A NEW APPROACH TO COMMON-VIEW TIME TRANSFER USING 'ALL-IN-VIEW' MULTI-CHANNEL GPS AND GLONASS OBSERVATIONS

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Abstract

The combined use of GPS and GLONASS for international time and frequency transfer is feasible despite differences between the two systems. The use of two systems in multichannel mode increases the number of observations by a factor of 20 in comparison to a one-channel one-system mode. This results in an improvement in frequency comparisons. Specially designed receivers for GPS + GLONASS multichannel time and frequency comparisons are described and some initial results are provided.

INTRODUCTION

For the past fifteen years international time transfer has been carried out using one-channel C/A-code GPS receivers and an international common-view schedule of standard 13-minute tracks [1]. Because older receivers have limited memory, no more than 48 tracks per day can be programmed; in practice, however, the useful number is even smaller. For regional time comparisons, within 1000 km, about 40 tracks are usually available, and for intercontinental distances about 10. At present, the estimated uncertainty of operational GPS time transfer is several nanoseconds for a single common-view observation and a few nanoseconds for a daily average, which corresponds to a few parts in 10^{14} in terms of frequency transfer. This performance is barely sufficient for the comparison of current atomic clocks and needs to be improved rapidly to meet the challenge of the clocks now being designed.

For this reason the timing community is engaged in the development of new approaches to remote clock comparison. Among them is the development of multichannel two-system C/A-code GPS and GLONASS receivers, and multichannel P-code GLONASS receivers.

The multichannel C/A-code receivers considered here observe all GPS and GLONASS satellites in view, 'all-in-view' operation, and use standard 13-minute tracks at the standard hours. At present, the standard hours are defined every six months by BIPM international common-view tracking schedules. Instruments which use the 'all-in-view' procedure necessarily observe the international schedule. This greatly simplifies

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their parallel introduction into the present system of one-channel observations. In the future, a fixed reference date, adopted by convention, will set standard hours permanently.

Although, in theory, up to 12 GPS or GLONASS satellites can be observed simultaneously, only about five satellites are observed above 15° (and thus are of interest for time transfer) for each system at an average urban site. As there are 89 useful 16-minute periods in a day, 89 tracks may be observed in each channel. Using all available observations above 15° (about five per 16-minute period), we may therefore observe 445 tracks per day for each system, and 890 for two systems. All these tracks may be used for regional common-view links. For very large baselines, between continents, 160 to 200 common-view tracks for two systems may be available using a multichannel approach. The increase by a factor of twenty in the number of common views in the GPS + GLONASS multichannel approach relative to the one-channel-one-system mode, makes it possible to expect a consequent improvement in the quality of time transfer. Such observations, however, may be subject to systematic variations, mainly caused by environmental effects on the receivers.

In the trial comparison described in this paper, between the BIPM and the VSL and using 'all-in-view' GPS + GLONASS C/A-code measurements, we had about 605 useful observations per day. As the GLONASS constellation at the time of the experiment comprised 15 satellites instead of 24, this number is less than that quoted above, but still increased the number of tracks by a factor of about 15. A consequent improvement in the frequency comparison was expected.

Although GPS and GLONASS have some similarities, they also differ in many respects. We describe how these differences were overcome to allow the simultaneous use of the two systems for international time and frequency transfer.

TIME REFERENCES

One major difference between GPS and GLONASS is that they use different references for time. For its time reference, GPS relies on UTC(USNO), Coordinated Universal Time (UTC) as realized by the USNO. GLONASS relies on UTC(SU), UTC as realized by Russian Federation. The deviation of UTC(USNO) and GPS time (modulo 1 s) from UTC generally remains within a few tens of nanoseconds. This is not the case for Russian time scales (see Figure 1).

