TIME DISTRIBUTION CAPABILITIES OF THE WIDE AREA AUGMENTATION SYSTEM (WAAS)

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Abstract

Because of the role of time as a secondary mission of the Wide Area Augmentation System (WAAS), the FAA has been interested in developing the use of the WAAS for time distribution. An economical, evolutionary approach to the development of the WAAS for time distribution has been pursued. Several groups have been participating in a program to develop a Time Distribution System (TDS). Data presented to date indicate that the WAAS is probably not at the same level as GPS for time distribution. Recent WAAS data indicate that the daily average values of the differences between UTC (USNO) and WAAS Network Time (WNT) range between +20 ns and –25 ns. Recent GPS data from USNO obtained with a single frequency GPS Time Transfer Unit indicate that 2-day average values of the differences between UTC (USNO) and GPS Time range between +6 ns and –15 ns. Because of foreseeable improvements in the not-too-distant future, it seems reasonable to expect that the WAAS will soon exceed the performance of GPS for time distribution. Among these improvements are operational improvements within the WAAS as it matures, and improved orbits for the geostationary satellites as more stations inaugurate satellite-based augmentation system (SBAS) observations for time.

INTRODUCTION

The Wide Area Augmentation System (WAAS) has the secondary mission of time distribution. The time standard reference for the WAAS is UTC (USNO), Coordinated Universal Time as determined by the Master Clock at the U.S. Naval Observatory (USNO) [1]. Time distribution will be accomplished by providing users with the time offset between WAAS Network Time (WNT) and UTC (USNO) in Message Type 12 (MT12). This time offset will be determined at USNO by a Time Distribution System (TDS). USNO will monitor the WAAS geostationary satellites within its view. It will compute the time difference between the epoch time of the start of a WAAS message and the 1 Pulse Per Second (PPS) of the USNO Master Clock, which is the physical realization of UTC (USNO), the time reference for GPS Time. The data collected from each observed WAAS satellite by the TDS receiver are passed to a USNO data acquisition system. The data are then transferred to the WAAS Master Stations (WMS) through an interface between the WAAS and USNO. The WMS uses the WNT/UTC offset to create a Type 12 Message that is then sent to the Geostationary Uplink Station (GUS), which transmits it to the geostationary satellite (GEO). The Type 12 Message provides time users with an accurate source of time referenced to UTC (USNO).

The WAAS promises to be the next generation of global time transfer system. Many features of the WAAS point to this deduction. The geostationary satellites are always in view. This offers the ability for multiple sights to be permanently "phase-locked" together by locking themselves to the common satellite signal. The geostationary satellites allow for the use of a high-gain directional antenna that can provide cleaner signals and is less prone to interference and cycle-slips. The geostationary satellite signals are generated and controlled by a network of cesium-based GPS receivers that provide a reasonably stable reference. In addition, the WAAS message from the geostationary satellites also provides real-time estimates of the delay of the GPS signals as they pass through the ionosphere employing a model based on real-time observations of GPS satellites.

EVOLUTIONARY DEVELOPMENT OF TIME DISTRIBUTION CAPABILITIES

Because of the role of time as a secondary mission of the WAAS, the FAA has been interested in developing the use of the WAAS for time distribution. But as the distribution of time is not a critical navigation function of the WAAS, time distribution has not been a critical element in its early stages. An economical, evolutionary approach to the development of the WAAS for time distribution has been pursued.

THE FAA TECHNICAL ASSISTANCE CONTRACT (TAC) DEVELOPMENT

The FAA GPS Satellite Program Office has been participating in a program to develop the TDS through a program to evaluate the capabilities of the WAAS for Time Transfer. Use of the WAAS for time transfer has been shown to be equal to, or better than, GPS common view in these early stages of development and, because of the already mentioned unique capabilities of a satellite-based augmentation system (SBAS), shows considerable promise for the future [2,3]. The program has enabled the U.S. Naval Observatory to gain experience with the WAAS and help it to prepare for using it as a time distribution system. The Time and Frequency Division of the National Research Council (NRC) of Canada and the National Institute of Standards and Technology (NIST) of the USA have also been participating in this program.

