# A Comparison of GPS Common-View Time Transfer to All-in-View[*]

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*Abstract*—**All-in-view time transfer is being considered to replace common-view for computing the links of International Atomic Time (TAI). The components in all-in-view GPS time transfer that do not cancel as they do in the common-view technique are the satellite clock estimate and the ephemeris estimate. We show that these components average down as white phase noise with a typical level of 2 ns with 13 minute averaging,and under 100 ps at 1 d. Looking at closures including stations in Europe, North America and Japan, we see evidence for a white PM level below 0.5 ns with an averaging time of 1 d, a flicker floor of 100 ps after 3 d, and systematic effects at a level of up to 1 ns. We also show evidence that errors in ionospheric maps and multi-path interference can cause noise processes at least as dispersive as flicker phase noise at 300 ps from 1 d to past 10 d. We conclude that all-in-view GPS time transfer improves stability over common-view for links as long as 5000 km, and is equivalent for links as short as 2500 km. We also find that ionosphere-free time transfer data may provide a significant improvement for averaging past 1 d.**

## I. INTRODUCTION

The GPS common-view (CV) time transfer method [1] has been used by the Bureau International des Poids et Mesures (BIPM) to compare the UTC time scales of timing labs in order to generate International Atomic Time (TAI) [2,3]. The all-in-view (AV) method has been proposed as an alternative with potential for decreasing time-transfer errors [4]. CV directly cancels any estimates of satellite clock against a reference time scale, whereas AV does not. CV cancels common components of ephemeris error, canceling more completely over shorter baselines [1]. AV does not, in principle, cancel ephemeris error. However, AV allows direct comparisons of stations around the globe, whereas CV does not. AV uses comparisons with significantly more data and with higher tracking elevation angles than CV, thus increasing statistical averaging while potentially decreasing systematic errors. Allowing higher elevation GPS measurements may reduce errors in estimating ionospheric and tropospheric delays, as well as in reducing multi-path interference. AV should have an important advantage if errors in estimates of satellite clocks are small enough.

We compare these techniques here in three ways:

1) We study the possible effect in AV of errors in satellite clock and ephemeris estimates. Looking at multi-channel data from a single receiver, we break the data into two sets and compute AV estimates of an International GPS Service (IGS) time scale [5] against local clock for each data set. The difference of these sets should be zero. Since non-zero values will be due largely to errors in estimating the satellite clock, plus other error sources (such as ephemeris errors, ionospheric and tropospheric estimation errors, and multi-path reflections) these results will give us an upper limit on the errors in the SV clock estimates.

2) We compute CV and AV time transfer between two pair of stations with hydrogen maser reference clocks, allowing us to look at the transfer noise for averaging times greater than 1 d.

3) A third test shows the level of systematic errors in CV by computing closure tests with GPS ionosphere-free, P3 code data [6]. We transfer time among three stations coming back to the original station. Again, non-zero results indicate errors primarily due to tropospheric estimation errors, multi-path interference, and coordinate errors. This technique cannot be used with AV, since the closure will be exactly 0 for a given time t, if simply the data exist for all stations.

## II. AN AV SATELLITE DIFFERENCE STUDY

Looking at multi-channel data from a single receiver, we break the data into two sets and compute AV estimates of an IGS time scale against local clock for each data set. The AV computation involves estimating the local reference clock against IGS time via each satellite. The estimate of reference clock (Ref) minus the IGS time scale (IGST) using PRN nn contains the following error terms.

$$Ref\text{-}IGST(nn) = Ref \text{ - } IGST + [MeasN + Etide + MPath + Tropo + Iono + Eph + Clk](nn), \quad (1)$$

where:

MeasN = measurement noise of the receiver

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Etide = error in estimating earth tides

MPath = multi-path interference

Tropo = error in the tropospheric model

Iono = error in the ionospheric model

Eph = ephemeris errors

Clk = errors in the satellite clock model against IGST.

A multi-channel receiver will supply pseudo-ranges for several satellites allowing us to obtain Ref-IGST(nn) for each of these satellites at the same time. If we difference Ref-IGST(nn) between two different satellites, nn and kk, we obtain:

Ref-IGST(nn) - Ref-IGST(kk) =

[MeasN + Etide + MPath + Tropo + Iono + Eph +Clk](nn)

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[MeasN + Etide + MPath + Tropo + Iono + Eph +Clk](kk). (2)

We want to study the magnitude and stability of the terms [Eph +Clk](nn), since these terms are precisely the new error contribution in AV that is not in CV. Of course Eph(nn) does appear in CV, but somewhat cancelled more over shorter baselines. We show that the differences, equation (2), are small and average appropriately. Hence the components [Eph +Clk](nn) must also be small and average appropriately.

