A TRANSATLANTIC GETT TIME TRANSFER EXPERIMENT — LATEST RESULTS

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Abstract

Two Geodetic Time Transfer terminals (GeTT) were installed at the Physikalisch-Technische Bundesanstalt (PTB), Braunschweig, Germany and at the U.S. Naval Observatory (USNO), Washington, DC. The receivers store GPS Carrier Phase (GPS CP) data as well as GPS Pseudorange (GPS PR) observations from both frequencies. This time and frequency transfer experiment over the Atlantic has now been running for more than 2 years. Comparisons of the results from our GPS-based time series with other, independent methods like Common View (CV) and Two-Way Satellite Time and Frequency Transfer (TWSTFT) allows one to study the long-term stability of these techniques.

The analysis of GPS data gives differences between two clocks with a high sampling rate (300 seconds or even less). Therefore, GPS permits the possibility of comparing two clocks nearly continuously over intercontinental distances.

High-quality GPS products, e.g. satellite orbits, are necessary to get good results for the clock estimation. We will compare the time transfer results using the final and the rapid products from the Center for Orbit Determination in Europe (CODE), one of the analysis centers of the International GPS Service (IGS). Using the rapid products the time transfer results are available at approximately 1800 UT the day after the observations. The final solution is usually available 1 week later.

INTRODUCTION

The Astronomical Institute of the University of Berne (AIUB) is operating the Center for Orbit Determination in Europe (CODE) which is one of the analysis centers of the International GPS Service (IGS). CODE routinely analyses a global network of GPS stations to produce improved orbits, Earth orientation parameters, ionosphere models, station coordinates,/usnovelocities, as well as additional results for geodetic and other applications. Since summer 1998 a small subnetwork of stations is processed separately in the framework of a time transfer experiment (see Figure 1). The procedures used in this experiment are focusing on the estimation of receiver clocks using all available code and phase observations. The network has currently produced a time series of time transfer data of more than 2 years.

The network includes two special Geodetic Time Transfer terminals (GeTT) developed at the Swiss Federal Office of Metrology (OFMET) - see [1] for more details. They are located at the Physikalisch-Technische Bundesanstalt, Braunschweig, Germany (PTB; the GPS station is named PTBA) and at the U.S. Naval Observatory, Washington, DC (USNO; the GPS station is named USNB). These terminals are based on the geodetic Ashtech Z-XII receiver. These receivers provide not only the code measurements on both frequencies, but also the carrier phase. For time transfer purposes, the receiver is driven directly by an external clock. All electronic equipment is installed in a thermostatic box together with the receiver itself. This design should minimize the influence of temperature changes in the laboratories on the time transfer results. [2]

ANALYSIS STRATEGY

For the time transfer solution we presently use the Bernese GPS Software, Version 4.3. The general analysis steps are:

1. Double difference solution for the network to get coordinates and troposphere information
2. Data screening of the zero difference files
3. Phase and code observations are taken for the time transfer (network) solution.

A more detailed description is given in [3].

Because of the high correlation between the station height, troposphere estimates, and clock parameters only observations to satellites with an elevation angle of more than 10° are used for the analysis (see [4]). The data received from satellites with low elevations are more noisy and the occurrence of multipath becomes more probable. Therefore, we use an elevation dependent weighting of the data. These basic analysis options have never been changed since the beginning of the transatlantic time transfer experiment.

Since May 2000 (MJD 51670) the routine processing at CODE is running on an new operating system. In the course of the transfer of the processing, some new software options were implemented to improve the time transfer results. The most important changes concerning the time transfer solution are:

- Improved data screening
- A priori values for the receiver clocks can be introduced
- Overlapping sessions are processed to get the possibility for concatenation of the daily solutions.
- Additional time transfer solution based on the CODE rapid products.

RESULTS

Continuous Time Transfer Results

The noise behavior of the pseudorange observations may cause discontinuities between consecutive time transfer solutions. For daily solutions they can reach a magnitude up to 1 ns at the day boundaries (see Figure 2). To get a continuous series of time transfer results, we propose to use all data twice: in a first session (computing batch) from 0:00 UTC until 24:00 UTC of the day and in a second session from 12:00 UTC to 12:00 UTC of the next day. The overlapping periods may be used to estimate and remove the day boundary discontinuities.