INDEPENDENT COMMERCIAL DEVELOPMENT (NOVATEL)

NovAtel Corp. has also been participating in this program through the corporate development of a WAAS Time Transfer Receiver. The output from this receiver will be in a format [4] that is close to that recommended by the Consultative Committee on Time and Frequency (CCTF) Group on GNSS Time Transfer Standards [CGGTTS]. This Working Group of the International Bureau of Weights and Measures (BIPM) developed this format [5] to promote the uniform exchange of GPS timing data between laboratories. This contribution of NovAtel has been a major contributing factor to the low-cost development of a TDS.

USNO PARTICIPATION

USNO is the source of the reference time for GPS and continually monitors the timing performance of the GPS satellites. USNO provides the offsets of GPS Time from UTC to the GPS Master Control Station (MCS) at Shriever AFB. The USNO data are obtained by the monitoring GPS signals using calibrated P and C/A code receivers. The P code data are communicated to the GPS MCS via a secure telephone line.

As the provider of time for the Department of Defense and to its bases located around the world, USNO is constantly seeking techniques to enhance the ways in which time can be distributed to them. Because of the promise of a Global Navigation Satellite System (GNSS) that can also be used for time distribution as GPS is, USNO is interested in evaluating the potential of an SBAS to GPS as a possible time distribution and transfer system.

CGGTTS FORMAT

Through an *ad hoc* working group called the CGGTTS, the timing community has developed a format to facilitate the exchange of timing data among users interested in high precision time transfer [5]. These users are primarily the major timekeeping laboratories of the world. While not going into the exact details of the format, suffice it to say that there are two columns that contain data relevant to the timekeeping process. They are shown in Table I. The first row is the heading of the columns and the second row indicates what data are contained in that column. "Lab MC" would refer to the master clock of the laboratory making and reporting the measurements. SVN refers to the clock of a particular satellite whose SVN number is also given in the message format. GPS Time would refer to GPS system time.

Table I

REFSV	REFSYS
Lab MC - SVN (for GPS satellite)	Lab MC - GPS Time

Because the message format and data coming from the WAAS satellites are different from that of GPS satellites, the standard format of the CGGTTS timing message had to be modified. It is the modified message, proposed by NovAtel, which is now being scrutinized by the CGGTTS. The proposed modification involves the augmentation of the already mentioned two columns contained in Table I. A new third column of timing information is entitled GAT, where the G stands for geostationary satellite, A stands for the WAAS (for EGNOS, this would be a B), and T stands for Time. This proposed format was made in order to maintain continuity with the prior adopted convention and still take into account the uniqueness of the WAAS navigation message and the manner in which the corrections are applied to the observed (measured) pseudo-range. Table II shows the interpretation that should be given to the data in the proposed revised CGGTTS format when they apply to an SBAS satellite.

Table II

REFSV	REFSYS	GAT
USNO – Geo	USNO – WAAS	USNO – WNT
Measured PSR + Iono + Tropo + Orbit	Slow Clock Corrections	Fast Clock and Orbit Corrections
Geo orbit from MT9	Clock from MT9	MT2 (fast corrections)

In the proposed CGGTTS format, the column labeled REFSV contains the offset of the local clock from the geostationary satellite time of transmission of the signal. It is similar to that for a GPS satellite. Referring to Table I, the first column in the second row of Table II is labeled USNO-Geo. "USNO" is "Lab MC" and "Geo" is "REFSV". However, "Geo" is still not WAAS Network Time (WNT). Application of the Slow Clock Corrections contained in Message Type 9 gets one closer to WNT. The second column is now called USNO-WAAS. "WAAS" is still not WNT, so it is called WAAS Time, something similar to GPS Time. After application of the Fast Corrections contained in Message Type 2 through 5, one finally derives the offset of the local clock from WNT.

