EXAMINING GPS CARRIER-PHASE ANALYSES TO EVALUATE THE ACCURACY OF FREQUENCY TRANSFER USING DATA FROM NIST AND PTB*

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Abstract

In recent work, comparisons were made between the primary frequency standards at the National Institute of Standards and Technology (NIST) and the Physikalisch-Technische Bundesanstalt (PTB) using dual-frequency geodetic receivers that measure the phase of the GPS carrier relative to the local standard. In this work we report on studies of the effects of data analysis lengths, bias vs. non-bias fixing, and troposphere estimation on the final solution. This was done in an effort to determine the effect of data merging routines and atmospheric modeling on these comparisons. Initial results indicate that these effects currently contribute to the error budget at parts in 10^{15}. We also show initial results using two different analytical software packages for the NIST/PTB baseline. This analysis was made in an effort to lower the overall error budget of the comparison technique.

INTRODUCTION

Our previous work has shown that it is possible to compare frequency standards at a few parts in 10^{15} using the GPS carrier phase technique [1]. However, we found that as we merged consecutive data series a frequency change appeared. This prompted us to investigate possible reasons for this rate difference. In this paper we investigate errors that mixing cross-correlating and non-cross-correlating receiver data in our network produces in the analysis. Also, we present the differences between the bias and non-bias fixed solutions, and look at the troposphere estimation to see what effect that has on the network solution. Initial results comparing two different software analysis packages are also presented.

CROSS-CORRELATING AND NON-CROSS-CORRELATING RECEIVER DATA

In our initial comparisons of NIST and PTB frequency standards we used both cross-correlating and non-cross-correlating receiver data in our network analysis. Figure 1 shows the results of making all the receiver data in our network non-cross-correlating. This change was made because of the way different receivers deal with the P1-C1 bias [2]. Over two runs of 3.5 d comparing the hydrogen maser at PTB, called H2(PTB), and UTC(NIST) we see a maximum difference of approximately 750 ps, largely near the start and stop times of the run. The difference in the two solutions is a few parts in 10^{15}.

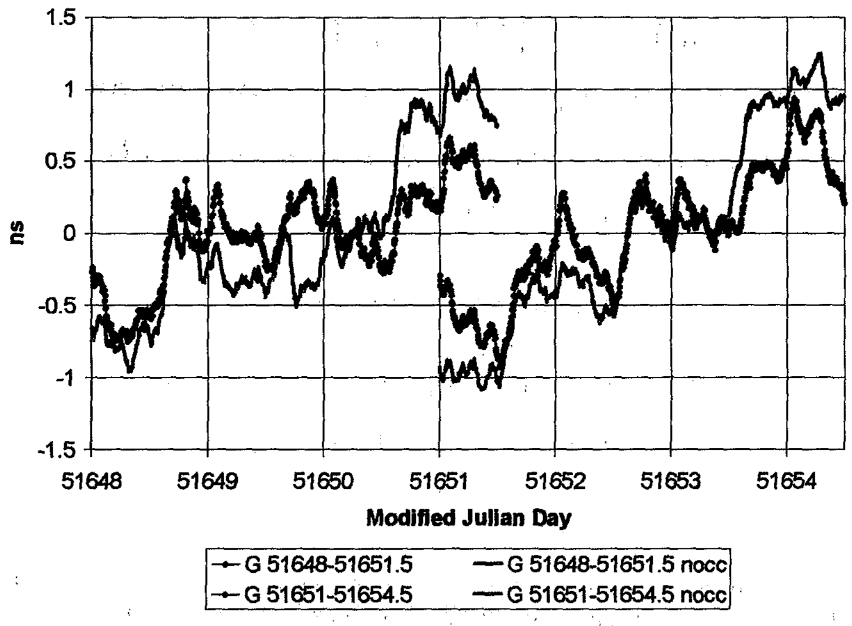


Figure 1: Differences between the H2(PTB)-UTC(NIST) network solution when using cross-correlating and non-cross-correlating receiver data. The black lines indicate a network using both data types. The gray lines represent the completely non-cross-correlating data type analysis. The analysis is performed using the GIPSY software package [3], indicated by the G in the series key.