After this concatenation of the individual session solutions, the GPS CP time transfer results constitute a nearly continuous series of time differences. The only remaining discontinuities stem from gaps in the data. Figure 3 shows the improvement of the Allan deviations caused by the concatenation of the time transfer results from the individual computing sessions. Because the receiver clock values are not corrected with local measurements, only the difference between the two curves in the diagrams can be interpreted – both curves contain, therefore, in addition the characteristic of the GPS receiver clocks. The improvement is nearly independent from the length of the baseline.

Comparing the concatenated GPS CP time transfer results with the results from TWSTFT, the scatter of the differences becomes smaller than the scatter of the differences between the non-concatenated GPS CP and the TWSTFT results. In both diagrams of Figure 4 a jump at MJD 51714 is visible when the antenna cable at USNB was changed. Another event shows up in the concatenated result only: a small jump in the order of 2 ns at MJD 51764. At this epoch the temperature stabilization electronics of the GeTT in USNB failed – the temperature dropped from 15°C to 4°C (e-mail 19 September 2000 from E. Powers, USNO). The magnitude of the jump can be explained with the calibration results of the temperature dependence of the receiver in [2].

Time Transfer Results Using CODE Rapid Products

Time transfer using GPS CP gives time differences with a high sampling rate and a high precision. Therefore, a large amount of data has to be transfered and analyzed (four measurements each 30 s to usually 6 to 10 satellites). This is done in a postprocessing mode. If the final orbits from one of the IGS analysis centers are used, it takes about 1 week from the measurement until the time transfer results are available. The CODE rapid orbits are available the day after the observation and have nearly the same accuracy as the CODE final orbits [5]. The time transfer solutions based on the CODE rapid orbits should, therefore, have nearly the same quality as those based on the final orbits.

Since May 2000 the time transfer network of Figure 1 is also processed the day after the observations based on the CODE rapid products. The time transfer results are available usually before 18 UTC of the day after the measurement. The overlapping sessions are also computed for rapid product. The processing is running in a completely automatic mode without manual interactions. The results have roughly the same accuracy as the final solution. This is confirmed by the Allan deviations for the rapid as well as for the final time transfer solutions based on 4 months of data (see Figure 5). Independent from the length of the baseline only small differences between the two solutions may be observed – even for the intercontinental baseline USNB→PTBA. This is essentially due to the high quality of the CODE rapid orbits.

COMPARISON WITH OTHER METHODS

From the beginning of this transatlantic time transfer experiment in summer 1998 until May 2000, neither the hardware installation on the sites nor the analysis strategy has been changed. Because the Ashtech receivers do not show any internal clock resets a continuous series of time transfer results between USNB and PTBA is available. This experiment offers, therefore, a good possibility to study the long-term stability of the GPS CP method in comparison with other time transfer methods.

In the Figure 6 the differences between the time transfer results from GPS CP and TWSTFT until September 2000 are shown when the GeTT terminal in Braunschweig was switched off and shipped back to the OFMET for maintaintance and calibration purposes. All differences are smaller than 4 ns – the standard deviation of the difference is 2 ns. Some systematic behavior may be observed in the plots. It can still not be explained, but it is also not significant. A correlation with the outside temperature – the GPS antennas are not temperature controlled – could not be found [6].

The differences between the GPS CP time transfer solution and the Circular T values – see Figure 7 – are of the same order of magnitude, but with an increased scatter. The evident jump of about 9 ns at MJD 51364 is explained by a changed ionosohere modeling in the Circular T computation from this date onwards (see [7]). For the time difference between UTC(USNO) and UTC(PTB), this change of the analysis model resulted in an offset of 9 ns (e-mail 10 January 2000 from G. Petit, BIPM).

A reprocessing of the 2 years from the beginning of the experiment until May 2000 is planned in order to generate a concatenated time transfer solution over the full period of observations. The comparison between the GPS CP and the other methods may then reveal more details on possible systematics in the differences between the results.

