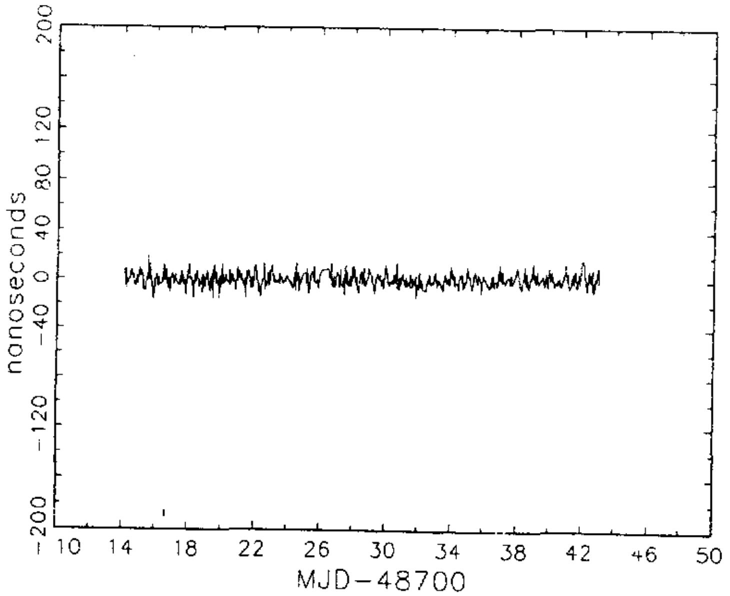

FIGURE 8. *[BIPM Cs Clock - VNIIFTRI H-maser] by raw GPS minus [BIPM Cs Clock - VNIIFTRI H-maser] by smoothed GPS.*

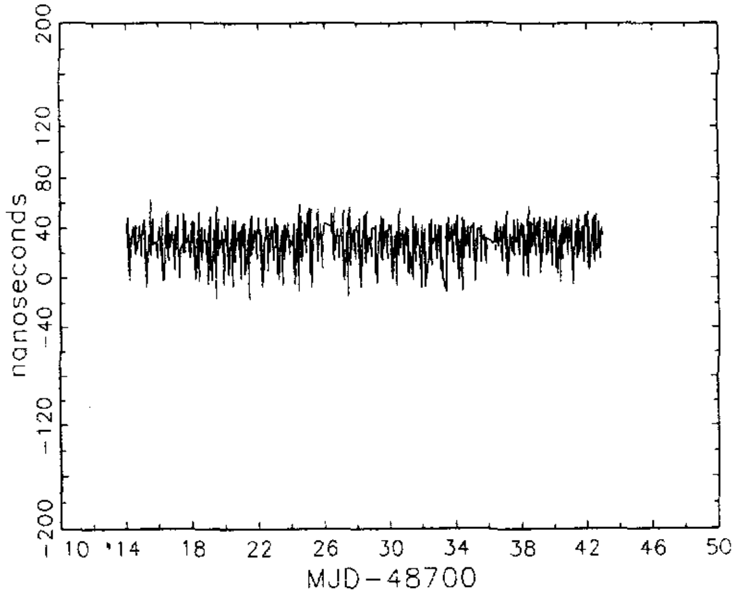

FIGURE 9. *[BIPM Cs Clock - VNIIFTRI H-maser] by raw GLONASS affected by artificially introduced 14 m antenna coordinate error minus [BIPM Cs Clock - VNIIFTRI H-maser] by smoothed GPS.*

TABLE I. *A sample of [BIPM Cs Clock - VNIIFTRI H-maser] by raw GLONASS minus [BIPM Cs Clock - VNIIFTRI H-maser] by smoothed GPS.*

Date April 1992	Start Time UTC h	m	SV GLO	GLO -GPS smoothed ns	GLO -GPS smoothed -43ns ns
3	7	40	7	28.0	-15
3	9	40	19	28.2	-14
3	14	20	22	43.0	0
6	6	48	2	44.7	4
6	7	40	3	24.8	-18
7	6	40	3	49.1	6
7	7	10	3	40.9	-2
7	11	10	17	51.4	8
7	13	15	15	27.8	-15
7	14	10	19	53.5	11
8	9	40	17	48.4	5
8	11	10	17	33.9	-9
8	13	10	19	44.8	2
8	14	10	20	53.9	11
9	6	40	5	58.0	15
9	11	10	19	55.0	12
9	12	10	19	43.1	0
9	14	10	20	41.8	-1
10	9	40	19	35.7	-7
10	13	40	22	45.0	2
10	14	10	22	39.7	-3
13	9	40	22	41.8	-1

TABLE II. *A sample of [BIPM Cs Clock - VNIIFTRI H maser] by raw GPS minus [BIPM Cs Clock - VNIIFTRI H maser] by smoothed GPS.*

Date April 1992	Start Time UTC h	 m	PRN	GPS raw - GPS smoothed ns
11	15	36	12	-2.8
11	16	4	3	-4.3
11	17	24	3	-2.2
11	19	32	3	0.1
11	20	4	23	-2.3
11	21	56	11	3.6
11	22	28	23	2.4
12	1	56	14	-0.1
12	3	16	15	-3.9
12	3	48	13	-1.9
12	4	36	14	-1.5
12	4	52	18	-1.9
12	5	24	24	-5.9
12	7	32	6	-7.2
12	9	24	6	5.5
12	11	0	12	-9.3
12	11	16	2	7.4
12	12	4	13	14.0
12	12	20	12	-1.7
12	13	40	12	3.2
12	13	56	13	-0.7
12	14	28	20	-0.9
12	15	0	24	6.1
12	15	32	12	0.9
12	16	0	3	-9.3

QUESTIONS AND ANSWERS

Professor Alley, University of Maryland: You were using the CA code in each instance, I gather. There is no SA or AS on the Soviet system at the present time. Do you have plans to use the P-code analog on the GLONASS?

Dr. Lewandowski: Of course, we would like to, but there are no receivers. Some are being developed, and as soon as they are ready, we will use them.

Questioner: I would like to point out that we do currently have a P-code, dual frequency GLONASS receiver that you can purchase any time you like.