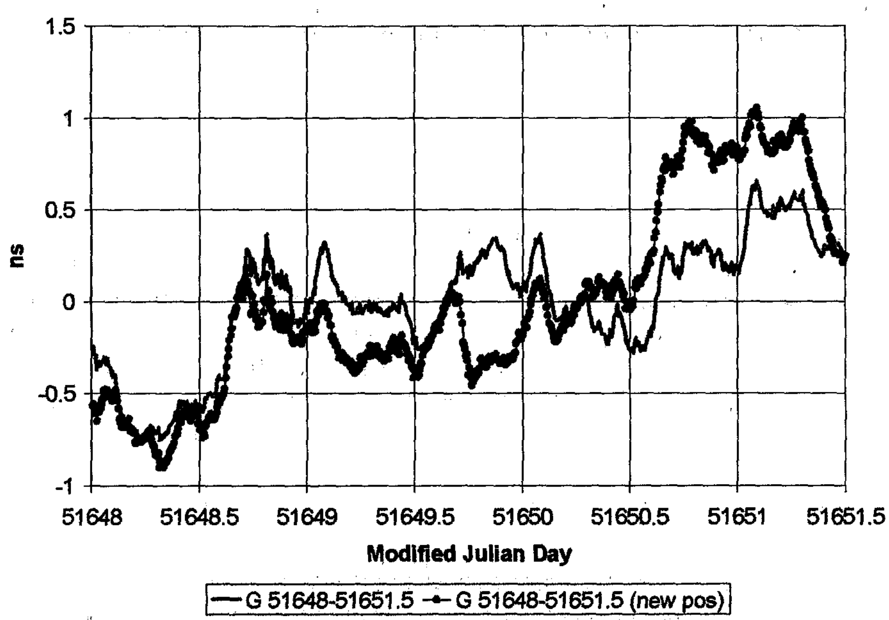


Figure 2: H2(PTB)-UTC(NIST) for solutions of 3.5 d. The black line with dots uses the estimated position of PTB1 entered as the a priori value. The gray line uses the original a priori coordinates for all stations.

Using the all non-cross-correlating data format we also compared solutions when we entered the final estimated coordinates of PTB back in as the a priori values. Figure 2 shows the differences in the solution made by changing the position according to the estimation results. Once again in the short term the structure is consistent, but over the length of the data span there are differences on the order of parts in 10^{15}.

LENGTH OF DATA RUN

To investigate why there is a significant difference in the frequency we looked at the length of data that we processed in each analysis. Figure 3 shows the differences in the solution when we processed each day separately, compared to the solution with the 3.5 d run. In the short term things are similar, but in the long term there are differences of parts in 10^{15}. Figure 4 shows the differences between runs of 1 and 1.5 days. These solutions also have significant frequency differences, even though the data spans differ by only half a day. From our previous work [1], it is also important to note the overlap regions of the data runs and the significantly different slopes there as well. It demonstrates the importance of determining exactly how the data are going to be merged together to form a multi-day solution, and why merging can contribute to a rate offset.