CONCLUSIONS

The time transfer using GPS CP is a very powerful method for clock comparisons. A network of about 15 stations in Europe and North America is processed at AIUB every day. Two of the stations are equipped with special GeTT terminals developed at OFMET.

Since May 2000 it is possible to concatenate the daily time transfer solutions to a continuous time series. This time series shows an improvement in the comparison with other time transfer methods such as TWSTFT. Independent from the length of the baseline, an improvement in the Allan deviation can be observed.

Because of the high quality of the rapid orbits from CODE the time transfer results based on the rapid orbits have nearly the same quality than the time transfer solutions based on the final CODE products. The rapid solution is available less than 18 hours after the last observation of a day, whereas the latency for the final solution is nearly 1 week.

Two years of data were collected with the GeTT terminals at USNO and at PTB without any changes in the hardware configuration or in the data analysis parameters. The acquired time transfer series is, therefore, very homogeneous. The differences to the results from TWSTFT have a standard deviation of about 2 ns. The differences to the Circular T values are a slightly more noisy and show a standard deviation of 3 ns.

ACKNOWLEDGMENTS

The authors wish to thank both USNO and PTB for accepting and maintaining the GeTT terminals in their laboratories. We are especially grateful to Dr. D. Matsakis and Dr. P. Hetzel and their co-workers for many helpful discussions and advice.

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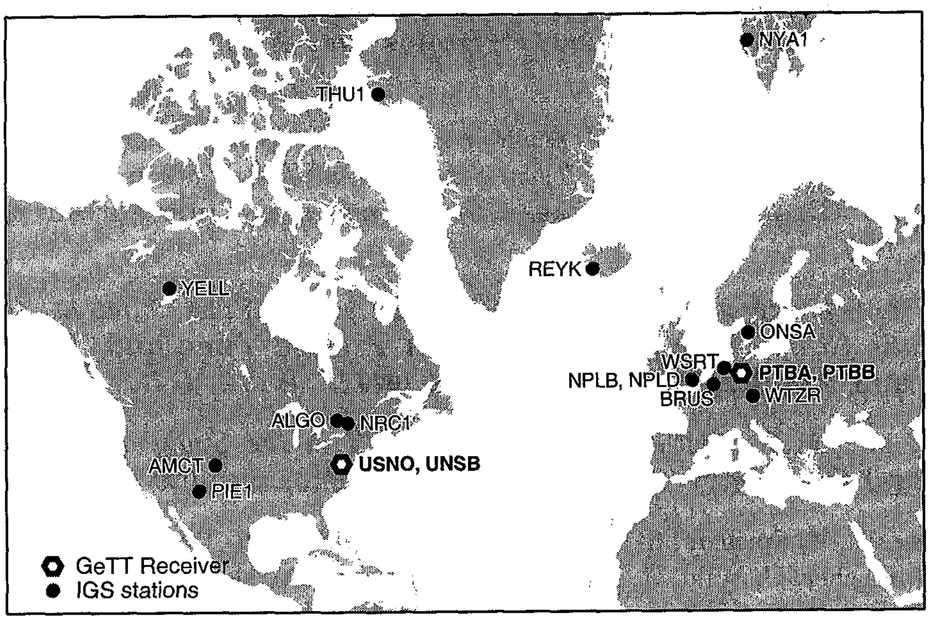
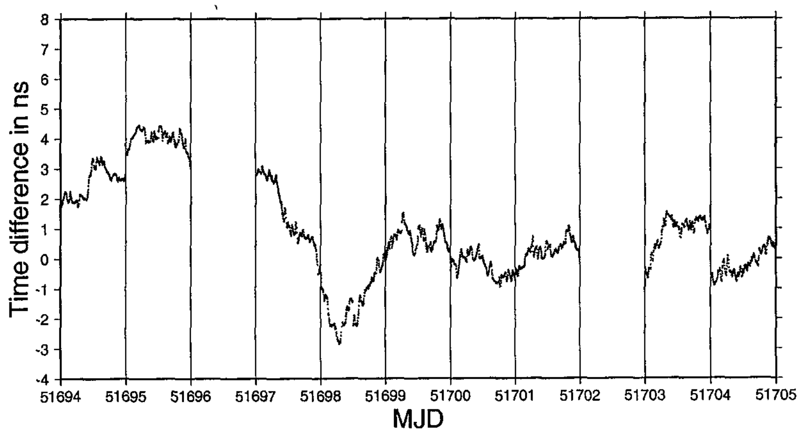
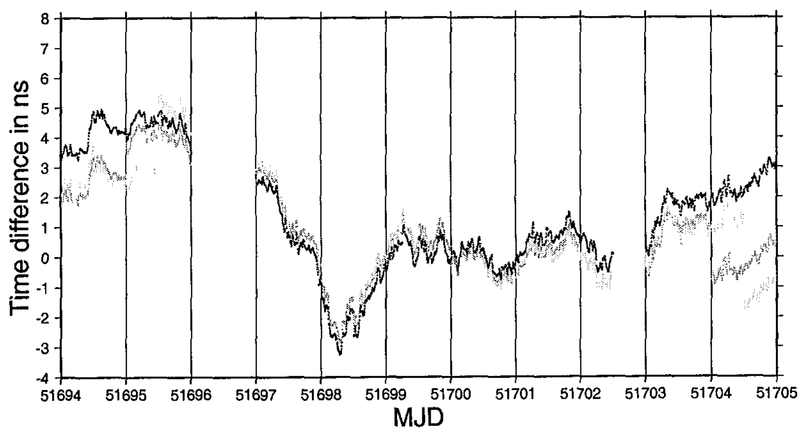


