INTERNATIONAL TIME COMPARISON BY A GPS TIMING RECEIVER

M.-K. Fujimoto, K. Fujiwara, and S. Aoki
Tokyo Astronomical Observatory, Mitaka, Tokyo 181

ABSTRACT

Tokyo Astronomical Observatory (TAO) has started a regular reception of the Global Positioning System (GPS) timing signals for the purpose of a precise international time comparison. A test operation of the GPS receiver was performed from September 1982 to January 1983 and achieved good accuracy in time comparisons. During the test run, a clock comparison was made by a USNO portable clock team and it was compared with the GPS reception. The difference between the comparisons was less than the error in the portable clock comparison. Since April 1983, regular reception of GPS signals has continued and the results in the GPS time error, UTC(TAO)-GPS, are transmitted every week on the General Electric (GE) Mark III system. By this means, the cesium clocks in the asian region will be related to TAI with better accuracies.

INTRODUCTION

The asian cesium clocks have been excluded from the contribution to the International Atomic Timescale (TAI) because of their poor links to the clocks in the other areas such as Europe, United States, and Canada. Loran C stations in the Northwest Pacific chain are so distant that the time-keeping organizations in the asian region cannot receive ground waves of the Loran C signals with sufficient accuracy.[1] The Global Positioning System (GPS) is considered to be one of the most promising methods for time transfers on a worldwide basis at the ten-nanosecond level.[2] Regular time transfers by the GPS will make it possible for the asian clocks to contribute information into the TAI.

Tokyo Astronomical Observatory (TAO) performed a test operation of a GPS timing signal receiver and achieved good accuracy in time comparisons with the U.S. Naval Observatory (USNO). During the test operation, a clock comparison was made by a USNO portable clock team and the result was compared with the one by the GPS time comparison. After the test run, some trouble-shooting and revisions were made on our receiver to increase the reliability of continuous operation. From April 1983, regular receptions of the GPS signals were started and the results are transmitted every week on the General Electric (GE) Mark III system.

This paper will deal mainly with the results of time comparisons with USNO by GPS.

GPS TIME TRANSFER SYSTEM

The GPS receiver used at TAO is a Stanford Telecommunications Inc. (STI) Time Transfer System Model 502 (TTS 502), for which a detailed description was given at the thirteenth annual PTTI meeting.[3] The system automatically acquires and tracks the L1 carrier and C/A code of GPS satellites according to a schedule which is initially set up by us. The system then processes the received data to calculate satellite position, satellite clock correction and propagation time between the satellite and the receiving station which includes corrections for ionospheric, tropospheric, and relativistic delays, and gives "time error" of the local clock referred to the GPS time.

Through an RS-232C port, all necessary information for calculation of the time error, obtained from the received data, are output to external peripherals; a printer and a recording system in our case. The real time recording system for GPS data is realized on a general-purpose minicomputer. All the data output from the receiver are recorded in a file of the minicomputer and are then transmitted to a large computer, by which they are processed and analyzed.

GPS DATA TRANSMISSION

We regularly transmit the results of GPS time transfers by two modes: Weekly data exchanges are made through a GE Mark III file in a format agreed upon, and monthly data are published in a printed form. Examples are shown in Figure 1 and 2. The former contains almost all of the measurements made at TAO and the latter does one measurement of good quality for each space vehicle (SV) each day, generally, a measurement at larger elevation is chosen.

We receive the GPS data of the other organizations on the GE Mark III. The data are stored in certain files on the large computer and are used in mutual time comparisons.

CLOCK COMPARISONS WITH USNO

Figure 3 shows the time differences, UTC(TAO)-GPS and UTC(USNO)-GPS, which were obtained by the GPS receptions. It covers the data in the period of half a year. Zigzag runnings appear in both the curves and are considered mainly due to the operational changes in the rate of the GPS time.

In order to see the time differences between USNO and TAO, the behavior of the GPS time against the UTC(USNO) is approximated tentatively by a broken line, denoted as REF(t), and both of the values UTC(TAO)-GPS and UTC(USNO)-GPS are corrected (subtracted) by the quantity REF(t). The results are shown in Figure 4. The upper curve, UTC(TAO)-GPS-REF(t), approximates UTC(TAO)-UTC(USNO) and the lower curve, UTC(USNO)-GPS-REF(t), shows the errors of the approximation, as well as transmission/receiving errors in the GPS clock link.