Following a recommendation on the coordination of satellite systems providing timing, adopted by the Comité International des Poids et Mesures (CIPM) at its 85th meeting held in September 1996 [2], the Russian Federation agreed to improve the synchronization of its time scales with UTC. On 27 November 1996 a time step of 9000 ns was applied to UTC(SU) in order to make it approach UTC. Next, on 10 January 1997, a frequency step was applied to GLONASS time to adjust its frequency to be close to that of UTC(SU). This was followed by a time step in GLONASS time of about 35300 ns on 1 July 1997. Following these changes, Russian time scales differ from UTC by a few hundred nanoseconds. As GLONASS time is linked to UTC(SU) with an accuracy of 200 ns, it is linked to UTC with the same accuracy. Further adjustments of these two time scales with respect to UTC are expected. This development is an important sign of goodwill and understanding.

Because GLONASS TIME receivers are not calibrated absolutely, we know [*UTC - GLONASS time*] to an accuracy no better than several hundreds of nanoseconds. GPS receivers are absolutely calibrated and [*UTC - GPS time*], after application of corrections for GPS precise ephemerides and ionospheric measurements, is known with an accuracy limited to about ten nanoseconds, mainly because of SA. It follows that GLONASS provides an average user with world-wide real-time dissemination of UTC, as produced by the BIPM, to an uncertainty no better than several hundreds of nanoseconds after the recent improvement of the synchronization between UTC(SU) and UTC. GPS does the same with uncertainty of several tens of nanoseconds.

Summing up, we note that persisting differences between Russian time scales broadcast by GLONASS and UTC affect real-time dissemination of UTC through GLONASS, and to some extent complicate the dual GPS + GLONASS navigation solution. However, this discrepancy does not affect common-view time transfer, because readings of the satellite clock vanish in the difference. Also, the lack of absolutely calibrated GLONASS receivers is easily overcome for common-view time transfer by differential calibration of receivers [3].

REFERENCE FRAMES

The CIPM recommendation cited above also specifies a basis for harmonizing the reference frames of global satellite navigation systems by asking for adoption of the ITRF, the internationally recognized ultra-accurate terrestrial reference frame. The GPS almost fulfils this recommendation as WGS 84 its reference frame, since its most recent improvement differs from the ITRF by no more than one decimeter. This is not the case for GLONASS as its reference frame, PZ-90, can differ from the ITRF on the surface of the Earth by up to 20 m. In addition, access to PZ-90 is in most places limited to several meters. This presents a difficulty when using both GPS and GLONASS in the most demanding time and frequency transfers. One possible solution to this problem is the adoption by time laboratories of a common accurate reference frame for GPS and GLONASS ground antenna coordinates, and for post-processed satellite precise ephemerides. Obviously the preferred frame is the ITRF. Laboratories engaged in the accurate GPS time transfer agreed already several years ago to express ground-antenna coordinates with centimetric uncertainties in the ITRF. A proposal that the ITRF should also be used for GLONASS time transfer was submitted to CCTF Sub-group on GPS and GLONASS Time Transfer Standards (CGGTTS) [4] and adopted at its last meeting in December 1997. For baselines of up to a few thousands of kilometers, there is no need to correct the broadcast satellite ephemerides but, for longer baselines, the use of post-processed precise ephemerides expressed in the ITRF frame is necessary. For GPS, such ephemerides are provided by the International GPS Service for Geodynamics (IGS). This is not yet case for GLONASS but, at the 7th IGS Governing Board Meeting in September 1997 in Rio de Janeiro, it was decided that an experiment, the International GLONASS Experiment (IGEX), should be conducted in the second half of 1998, its goal being to provide GLONASS precise ephemerides expressed in terms of the ITRF. If successful, this project could become a permanent service.

BRIEF DESCRIPTION OF GPS + GLONASS MULTICHANNEL TIME RECEIVERS

Already several major timing centers around the globe observe GPS and GLONASS in multichannel mode. All receivers are of type R-100/30, manufactured by 3S Navigation. These take the form of a 12-channel GPS + GLONASS C/A-code card, and two or more cards with GLONASS P-code channels. The number of GLONASS P-code cards can be increased. Four to six satellites of each of the two systems are usually observed simultaneously on the 12-channel C/A-code part of the receiver. Only one antenna is used by each receiver. The receivers are controlled by a PC and use a standard format, developed for the GPS common-view technique by the CGGTTS [5], adapted to suit two-system two-code multichannel observations [4]. For the GLONASS part the receivers use the standard formulae and parameters adopted for GPS. These receivers have operated correctly over long periods of time and no bugs have been identified in the software. Their metrological quality have been confirmed by comparison with other GPS time receivers [3]. 3S Navigation has recently introduced a new GPS + GLONASS time receiver, an 18-channel C/A-code GNSS-300T.