Figure 1: Geographical distribution of the stations in the network for the clock solution.

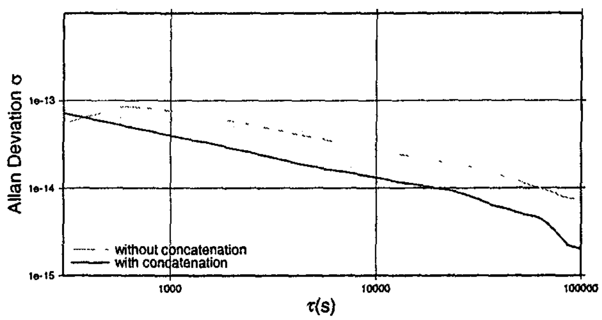


Daily solutions may show discontinuities at the day boundaries

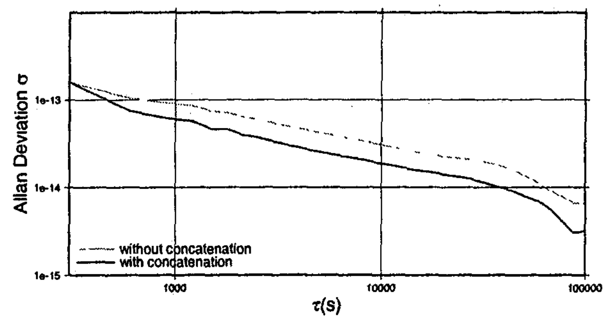


Concatenated time transfer results without discontinuities (in black)

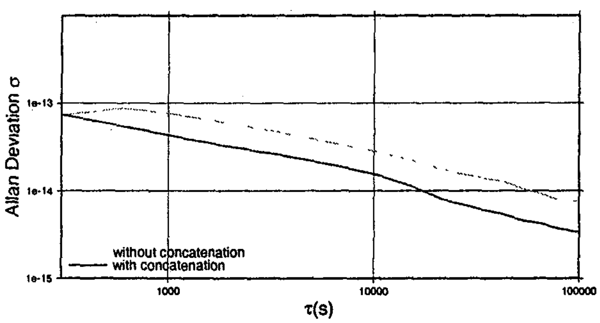
Figure 2: Effect of the concatenation of time transfer results to avoid the discontinuities at the day boundaries for the transatlantic baseline USNB→PTBA – time window MJD: 51694 to 51705. (The values have been shifted by an arbitrary amount.)