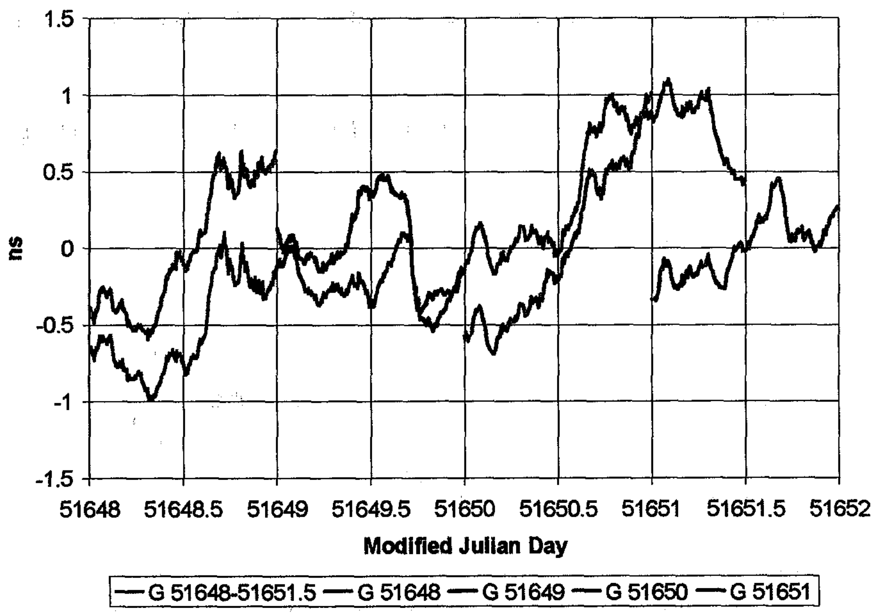


Figure 3: H2(PTB)-UTC(NIST) 1 d vs. 3.5 d run. The black line is the run of 3.5d. The gray lines are the runs of 1d, over the same time period.

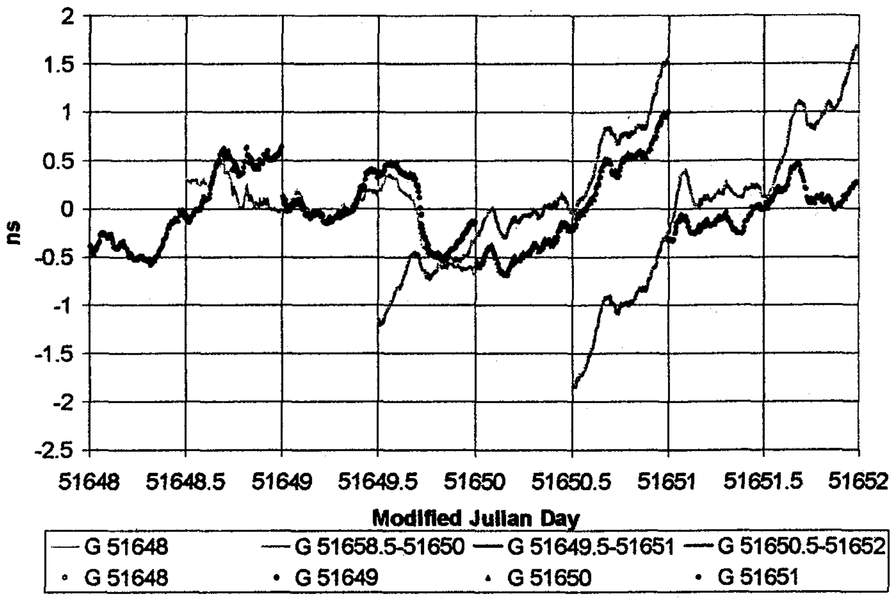


Figure 4: H2(PTB)-UTC(NIST) 1 d vs. 1.5 d runs. The black dots are the runs of 1d. The gray lines are the runs of 1.5 d.

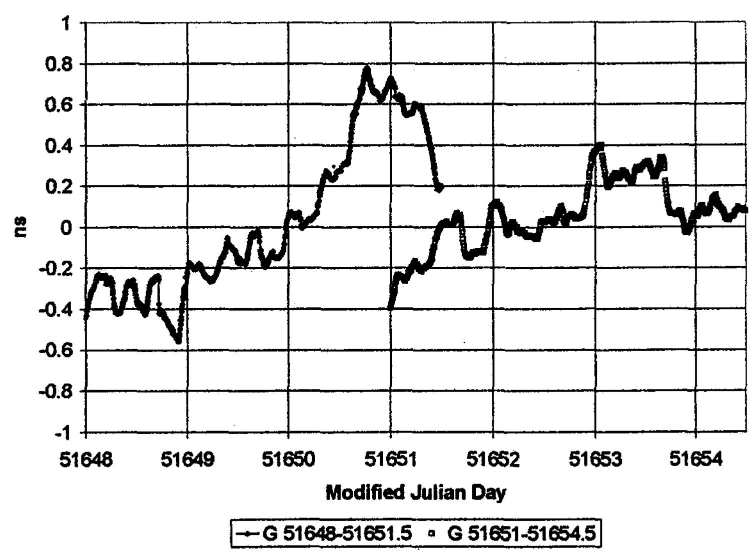
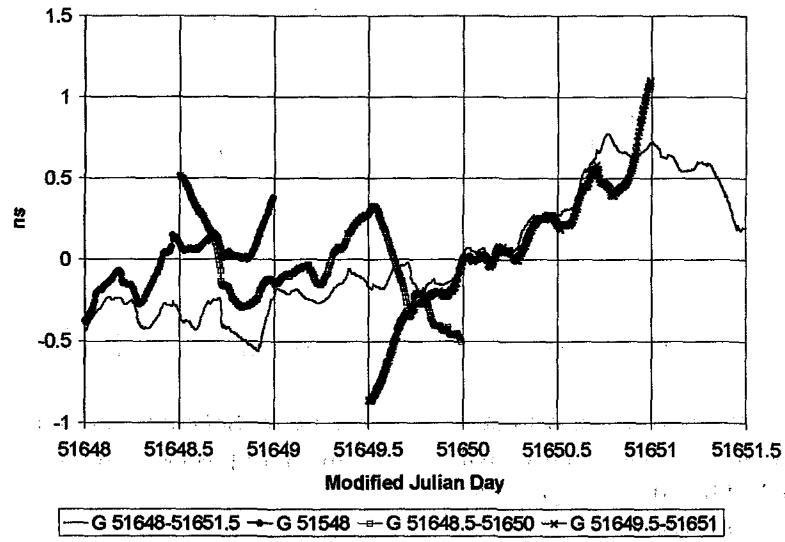


