COMPARING CODE DATA FROM CARRIER-PHASE GPS RECEIVERS TO OTHER TIME TRANSFER METHODS AT THE U.S. NAVAL OBSERVATORY

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Abstract

There has been considerable interest in recent years concerning the use of pseudorange data from RINEX files to perform time transfer. The U.S. Naval Observatory (USNO) has been actively involved in developing this technology as an alternative time transfer method between its Washington, DC and Colorado Springs, CO sites. This paper compares the time solutions derived from the IGS RINEX files to Two-Way Satellite Time Transfer (TWSTT). It will also show the IGS data, when converted to Common GPS GLONASS Time Transfer Standard (CGGTTS) format, can be useful in detecting problems and act as an additional verification tool when time transfer operations appear to be normal.

INTRODUCTION

The US Naval Observatory (USNO) currently uses Two-Way Satellite Time Transfer (TWSTT) as the primary method to compare the time between its DC and Colorado sites. Precise Positioning Service (PPS) data GPS Common View (GPSCV) is used as a backup method. While TWSTT is clearly a more accurate and precise method, the GPSCV is currently sufficient to act as a backup when TWSTT is not available. However, two problems are involved. First, if the TWSTT and GPSCV methods do not agree, which one is correct and what is the cause of the difference? Second, operational demands for improved accuracy and precision between the two sites cannot currently be met with GPSCV.

While improvements are being pursued in GPSCV processing, this paper concerns work toward a solution to those two problems. Having a third completely independent time transfer method would enable three-cornered-hat comparisons of the time difference between the two locations. And, because the RINEX data converted to CGGTTS format use different equipment than the GPSCV method, some equipment-level diagnostics can be performed if a problem is determined to be in one of the GPS methods of time transfer.

The processes done to get the results presented here were not optimized for the best precision and accuracy possible through postprocessing operations. Rather, the processes were optimized to achieve the best results as close to real time as possible. The results are also presented with an eye toward creating an operational system. Hence, no back-processing was done if a data gap existed. If such missing data were later made available, the processing did not attempt to fill in the gaps.

DATA PROCESSING

The continuous TWSTT data are collected in 5-minute bins, in which the data are linear fitted. These 5-minute points are then linear fitted with midpoint reporting to produce a 24-hour data set and a 1-hour data set, and kept in 5-minute data set form for comparison with the other transfer methods. The 5-minute information is not presented in this paper, as it provided no additional insight beyond that available from the 1-hour results.

The GPS (D) and GPS (G) data values were derived from processing the IGS observation and navigation files through Defraigne's conversion program **[1]** and from a special output of the Jet Propulsion Lab (JPL) GIPSY program respectively. Each data set was linear fitted to produce a 24-hour data set, a 1-hour data set, and, in the case of the GPS (G) data, a 5-minute data set. Again, the 5-minute results are not presented, as they did not show any additional insight into the data characteristics.

COMPARING RESULTS

All of the results presented will be compared to TWSTT results. This is done because, as stated above, TWSTT between the two points of concern (USNO's DC and AMC sites) is taken as "truth." TWSTT is the method used to control the USNO (AMC) clock relative to the USNO (DC) clock. If a common clock was used, then the TWSTT would show the noise of the transfer method and calibration of the individual TWSTT systems. But, because each end of the transfer is relative to a different (and presumably stable) clock, the TWSTT plot shows the relative difference between the clocks and the instability of the transfer method, provided both TWSTT systems are properly calibrated and all errors properly accounted for in the processing.

Figure 1 below shows the TWSTT 24-hour fit results. Outliers such as those below minus 2 nanoseconds were caused by equipment changes, equipment problems, or weather. The AMC clock steering algorithm filters out such outliers.

