EVALUATION OF A GPS RECEIVER FOR CODE AND CARRIER-PHASE TIME AND FREQUENCY TRANSFER

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Abstract

We evaluate a dual-frequency, multi-channel GPS receiver for time and frequency transfer applications. The receiver is able to lock its internal clock to an external reference frequency and synchronize the receiver clock to an external timing signal. The receiver is capable of measuring GPS L1 C/A code, L1P, and L2P semi-codeless signals. The receiver also makes L1 and L2 frequency measurements. We report the receiver performance for code-based and carrier-phase time and frequency comparisons.

I. INTRODUCTION

Global Positioning System (GPS) signals are routinely utilized for time and frequency transfer applications at the National Institute of Standards and Technology (NIST). These applications compare and synchronize remote clocks to the UTC (NIST) time scale. Several types of receivers are operated, and several GPS time transfer techniques are utilized, including: code-based common-view **[1]**, ionosphere-free code (P3) common-view **[2]**, and carrier-phase **[3]**. NIST also employs GPS time transfer as the backup link to Two Way Satellite Time and Frequency Transfer (TWSTFT) **[4]** when contributing clock data to International Atomic Time (TAI) and Coordinated Universal Time (UTC). When a new GPS receiver becomes available to the NIST Time and Frequency division, we examine its performance and suitability for existing and future time and frequency transfer applications.

This paper reports results from our evaluation of a Javad TRE-G2T* receiver, named *NISJ*. *NISJ* is a dual-frequency, multichannel receiver, configured to receive only GPS signals. *NISJ* can lock its internal oscillator to an external 5 MHz or 10 MHz reference frequency and can synchronize the internal oscillator to an external 1 pulse per second (pps) signal. In this way, the receiver can measure the difference between the local reference clock and GPS time (REF - GPST). *NISJ* makes the REF - GPST measurements by use of the L1 C/A code, semi-codeless L1P and L2P signals, and the L1 and L2 carrier frequencies. Data from *NISJ* can be used for code-based and carrier-phase time and frequency comparisons.

We evaluated *NISJ* by comparing its measurements to measurements of the receivers named *NIST* and *NISA*. *NIST* is a Novatel ProPak G2 OEM4* receiver that serves as the primary time transfer receiver at NIST. *NISA* is an Ashtech Z12T* receiver operated at NIST in support of a Jet Propulsion Laboratory

(JPL) service. Each receiver connects to its own antenna via an antenna cable with a low temperature coefficient. *NISJ* and *NIST* each use a NovAtel GPS-702-GG* antenna. *NISA* uses an Ashtech* choke-ring antenna. Each receiver's antenna coordinates are accurate to within 20 cm. All three receivers use 5 MHz and 1 pps signals from UTC (NIST) as their reference clock.

We utilized a common-clock scheme while performing the evaluation. We obtained the relative instability between two receivers by differencing the REF – GPST data collected from both receivers. This technique works because both the reference clock and the GPS time in the two data sets drop out. We examine *NISJ*'s instability for the P3 common-view and for carrier-phase comparison. The carrier-phase comparison data for *NISA*, *NISJ*, and *NIST* receivers are produced by the TAIPPP (TAI Precise Point Positioning) analysis **[5]**. In Section II, we show the estimate of *NISJ*'s temperature coefficient for the P3 common-view. Sections III and IV contain the results of for the P3 common-view and for carrier-phase comparisons. Section V summarizes the *NISJ* evaluation results.

