TIME RECOVERY MEASUREMENTS USING OPERATIONAL GOES AND TRANSIT SATELLITES*

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ABSTRACT

Users with requirements for timing signals available over wide geographical areas that are accurately referenced to UTC(NBS) or UTC(USNO) can conveniently access either of two operational satellite systems. Two geostationary GOES (Geostationary Operational Environmental Satellite) satellites located at 75° and 135° W longitude provide a continuous NBS-referenced time code to the Western hemisphere, including large portions of the Atlantic and Pacific Ocean areas. Five operational TRANSIT satellites provide timing signals referenced to UTC(USNO) from low-altitude polar orbits, resulting in worldwide coverage on a non-continuous basis. Convenient, fully automatic, microprocessor-based commercial receivers are now available for use with both satellite systems.

Results of regular monitoring of both the GOES and TRANSIT timing signals over a number of months at NBS, Boulder, CO are presented. The TRANSIT results include an analysis of how received timing accuracy and stability are affected by: (1) averaging over varying numbers

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of satellite passes; (2) averaging over different combinations of the 5 available satellites; (3) using several independent receivers of the same type; and (4) application of [TRANSIT-UTC(USNO)] published corrections to the received data. Based on monitoring experience to date at NBS, some pros and cons of using each of the available operational systems are discussed.

Updated information on recent improvements incorporated into the GOES time code generation and monitoring system at Wallops Island, VA is also included.

INTRODUCTION

Time transfer techniques using satellites are being investigated in one form or another by almost every major timing laboratory in the world. While much of the work reported on to-date has dealt with highly successful, experimental time transfers among international laboratories at the highest attainable accuracy levels, there are also very real needs for the more general dissemination of reliable timing signals at more modest accuracy levels in the 1-100 μs range. Currently, there are two major satellite-based systems which offer such timing capabilities to general users on an operational basis. These are the U.S. Navy's TRANSIT satellite navigation system, also referred to as the "Navy Navigation Satellite System," and the Dept. of Commerce's GOES System, which is an acronym for "Geostationary Operational Environmental Satellites." Relatively low-cost timing receivers are available commercially for use with either of these operational satellite systems. The National Bureau of Standards has been systematically monitoring and evaluating both the TRANSIT and GOES timing capabilities over a period of about 8 months. The approach has been to use only commercially available receivers, treating them essentially as a "black box" with a 1 pulse-per-second output that is analyzed and evaluated as a timing reference with respect to the UTC(NBS) time scale.

TIME DISSEMINATION RESULTS VIA TRANSIT*

There are currently 5 operational TRANSIT satellites providing timing signals in a one-way mode from nearly circular, polar orbits.(1) With this satellite configuration a user at a particular location has access to the TRANSIT signal for about 15 minutes each time one of the satellites flies over within range. Coverage is therefore worldwide, although at any particular location intervals between successive satellite passes might range anywhere from a few minutes to several hours. The TRANSIT signal format contains a fiducial time marker each 2 minutes derived from an on-board crystal oscillator and satellite ephemeris information that can be processed by the receiver to compute the path delay from satellite to user for each 2-minute interval. The receivers used in the NBS measurements, priced at about $12,000 each, automatically acquire the 400 MHz TRANSIT signals, compute the path delays, and correct the output 1 pps to be on-time with respect to the satellite clock.(2) Since the satellite clocks are carefully monitored and controlled by the Navy Astronautics group and the U.S. Naval Observatory, the receiver output can provide an excellent local representation of UTC(USNO).

The block diagram in Figure 1 indicates the way in which the commercial TRANSIT receivers available to NBS for these evalua-

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tions were used. Although these particular receivers include capabilities for averaging over any number of satellite passes from 1 to 100 and for selectively deleting one or more of the 5 operating satellites from the ensemble used to correct the output 1 pps, NBS chose to use a multi-channel data logger to accumulate data separately from each successful satellite pass. For each pass data were recorded providing a measurement of the TRANSIT receiver 1 pps relative to UTC(NBS), identification numbers for the particular satellite and receiver involved, the amount of correction computed and applied by the receiver, the date and time of correction, and the standard deviation of the individual 2-minute points as supplied by the receiver. After the fact the data file was completed by adding a "TRANSIT clock-UTC(USNO)" correction as published by USNO and the elevation angle for each pass. These data were then analyzed in various ways to show the dependence on the particular satellite ensemble used, the number of passes averaged, the particular receivers used, the application of the USNO corrections, and satellite elevation angle.

In all cases TRANSIT measurements deviating by more the 100 μs from UTC(NBS) were discarded.

Dependence on Satellite Ensemble

Figures 2-6 present the received TRANSIT data from each of the 5 operational satellites separately for the 8-month period of the measurements. In each case, each plotted point is the average of 5 successfully received satellite passes (normally, there are about 2 satellite passes per day for each satellite). Also, on each plot are tabulated the mean values and standard deviations applicable to smaller time segments of the 8-month period.

UTC(NBS) is used as the reference, but since NBS and USNO differed by only 2 μs during this period plots in terms of UTC(USNO) would differ only by that amount. Satellite #120, the oldest of the current group, consistently had the highest offset of about +30 μs. #130, also one of the oldest TRANSIT's, was offset by only -0.5 μs. Similarly, #140 was offset by about +14 μs on the average, #190 by +3 μs, and the newest satellite, #200, by -2.8 μs. The standard deviations of the 5-pass averages ranged between 8 and 18 μs for the 5 satellites. Figure 7 also shows the long-term behavior of each satellite over the 8-month period, where each plotted point in this case is an average over 60 days. It is apparent that for best accuracy with respect to either NBS or USNO during this period satellite #120, and possibly also #140, could have been excluded from the ensemble. This effect is shown in Figure 8 where the solid line refers to the complete 5-satellite ensemble, averaging 20 passes per point in this case, while the dashed line is the result if #120 is excluded. The ensemble mean offsets are about 8 μs including all satellites and 4 μs with #120 excluded.

Dependence on Number of Satellite Passes Averaged

Figures 9-11 illustrate how the measurement precision varies with the number of satellite passes averaged. As mentioned previously, the receiver can be easily set to average anywhere from 1 to 100 passes automatically. In the first case for illustration (Figure 9) all satellite passes are used and each plotted point is the average of 5 such passes successfully processed by the receiver. Since typically about 11 good passes per day were received in Boulder, this average corresponds to about one-half day. The standard deviation of the 5-pass averages is about 9 μs. By comparison, a plot of 30-pass averages (Figure 10) corresponding to about 3-day averages, shows that the standard deviation improves to about 5 μs. When all of the data are analyzed in more detail, the plot in Figure 11 of standard deviation vs. the number of passes averaged results. One might interpret this as a dependence on the number of passes averaged, N, that varies as $N^{-\frac{1}{2}}$ down to a "flicker floor" level of about 3 μs for N = 50 passes. The standard deviation for a single pass is about 20 μs.

Dependence on the Particular Receivers Used

Although two independent, co-located receivers observing the same satellite pass occasionally disagreed by more than 50 μs, their long-term agreement was excellent. Figure 12 compares two different receivers based on 30-pass averages. The tabulated mean values in the plot show that 50-60 day averages agreed to within better than 3 μs for these receivers.

Dependence on USNO Published Corrections

Figure 13 illustrates the effect of correcting the observed data by applying the "TRANSIT-UTC(USNO)" corrections from USNO's Time Service Announcement Series 17. Data from all 5 satellites are included and each point is an average over 10 passes, or about 1 day. The dashed curve has the USNO corrections applied while the solid curve is the uncorrected output of the receiver. One reason that its hard to distinguish the two separate curves is that the means are essentially identical-in fact, applying the USNO corrections for this data sample actually moves the ensemble average farther away from UTC(USNO) by about a microsecond. From the tabulated standard deviations at the bottom of the plot, however, it can be seen that applying the USNO corrections to the measurements does seem to reduce the standard deviation of the 10-pass averages by about 20%.

Dependence on Satellite Elevation Angle

The TRANSIT data were also analyzed for any correlation between the elevation angle of a pass and the scatter of the measurements. There was no significant correlation, which is probably not too surprising since the TRANSIT receiver automatically rejects any satellite pass corresponding to elevation angles of less than 10°.

Using TRANSIT Timing Signals to Control a Cesium Clock

Using the months of accumulated TRANSIT monitoring data as a starting point, one of the authors (JAB) developed a procedure for steering a cesium clock with the TRANSIT satellite signals in such a way as to realize a time accuracy of at least 20 μs at any time. The study involved (1) data analysis; (2) the development of computer models to simulate the performance of the satellite-receiver combination and cesium clocks; and (3) devising and testing different control algorithms using computer simulation.