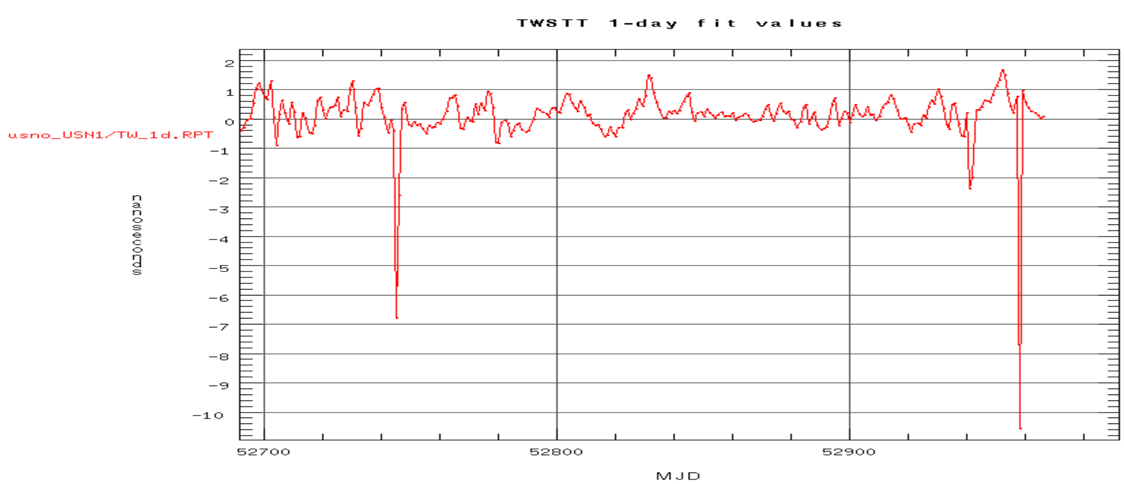

Figure 1. Two-Way Satellite Time Transfer differences between USNO (DC) and USNO (AMC) data that have been linear fitted for 24-hour periods. Data spikes were caused by documented equipment problems.

As stated, the IGS observation and navigation files were processed using Defraigne's conversion program, which produces CGGTTS formatted files with the Bureau International des Poids et Mesures (BIPM) common-view schedule reporting times. Thus, the data can be common-view differenced with other CGGTTS data. Figure 2 below shows the common-view differenced data [GPS (D)] linear fitted over 24-hour periods between DC and AMC. While the results are noisier than those from the TWSTT method, the plot shows that an organization requiring only 10-nanosecond accuracy not in near real time could use this method of processing. The results cannot be obtained in near real time because a day's IGS data files are not available until the next day.

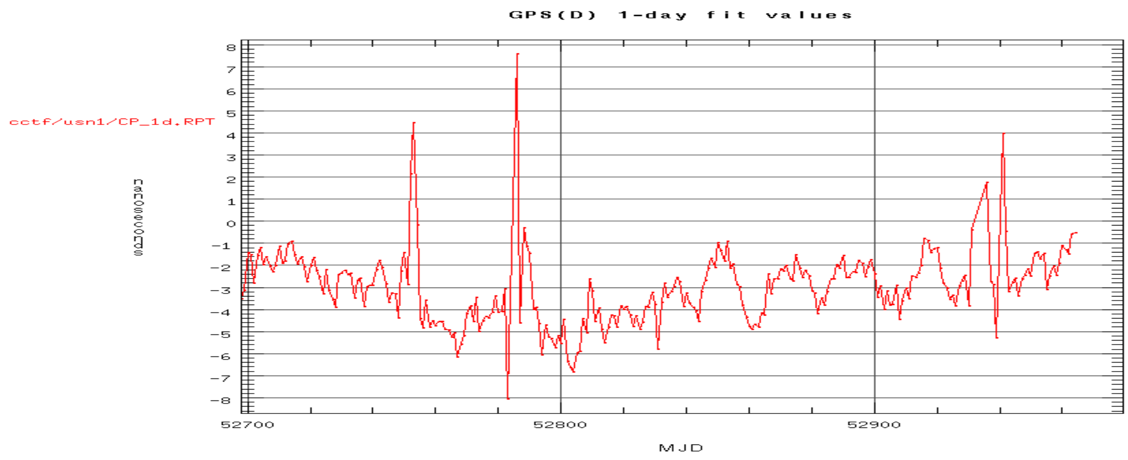

Figure 2. IGS observation and navigational USNO (DC) and USNO (AMC) files processed through Defraigne's program to create CGGTTS formatted time data, common-view differenced, and linear-fitted over 24-hour periods.

The data variation is shown by differencing the GPS (D) results above and the TWSTT results presented earlier (see Figure 3). Comparing these results with the TWSTT transfer results confirms that using Defraigne's conversion program on the IGS data, common-view differencing the points, and linear fitting the results to reduce the effects of bad measurements show again that an organization could use this method of processing.

Another way that the IGS information can be processed is through the use of the GPS Inferred Positioning System Orbit Analysis and SImulation Software (GIPSY/OASIS or GIPSY for short). James Rohde (formerly of USNO) set the software to produce an extra output file containing the time difference between the GIPSY reference clock and the clocks of selected IGS monitoring sites. Differencing these files produces the difference between the two stations, in this case USNO (DC) and USNO (AMC). These time difference values are linear fits themselves and reported every 5 minutes. Figure 4 shows the 24-hour fitting of these difference points [GPS (G)] between USNO (DC) and USNO (AMC).

This provides good information, but until it is compared to the TWSTT method, one cannot tell just how good or useful the processing might be to operations. Figure 5 shows the GIPSY time difference results differenced with the TWSTT data presented earlier.