II. TEMPERATURE EFFECT ON P3 COMMON-VIEW

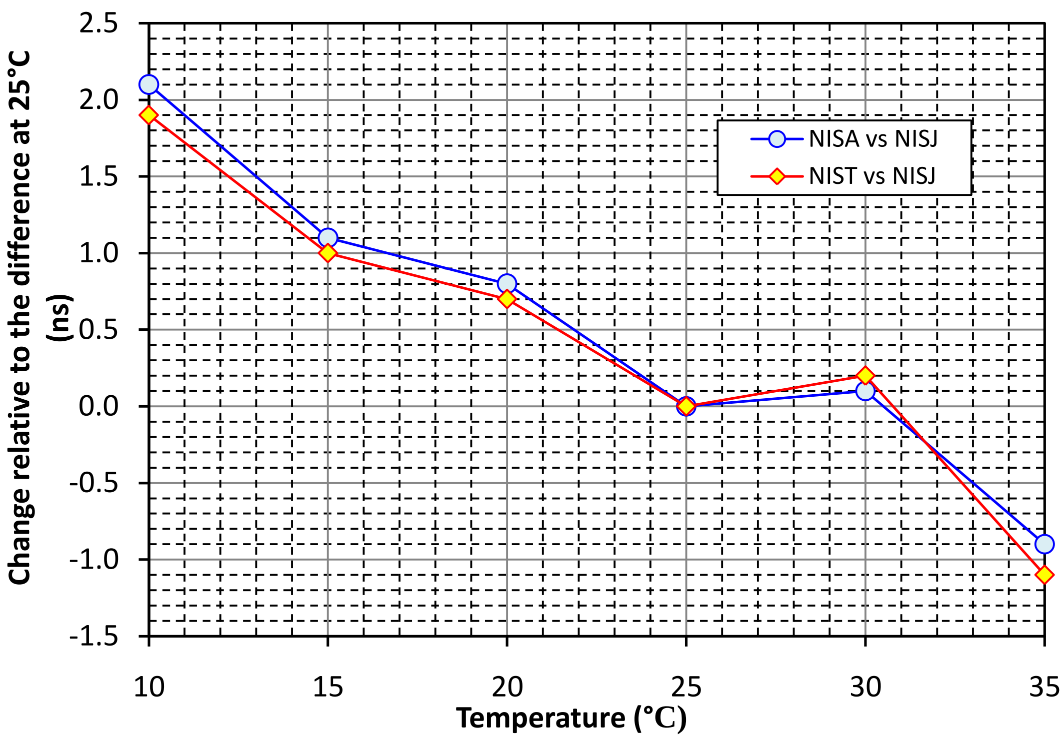

Figure 1. Temperature effect on *NISJ*'s code measurements relative to *NIST* and *NISA.*

Colleagues from the U.S. Naval Observatory (USNO) GPS Division have previously reported on the temperature sensitivity for the code and carrier-phase measurements of an Ashtech Z12T* receiver, a Septentrio PolaRx2eTR* receiver, a NovAtel ProPak-V3* receiver, and a Javad Lexon-GGD* receiver **[6].** Because NIST does not process the carrier-phase measurements, we estimated the temperature effect on *NISJ*'s code measurements by analyzing the changes in P3 common-clock, common-view differences with *NIST* and *NISA* with respect to temperature variations. The *NIST* receiver is operated in a laboratory where the temperature is controlled to within ±2 °C of 23°C. The *NISA* receiver is operated in a temperature-controlled chamber with a temperature of 25°C. During the temperature test, the *NISJ* receiver was housed in an environmental chamber where the temperature was shifted from 10 to 35°C in 5°C steps. Each temperature was maintained for 2 days and was repeated at least twice over a 1-month period. The temperature effects on *NISJ*'s code measurement with respect to *NIST* and *NISA* are shown in Figure 1. These results were obtained by averaging the *NIST* - *NISJ* and *NISA* - *NISJ* differences for each temperature over a period when the temperature had stabilized. The results are normalized with respect to the time difference when *NISJ* was operated at 25°C.

The temperature effect on *NISJ*'s code measurements exhibits the same trend with respect to both *NIST* and *NISA*. Because *NISA* is operated in a temperature-stable chamber, it appears that most of the temperature effect is caused by *NISJ*. The temperature effect is not linear. For temperatures between 10 °C and 35°C, the averaged *NISJ*'s temperature coefficient for code measurements is 120 ps/°C. The temperature coefficient is higher, about 150 ps/°C, when *NISJ* is operated between 20°C and 25°C. The temperature coefficient is 40 ps/°C or less for temperatures between 25°C and 30°C. This suggests that *NISJ* should be operated between 25°C and 30°C to minimize the temperature effect on code-based time transfer results.