PRELIMINARY DATA ANALYSIS LEADING TO MESSAGE TYPE 12 (MT12)

PROCEDURES

The WAAS transmissions have been monitored at USNO using a NovAtel Narrow Band Correlator system. Data are processed daily using a program that produces output data according to the proposed revised CGGTTS format. The result of the processing yields the offset of the USNO Master Clock from WNT. These data will eventually be used for the preparation of a Message Type 12. MT12 will be transmitted by the WAAS geostationary satellites to allow users to obtain the difference of WNT from UTC (USNO). It should be pointed out that the USNO Master Clock (MC) that provides the time for the WAAS Narrow Band Correlator used to make the measurements is a real-time estimate of UTC (USNO).

For this analysis, a recent 40-day span of data was chosen (MJD 52167 to MJD 52207). It is not a continuous data set. In order to facilitate the transfer of data from USNO to another computer over a telephone modem, several subsets of the data were transmitted during times of minimum usage.

CALIBRATION OF RECEIVER

Because the receiver used in this experiment has not been calibrated in the absolute sense, i.e., delays measured through all components of the system, values obtained for USNO MC – GPS Time, obtained with the WAAS receiver, were compared with values obtained with the USNO calibrated receivers. An average value of the differences over 1 day was formed. This average was used as an estimate for the systematic differences between the NovAtel receiver and the USNO receiver used to report GPS data to the GPS Master Control Station.

DISCUSSION

Figure 1 illustrates the data contained in the column labeled REFSV that is produced following the revised CGGTTS format. It shows the difference between the USNO MC and time from the WAAS geostationary satellite after application of corrections for the delays caused by the ionosphere, troposphere, and corrections to the orbit of the geostationary satellite contained in MT9 to the measured pseudo-ranges.

The clock corrections contained in MT9 were next applied to the data and the results are exhibited in Figure 2. One can see a dramatic reduction in the offsets. However, there is still a reasonably large deviation starting around Day 38. This corresponds to a rather large ionospheric disturbance that occurred about 13 October 2001.

Application of the fast corrections contained in MT2-5 shows even further improvement, as shown in Figure 3. While the values for UTC (USNO) - WNT are reduced to levels that are within the WAAS specification, they are still large for time distribution when compared with similar values obtained using GPS. Figure 4 shows daily averages made from the individual points that were contained in Figure 3. There is a spread of about 40 nanoseconds in the values. This large spread is probably due to variations in the operating procedures being implemented during the early phases of WAAS implementation.

Figure 5 shows 2-day averages for the values of UTC (USNO)-GPS System Time. The spread in this case is about 20 nanoseconds.

FUTURE CAPABILITIES

The data presented here are an initial attempt at providing data to be used in the formulation of a MT12 for the WAAS. There are many areas that will see change as experience is gained and as the WAAS matures into an operational system. Some of possible areas for improvement are briefly discussed below.

METHOD AND PROCEDURES FOR DATA TRANSFER TO THE WMS

On an ongoing basis, USNO will be continually reviewing the procedures that have been adopted. They will make provision for changing the frequency of the data supplied and they will also verify the required precision of the numbers that are supplied. On an ongoing basis, USNO will continually review the procedures used to transfer the data from USNO to WMS. USNO would seek to more fully automate the process of data transfer.

IONOSPHERIC CORRECTIONS

In the initial phases, the WAAS transmitted corrections will be used in the reduction process. However, some research effort will go into investigating other possible procedures to be used, such as a C band translator, International GPS Service (IGS) ionospheric maps, etc. to see if there might be a better way to correct for ionospheric delays. This might be necessary for stations located in areas that do not fall within the Service Volume of the WAAS and where ionospheric disturbances may be more significant.