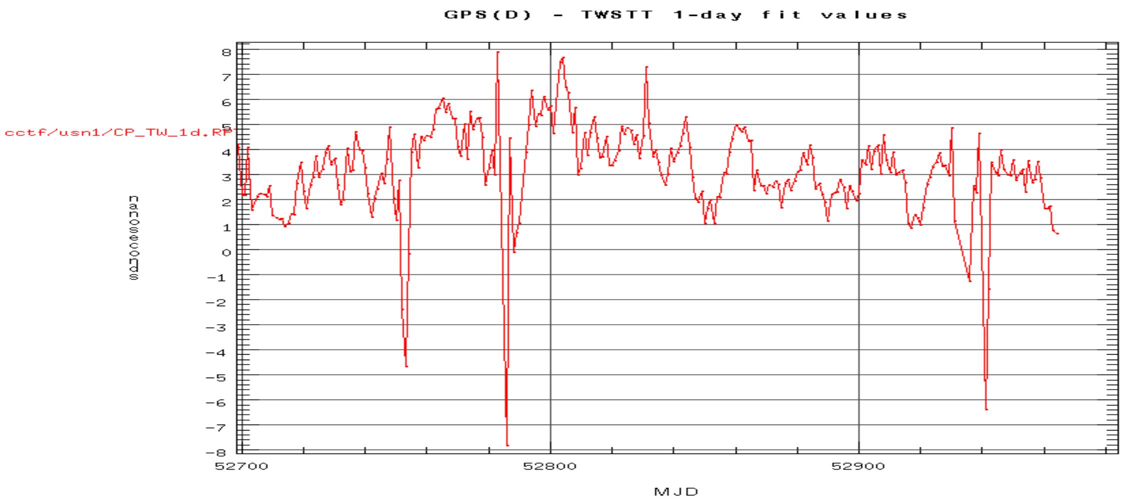

Figure 3. GPS (D) 24-hour linear fit data points differenced from the TWSTT 24-hour linear-fitted data points to show how the two processes results differ.

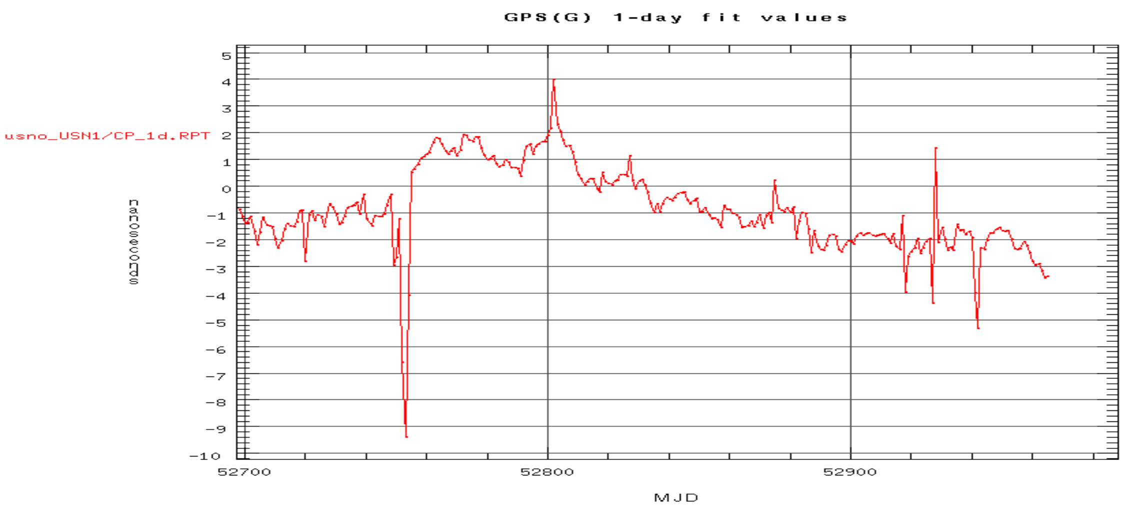

Figure 4. IGS observational and navigational files for USNO (DC) and USNO (AMC) processed using the JPL GIPSY program with special time information output files differenced to get the relative difference between the stations. The results are 24-hour linear fits. The step at 52752 to 52753 is due to an equipment change affecting the USNO (DC) GPS receivers' reference frequency. The processing was not adjusted for the resulting offset.

Next we consider what goes into the 24-hour data points and determine if improvements to the GPS processing using the IGS data can be made. One method is to do the same processing as noted, but have the results posted more often. It was decided that one logical report period would be every hour. (Every 5 minutes was also tried for the GIPSY processing, but no further insight into the data structure was found.)