III. INSTABILITY OF P3 COMMON-VIEW

From MJD 55320 to MJD 55420 (4 May 2010 to 12 August 2010), *NISJ* was continuously operated so we could study the long-term stability of its code and carrier-phase measurements. The laboratory temperature was 23°C ± 2 °C during this test. We utilized the *NISJ* - *NIST* and *NISJ* - *NISA* P3 common-clock, common-view differences to estimate the instability of the *NISJ*'s code measurements. The time difference plots are shown in Figure 2 and Figure 3.

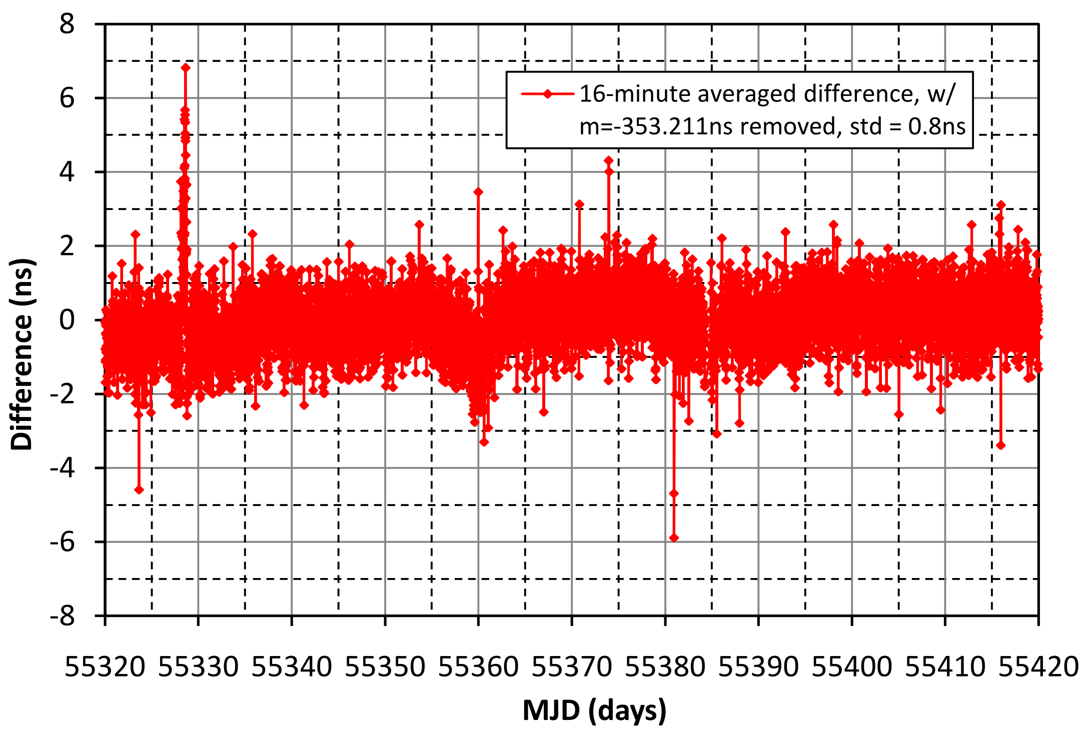

Figure 2. *NISJ* - *NIST* common-clock, common-view difference.

Because *NISJ* had not been calibrated with respect to *NIST* and *NISA*, we removed an offset from each of the time difference plots. The standard deviation of the 100-day *NISJ - NISA* and *NISJ - NIST* common-clock, common-view difference comparison is 0.8 ns. However, the common-clock, common-view differences show some unexpected events, such as an excursion of about 7 ns on 55328 in the *NISJ - NIST* difference, and a time step of about 1 ns on 55385 in the *NISJ - NISA* difference. To understand the cause of these events, we examined the *NISA - NIST* differences as shown in Figure 4.