GPS AND GLONASS COMMON-VIEW SCHEDULES VERSUS 'ALL-IN-VIEW' OBSERVATIONS

The BIPM issues GPS and GLONASS international common-view schedules for international time and frequency comparisons twice a year. They indicate to receivers which satellites to observe at which time. Times of observations are redefined for each new schedule in order to start 13-min tracks at 00 h 02 UTC of the reference date and continue at 16-min intervals. These times are decremented by 4 minutes each day, to account for the sidereal orbits. This procedure means that we can use 89 of the 90 16-min intervals each day, the 90th being sacrified to allow the 4-min correction.

The multichannel GPS + GLONASS time receivers considered here observe all the GPS and GLONASS satellites in view, in standard 13-min tracks every 16 minutes at scheduled standard times. Obviously there is no need to tell these receivers which satellites to observe, as is done for one-channel receivers, because such an ensemble of 'all-in-view' tracks necessarily includes the international schedules. This greatly simplifies the parallel introduction of GPS + GLONASS multichannel time receivers into the present system of scheduled GPS and GLONASS one-channel receivers. A further simplification will be the use of a permanent reference day for standard times adopted by the CGGTTS. In this case, multichannel receivers will not have to be updated for standard times when international schedules are changed for one-channel receivers.

TRIAL COMPARISON

The time link between the BIPM and the VSL considered in this trial comparison has a baseline of 400 km. Both laboratories are equipped with R-100/30 receivers and their ground-antenna coordinates are expressed in the ITRF with an uncertainty of 0.3 m. The same coordinates were used for GPS and GLONASS (see above paragraph on reference frames). At both laboratories, receivers were connected to HP5071A clocks. For this study we used data covering roughly 10 days. Both receivers were calibrated using a portable R-100/30 receiver [3]. We observed a constant bias of 6 ns between GPS and GLONASS links. After this correction was applied, the GPS and GLONASS data could be mixed and we computed [*BIPM clock* - *VSL clock*] using GPS + GLONASS. Figures 2 - 6 compare the two clocks over a common period of time using the same receivers to establish different time links. Table 1 shows the number of common views available for each link.

The level of noise for the above links is about 3 ns. The unusual level of noise of about 7 ns obtained for the same links during previous study [6] is now known to have been caused by an error of 2.5 m in the differential coordinates between the two laboratories: this has now been corrected. Our current interest is to point out the advantage obtained by increasing the number of daily common views from 38, for the one-channel GPS link, to the 605, for the multichannel GPS + GLONASS link. A theoretical gain in stability of $(605/38)^{1/2} = 4$ is expected in the regions where white phase noise is preponderant. This can be seen on the stability curves of Figure 7 for averaging times of less than 10^4 seconds. Additional systematic effects are observed for averaging times above 10^4 seconds. These are probably linked to the environmental sensitivity of the antennas or of receivers themselves. This problem has already been resolved, at least partially, by stabilizing ground-antenna temperature [7]. Following this study the two R-100/30 receivers operating at the BIPM were equipped with 3S Navigation Temperature-Stabilized Antennas (TSA). A preliminary comparison shows the removal of the systematic effects observed on Figure 7, and a fractional frequency stability of a few parts in 10^{15} for averaging times of about one day.

CONCLUSIONS

- This study confirms the feasibility of GPS + GLONASS multichannel time transfer. The dual-system multichannel and multicode receivers operate smoothly and no bugs have been found in the software. They use standard software and format. Comparison with other GPS time receivers provides a test of their metrological quality.