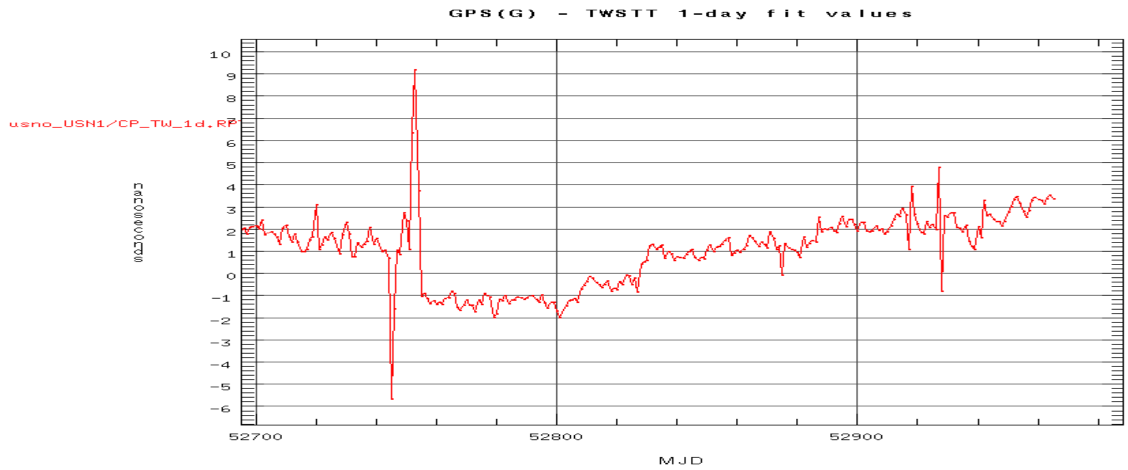

Figure 5. The GPS (G) 24-hour linear fit data points differenced from the TWSTT 24-hour linear-fitted data points to show how the two processes results differ. The step at 52752 to 52753 is due to an equipment change affecting the USNO (DC) GPS receiver's reference frequency. The processing was not adjusted for the resulting offset.

Figure 6 shows the TWSTT results fitted to 1-hour report values. It is fairly obvious from this plot that the 24-hour fitting does do some smoothing of the data, but the effect is not large when compared to the overall variation of the data over a long time period.

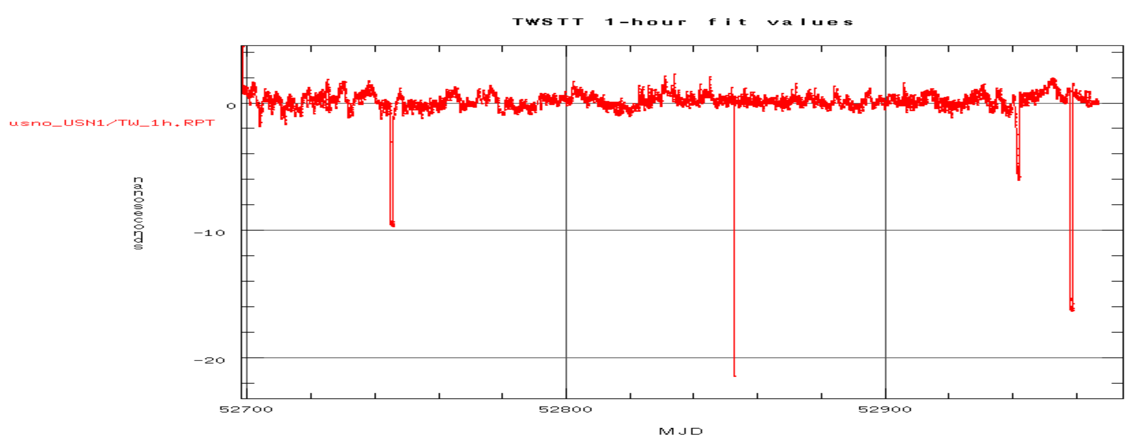

Figure 6. Two-Way Satellite Time Transfer differences between USNO (DC) and USNO (AMC) data that have been linear fitted for 1-hour periods. Data spikes were caused by documented equipment problems.

Doing the same 1-hour fit processing with the Defraigne-converted data, however, does reveal something interesting. Figure 7 shows these 1-hour fit values for the complete data period and Figure 8 shows the last 60 days' values.