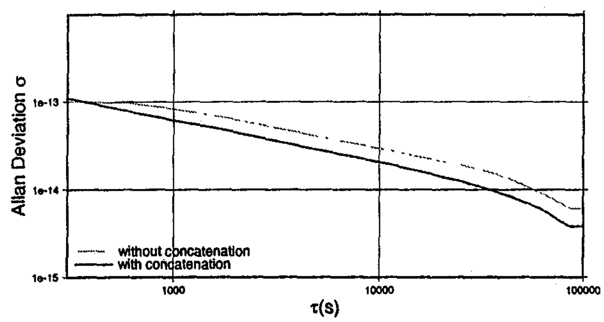
PTBA→PTBB (6 m)



PTBA→NPLB (749.2 km)

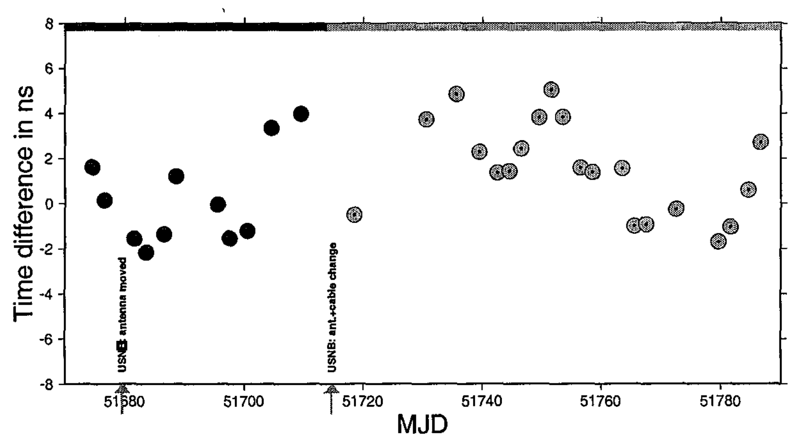


USNB→AMCT (2,360.9 km)

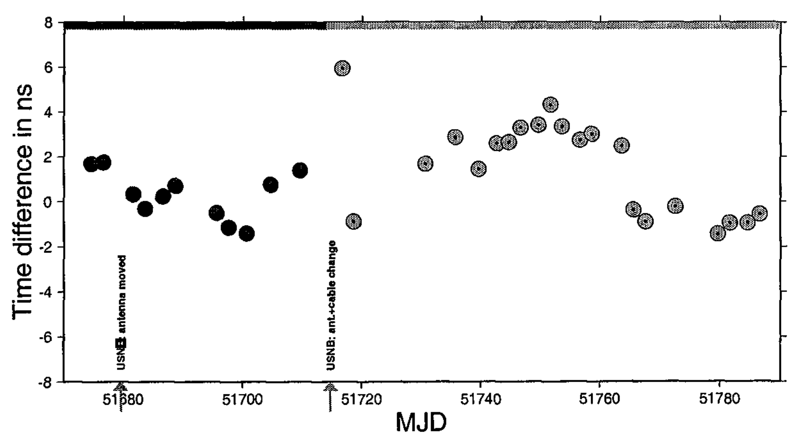


USNB→PTBA (6,274.7 km)

Figure 3: Allan deviations based on four months of time transfer solution using GPS CP for the original and the concatenated results for different baselines in the network.