The recommended algorithm is to use a TRANSIT timing receiver set to accept all TRANSIT satellites except #120. The receiver should be set to reject points in error by more than 150 μs and average for about one week. This should require averaging about 80 individual passes. Once per week an operator compares the cesium clock with the TRANSIT timing receiver output (i.e., the week's average) pulse using a time interval counter. If the ticks are within ± 10 μs, the operator makes no changes. If the time difference exceeds the ± 10 μs tolerance, then the cesium clock output is shifted exactly 10 μs toward the output of the TRANSIT receiver. No use is made of the USNO published corrections.

While it is recognized that it is risky to extrapolate years into the future based on only six months of satellite data, still this data provides a reasonable basis to design a control algorithm. Assuming no deterioration in the operation of the satellites the models used should reasonably account for long-term trends in the clocks. The expected performance is an RMS time error of the cesium clock of about 7 μs, with less than a 1% probability of exceeding ± 20 μs error relative to UTC. On the average, the cesium clock will be reset every two months.

TIME DISSEMINATION RESULTS VIA GOES

In contrast to TRANSIT with its 5 polar-orbiting satellites, the GOES system employs two operational geostationary satellites, backed-up by at least one in-orbit spare. The GOES satellites, designated GOES/East and GOES/West, are positioned over the equator at 75° and 135° W. longitude, respectively.(3) From these locations they provide continuous coverage to most of the western hemisphere as indicated in Figure 14. Although their primary mission for NOAA involves the collection of large quantities of environmental data from many kinds of sensing platforms, the GOES signal format transmitted from satellite to Earth at 468 MHz also includes a digital time code generated and controlled by the National Bureau of Standards' equipment at the satellite control facility in Wallops Island, VA. In addition to complete time-of-year information referenced to NBS the transmitted code also contains satellite position predictions updated each 4 minutes, generated in Boulder from orbital elements supplied periodically by NOAA and NASA tracking facilities. A two-way, dial-up telephone data link between Boulder and Wallops Island allows NBS to send updated position predictions and clock control commands to the automated system and to receive back on demand Loran-C and TV monitoring data and equipment status indicators.

Commercial GOES time code receivers are currently available in two basic versions, aimed at different accuracy levels. The more sophisticated type was used for most of the measurements being reported here. As in the TRANSIT case, it is microprocessor-based, enabling it to decode the satellite position data, compute the appropriate source-to-user path delay, and adjust its 1 pps output signal to be "on-time" with respect to the NBS-controlled atomic clock system at Wallops Island. Its base price is about $4,000. A second receiver version used for some of the measurements ignores the satellite position data in the code and simply provides a time display and output timing signals usable at the ± 1 ms level at a cost of about $2,000.

The GOES data to be discussed here resulted from monitoring the received timing signals in Boulder from both the GOES/East and GOES/West satellites, and recording the difference between the receiver 1 pps outputs and the UTC(NBS) time scale. During the full 8-month period occupied by the TRANSIT measurements, single measurements of UTC(NBS)-GOES/East and UTC(NBS)-GOES/West at a specified time each day were recorded. For a more limited 45-day period measurements of 1000-second averages were also recorded continuously from both satellites.

Medium-term (1000 seconds) GOES Performance

Figure 15 displays the 1000-second averages as received from GOES/East over a 45-day period. The Y-axis ranges from 0-1000 μs so that essentially all of the several thousand data points - good and bad, can be included. (For comparison it should be kept in mind that the TRANSIT data plots discussed earlier excluded all outliers beyond ± 100 μs.) Figure 15 has at least 3 distinctive features. The first is the rather random sprinkling of outlier measurements with values mainly between the baseline at about 50 μs and something like 500 μs. At first it was assumed that these points correspond to offsets of the receiver 1 pps that occured during periods of land-mobile radio interference in the local Boulder/Denver metropolitan area. Since the GOES frequency allocations near 468 MHz used for the NBS time code are coincident with communication frequencies assigned to the land-mobile service in the U.S., a significant potential for interference in large urban areas exists. During some such interference conditions our GOES timing receivers tended to go "out-of-lock" fairly often. According to the receiver manufacturer, however, such large offsets in the presence of noise are not normal and rather indicate a malfunction in the calculator circuitry which computes the path delay correction. Apparently this symptom has been observed on some other early models of this receiver. At least one of the NBS receivers with this symptom has been subsequently modified by the manufacturer with encouraging results.

The second distinctive feature of the plot in Figure 15 is the pronounced diurnal variations with an amplitude varying from nearly zero up to about 30 μs. These variations are likely due to small imperfections either in the complex computer program used to compute the 4-minute updates of the satellite positions or in the orbital elements. The changes in amplitude that obviously occur from time to time are generally correlated with new sets of position predictions and are believed to reflect the varying quality of satellite orbital elements supplied to NBS. The third noticeable feature of this plot is the generally flat trend of the GOES/East average baseline over the 45-day period in spite of the interference effects and orbital-element problems.

Figure 16 is the corresponding data for the GOES/West received time code. Again we see frequent outliers, diurnal variations which do not seem to be correlated with those on GOES/East, and a somewhat greater long-term variation amounting to about 50 µs relative to UTC(NBS). Such variations are most likely due to imperfect orbital elements. Note the almost total absence of outliers during the first 10 days. Since the local interference conditions presumably weren't that much better, one possible explanation is that the receiver calculator circuitry was operating properly only during this period. In the next two figures an ARIMA-model filtering technique has been used to reject many of the obvious outliers and the remaining data points are plotted on an expanded 0 to 100 µs scale. The GOES/East filtered data in Figure 17 show a fairly constant average value to within about 15 µs over the 45 days. The GOES/West measurements in Figure 18 when filtered show about the same magnitude of diurnal variations but a larger systematic variation of the mean.

GOES Performance Averaged Over One Day

Figure 19 shows the improvement obtained by averaging the GOES/East filtered measurements over 1 day. The resulting daily means have a standard deviation of about 6 µs.

Long-term GOES Performance

Figures 20-22 display some longer-term, once-per-day measurements during an 8-month period. Each point in this case is essentially just an instantaneous measurement of the receiver 1 pps vs. UTC(NBS) as recorded at 0000 UT each day. Such individual measurements are, of course, rather sensitive to local interference conditions. In the case of GOES/East (Figure 20) it's apparent that a shift of about 50 μs in the mean value occured sometime in April, 1979, but in general the average has been stable to within about ± 50 μs overall. Interestingly, the GOES/ West data in Figure 21 also shows about a 50 μs shift at about the same time, and at present there is no clear explanation for this observation. As often seems to happen in such cases, an unrelated gap in the recorded data occurred at about that time that prevented pinpointing the shift more exactly. Aside from these few anomolies, however, the plots indicate that the long-term stability can be as good as ± 10 μs for many months.

Figure 22 is again based only on single, daily measurements of UTC(NBS)-GOES/West at 0000 UT. It differs from all the preceding ones in that these measurements are made with the simpler version GOES receiver that does not use the position information to compensate for path delay. Its output 1 pps rather fluctuates as the actual path delay changes due to various satellite motions. Note that the Y-axis in this case extends from 0 to 2 ms. The reason that the received signal ends up within 2 ms of UTC(NBS) even without any delay correction is that the time code as transmitted from Wallops Island is advanced by exactly 260 ms, which makes the signal arrive at the user's location nearly on time. This simpler receiver can provide a timing reference stable to a few tenths of a millisecond relative to a fixed mean delay bias that can be calibrated out of the measurement. This bias for GOES/West is about 1.5 ms for the Boulder location. For many applications this level of accuracy may be sufficient and offers a reduced receiver cost of about $2,000.

Recent Improvements in GOES Time Code Generation System

Very recently, the NBS time code generation and control equipment has been replaced with an upgraded system that provides the improvements listed in Figure 23. As a result, it can be expected that the GOES time code will be even more reliable in the future and will show improved stability relative to UTC(NBS), both at the trasmitter and the receiver ends of the NBS-to-user-link. The preliminary data from the upgraded system suggests that the Wallops Island clocks can be maintained within a few microseconds of UTC(NBS) indefinitely.

CONCLUSION

To conclude, Figure 24 summarizes some of the more important advantages, as NBS sees them, of the TRANSIT and GOES time dissemination systems. The first group of advantages apply equally well to both these systems. In terms of long-term continuity it may be worth noting that new, improved TRANSIT and GOES satellites are scheduled for launch during the next year and there is every indication that both systems will be around for many years. In addition to these general advantages each system offers some special, more-unique features. For TRANSIT the coverage from the polar-orbiting satellites is global, clearly of great importance for some applications. Because the TRANSIT signals operate at different frequencies than GOES, they are not subject to the land-mobile interference problems. Based on the 8 months of data monitored at NBS, received TRANSIT signals, when averaged over an appropriate satellite constellation, can provide a highly-accurate local time reference with respect to UTC(USNO) at the better-than-25 μs level. Finally, the use of 5 operational satellites provides excellent service reliability. In the case of the GOES time code coverage is only hemispheric rather than global, but the signals are available continuously within this area. The code provides complete time-of-year information at two different accuracy levels, so that users have an option to accept lower accuracy with a cost savings of several thousand dollars per receiver. Even the full-accuracy user can find GOES highly cost-effective at a receiver cost of less than $5,000.