The former curve is comparable with that in Figure 5, which shows UTC(TAO)-UTC(USNO) obtained from the GPS receptions in a common view mode,[4] where the data of the same SV were measured by both observatories within 4 minutes. The values of UTC(TAO)-UTC(USNO) in the first half of the data period are relatively scattered mostly because of small sampling numbers (less than 10) of the measurements at both or either site. Small but clear frequency drift was found in the TAO clock before the 1st of October 1983, when the master clock at TAO was replaced.

These three figures show that the time comparison between TAO and USNO by GPS is achieved, roughly speaking, to an accuracy of less than 50 ns.

TEST OPERATION

A test operation of the GPS receiver was performed from September 1982 to January 1983 as mentioned before.

Figure 6 shows the residuals of a linear-fit through approximately three months' data, UTC(TAO)-GPS, which were obtained from the reception of SV#5 during the test run. For a comparison, the corresponding data of the USNO, UTC(USNO)-GPS, are shown in the same manner. USNO data approximately once a day are taken from the USNO publication, Series 4. TAO data are plotted twice a day, when the signals from the SV of the subsequent passes are received. It is clearly seen in the figure that the values of UTC(TAO)-GPS at the different sidereal times are different from each other.

The conditions in the alternate measurements are quite different. In our case, for example, the maximum elevation changed alternately by a large amount. Differences of the elevation and of the local solar time may cause errors in the estimation of propagation delays, especially of the ionospheric delay. Figure 7 shows raw (every 6 seconds) data of UTC(TAO) -GPS during continuous tracking (about 6 hours) of the same SV. Elevation of the SV and the applied ionospheric corrections are also shown in the figure, for which a timescale is indicated by UT and Japan Standard Time (JST). From the figure, correlation is not as obvious between the variation of the time difference data and the above mentioned conditions.

Errors in the estimation of satellite position from the transmitted ephemeris may be another possible cause of the variations as was pointed out by Klepczynski.[5]

Further study on the cause of such semi-systematic variations in the GPS data may be useful to improve the GPS time links to the accuracy of 10 ns.

COMPARISON WITH A PC TIME TRANSFER

During the test operation, a USNO Portable Clock (PC) team made a clock comparison between the USNO and the TAO. Table 1 shows the results of comparison of the PC trip and the GPS time transfers.[6] Difference of 113 ns (average) between the GPS and PC determinations for UTC(USNO)-UTC(TAO) is not significant, because the PC time determination has an uncertainty of 170 ns as was reported by USNO. From this comparison, we know that the values of time comparisons by GPS seem to be better than or at least comparable with the PC results. As a matter of course we must check the existance of systematic differences between the two time determinations for every subsequent PC trip.

SUMMARY

GPS capability for international time transfers is established with an accuracy better than fifty nanoseconds. By regular operation of the GPS receiver at Tokyo Astronomical Observatory, the asian cesium clocks, which are connected to TAO through a Loran C chain, will contribute information to the International Atomic Timescale (TAI) very soon. This will be an epoch-making event in the history of TAI.

Further improvement in the accuracy of the time transfer may be expected by studies of the cause of data variations.

ACKNOWLEDGEMENT

The authors wish to thank Dr. Gernot Winkler and Dr. William Klepczynski for their valuable advice on purchasing and operating the GPS receiver. They acknowledge Mr. J. R. McLean and Mr. Q. D. Hua, STI, for their kind efforts in improving the reliability of the receiver. They also thank Mr. T. Yamazaki of the time division and the staff of the computing facility at TAO for their cooperative operation and management to connect the GPS receiver to the computer, FACOM M-380R, through the mini-computer, PANAFACOM U-1200. This work was supported in part by the Scientific Research Fund of the Ministry of Education, Science, and Culture under Grant No. 56420002 in the fiscal years 1981 and 1982.

REFERENCES

1) S. Iijima, "Time and Frequency in Japan," Journal of the Institute of Electronics and Telecommunication Engineers, Vol. 27, No. 10, pp. 372-378, 1981.

2) K. Putkovich, "Initial Test Results of USNO GPS Time Transfer Unit," presented at 34th Annual Symposium on Frequency Control, May 1980.