Figure 5: Difference in bias and non-bias fixed solutions runs of 3.5 d.

Bias and Non-Bias Fixing

Our analysis also showed a significant difference in frequency between the bias and non-bias fixed solutions. Bias fixing is when we attempt to resolve the ambiguities, or integer number of cycles in the carrier phase observation, to a more accurately measure the range. If bias fixing is not performed we do not completely determine the unknown number of internal cycle slips, or loss of lock conditions, in the receiver. Figures 5–7 show the differences in the bias and non-bias fixed cases for the runs of 3.5 d, 1.5 d, and 1 d. There are significant differences between the lengths of the various data runs and the ways in which the ambiguities are being resolved. The solutions differ by parts in 10^{15}.



gure 6: Difference in bias and non-bias fixed solutions runs of 1.5 d and 3.5 d.

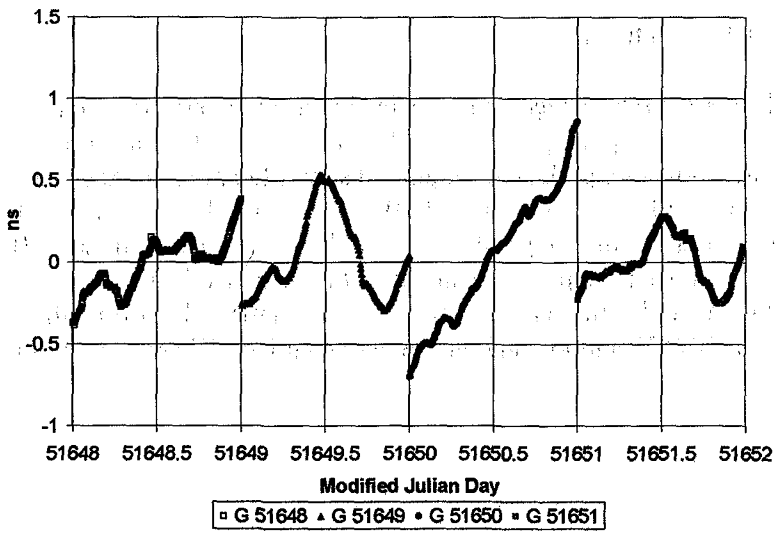


Figure 7: Difference in bias and non-bias fixed solutions for runs of 1 d.

Troposphere Estimation

We also looked at the troposphere estimation parameters to determine their effects. We found them to be less than a part in 10^{15} over the 3.5 d interval and the shorter 1.5 d intervals, as shown in Figures 8 and 9. They do not appear to be the cause of the frequency change of the final solution.