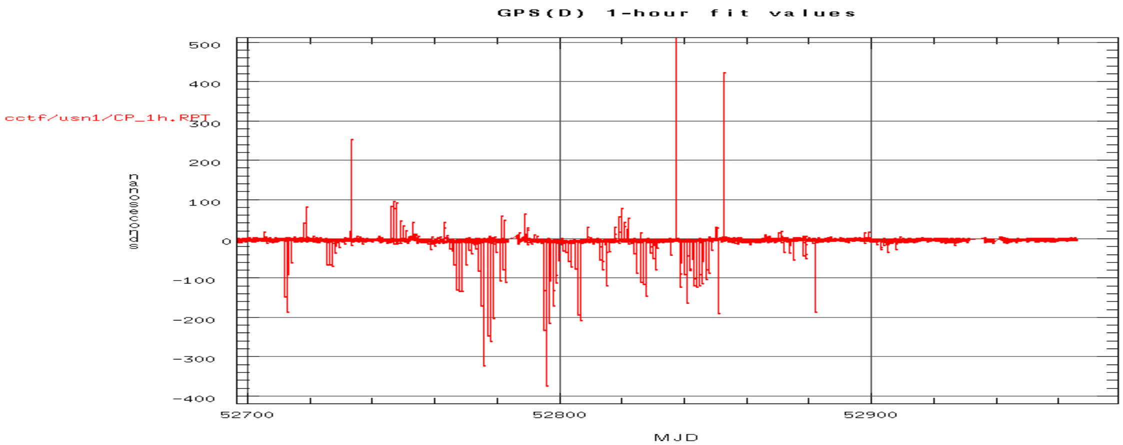

Figure 7. The IGS observational and navigational files for USNO (DC) and USNO (AMC) processed as before, but now linear-fitted over 1-hour periods. The data spikes are due to a program problem that has been fixed. USNO started using the modified program on MJD 52910.

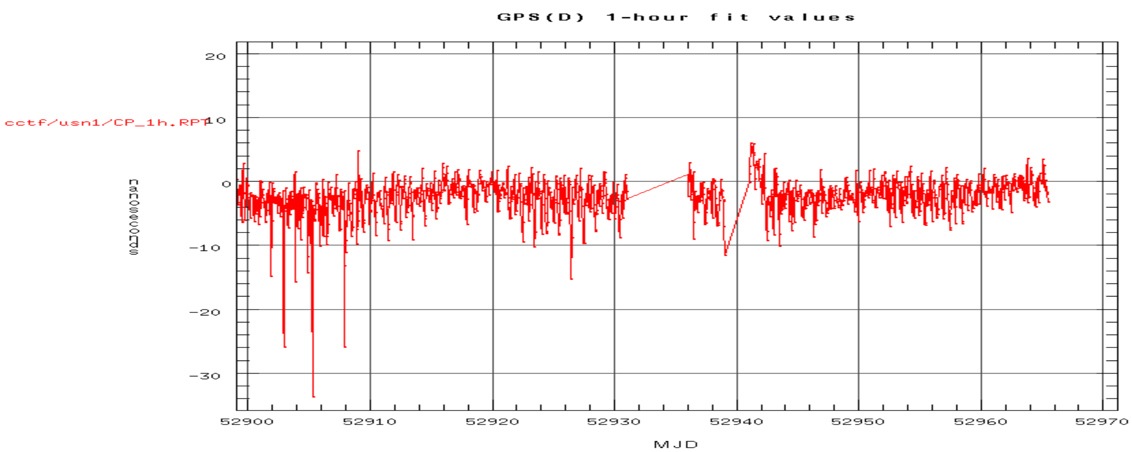

Figure 8. An enlargement of the last 60 days' results showing the improvement using the modified program.

Investigation of the spikes revealed that those outlying points occur mostly at the end of the day, specifically in the last 2 hours of each day. A program change made by Defraigne and implemented by USNO on MJD 52910 corrected the problem.

The other features of note are the two straight-line periods when no results were reported. These events are in part due to the design and objective of the project this data processing supports. As stated in the Introduction, the object of this project is to develop an alternative or check system to the currently operational TWSTT between the two USNO sites. These two no-result periods were caused by the lack of data at the time required. When the data became available, it was after newer data was already available and processed through the system. There is no provision for postprocessing data and filling in missing data points.

Figures 9 and 10 show the differencing of the IGS data processed through Defraigne's conversion program and 1-hour fitted differences from the TWSTT results that were also 1-hour fitted. Again, Figure 10 is an enlargement of the last 60 days when the fix had been applied to the conversion program.

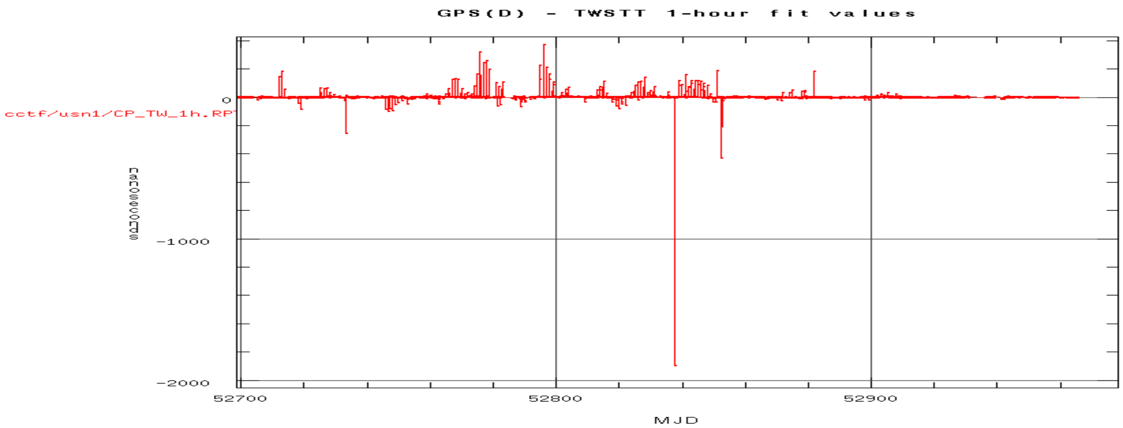

Figure 9. GPS (D) 1-hour linear fit data points differenced from the TWSTT 1-hour linear fitted data points to show how the two processes results differ.