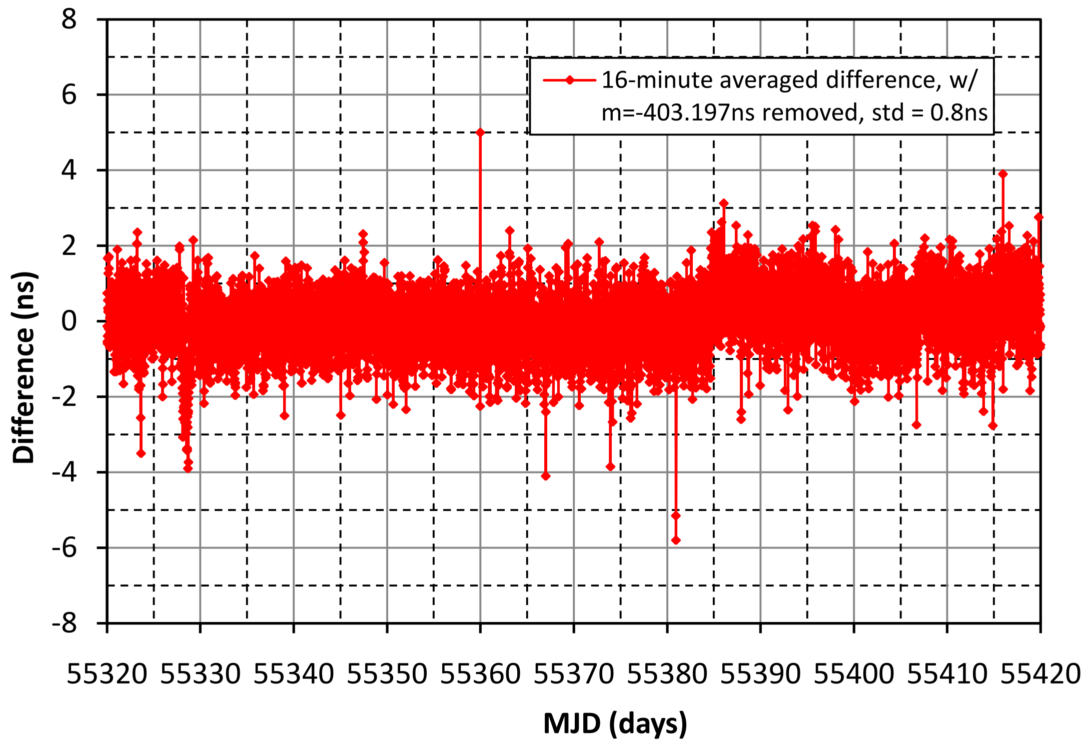

Figure 3. *NISJ - NISA* common-clock, common-view difference.

Figures 2 and 4 illustrate that the *NISJ - NIST* and *NISA - NIST* differences each show the same excursion on MJD 55328, as well as a slow moving difference change for MJDs from 55320 to about 55385. Since these events are common to both the *NISJ - NIST* and *NISA - NIST* differences, but are not shown in the *NISJ - NISA* difference, they likely were caused by the *NIST* code measurements. By comparing the *NISJ - NISA* and the *NISA - NIST* differences, as shown in Figures 3 and 4, we see that both differences contained the same time step on MJD 55385, and a similar slow moving difference change for the period of MJD 55385 to 55420. The time step and difference change are in opposite directions because the *NISA* data were subtracted from *NISJ* in Figure 3, but the *NIST* data were subtracted from *NISA* in Figure 4. We conclude that these events are from the *NISA* code measurements, since they are not shown in the *NISJ - NIST* difference.