GEO ORBIT IMPROVEMENT

Probably one of the most significant factors contributing to the large scatter in the differences between UTC (USNO) - WNT is a poorly determined orbit for the WAAS geostationary satellites. As more WAAS receivers are deployed throughout the world, the possibility of computing improved orbits for the WAAS geostationary satellites through cooperation with the IGS network will be investigated. On an ongoing basis, USNO will be analyzing the WAAS data to identify the existence of any systematic errors affecting the data and taking the appropriate action to mitigate them.

CONCLUSIONS

Data presented to date indicate that the WAAS is probably not at the same level as GPS for time distribution. Recent WAAS data indicate that the daily average values of the differences between UTC (USNO) and WNT range between +20 ns and –25 ns. Recent GPS data from USNO obtained with a single frequency GPS Time Transfer Unit indicate that 2-day average values of the differences between

UTC (USNO) and GPS Time range between +6 ns and –15 ns. Because of foreseeable improvements, it seems reasonable to expect that the WAAS will soon exceed the performance of GPS for time distribution. Among these improvements are operational upgrades within the WAAS as it matures and improved orbits for the geostationary satellites as more stations inaugurate SBAS observations for time.

REFERENCES

[1] Specification for the Wide Area Augmentation System (WAAS), FAA-E-2892C (Federal Aviation Administration, Washington, D.C.).

[2] P. Fenton, W. Klepczynski, E. Powers and R. Douglas, 2000, *"Time Transfer Using WAAS: An Initial Attempt,"* in Proceedings of the 31st Precise Time and Time Interval (PTTI) Systems and Applications Meeting, 7-9 December 1999, Dana Point, California, USA (U.S. Naval Observatory, Washington, DC), pp. 191-202.

[3] P. Fenton, W. Klepczynski, E. Powers, and R. Douglas, 2000, *"The Use of the Wide Area Augmentation System (WAAS) as Time Transfer System,"* in Proceedings of the ION National Technical Meeting, 26-28 January 2000, Anaheim, California, USA (Institute of Navigation, Alexandria, Virginia), pp. 375-380.

[4] P. Fenton, 2001, *"Proposed format extension of GGTTS Version 2.0 to include WAAS & EGNOS,"* NovAtel Document D03227, Rev. B, 23 March 2001.

[5] D. W. Allan and C. Thomas, 1994, *"Technical Directives for Standardization of GPS Time Receiver Software,"* **Metrologia, 31**, 69-79.