REFERENCES

1. Theodore D. Finsod, "Transit Satellite System Timing Capabilities", Proc. 10th Annual PTTI Applications and Planning Meeting (Washington, D.C.), November 1978, pp. 511-537.
2. G. A. Hunt and R. E. Cashion, "A Transit Satellite Tuning Receiver", Proc. 9th Annual PTTI Applications and Planning Meeting (Washington, D.C.), March 1978, pp. 153-167.
3. D. W. Hanson, D. D. Davis, and J. V. Cateora, "NBS Time to the Western Hemisphere by Satellite", Radio Science, Vol 14, No. 4, July-August, 1979, pp. 731-740.

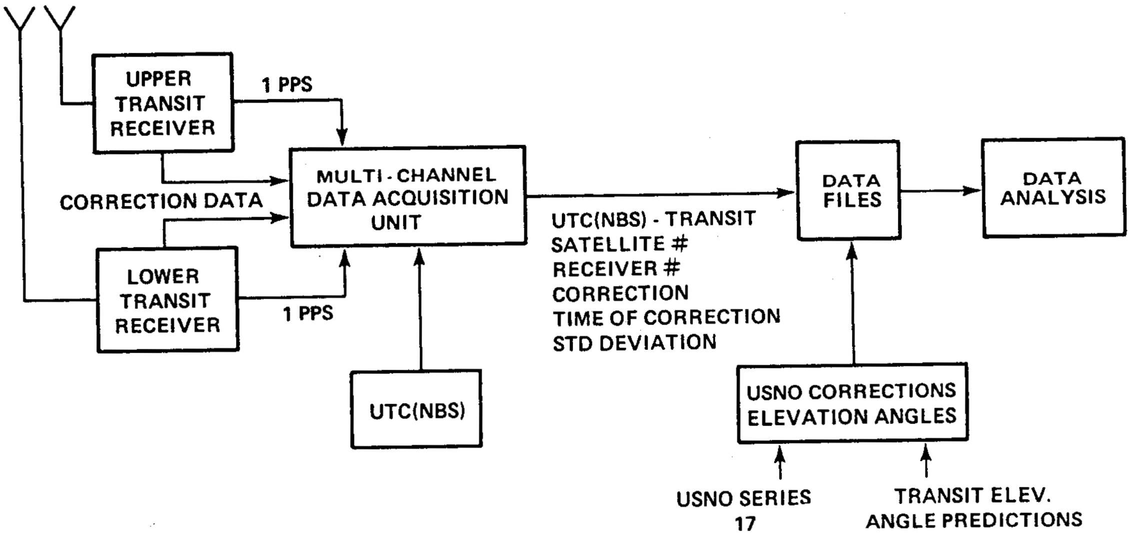
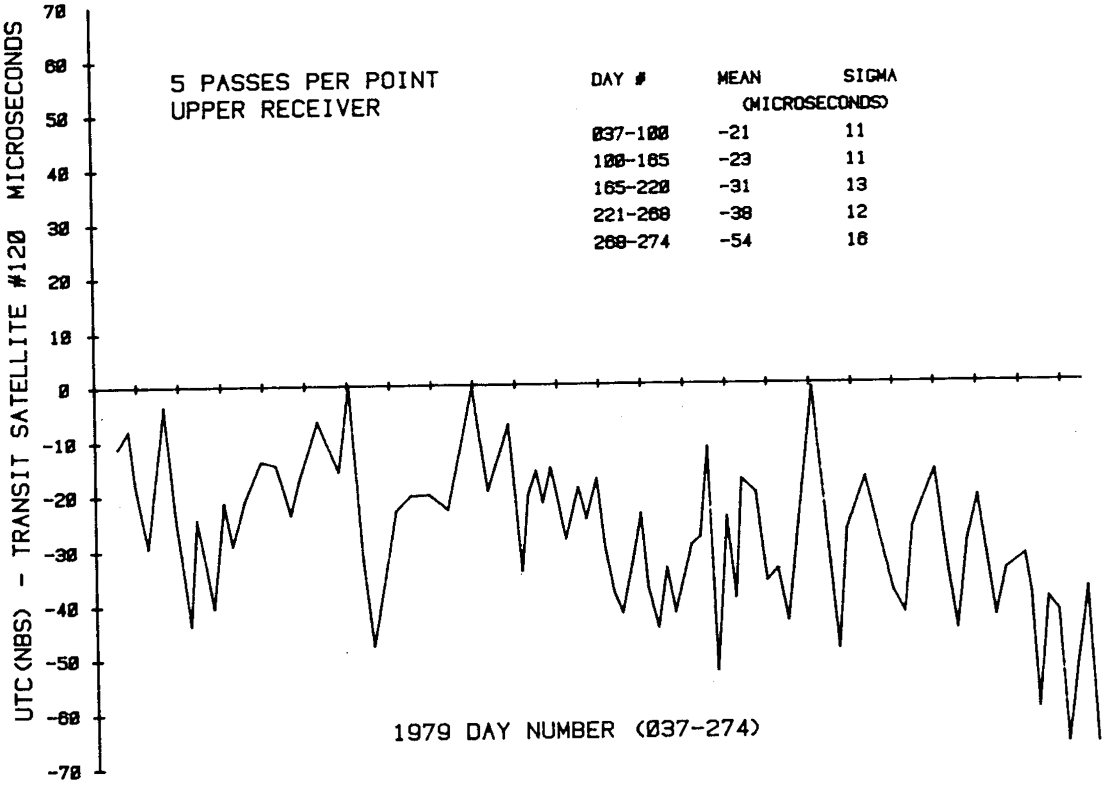
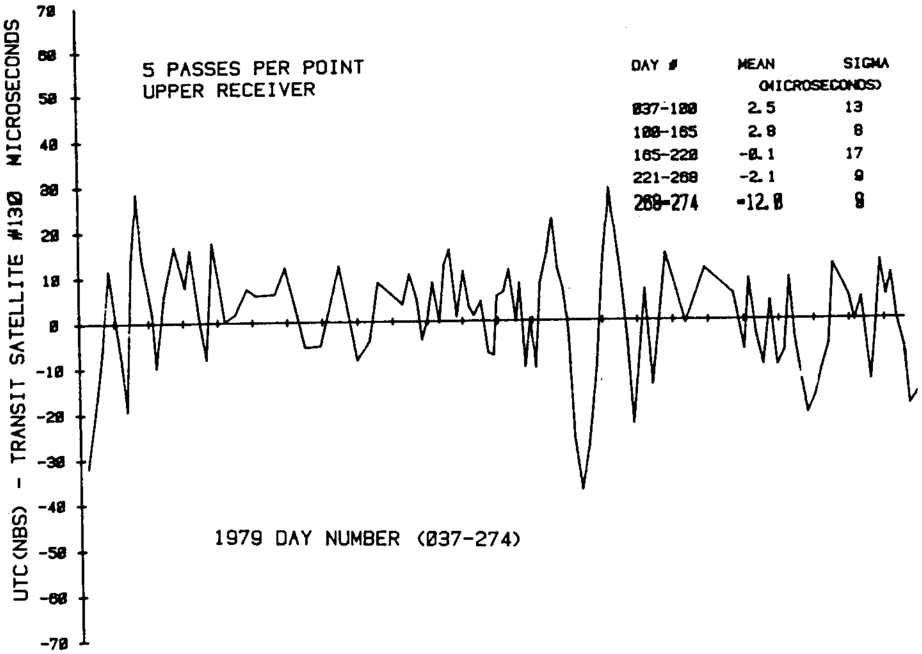