3) A. J. Van Dierendonck, Q. D. Hua, J. R. McLean, and A. R. Denz, "Time Transfer using Navstar GPS," presented at 13th Annual Precise Time and Time Interval (PTTI) Applications and Planning Meeting, December 1981.

4) D. W. Allan and M. A. Weiss, "Accurate Time and Frequency Transfer during Common-View of GPS Satellite," Proceedings, 34th Annual Frequency Control Symposium, May 1980.

5) W. J. Klepczynski, "Systematic Effects in GPS Time Transfer," presented at 14th Annual Precise Time and Time Interval (PTTI) Applications and Planning Meeting, December 1982, and private communication with William J. Klepczynski, USNO, August 1983.

6) Private communication with W. J. Klepczynski, November 1982.

TABLE 1

COMPARISON OF PC TRIP AND GPS TIME TRANSFER

	U.T.	USNO - TAO via PC	USNO - TAO via GPS	PC - GPS
1982				
15 October	1344	-6196 ns	-6329 ns	133 ns
18 October	0128	-6139	-6263	124
18 October	0131	-6147	-6263	116
18 October	0542	-6142	-6260	118
18 October	2106	-6154	-6230	76
			average	113 ns

SV	CL	MJD'	HH	MM	SS	TRCK SEC	AG HR	EL DG	AZM DEG	ION NS	MC-SATCL NS	SLOPE PS/S	MC-GPS NS	SLOPE PS/S	RMS NS
6	FB	5639	03	42	00	300	11	13	331	38	829379	109	2159	38	13
8	10	5639	04	26	00	780	12	48	315	20	-355159	-54	2158	7	15
6	10	5639	04	42	00	780	12	30	310	27	829649	82	2174	11	10
9	FB	5639	05	10	00	480	12	8	333	42	9287	21	2134	18	14
6	FB	5639	05	22	00	480	13	32	287	27	829831	91	2185	20	11
11	10	5639	05	46	00	780	12	30	309	27	648356	10	2167	-1	11
8	28	5639	06	26	00	780	14	54	53	18	-355584	-56	2175	6	14
11	FB	5639	07	26	00	600	14	62	1	17	648444	5	2177	-10	14
5	10	5639	07	50	00	780	10	28	323	28	190484	16	2167	16	11
5	FB	5639	09	25	00	600	11	72	334	16	190500	8	2181	6	10
6	28	5639	15	02	00	780	23	40	39	20	832229	74	2145	4	12
6	20	5639	15	24	00	780	23	31	34	24	832319	73	2147	-40	13
9	28	5639	16	46	00	780	0	39	32	21	9283	-10	2134	-13	13
9	20	5639	17	06	00	780	0	30	33	25	9278	2	2125	-1	13
5	FB	5639	19	36	00	540	1	10	35	38	190503	5	2125	5	15
5	FB	5639	20	14	00	600	2	3	21	43	190513	-18	2135	-18	15
6	FB	5640	03	38	00	300	12	13	331	38	835463	104	2159	33	12
8	10	5640	04	22	00	780	12	48	315	20	-360392	-52	2164	9	14
6	10	5640	04	38	00	780	12	30	310	27	835739	73	2179	1	10
9	FB	5640	05	06	00	480	12	8	333	42	9314	5	2152	2	13
6	FB	5640	05	18	00	480	13	32	287	27	835920	80	2189	9	9
11	10	5640	05	42	00	780	13	30	309	27	649577	17	2170	5	11
8	28	5640	06	22	00	780	14	54	53	18	-360815	-60	2182	1	13
11	FB	5640	07	22	00	600	15	62	1	17	649659	14	2173	-1	15
5	10	5640	07	46	00	780	13	28	323	28	190593	16	2173	16	13
5	FB	5640	09	21	00	600	15	72	334	16	190619	9	2198	7	11
6	28	5640	14	58	00	780	23	40	39	20	838302	67	2125	-4	13
6	20	5640	15	20	00	780	23	31	34	24	838390	74	2122	-7	13

FIGURE 1 GPS DATA TRANSMISSION FORMAT (GE MARK III FILE)