- Increasing the number of daily common views from 38 for a one-channel GPS link to 605 for a multichannel GPS + GLONASS link greatly improves the reliability of time transfer.

- A stability gain of 4 was observed between a one-channel GPS link and a GPS + GLONASS multichannel link for averaging times less than 10^4 seconds.

- Additional systematic effects were observed for averaging times above 10^4 seconds. These are probably linked to the environmental sensitivity of the antennas or of receivers themselves. Once these systematic effects are removed by thermal protection of the receiving equipment, multichannel GPS and GLONASS code measurements can provide, for integration times of one day, the frequency differences between the remote atomic clocks at a level of few parts in 10^{15}. This performance approaches theoretical possibilities of phase measurements and Two-Way Satellite Time Transfer.

REFERENCES

[1] Allan D., Weiss M., 1980, "Accurate Time and Frequency Transfer During Common-view of a GPS Satellite", Proc. 1980 Frequency Control Symposium, pp. 334-346.

[2] Comité International des Poids et Mesures (CIPM), 1996, Recommendation 1 (CI-1996), Report of the 85th Meeting, Tome 64, p. 145.

[3] Azoubib J., de Jong G., Lewandowski W., 1997, "Determination of differential time corrections for multichannel GPS and GLONASS time equipment located at 3S Navigation, BIPM and VSL", Rapport BIPM-97/6, Part 1.

[4] Lewandowski W., Azoubib J., Gevorkyan, A.G., Bogdanov P.P., Klepczynski W.J., Miranian M., Danaher J., 1996, "A Contribution To the Standardization of GPS and GLONASS Time Transfers", Proc. 27th PTTI Meeting, pp. 367-383.

[5] Allan D.W. and Thomas C., 1994, "Technical Directives for Standardization of GPS Time Receiver Software", Metrologia, 31, pp. 67-79.

[6] Lewandowski W., Azoubib J., de Jong G., Nawrocki J., Danaher J., 1997, "A New Approach to International Satellite Time and Frequency Comparisons: 'All-in-View' Multichannel GPS+GLONASS Observations", Proc. ION GPS-97, pp. 1085-1091.

[7] Lewandowski W., Moussay P., Danaher J., Gerlach R., LeVasseur E., 1997 "Temperature-Protected Antennas for Satellite Time Transfer Receivers", Proc. 11th EFTF, pp. 498-503.