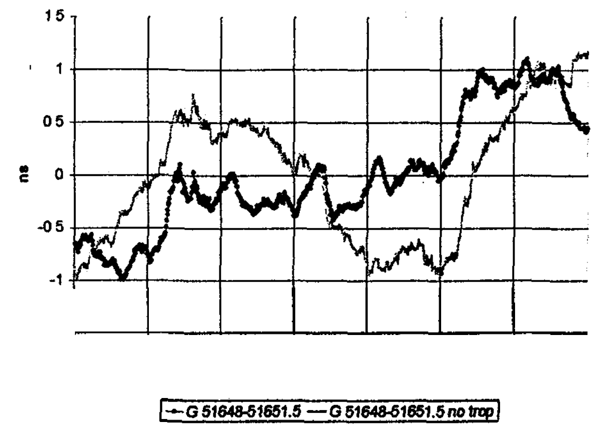


Figure 8: Solutions for the run of 3.5 d with and without troposphere estimation. The black dotted line is with troposphere estimation. The gray line is without troposphere estimation.

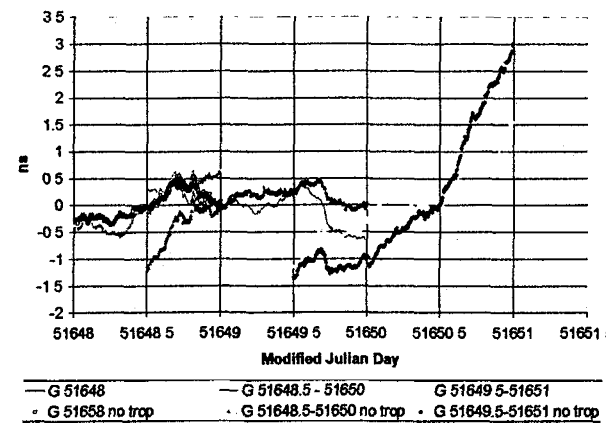


Figure 9: Solutions for runs of 1.5 d with and without troposphere estimation.

Different Software Solutions

In order to determine whether the rate change might be due to our processing technique we also explored the use of a different analytical software package, Bernese [4]. We performed the analysis on a daily basis using both the GIPSY and Bernese software packages. Figure 10 shows the differences between the two solutions for H2(PTB)-UTC(NIST) for both analyses. Days 51648, 51649, and 51651 all show differences of parts in 10^{15}, with the biggest differences at the endpoints of the analysis. On the third day, 51650, we found that the solutions had almost the opposite slopes. We are not yet clear why this is the case for this day, but first indications are that it might be in the differences in ambiguity resolution. Figure 11 shows the differences in the bias and non-bias fixed GIPSY solution and the Bernese solution. We are continuing to investigate the differences in the solutions.

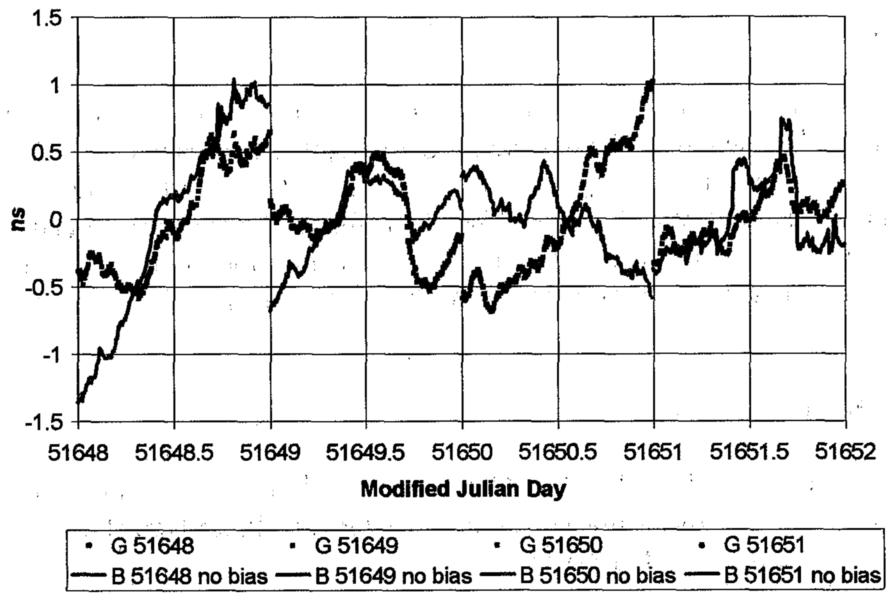


Figure 10: Different Software Solutions. Bias fixed GIPSY solutions are indicated by the black dots and Bernese solutions by the gray lines. Each is processed in daily batches. In the key the GIPSY solutions are indicated by G, and the Bernese solutions by B.