Figure 1. Block Diagram of Transit Monitoring System



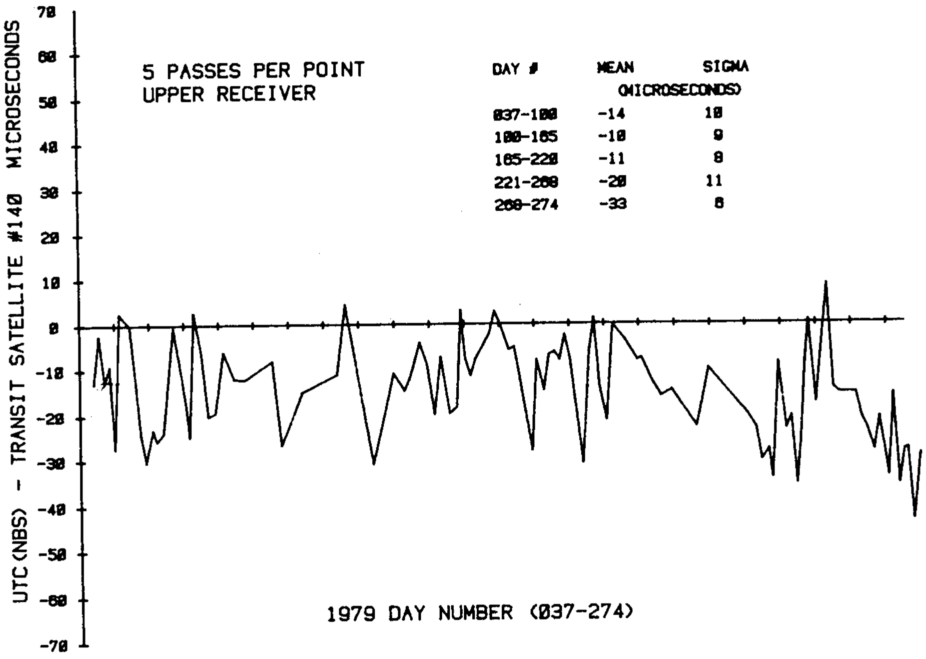
DAY #	MEAN	SIGMA
	(MICROSECONDS)	
037-100	-21	11
100-165	-23	11
165-220	-31	13
221-268	-38	12
268-274	-54	16

Figure 2. UTC (NBS) - Transit Satellite #120



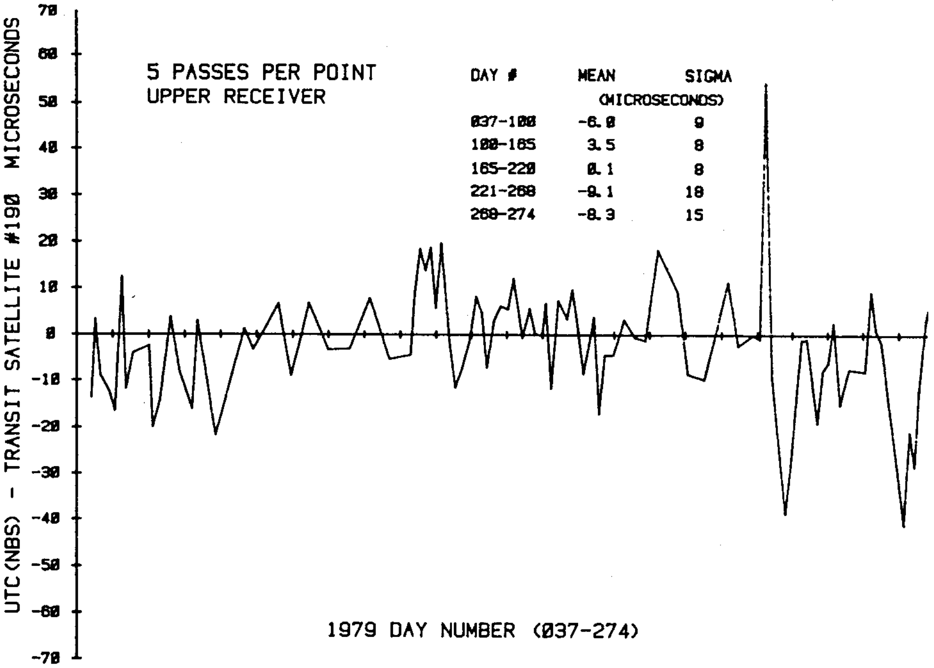
DAY #	MEAN	SIGMA
	(MICROSECONDS)	
037-100	2.5	13
100-165	2.8	8
165-220	-0.1	17
221-268	-2.1	9
268-274	-12.0	8

Figure 3. UTC (NBS) – Transit Satellite #130



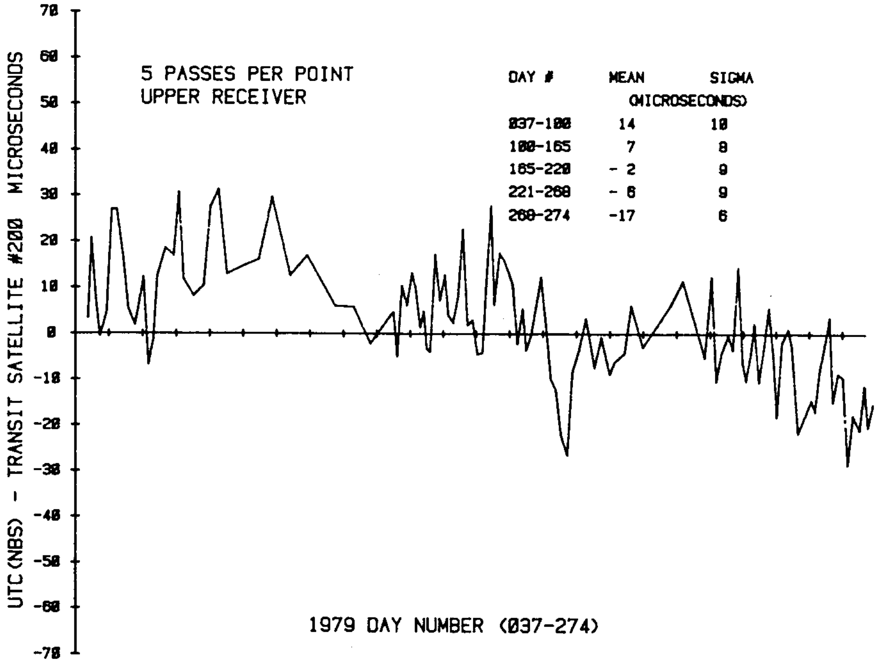
DAY #	MEAN	SIGMA
	(MICROSECONDS)	
037-100	-14	10
100-165	-10	9
165-220	-11	8
221-268	-20	11
268-274	-33	8