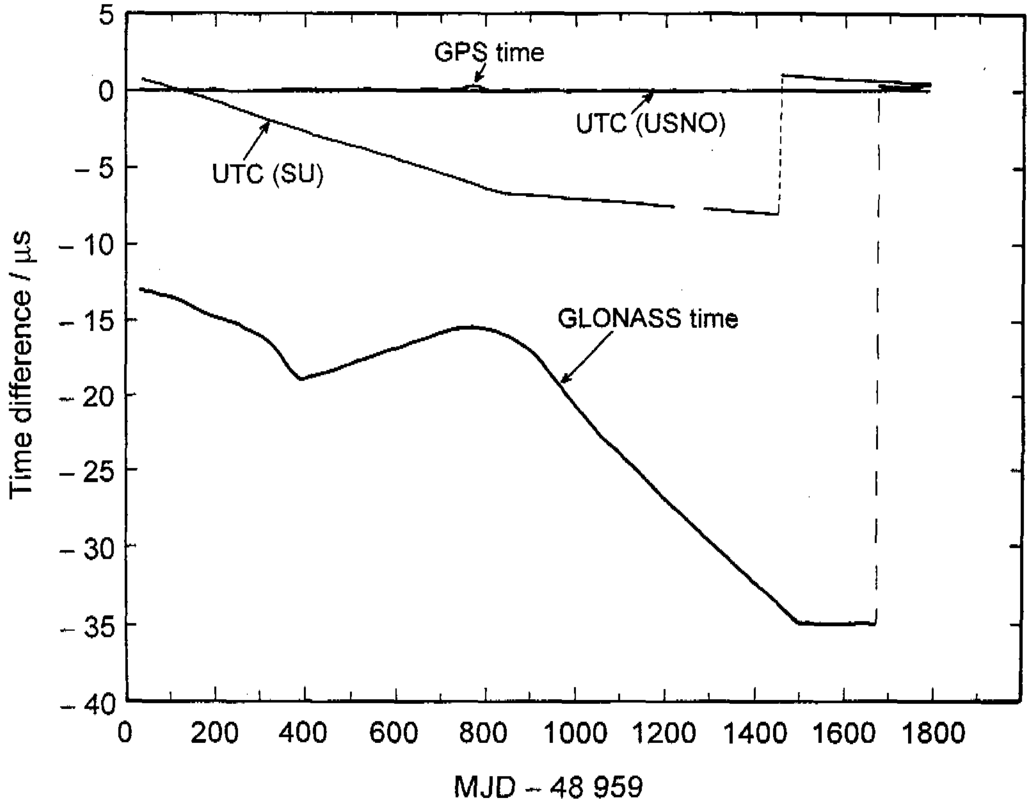

Figure 1: Deviation of UTC(USNO), UTC(SU), GPS time and GLONASS time from UTC from 3 December 1992 to 27 November 1997.

Table 1. Number of common views per day by different methods for [*BIPM clock - VSL clock*] comparison.

Method	Average number of common views per day	Average number of simultaneous common views
GPS one-channel	38	1
GLONASS one-channel	25	1
GPS multichannel	350	4.5
GLONASS multichannel	255	3.3
GPS+GLONASS mutichannel	605	7.8

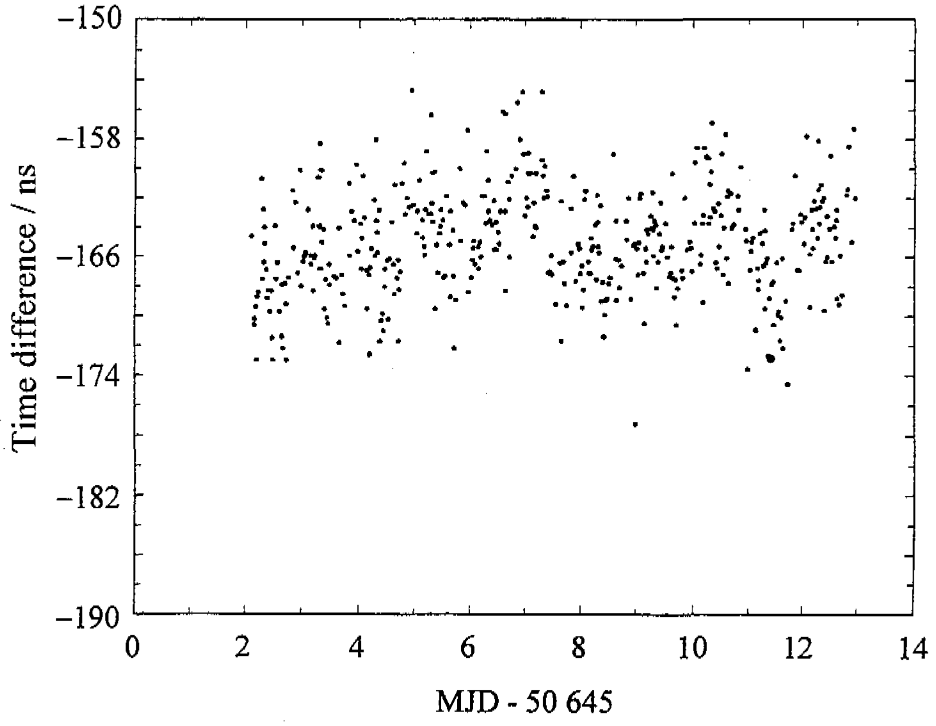

Figure 2. [*BIPM clock - VSL clock*] by one-channel GPS common views.