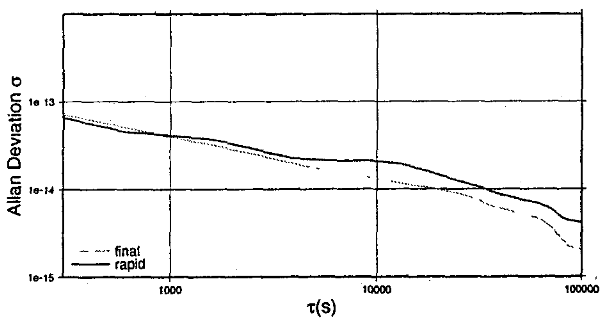


Original GPS CP time transfer solution

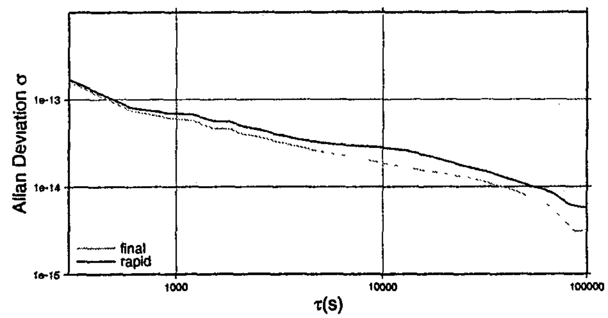


Concatenated GPS CP time transfer solution

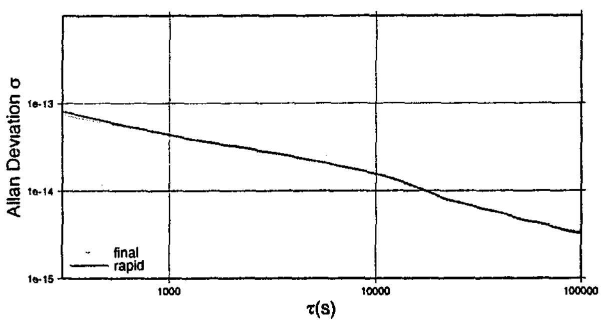
Figure 4: Differences between the time transfer solutions for the transatlantic baseline USNB→PTBA obtained from TWSTFT and the GPS CP method. (The values have been shifted by an arbitrary amount, independent for black and gray symbols.)



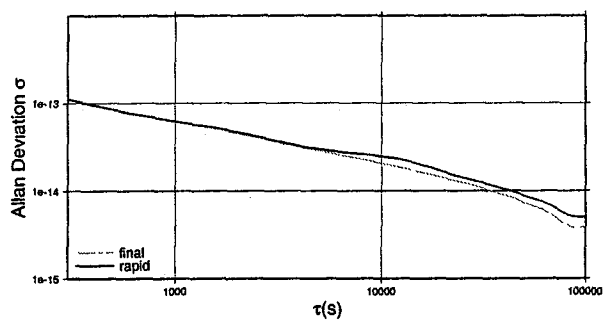
PTBA→PTBB (6 m)



PTBA→NPLB (749.2 km)



USNB→AMCT (2,360.9 km)



USNB→PTBA (6,274.7 km)

Figure 5: Allan deviations based on four months of time transfer solution using GPS CP for the results based on the CODE rapid resp. final orbits for different baselines in the network.

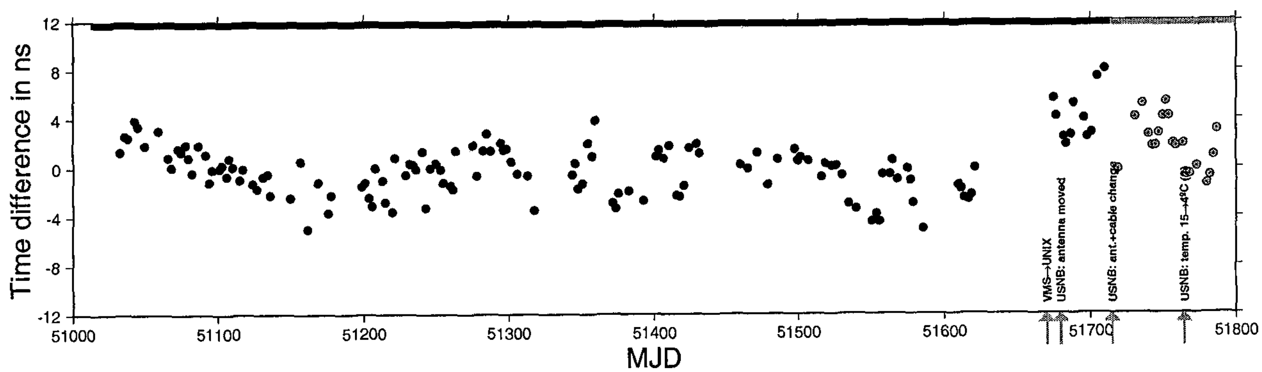


Figure 6: Differences between the time transfer solutions for the transatlantic baseline USNB→PTBA obtained from TWSTFT and the GPS CP method. (The values have been shifted by an arbitrary amount, independent for black and gray symbols.)