Figure 4. UTC (NBS) – Transit Satellite #140



DAY #	MEAN	SIGMA
	(MICROSECONDS)	
037-100	-6.0	9
100-165	3.5	8
165-220	0.1	8
221-260	-9.1	10
260-274	-8.3	15

Figure 5. UTC (NBS) – Transit Satellite #190



DAY #	MEAN	SIGMA
	(MICROSECONDS)	
037-100	14	10
100-165	7	8
165-220	- 2	9
221-260	- 6	9
260-274	-17	6

Figure 6. UTC (NBS) – Transit Satellite #200

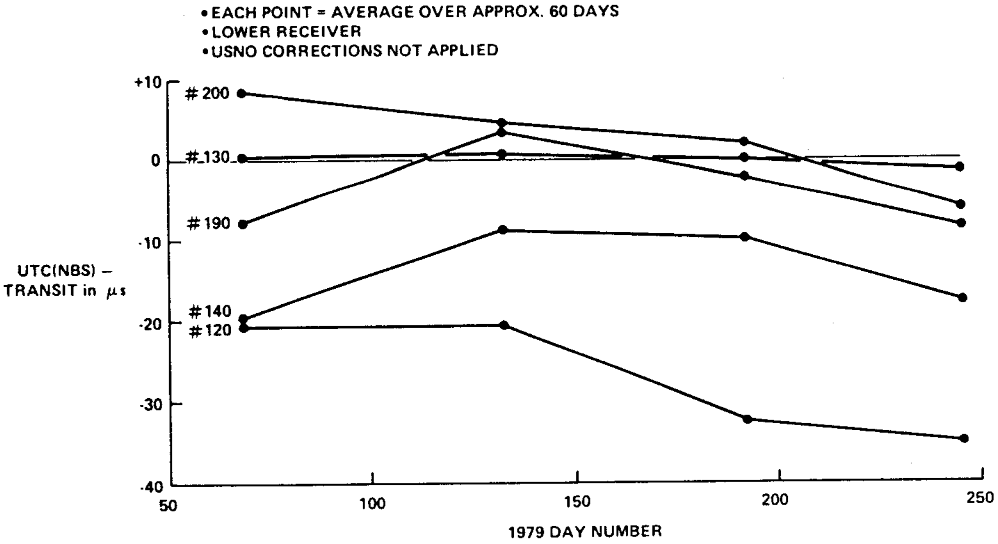
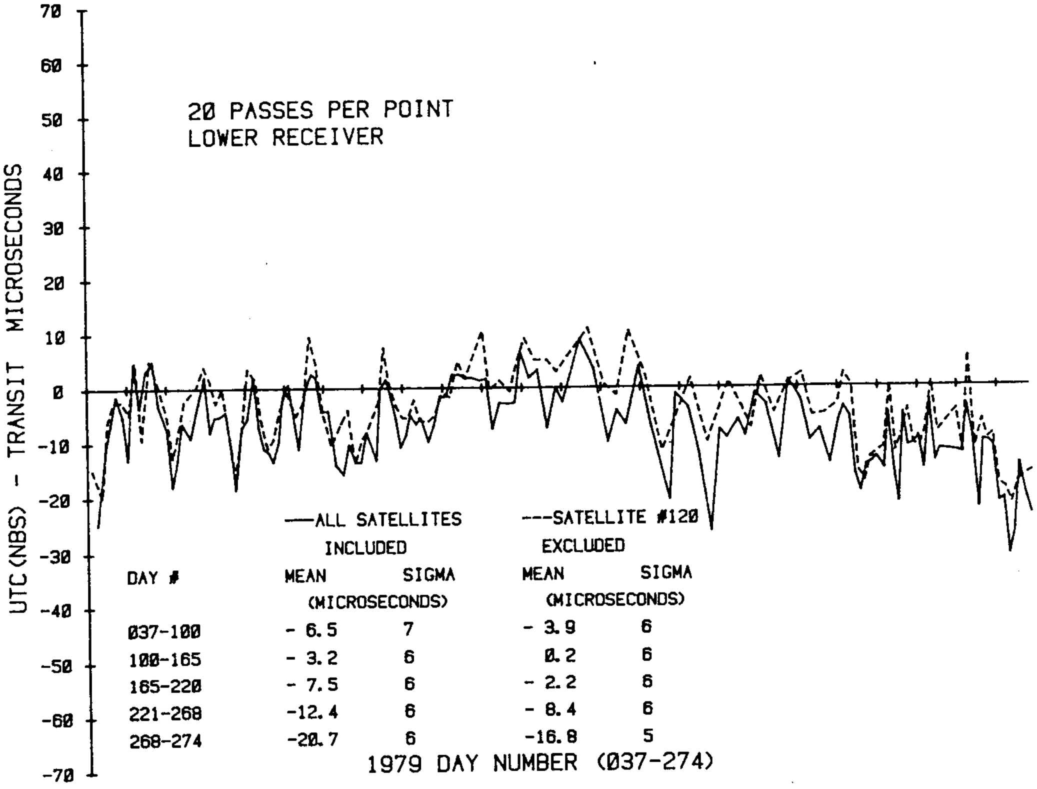
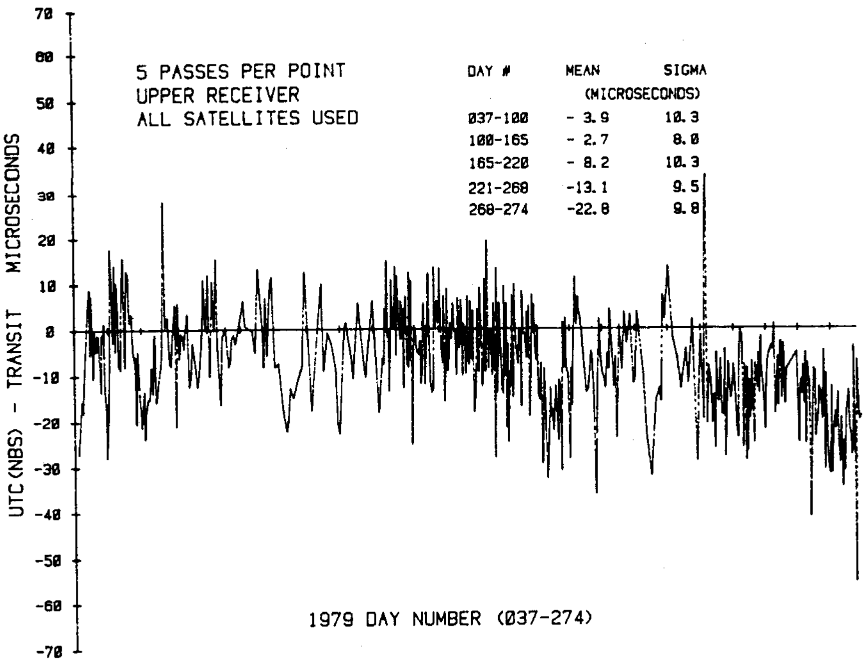


Figure 7. UTC (NBS) - Transit for Individual Satellites



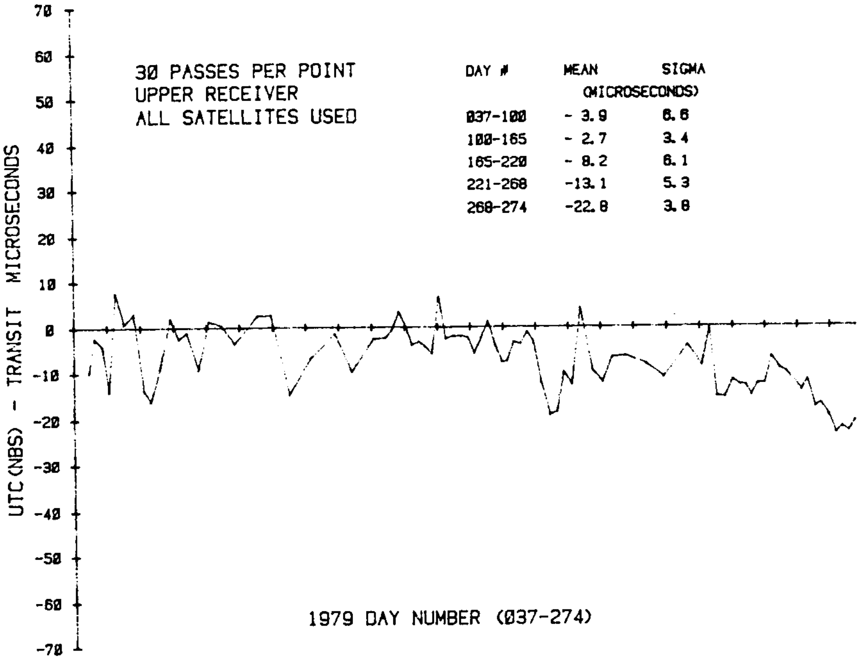
DAY #	ALL SATELLITES INCLUDED MEAN (MICROSECONDS)	ALL SATELLITES INCLUDED SIGMA (MICROSECONDS)	SATELLITE #120 EXCLUDED MEAN (MICROSECONDS)	SATELLITE #120 EXCLUDED SIGMA (MICROSECONDS)
037-100	- 6.5	7	- 3.9	6
100-165	- 3.2	6	0.2	6
165-220	- 7.5	6	- 2.2	6
221-268	-12.4	6	- 8.4	6
268-274	-20.7	6	-16.8	5

Figure 8. Effect of Deleting Satellite #120 from Ensemble



DAY #	MEAN	SIGMA
	(MICROSECONDS)	
037-100	- 3.9	10.3
100-165	- 2.7	8.0
165-220	- 8.2	10.3
221-268	-13.1	9.5
268-274	-22.8	9.8

Figure 9. UTC (NBS) – Transit



DAY #	MEAN	SIGMA
	(MICROSECONDS)	
037-100	- 3.9	6.6
100-165	- 2.7	3.4
165-220	- 8.2	6.1
221-268	-13.1	5.3
268-274	-22.8	3.8