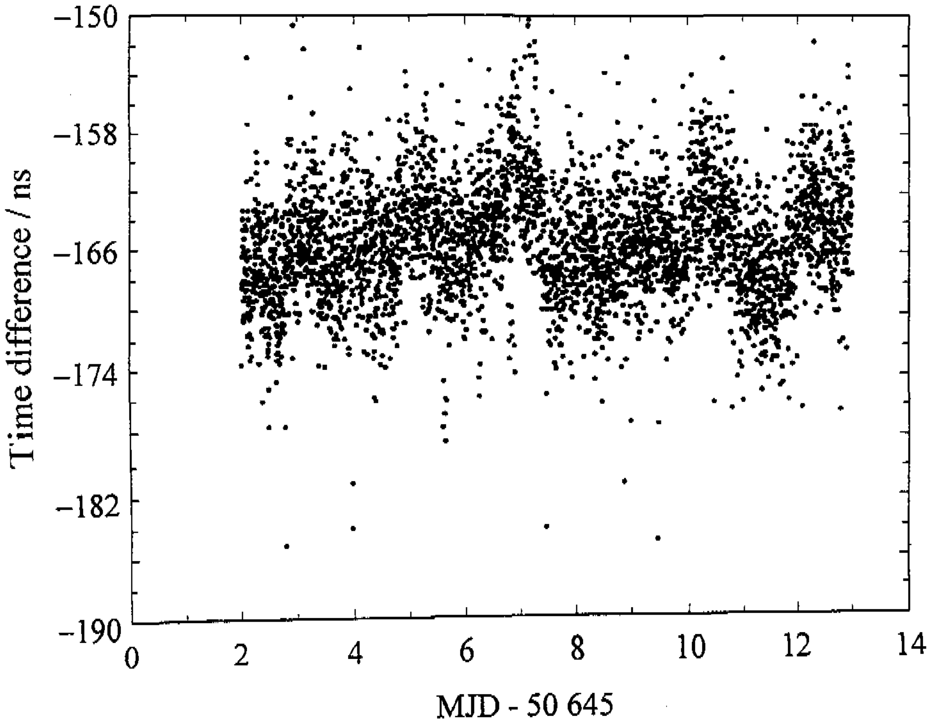

Figure 3. [*BIPM clock - VSL clock*] by GPS multichannel common views.

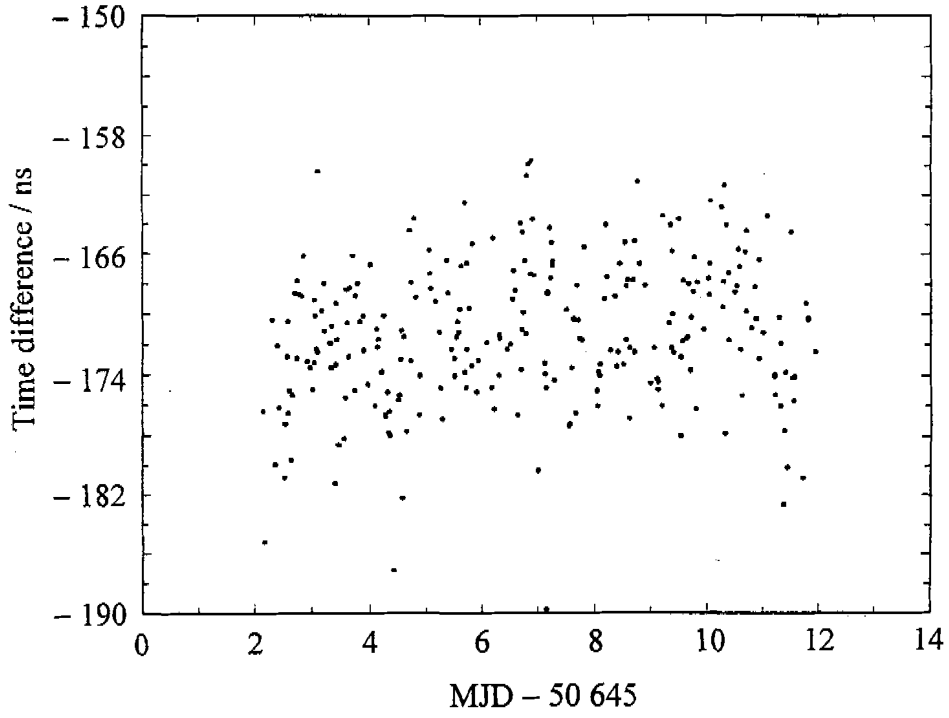

Figure 4. [*BIPM clock - VSL clock*] by GLONASS one-channel common views.