International Precise Time Comparison

at Tokyo Astronomical Observatory

(UTC(TAO MC) - Signal) NO. 83- 4

** Global Positioning System(GPS) **

Date 1983		MJD	SV#5 MC-GPS UT*	SV#6 MC-GPS UT*	SV#8 MC-GPS UT*
10	1	45608	2.359(112900)	2.334(173000)	2.354(071700)
	2	45609	2.325(112500)	2.313(172600)	2.362(071300)
	3	45610	2.339(112100)	2.307(172200)	2.351(070900)
	4	45611	2.364(111700)	2.285(171800)	2.327(070500)
	5	45612	2.322(111300)	2.288(171400)	2.307(070100)
	6	45613	2.276(110900)	2.291(171400)	2.321(065700)
	7	45614	2.311(110500)	2.284(171000)	2.322(065300)
	8	45615	2.295(110100)	2.241(170600)	2.302(064900)
	9	45616	2.323(105700)	2.262(170200)	2.324(064500)
	10	45617	2.301(105300)	2.264(165800)	2.297(064100)
	11	45618	2.303(104900)	2.252(165400)	2.298(063700)
	12	45619	2.271(104500)	2.297(061400)	2.292(055800)
	13	45620	2.291(104100)	2.293(061000)	2.301(055400)
	14	45621	2.263(103700)	2.289(060600)	2.286(055000)
	15	45622	2.261(103300)	2.285(060200)	2.278(054600)
	16	45623	2.269(102900)	2.277(055800)	2.262(054200)
	17	45624	2.274(102500)	2.283(055400)	2.267(053800)
	18	45625	2.271(102100)	2.251(055000)	2.247(053400)
	19	45626	2.212(101700)	2.242(054600)	2.235(053000)
	20	45627	2.246(101300)	2.252(054200)	2.243(052600)
	21	45628	2.267(100900)	2.233(053800)	2.226(052200)
	22	45629	2.151(100500)	2.226(053400)	2.211(051800)
	23	45630	1.670(201200)	------	------
	24	45631	2.215(095700)	2.209(052600)	2.201(051000)
	25	45632	2.195(095300)	2.203(052200)	2.190(050600)
	26	45633	2.129(094900)	2.196(051800)	2.186(050200)
	27	45634	2.178(094500)	2.187(051400)	2.179(045800)
	28	45635	2.160(094100)	2.197(051000)	2.178(045400)
	29	45636	2.182(093700)	2.187(050600)	2.164(045000)
	30	45637	3.183(093300)	0.102(050200)	2.153(044600)
10	31	45638	2.146(092900)	2.178(045800)	2.155(044200)