Figure 10. UTC (NBS) – Transit

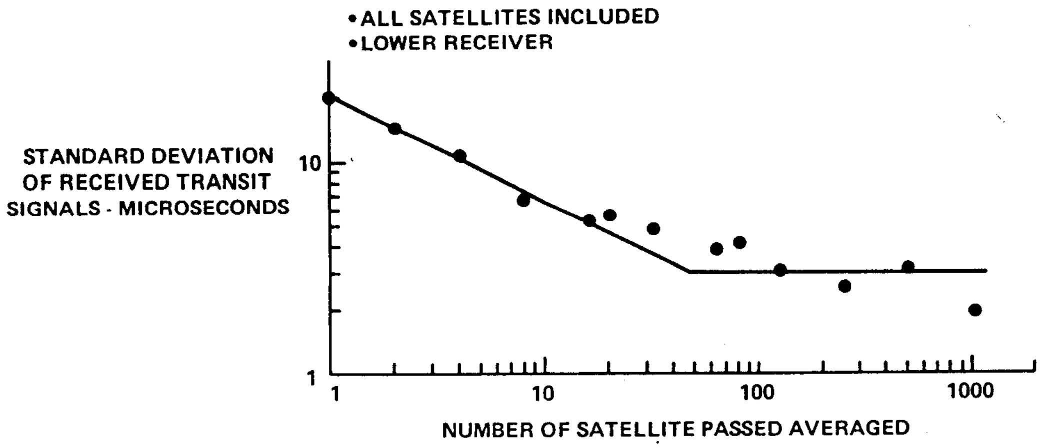
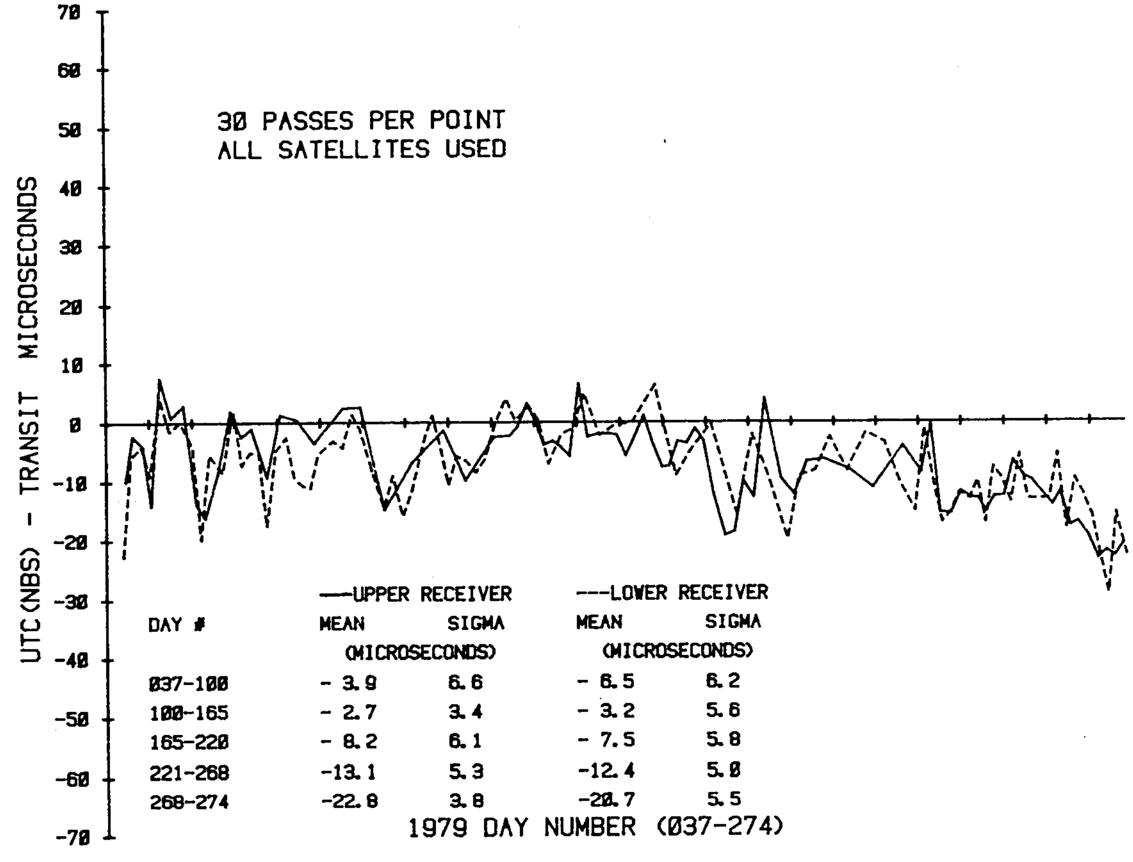
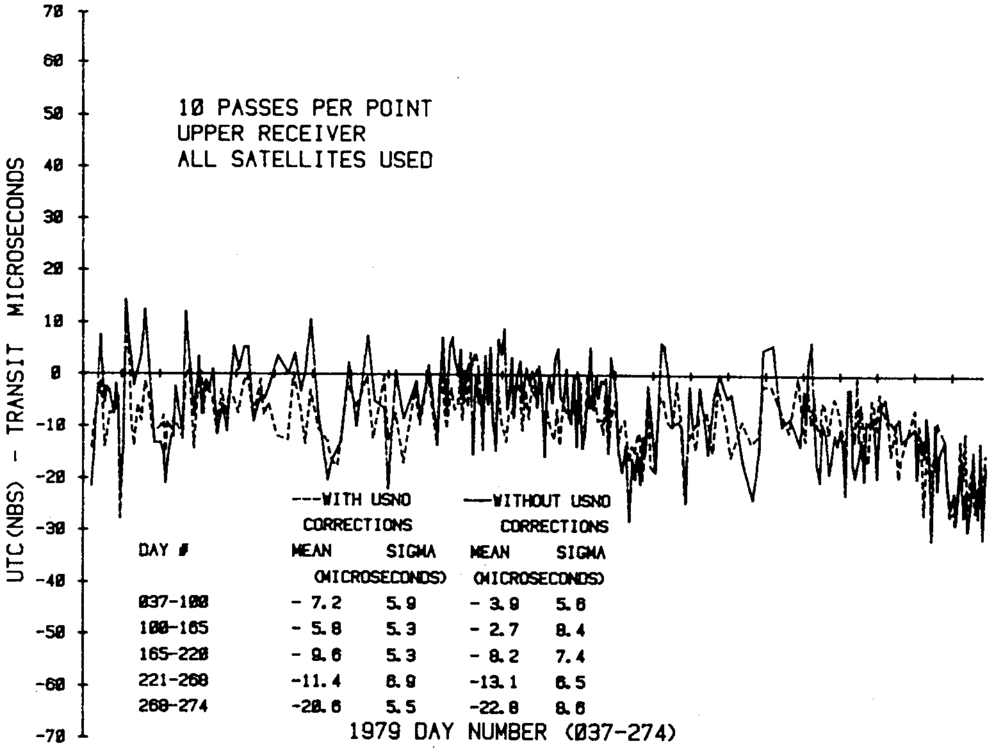


Figure 11. Standard Deviation of Received Transit Signals vs. Number of Satellite Passes Averaged



	—UPPER RECEIVER		---LOWER RECEIVER	
DAY #	MEAN	SIGMA	MEAN	SIGMA
	(MICROSECONDS)		(MICROSECONDS)	
037-100	- 3.9	6.6	- 6.5	6.2
100-165	- 2.7	3.4	- 3.2	5.6
165-220	- 8.2	6.1	- 7.5	5.8
221-268	-13.1	5.3	-12.4	5.0
268-274	-22.8	3.8	-20.7	5.5

Figure 12. UTC (NBS) – Transit for Two Different Receivers



DAY #	WITH USNO CORRECTIONS MEAN (MICROSECONDS)	WITH USNO CORRECTIONS SIGMA (MICROSECONDS)	WITHOUT USNO CORRECTIONS MEAN (MICROSECONDS)	WITHOUT USNO CORRECTIONS SIGMA (MICROSECONDS)
037-100	- 7.2	5.9	- 3.9	5.6
100-165	- 5.8	5.3	- 2.7	8.4
165-220	- 9.6	5.3	- 8.2	7.4
221-268	-11.4	6.9	-13.1	6.5
268-274	-20.6	5.5	-22.8	8.6

Figure 13. Comparison of Received Transit Data With and Without Additional USNO Corrections