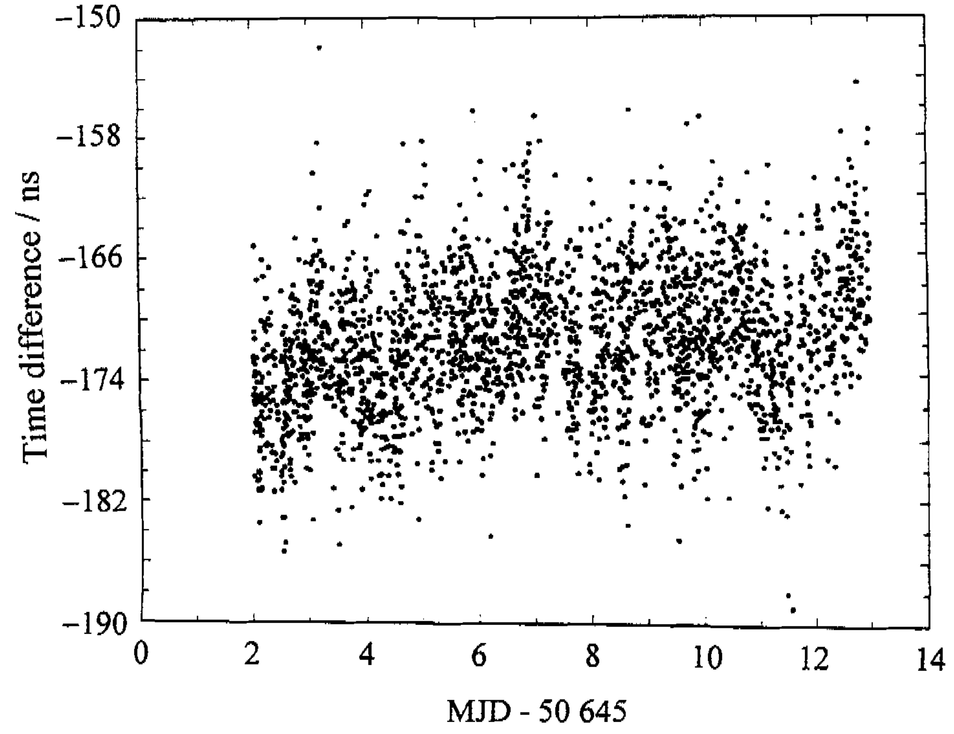

Figure 5. [*BIPM clock - VSL clock*] by GLONASS multichannel common views.