- 1 -

FIGURE 2 A MONTHLY PUBLICATION ON TAO GPS DATA

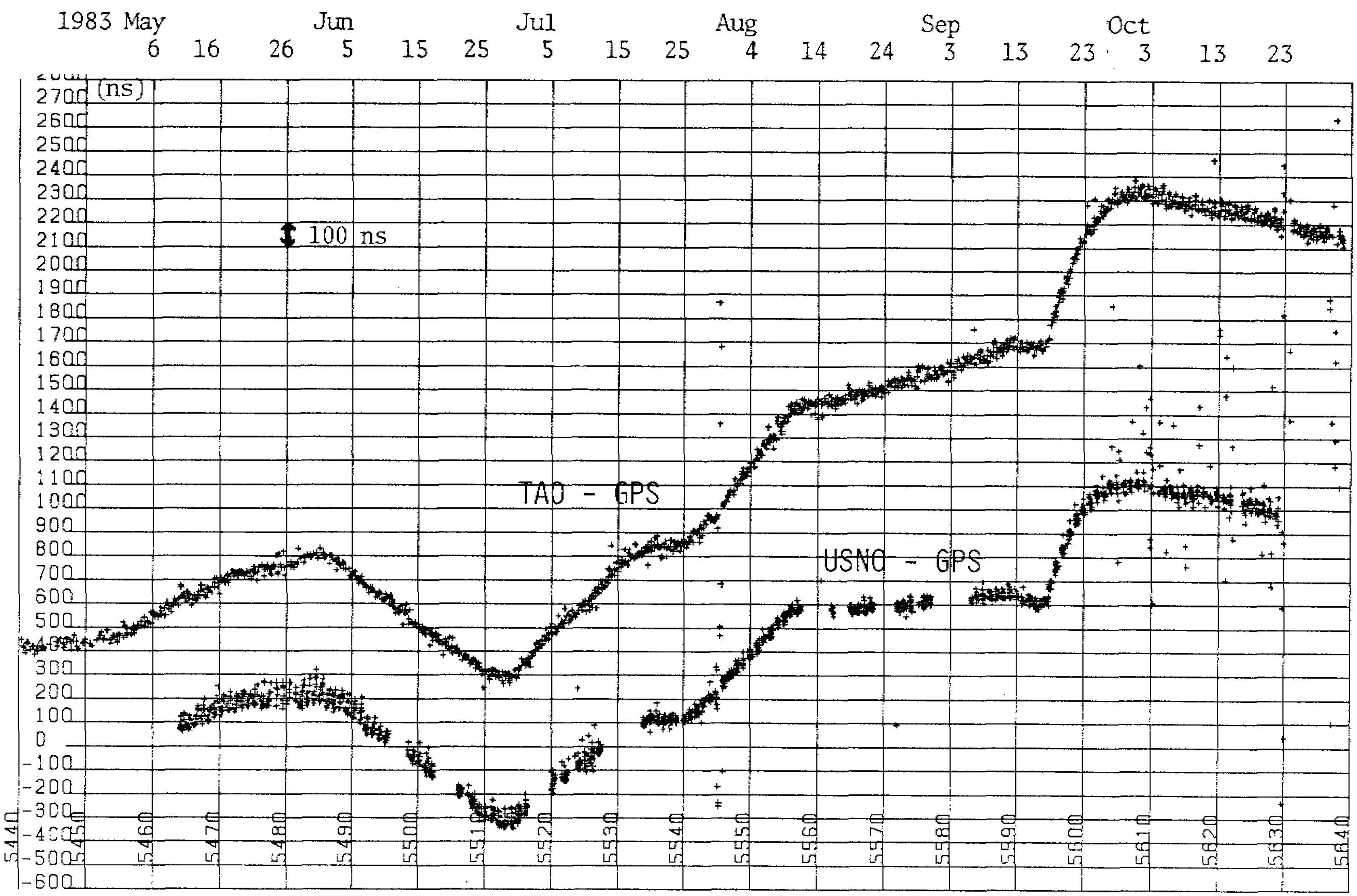

FIGURE 3 UTC(TAO)-GPS AND