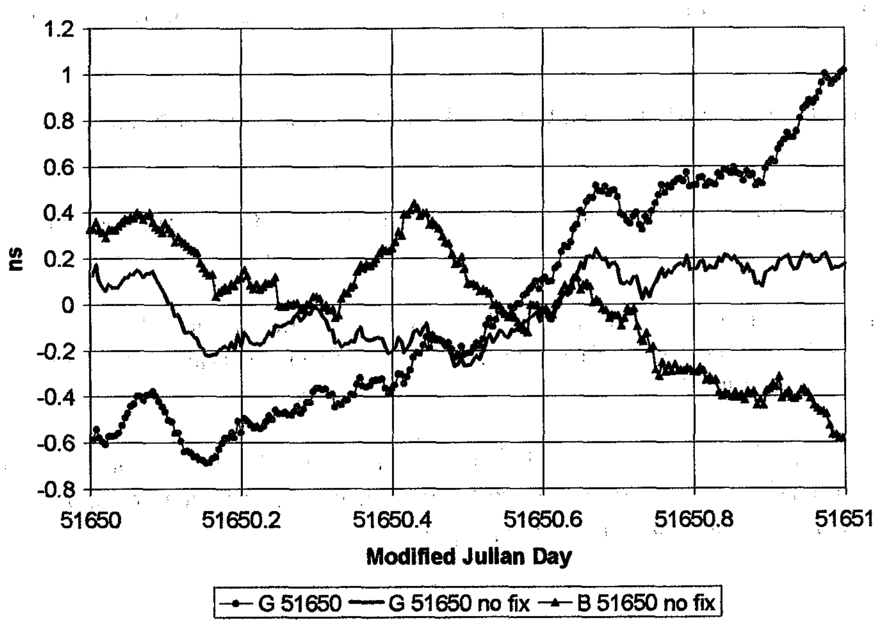


Figure 11: Different Software Solutions for Modified Julian Day 51650. The gray lines, with and without markers, indicate GIPSY solutions. The Bernese solution is the black line with triangle markers.

CONCLUSIONS

We have shown that some of the frequency differences are dependent on the length of the data series that is processed. The longer the data series the smoother the results. We have also shown that differences made by the bias fixing process significantly affect on the rate regardless of the length of the data series, and that the rate offset depends on the analysis procedure used. We have determined that the troposphere estimation is not a significant source of error. We plan to continue our investigation of the reason for these frequency changes in hopes of reducing the uncertainty to less than parts in 10^{15}.

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REFERENCES

[1] L. Nelson, J. Levine, and P. Hetzel 2000, *"Comparing primary frequency standards at NIST and PTB,"* Proceedings of the 2000 IEEE/EIA International Frequency Control Symposium and Exhibition, 7-9 June 2000, Kansas City, Missouri, USA, pp. 622-628.

[2] J. Ray (EO Dept., U.S. Naval Observatory), IGSMAIL-2744: new pseudorange bias convention, personal communication.

[3] GIPSY-OASIS II software, NASA Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA.

[4] G. Beutler, E. Brockmann, R. Dach, P. Fridez, W. Gurtner, U. Hugentobler, J. Johnson, L. Mervart, M. Rothacher, S. Schaer, T. Springer, R. Weber, Bernese GPS Software, version 4.2, Astronomical Institute, University of Berne, August 2000.

Questions and Answers

DEMETRIOS MATSAKIS (USNO): A few months ago, I heard a paper, and I think you did too, by Rolf Dach. I know he's talking next and will probably be repeating some things. I might be stealing some of his fire. He found there was a correlation between the position error and ambiguity-fixing that could result in funny things like you are seeing there. Have you looked at the actual values for the parameters you're getting?

LISA NELSON: Actually, because of such initial data, I haven't had a chance to look at all that yet. But yes, I am aware of what he's worked on. I just haven't gone through to check all this recent stuff out with that.

THOMAS CLARK (NASA Goddard Space Flight Center): I presume that this is all dual-frequency data. Did you assume the receiver offset between L-1 and L-2 was constant between these days or was that a solved-for parameter?

NELSON: I'm not sure about that; I would have to look.