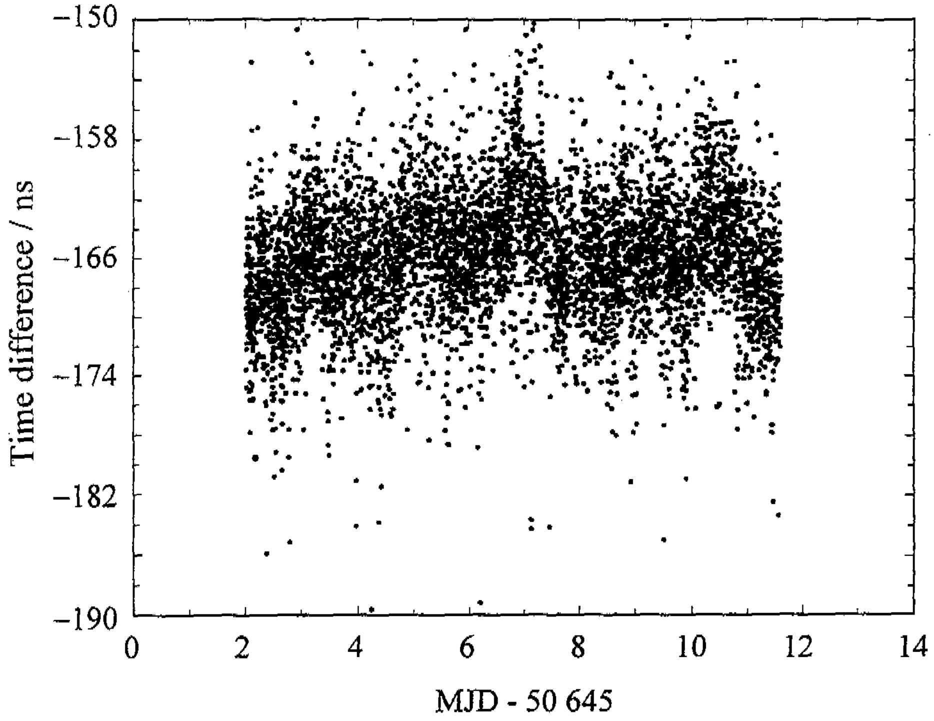

Figure 6. [*BIPM clock - VSL clock*] by GPS + GLONASS multichannel common views.

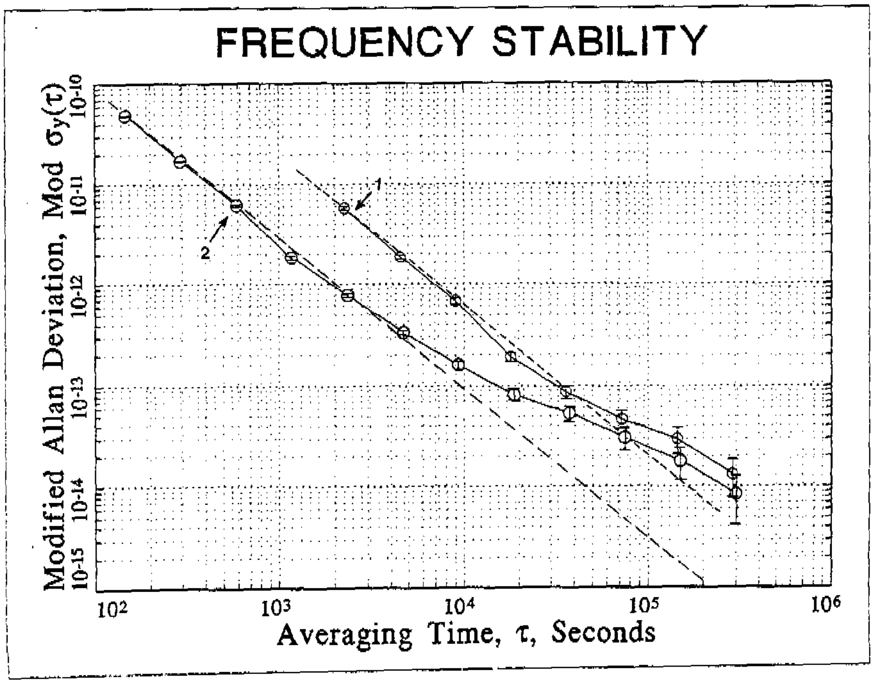

Figure 7. Modified Allan standard deviation of [*BIPM clock - VSL clock*] as given by one-channel GPS (1) and by multichannel GPS+GLONASS (2) observations.

Questions and Answers

ROBERT WEAVER (UNIVERSITY OF SOUTHERN CALIFORNIA): I did not quite understand your point about the multi-channel accuracy being improved by the use of an oven. Would not those temperature effects occur also for single-channel measures?

WLODZIMIERZ LEWANDOWSKI (BIPM): Of course, but we do not see this because the level of noise is higher; so we do not see this jump, this bump due to temperature.

ROBERT WEAVER: So you're saying that the single-channel performance is limited by the temperature drops.

WLODZIMIERZ LEWANDOWSKI: And other noises. What adds to multi-channels, many noise effects. The stability curves go down, and then we cross through the bump, which we cannot observe with one channel.