UTC(USNO)-GPS BY GPS TIME TRANSFER

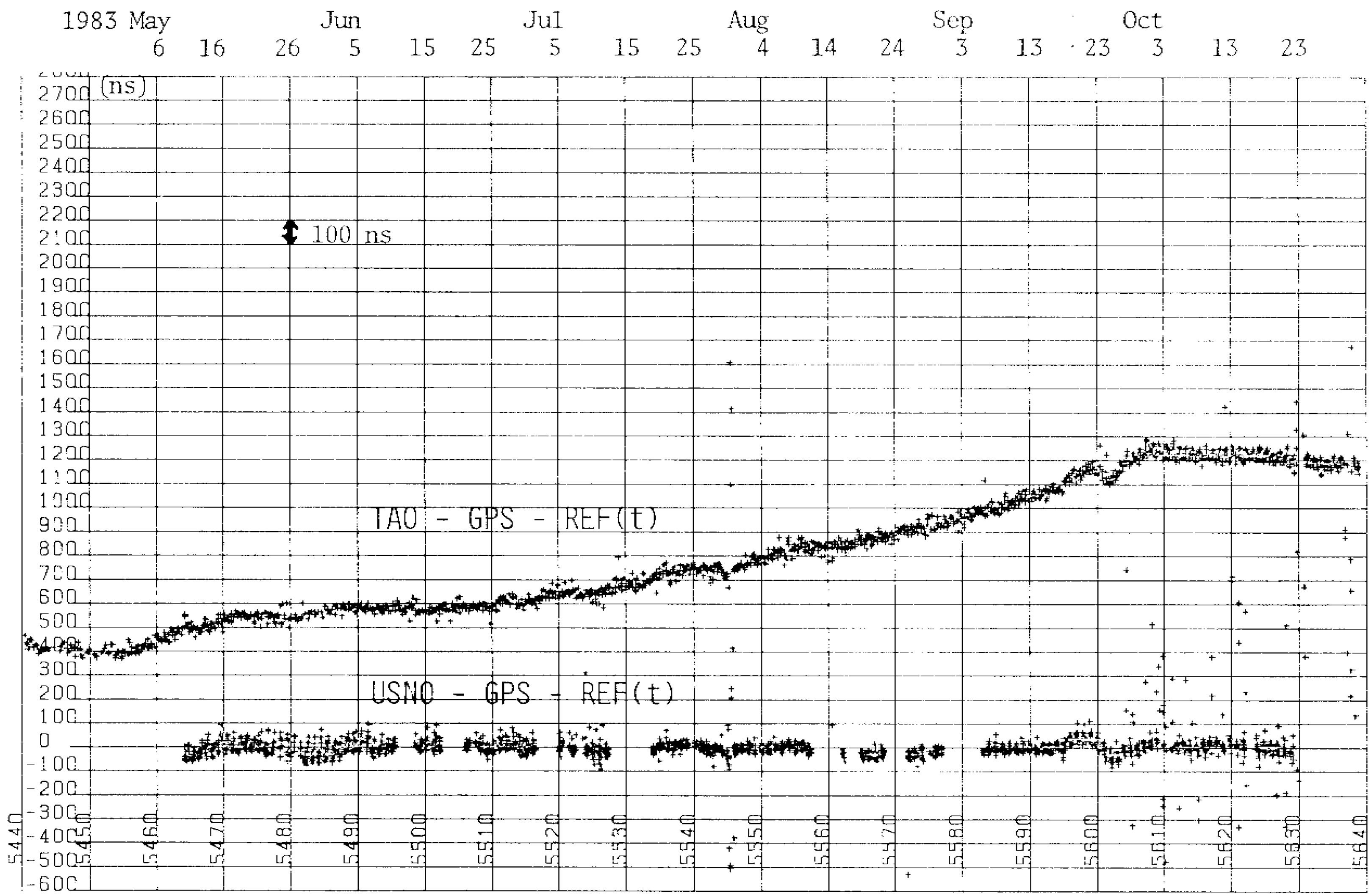

FIGURE 4 APPROXIMATION OF UTC(TAO)-UTC(USNO)