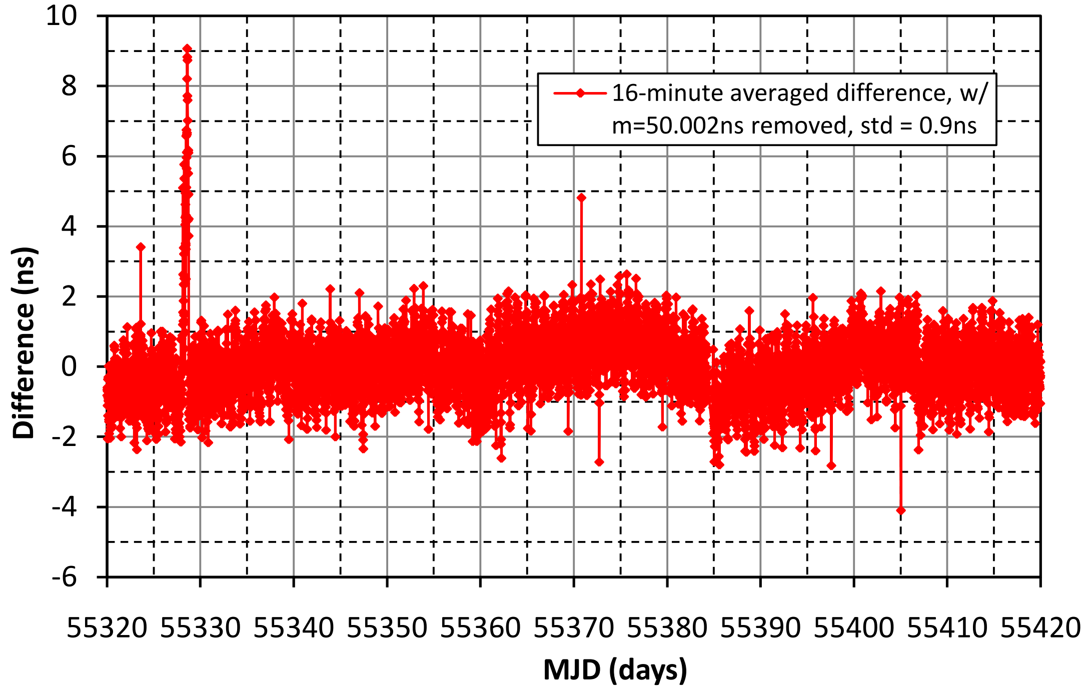

Figure 4. *NISA* - *NIST* common-clock, common-view difference.