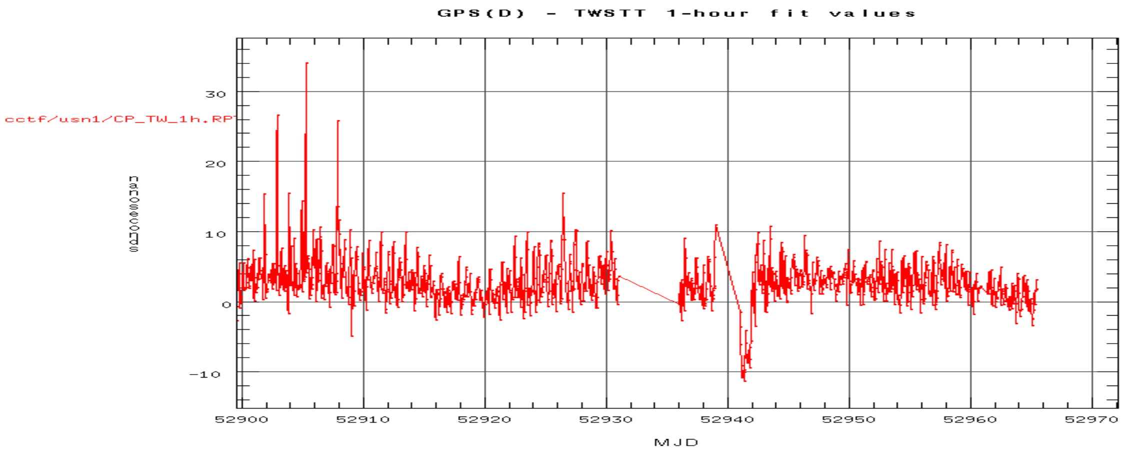

Figure 10. An enlargement of the last 60-days GPS (D) – TWSTT differences to show the improvement because of the program modification.

Lastly, the results of 1-hour fitting the GIPSY processed data [GPS (G)] are presented in Figure 11, which shows that the 24-hour fitting does remove some outlying data points.

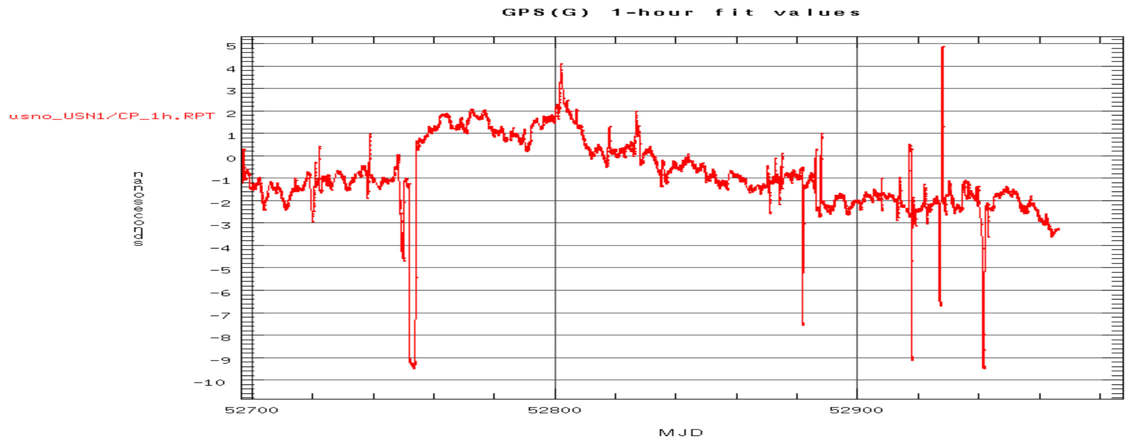

Figure 11. IGS observational and navigational files for USNO (DC) and USNO (AMC) processed using the JPL GIPSY program with special time information output files differenced to get the relative difference between the stations. The results are 1-hour linear fits.

Figure 12 shows these 1-hour differenced fitted points subtracted from the TWSTT results. Thus, this might be considered to be the best real-time (1-hour delay) alternative method to TWSTT between two remotely located sites. It is referred to here as the best because the GIPSY program is a much more computationally intense program than Defraigne's and, to date, the author is unaware of any other methods that compare as well to TWSTT accuracy.