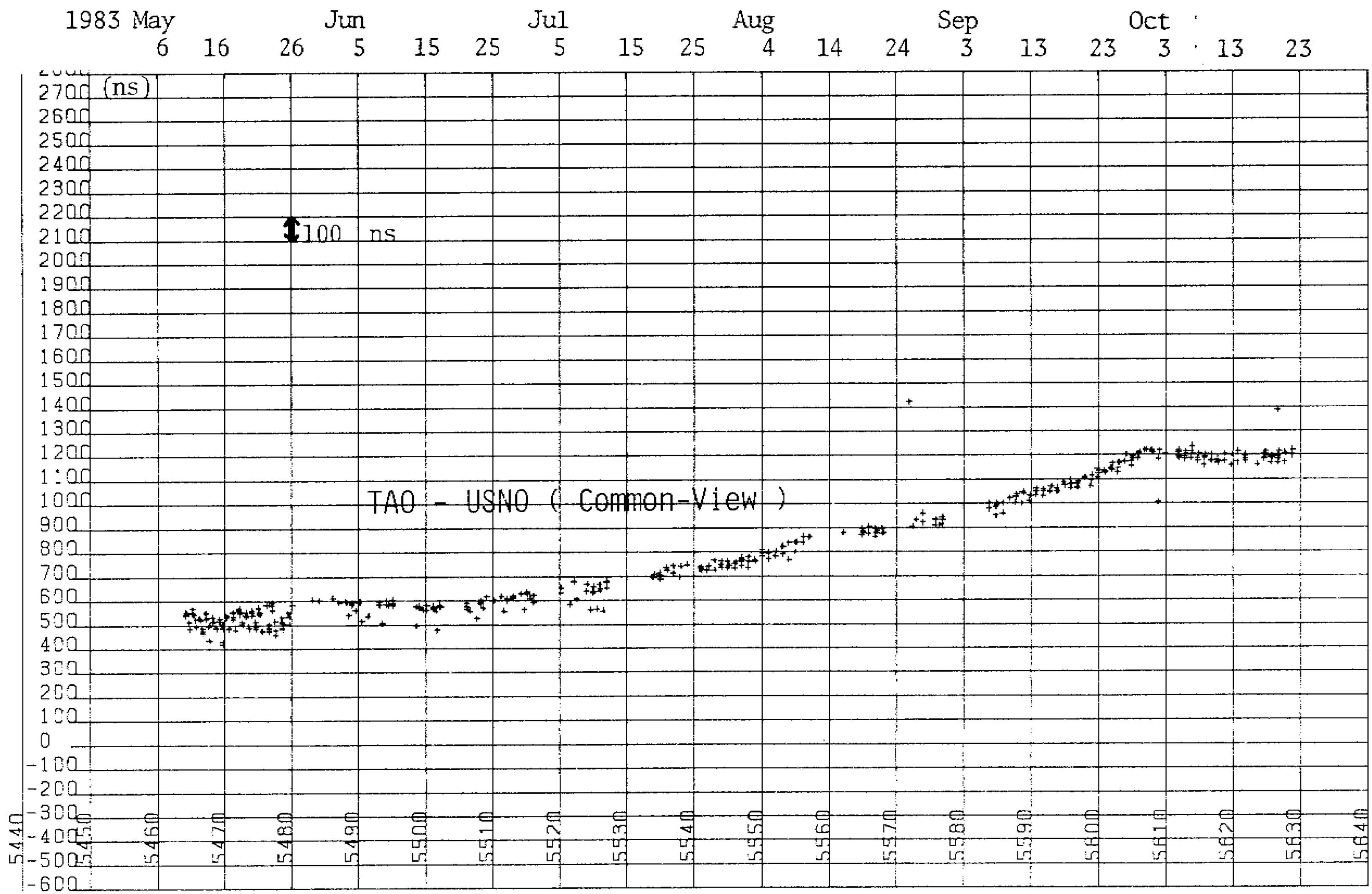

FIGURE 5 UTC(TAO)-UTC(USNO) FROM COMMON-VIEW RECEPTIONS

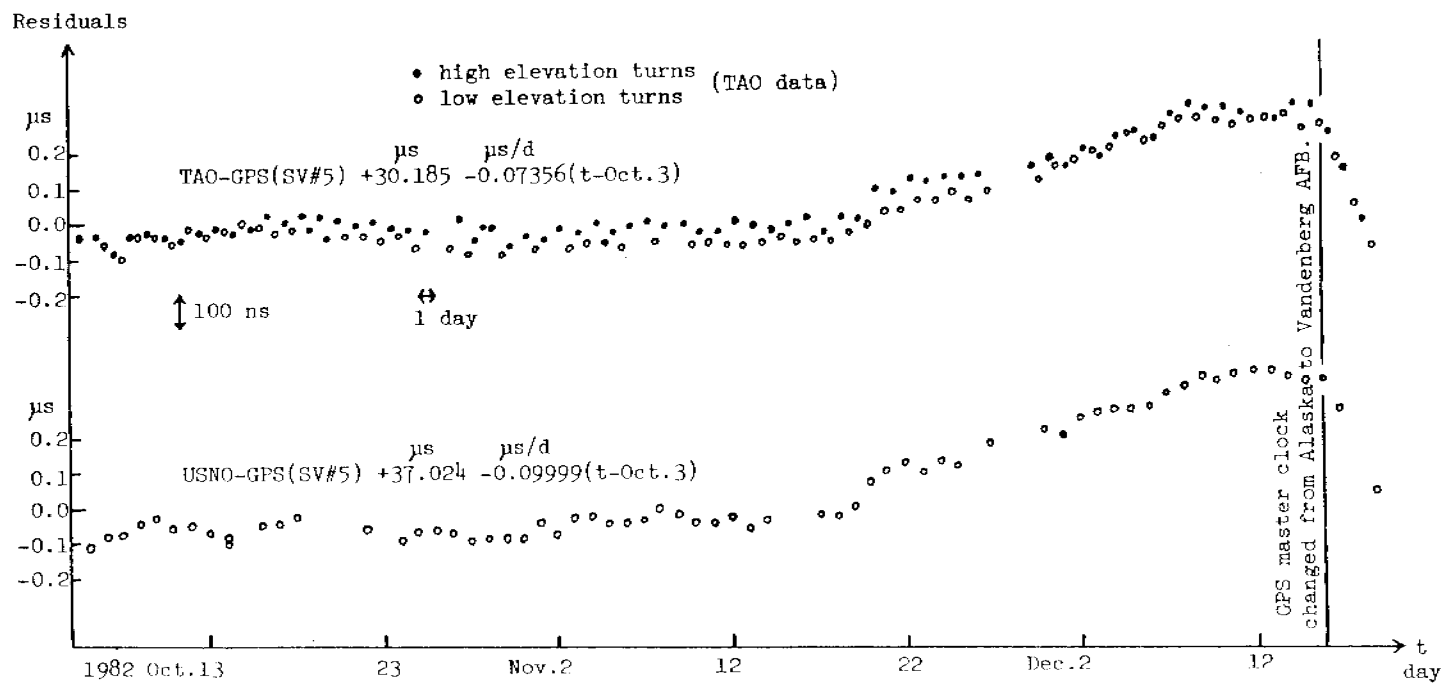