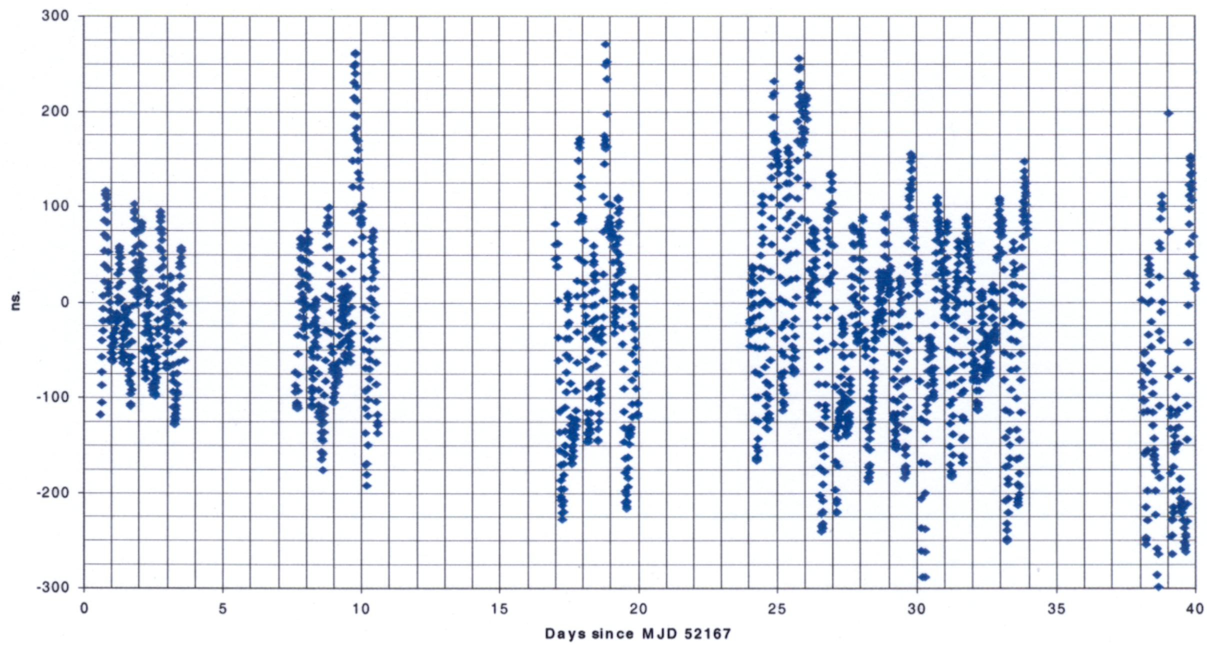

Figure 1- UTC (USNO) - Geo

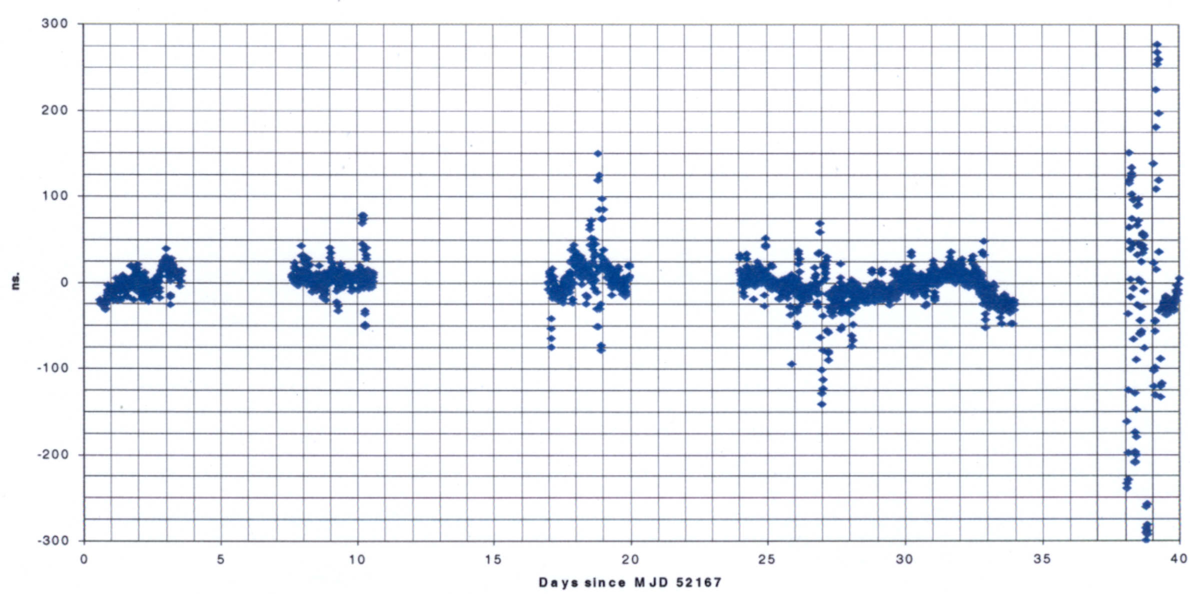

Figure 2 – UTC (USNO) - WAAS