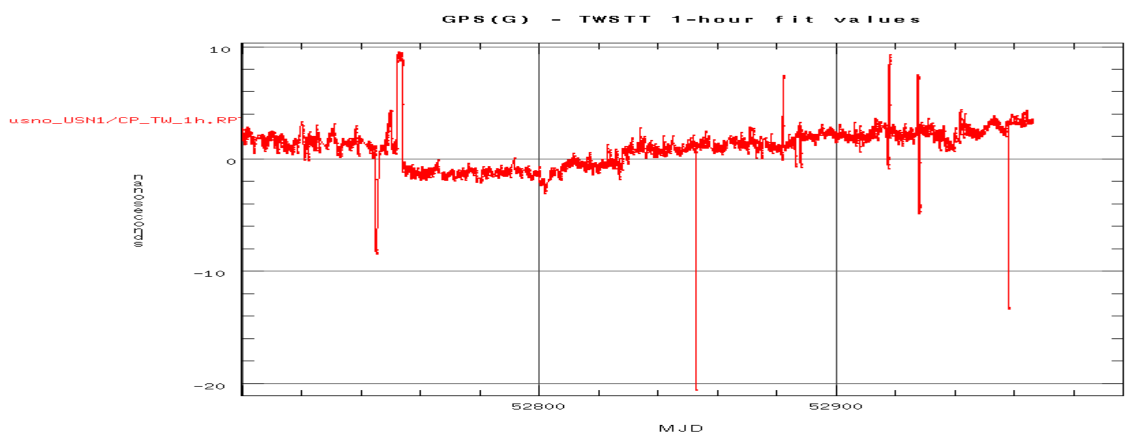

Figure 12. The GPS (G) 24-hour linear fit data points differenced from the TWSTT 24-hour linear-fitted data points to show how the two processes results differ.

USES FOR ALTERNATIVE PROCESSING

The two needs driving the development of this research are for the creation of a tie-breaker between the two common time transfer methods (TWSTT and GPSCV) and for fault detection/confirmation of established time transfer methods. So far, we have only discussed the issue of data accuracy. The reason is that the GPS results presented here were empirically calibrated only once to the TWSTT results. Any differences between the IGS-derived GPS results and TWSTT since the time of calibration are due to changes in equipment. Absolute time transfer comparisons are not presently being done. A better method of calibration will need to be developed for that to occur.

An advantage to using the IGS-derived data for time transfer is that its system equipment is completely different from that used for GPSCV at the sites being studied. While the reference clocks are the same, this separate equipment/data path enables some equipment-level troubleshooting.

An example demonstrating use of IGS-derived data can be found in the recent past. USNO constantly computes 1-day fit value differences between the TWSTT and GPSCV methods. The GPSCV data are 13-minute linear-fitted values from the USNO (DC) and USNO (AMC) PPS receivers. The data are common-view differenced and linear fitted, with midpoint reporting of 24-hour data set. Figure 13 is a plot of the operational file showing this difference data plotted over a recent short period.

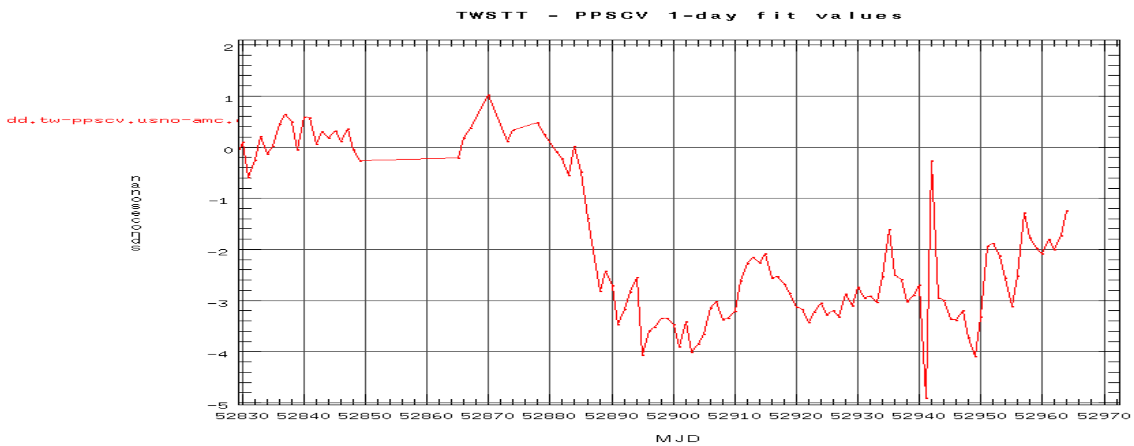

Figure 13. This plot shows the difference between the TWSTT and GPSCV methods between USNO (DC) and USNO (AMC). The GPSCV data uses the PPS receivers at each location common-view differenced. Note the missing data period from MJD 52850 to 52864 and the data step from MJD 52884 to 52886.

Two problems are present in these data. The first concerns the missing data from MJD 52850 to 52864. Which data set is missing (or are both?) and how can operations handle such a problem? The second concerns the source of the result's step between MJDs 52884 and 52886. Which method (TWSTT or GPSCV) caused the change and why?