FIGURE 6 RESIDUALS OF A LINEAR FIT FOR GPS DATA DURING A TEST RUN

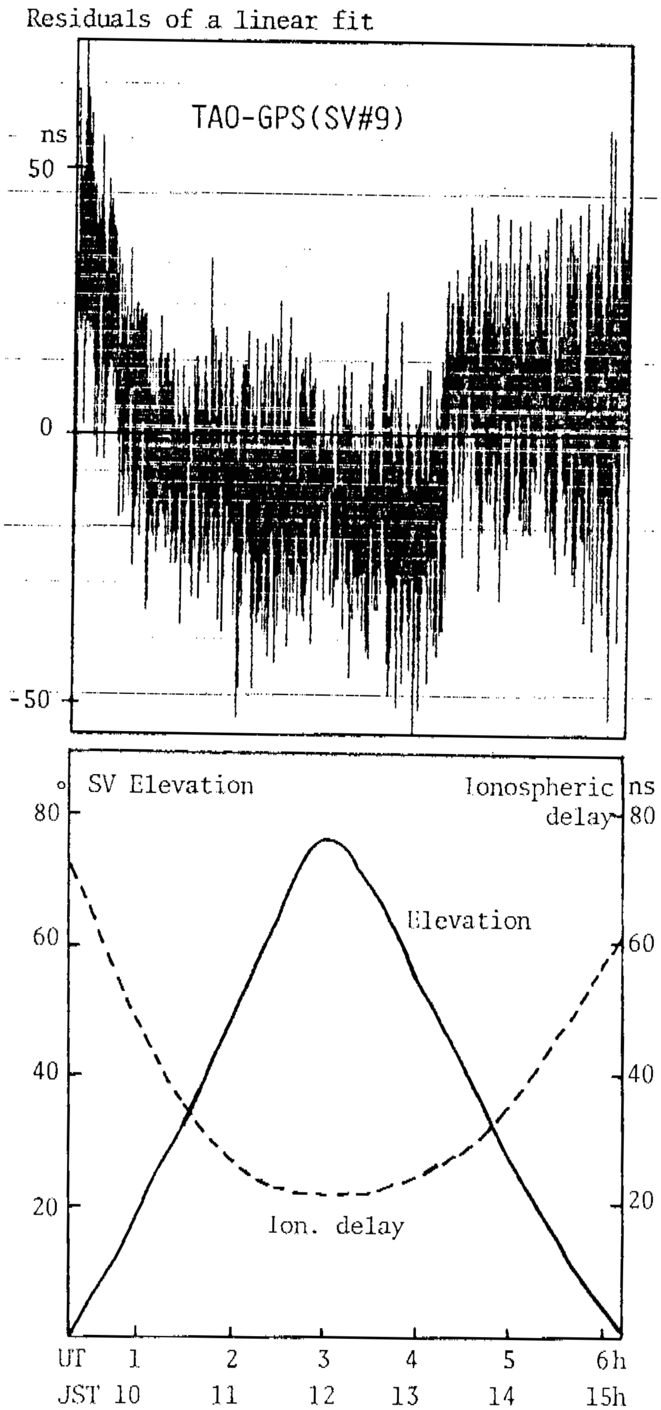

FIGURE 7 RAW DATA OF UTC(TAO)-GPS (6 HOURS TRACKING)