We take a set of AV data from the multi-channel receiver at the IGS station for the Royal Observatory of Belgium (ORB). The data are P3 code data, i.e. ionosphere-free, in the GGTTS format used for time transfer by the BIPM [7,8]. The format organizes data into one point for each satellite tracked every 16 minutes. We group the data into two sets: PRNs 1-15, and PRNs 16-31. For any 16 minute interval in the GGTTS data where there are at least 2 satellites tracked in each set, we average the Ref-IGST(nn) data for each set, and difference them (Fig. 1). Even though the data are unevenly spaced, we compute TDEV [9] of the results by using the average minimum spacing, i.e. the last reference time minus the first, divided by the number of data intervals (Fig. 2). Of particular interest is the -1/2 slope on the log-log plot, indicating a noise type consistent with white phase modulation (PM).
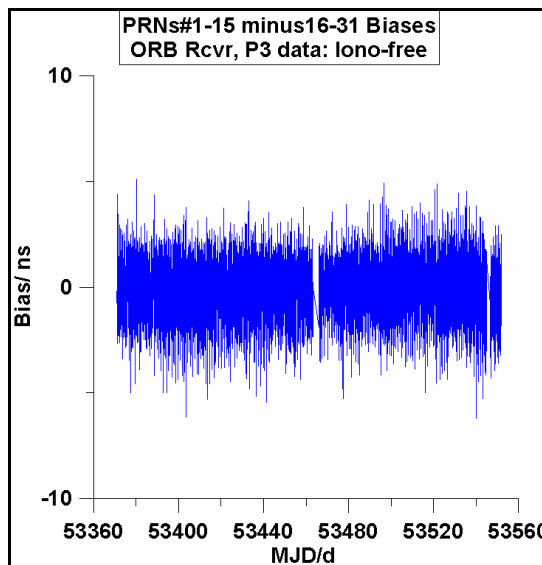


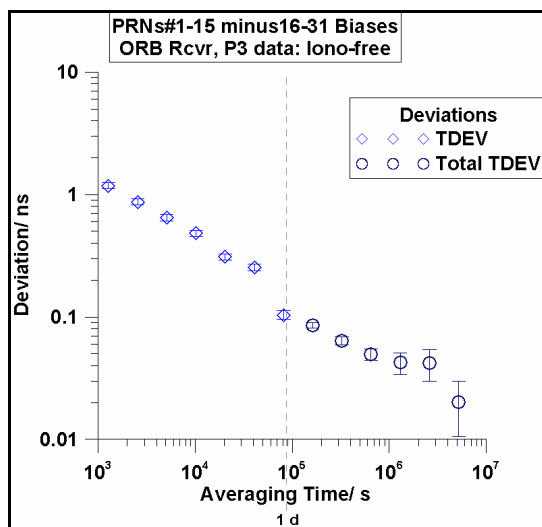Figure 1. The difference between two sets of all-in-view computed data, Ref-IGST.



Figure 2. TDEV of the data in Figure 1. The -1/2 slope indicates white PM noise averaging down from 16 minutes past 10 d, with a diurnal variation.

The data appear to average down as white PM to at least 10 d, though there appears to be a diurnal variation. At 16 minutes averaging the level is about 1 ns. At 1 d, the level is 100 ps. Note that the values in Figure 2 also include contributions from measurement noise, multi-path interference and troposphere estimation errors and that the latter two are expected to provide diurnal signatures at some level. The Figure indicates that the [Eph +Clk](nn) terms probably will

not contribute new instabilities to time transfer when used in AV as opposed to CV.

Similar results appeared looking at P3 data from the NISA receiver at NIST. Also, similar results occurred when studying individual satellites against the average of all others tracked simultaneously. We show that the noise for the PRN#18 errors as seen from ORB in Figure 3, is consistent with a white PM model with a diurnal variation. The level was about two times higher than in Figure 2, suggesting an average of four satellites in each data set averaged in Figure 2.

When we looked at data with the same analysis as in Figure 2, but using the IGS ionospheric maps, instead of P3 data [10] we obtain the data in Figure 4, which do not average as white PM, but rather appear to be consistent with a model of flicker PM at 300 ps after 3 d. This receiver antenna has no choke ring, unlike ORB and NISA, increasing the effects of multi-path interference. We expect this implies that some combination of errors in ionospheric maps and multi-path interference produce a persistent flicker PM over days. The coordinate uncertainty for the M1 receiver was higher also, about 1 m, but we expect deviations due to coordinates to average as white PM past 1 d.

## III. AV AND CV TIME TRANSFER

AV time transfer can contain CV. When we difference an average of one station's data from another for a common time, tracks in common produce common-view transfer. The question is whether adding extra tracks helps or hurts the transfer. The TDEV values of the last section suggest that the extra AV data should average appropriately, improving the transfer. Figure 5 shows the TDEV of AV and CV time transfer, as well as of only those AV tracks not in CV, using P3 data between the NISA receiver at NIST Boulder, Colorado, USA and Brussels, Belgium, the ORB receiver, a baseline of about 5000 km. The stability of the AV data is better than the CV until the clock noise dominates. Both sites are driven by H-masers. The TDEV of the AV tracks not in CV gives an indication of how the extra data can affect stability.
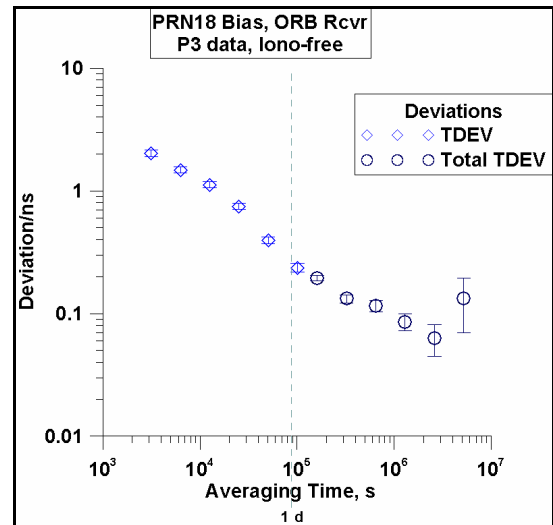