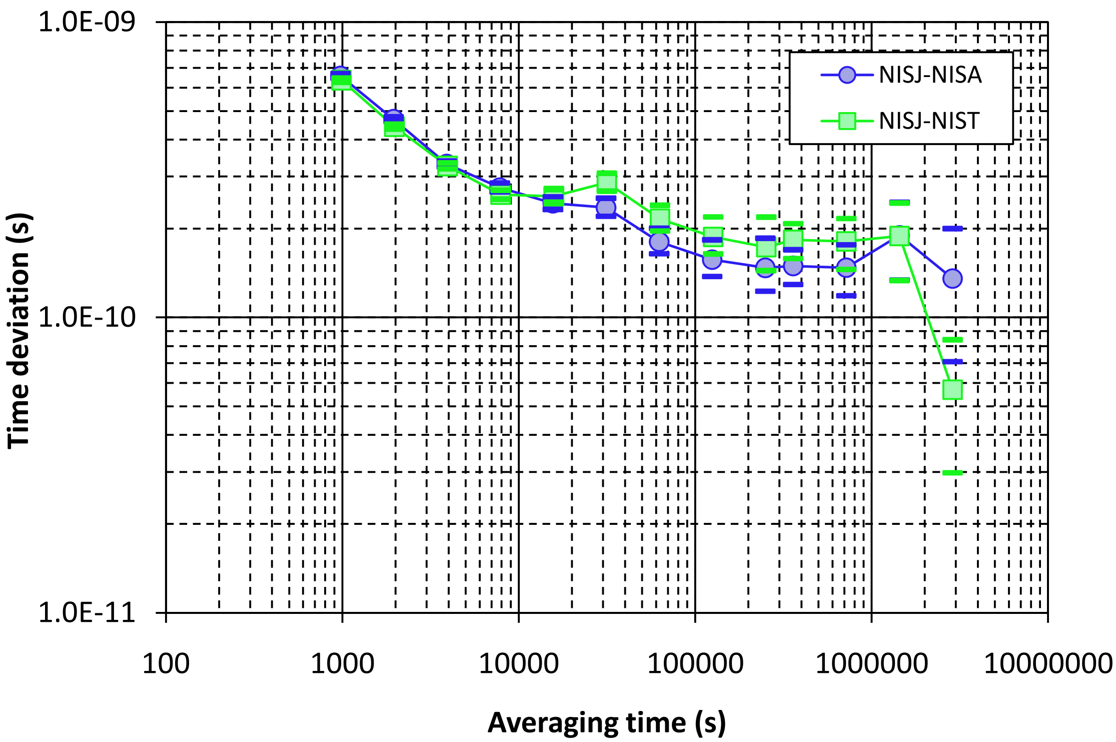

Figure 5. Time deviations of *NISJ* - *NIST* and *NISJ* - *NISA* common-clock, common-view differences.

The time deviations of *NISJ - NIST* and *NISJ - NISA* common-clock, common-view differences are shown in Figure 5. The time deviations are computed using the difference data shown in Figures 2 and 3. The time deviations are about 600 ps at an averaging time of 900 s, and 200 ps or less at averaging times of one day and longer. The time deviations show a small diurnal, which could be caused by the effects of multipath and temperature on the *NISJ* receiver. The time deviations are dominated by flicker phase noise at averaging times of longer than 1 day. The time deviations show the characteristics and levels that are typical for common-clock, common-view differences between two different types of receivers.

IV. INSTABILITY OF CARRIER-PHASE COMPARISON

We analyzed *NISJ*'s carrier-phase measurements from MJD 55342 to 55406 (May 26, 2010 to July 29, 2010) to study its instability with respect to *NIST* and *NISA*. The carrier-phase comparisons are based on the TAIPPP results at 5-minute intervals. Unfortunately, the TAIPPP results revealed that the *NIST* and *NISA* carrier-phase data contained unusual time steps and excursions of more than 1 ns on MJD 55384, 55385, and 55406 as shown in Figure 6. Because these time steps and excursions do not represent the normal performance of *NIST* and *NISA*, we used the *NIST* and *NISA* TAIPPP results for the period before the time steps occurred (MJD 55342 to 55384) for analyzing the instability of *NISJ*'s carrier-phase measurements. The common-clock, TAIPPP differences and the corresponding time deviations are shown in Figures 7 and 8.