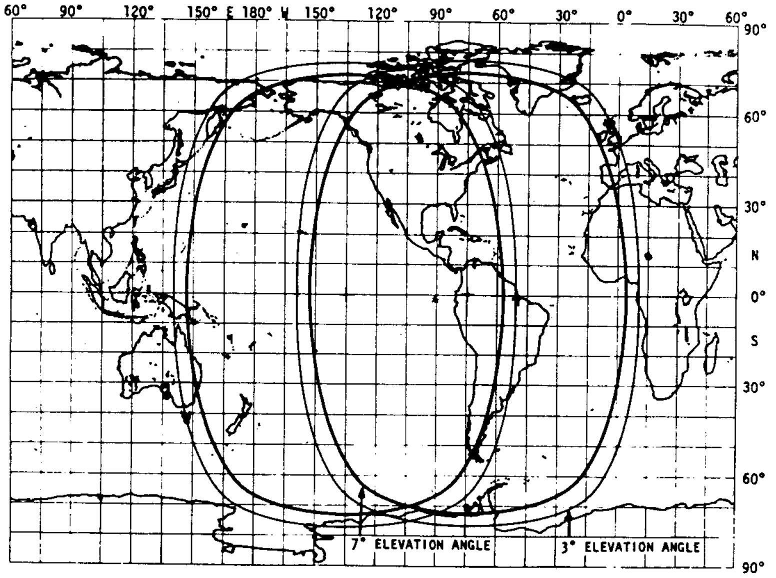


Figure 14. Coverage Areas for GOES/East and GOES/West Satellites

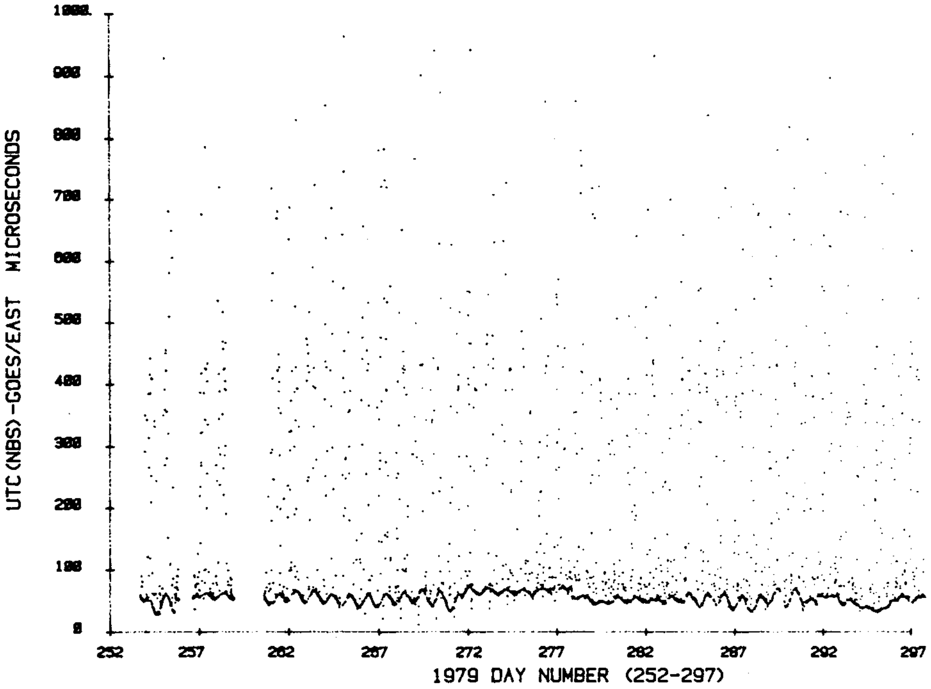


Figure 15. UTC (NBS) – GOES/East: 1000–Second Averages

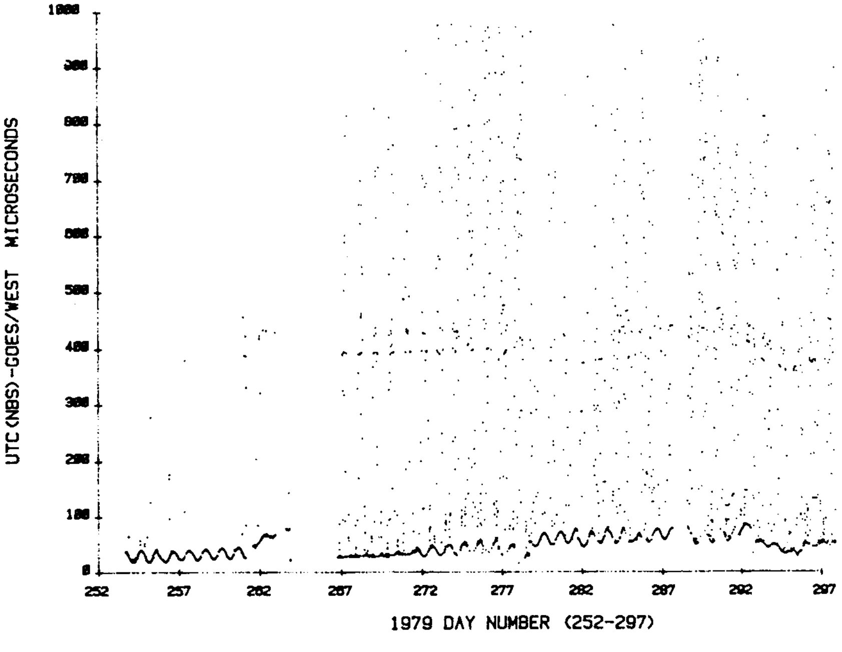


Figure 16. UTC (NBS) – GOES/West: 1000–Second Averages

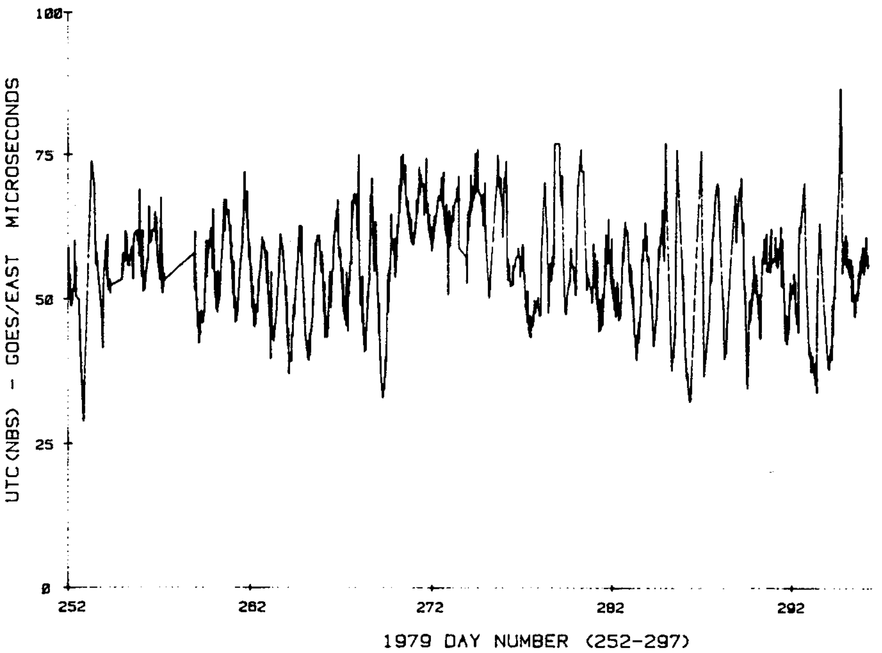


Figure 17. UTC (NBS) - GOES/East: 1000-Second Filtered Averages

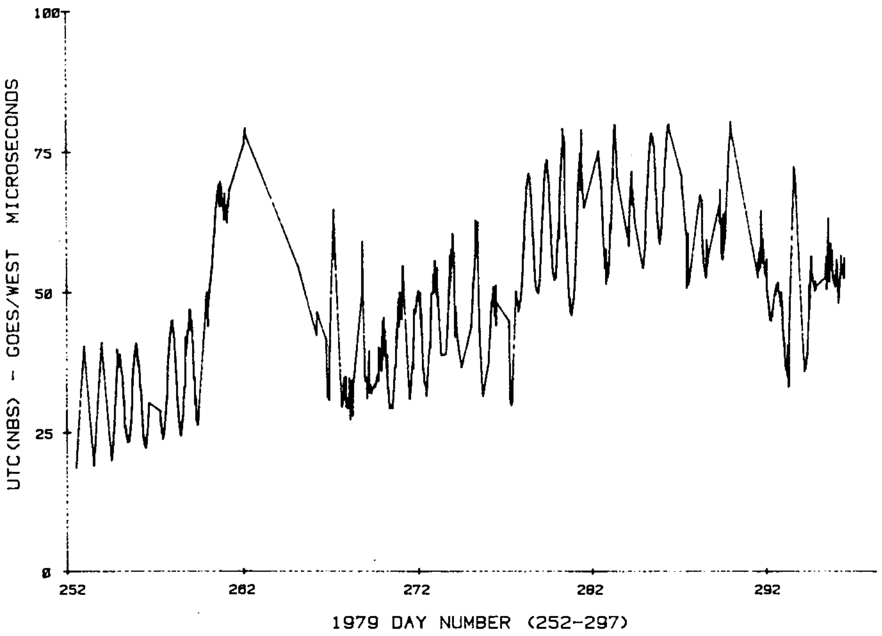


Figure 18. UTC (NBS) - GOES/West: 1000-Second Filtered Averages

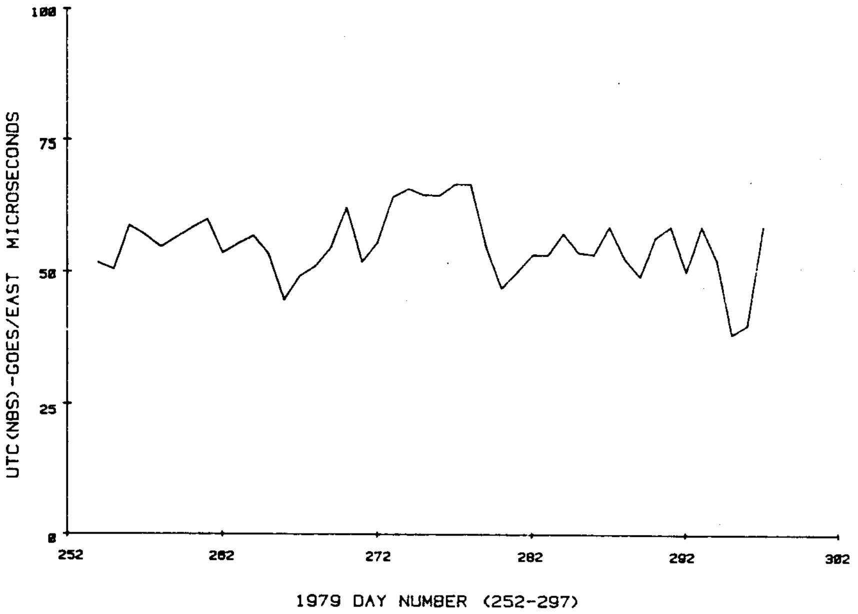


Figure 19. UTC (NBS) – GOES/East: Filtered Daily Averages

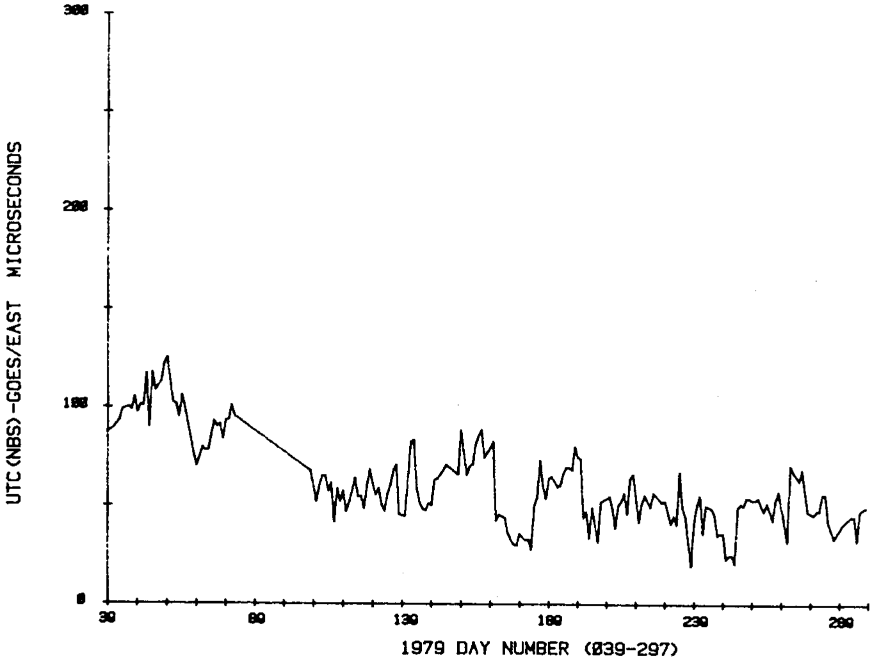


Figure 20. UTC (NBS) – GOES/East: Single Daily Measurements at 0000UT

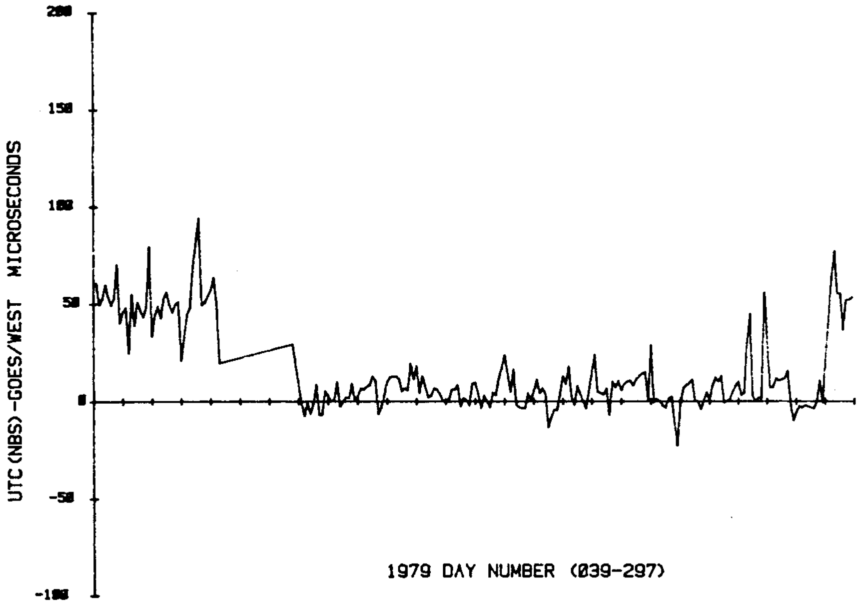


Figure 21. UTC (NBS) - GOES/West: Single Daily Measurements at 0000UT

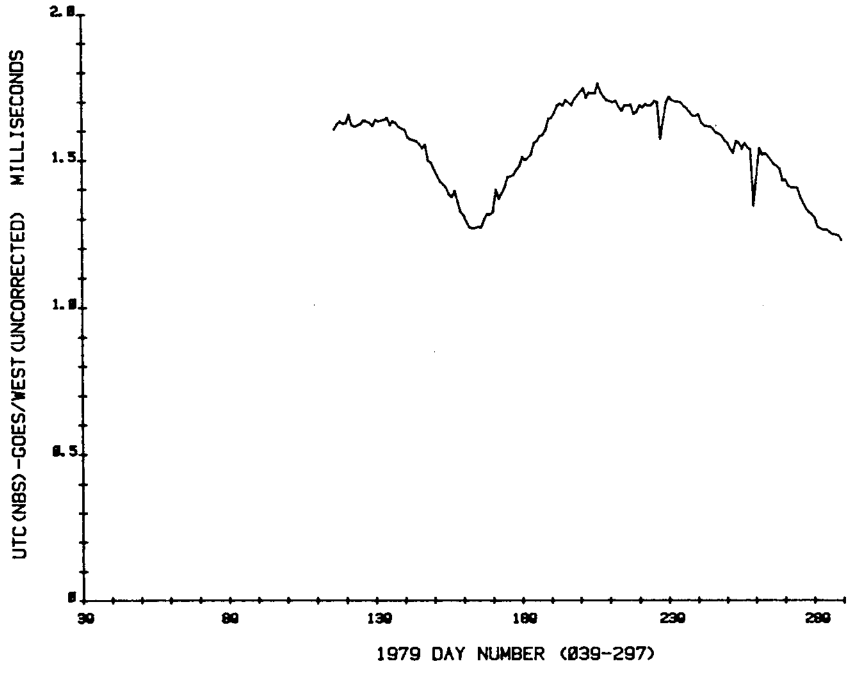


Figure 22. UTC (NBS) - GOES/West (Uncorrected for Path Delay): Single Daily Measurements at 0000UT