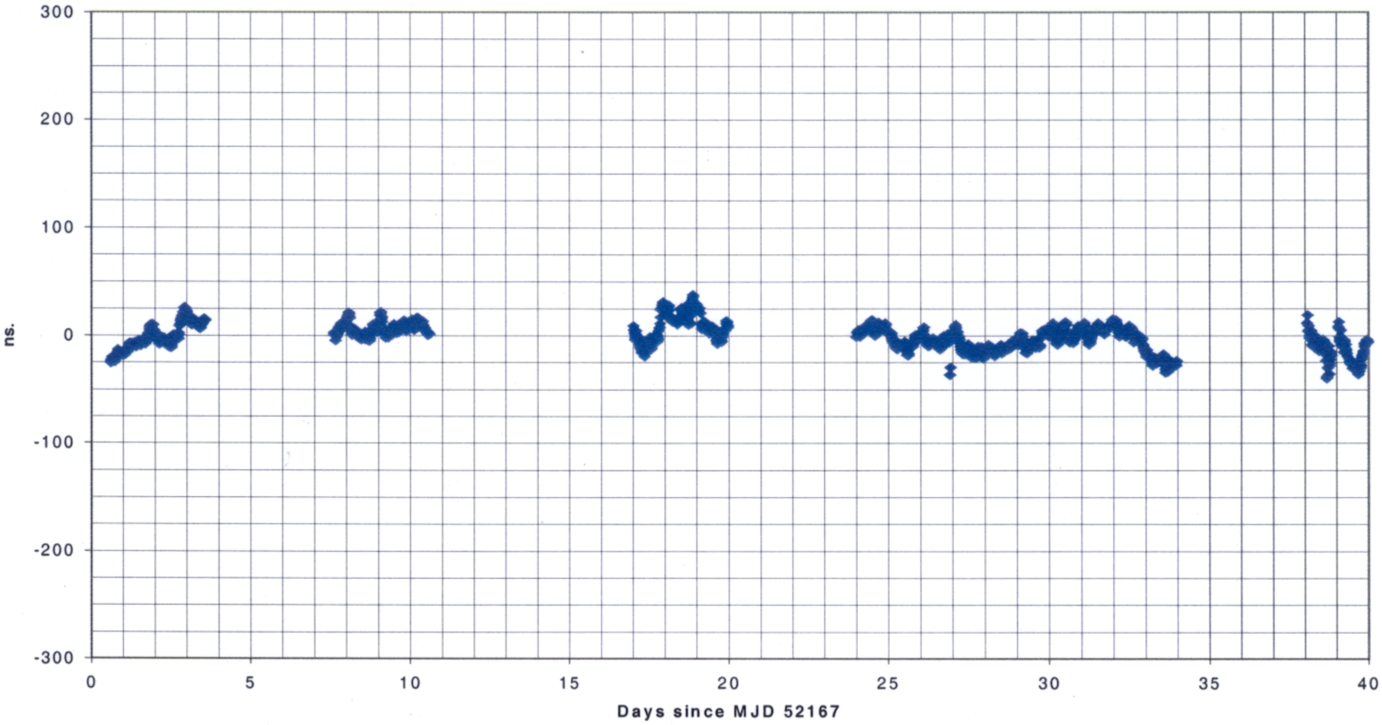

Figure 3 – UTC (USNO) - WNT

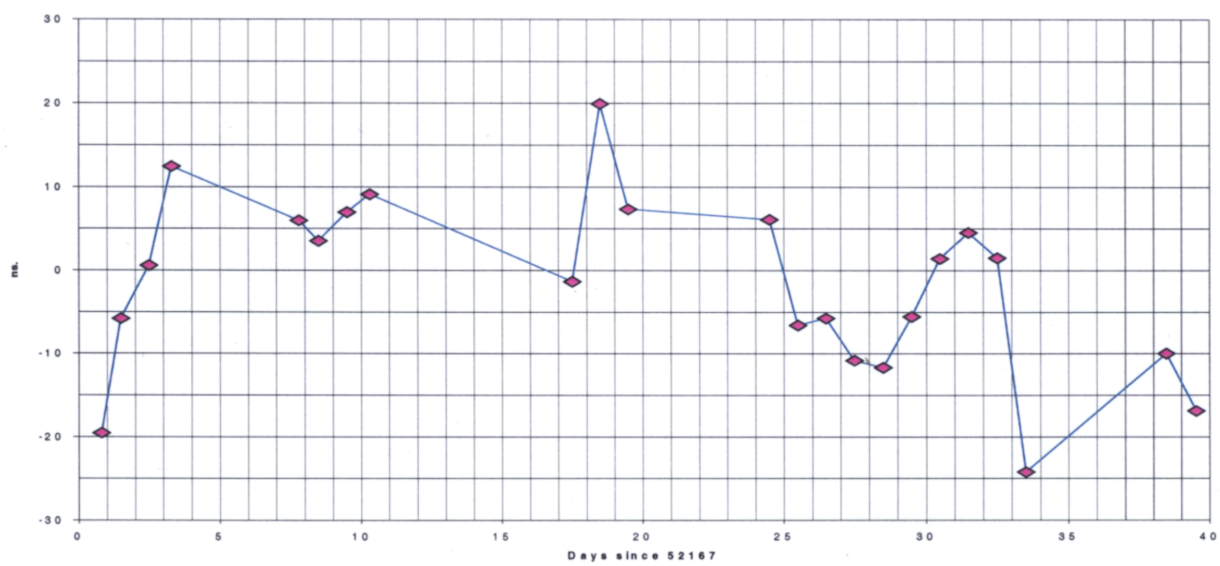