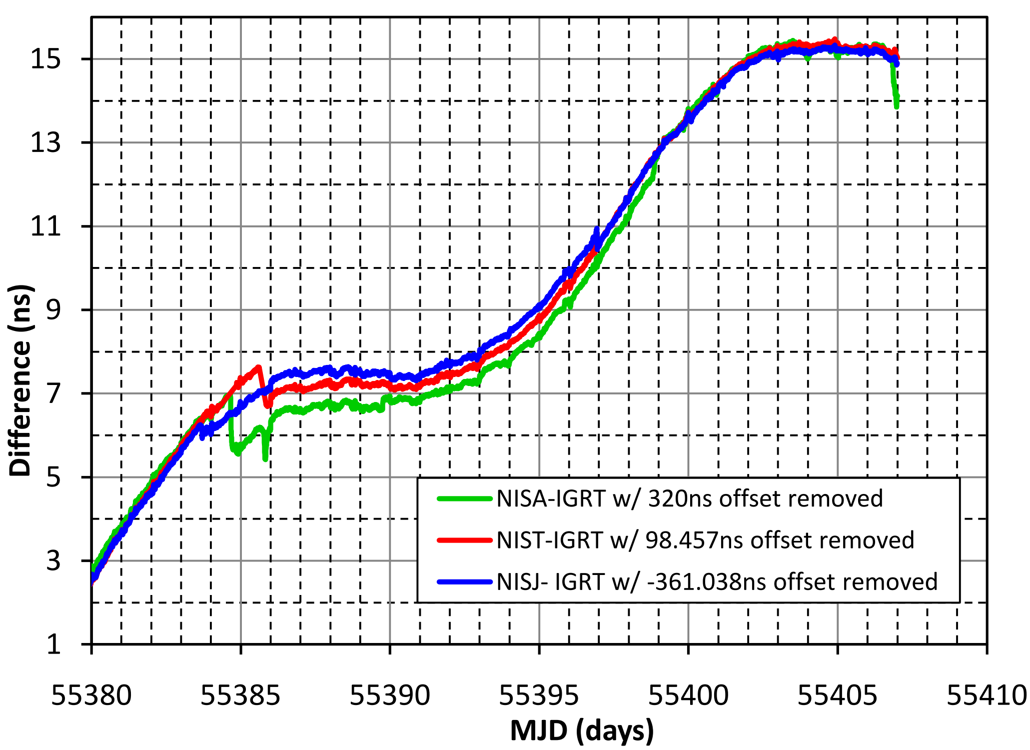

Figure 6. Carrier-phase differences from TAIPPP analysis (IGRT stands for the rapid solution of the International Global Navigation Satellite System time scale).

The *NISJ* common-clock, TAIPPP difference data with *NIST* and *NISA* contains jumps ranging from 200 ps to 400 ps on MJD 55346, 55361, and 55376. These jumps were from the *NISJ* data at the day boundaries, or after missing data. Figure 8 shows that the time deviations for all three comparisons are about 10 ps for an averaging time of 5 minutes. The common-clock, TAIPPP differences are dominated by random walk noise for averaging times ranging from 1000 s to about 1 day. The time deviations are about 50 to 60 ps and exhibit flicker phase noise for averaging times longer than 1 day.

V. SUMMARY AND CONCLUSIONS

Our evaluation shows that *NISJ*'s temperature coefficient for code measurements is relatively large when compared to similar types of receivers. To minimize the temperature effect, *NISJ* should be operated with temperatures between 25°C and 30°C. *NISJ* demonstrates typical performance for code and carrier-phase time transfer when compared to similar receivers. When data are averaged for 1 day or longer, the instability introduced by the receiver is about 200 ps for code-based clock comparisons, and about 60 ps for carrier-phase clock comparisons.