GOES TIME CODE SYSTEM IMPROVEMENTS
AT WALLOPS ISLAND, VA

- SATELLITE - POSITION PREDICTIONS UPDATED EACH 4 MINUTES
- TRIPLE - REDUNDANCY TIME - CODE - GENERATION SYSTEM
- HIGHER RESOLUTION POSITION PREDICTIONS
- IMPROVED MONITORING CAPABILITIES
- COMPLETE SYSTEM STATUS AVAILABLE ON DEMAND TO NBS/BOULDER VIA DIAL - UP LINK
- CAPABILITY FOR IMPROVED CONTROL OF CLOCKS

Figure 23

ADVANTAGES APPLICABLE TO BOTH TRANSIT & GOES

- RELIABLE TIME SIGNALS
- PROVIDES 100 μs - OR - BETTER LINK TO USNO & NBS
- EXTENSIVE COVERAGE AREAS
- LONG - TERM CONTINUITY
- AUTOMATIC COMMERCIAL RECEIVERS AVAILABLE
- MINIMAL ANTENNA REQUIREMENTS

SPECIAL ADVANTAGES : TRANSIT

- GLOBAL COVERAGE
- INSENSITIVE TO LAND - MOBILE INTERFERENCE
- CAN PROVIDE <25 μs LINK TO USNO
- FIVE OPERATIONAL SATELLITES

SPECIAL ADVANTAGES : GOES

- CONTINUOUS AVAILABILITY IN COVERAGE AREA
- COMPLETE TIME - OF - YEAR INFORMATION
- RECEIVER COST <$ 5,000
- ± 1 MS OPTION AVAILABLE FOR <$ 2,000

Figure 24