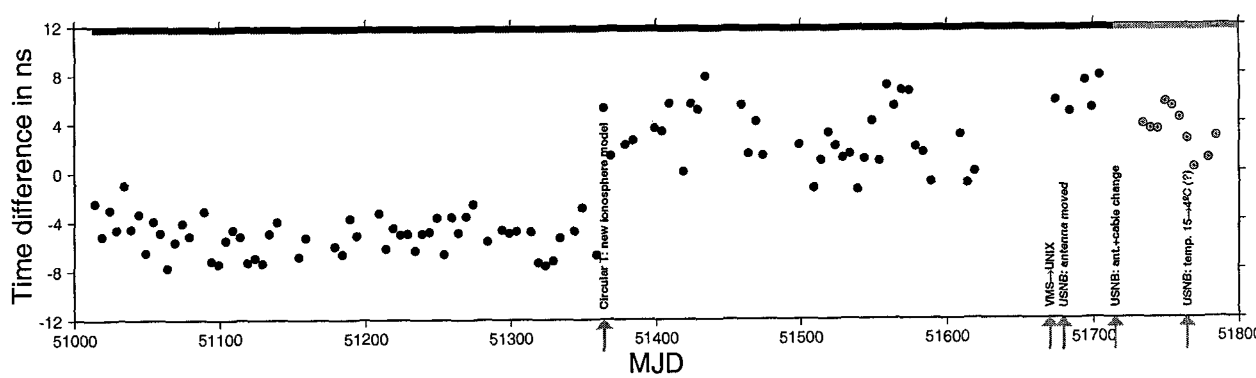


Figure 7: Differences between the time transfer solutions for the transatlantic baseline USNB→PTBA obtained from Circular T and the GPS CP method. (The values have been shifted by an arbitrary amount, independent for black and gray symbols.)

Questions and Answers

DEMETRIOS MATSAKIS (USNO): I wonder if you could just clarify – maybe I misunderstood – earlier in the talk, I thought you had said that concatenating your results made things a little worse when compared to two-way. Is that right? In your conclusions, I thought you said that it made things a little better. This is comparing concatenated results with single-day results.

ROLF DACH: We could see an improvement. The difference was the two-way looked more systematic. The reason for this is one we don't have.

MATSAKIS: Which is better, of the two of them?

DACH: These are the concatenated results. Okay, these are smoother. But in this version you can see, for instance, this nanosecond jump. If we put it together, then the maximum and minimum values are smaller. But if you look at this blue part, then the maximum and minimum results are the same. But it comes from another epoch. The points between the maximum and minimum values look more systematic. We plan to recompute the 2 years of this experiment in a way that we can do a concatenation over the 2 years. Then we can see if we can really find systematic results. We can then look where it comes from, and hopefully it will be smoother over all this time.

But from this, it's hard to say. It became better this hour by 10 points, and the statistic from 10 points is nothing.

MATSAKIS: Okay, smoother is not better. Let me correct what I said.

DACH: Therefore, I would not say that this is better or this is better because in comparison to two-way, we have about 30 comparison points in these 4 months and not more. But I'm very encouraged from the deviation to do this reprocessing.

DAVID HOWE (NIST): Have you ever run a T-Dev statistic on that nice, very long run of data that you had toward the end?

DACH: Yes, we did all the 3-day solutions. Here we have the 1-day solutions. Then we can find, for instance for a 3-day solution, that they are through these 1-day solutions. The jumps between the end and the beginning of the next 3-day solution become smaller. This can be explained if this is a question of the behavior of the pseudo-range noise on this day.

So if you have a 3-day solution, then you have a mean of the pseudo-range noise behavior of these 3 days. If you have a longer time span, the jumps between the solutions become smaller. But 3 days of time transfer doesn't mean three times computing time, but much more.

HOWE: The question was really motivated to see whether you had a statistical summary using the time deviation statistic for that long run of data.

DACH: I have to look at the data again.

HOWE: Yes, underlying both yours and Lisa's talk, obviously, is that the mean is changing as a function of the length of the data set. T-Dev will allow you to interpret some of that, since it's a broad band spectral analysis. That was the reason for my question, and it might be very useful to run those data through that statistic.

DACH: I believe this loss over the different lengths of the computing figures is the same, the noise behavior of the pseudo-range. I hope this is right.