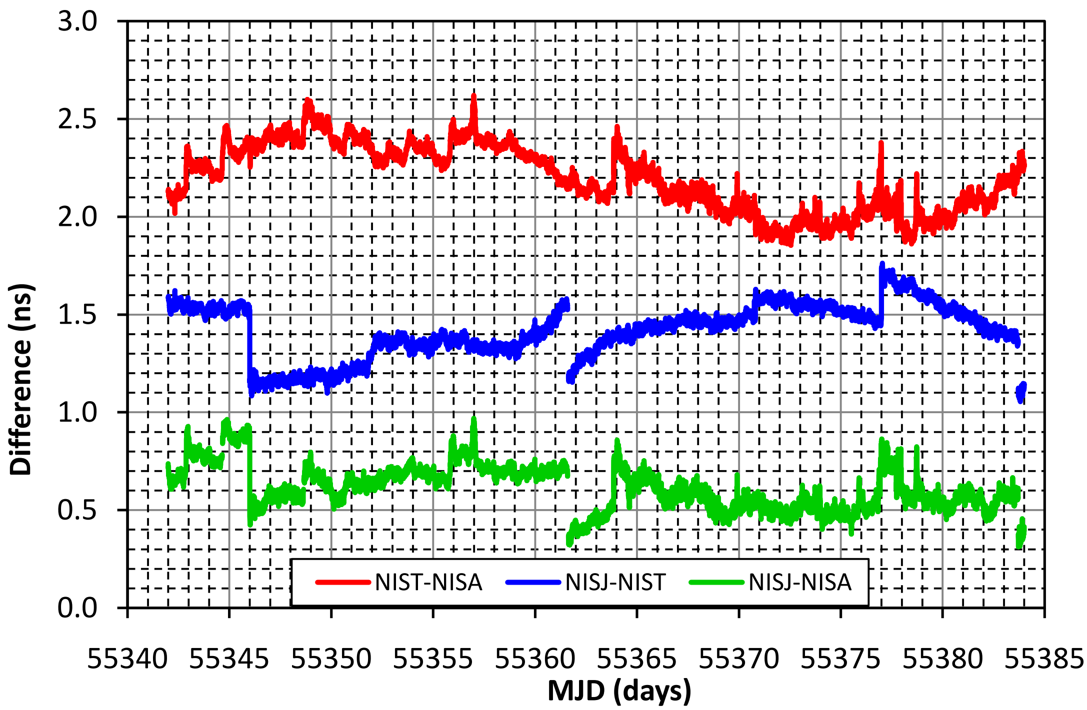

Figure 7. Common-clock, TAIPPP differences (offset for demonstration purposes).

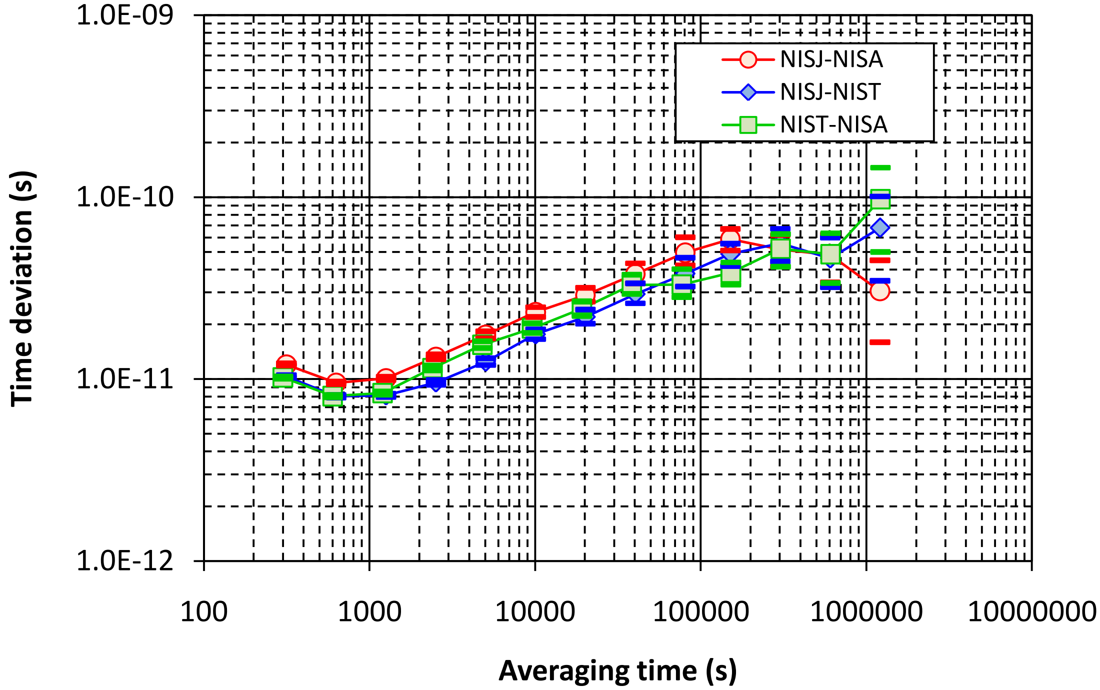

Figure 8. Time deviation of common-clock, TAIPPP differences.

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VII. ACKNOWLEDGMENTS

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