Figure 4 - Daily averages of UTC (USNO)-WNT

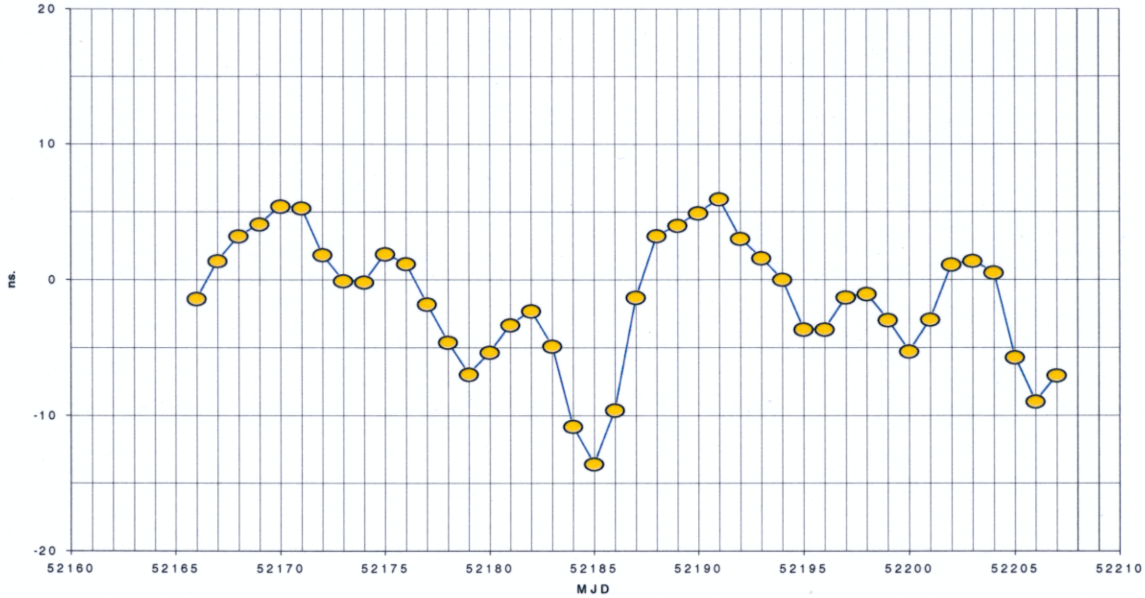

Figure 5 – Two-day averages of UTC (USNO)-GPS Time