The first question can be answered by looking at the individual data sets used to make the difference. However, both questions can be answered by performing the data differencing using the IGS-derived results. Skipping many analysis steps and presenting only the final conclusions, Figure 14 shows the GPS (D) – TWSTT (green line), the GPS (G) – TWSTT (blue line), and a complex GPSCV – TWSTT (red line). The GPSCV is complex in that it is the GPS (G) data linear fitted to a 24-hour period minus the GPSCV data from the USNO (AMC) PPS receiver that is itself 24-hour linear fitted. This difference is then subtracted from the TWSTT. While this processing is not the most accurate or precise for time transfer, it is a useful troubleshooting tool.

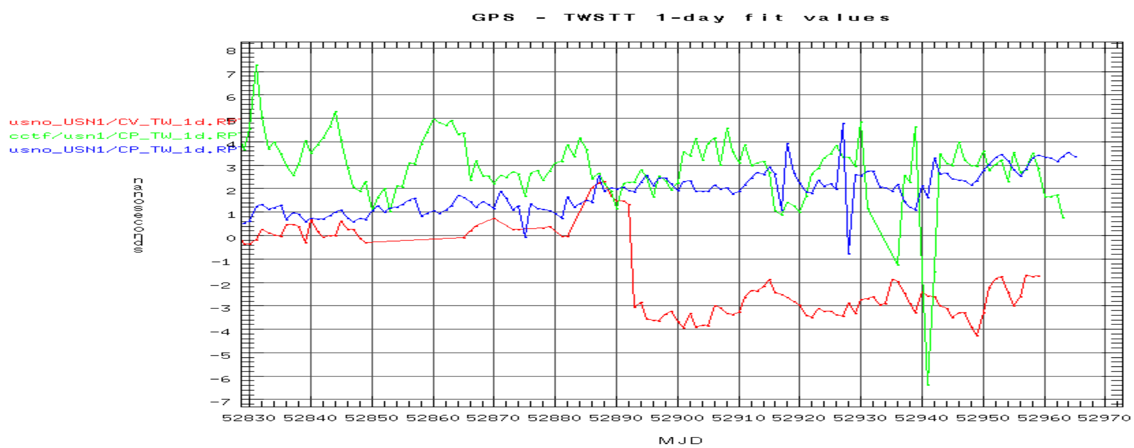

Figure 14. This is a plot showing various time transfer methods compared to TWSTT. The green line represents the IGS data processed using Defraigne's program GPS (D) minus TWSTT. The blue line represents the IGS data processed through the JPL GIPSY program GPS (G) – TWSTT. The red line represents the GPS (G) data from USNO (DC) 24-hour linear-fitted – the IGS data processed through GIPSY 24-hour linear fitted, and those results – TWSTT 24-hour linear-fit data. While the red line results are not of high quality, they do show that the problems are with the USNO (AMC) located PPS receiver.

Both the GPS (D) and GPS (G) data continue through the no-data period. This leads to the conclusion that the no data period in Figure 13 is caused by missing GPSCV data. Also, both IGS-derived GPS results do not show the time transfer step. The outage problem was eventually traced to failure of the PPS receiver at USNO (AMC). Investigation of the data logs showed that the step in the GPSCV results in both Figures 13 and 14 was due to a change in the equipment related to the GPSCV PPS receiver at USNO (AMC).

FURTHER DEVELOPMENT

These results and processes are a start toward a useful operational system because of the short time delay between an event and the processing necessary to detect it. Further development of the processing for a more real-time operation is planned. This can be done either through the use of the hourly IGS-reduced solutions and/or creation of an IGS-independent system to process the data directly from several receivers.

More programming remains to be done, mostly serving to notify users when problems such as those noted above occur. However, further consideration of potential problems and detection methods will be required.

Lastly and most important, a better calibration of the results is required. While using the empirically calibrated results worked in the example presented, that is no assurance that the results are correct. Also, better calibration of the IGS-derived results would enable them to be used as an alternative time transfer method, should other methods be unavailable.

CONCLUSIONS

The IGS navigational and orbital data files transformed into CGGTTS format can provide a useful time transfer method. It must be remembered though that the data will provide only a relative, and not an absolute, means of time transfer. The system calibration issue must be understood and resolved before this method will work as a true alternative to established time transfer methods currently in use at USNO.

Although the IGS-derived data process is only relatively calibrated at present, it is useful as a short-term check of existing time transfer methods. It is possible to process the data in such a way as to determine possible equipment problems. The data results may also be acceptable as a short-term fix to maintain time transfer operations when other methods or equipment are not available due to failures of equipment or data processing.

ACKNOWLEDGMENTS

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REFERENCE

[1] P. Defraigne and G. Petit, 2003, *“Time transfer to TAI using geodetic receivers,”* **Metrologia, 40,** 184-188.