Figure 3. Ref-IGST via PRN#18 minus the average of all PRNs tracked simultaneously. Again, the data average down as white PM from 16 minutes past 10 d, with a diurnal variation.
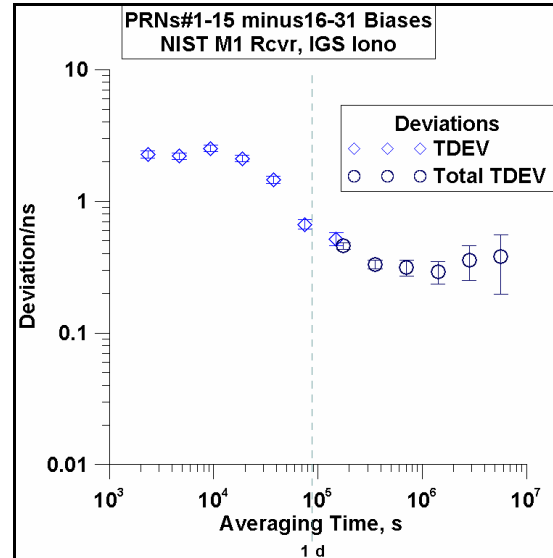


Figure 4. Data computed as in Figure 2, but for a different receiver. Here we use the IGS ionospheric maps, and the antenna lacks a choke ring, which the NISA and ORB receivers have. We see apparent flicker PM at 300 ps from 3 d past 10 d.
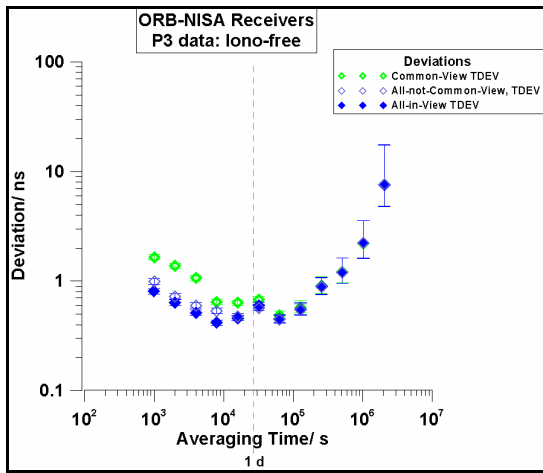
Figure 5. Time transfer between the ORB and NISA receivers. Both use P3 data and are driven by H-masers. Hence the transfer noise is visible past 1 d. The AV stability seems to be slightly better than the CV stability.
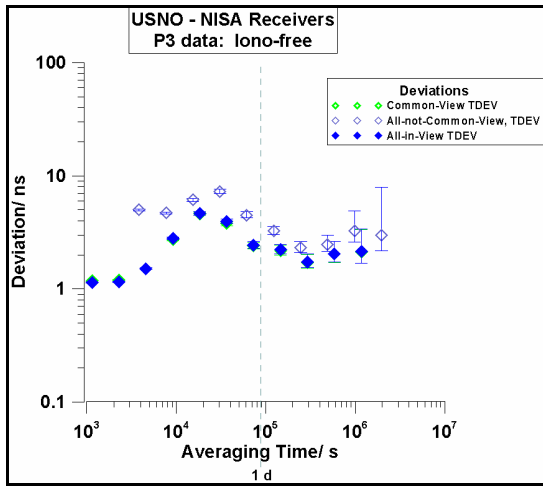


Figure 6. Time transfer between the USNO and NISA receivers. The NISA receiver uses P3 data. The USNO data are adjusted using IGS ionospheric maps. Both are driven by H-masers. Hence the transfer noise is visible past 1 d. The AV and CV stabilities are comparable.

It is expected that AV would show more improvement with longer baselines. In Figure 6 we see for transfer between NIST, Boulder Colorado, USA to the United States Naval Observatory (USNO), Washington D.C., USA, a shorter baseline of about 2500 km, that AV and CV seem to be equivalent out to the clock noise. Note that the USNO data are corrected for ionospheric delays with IGS maps. Both sites are driven by H-masers, so that transfer noise should be dominant past averaging times of 1 d. Here we see that the AV tracks

not in CV have a higher noise level, probably because there are fewer of them.

## IV. CV CLOSURES

We computed eight CV closures, Europe-Japan-America, for all combinations using PTB/NPL, NICT/NMIJ, NIST/USNO for March-May 2005. The results for two of these closure computations are shown in the Figures 7-10. The data use dual frequency P code data (the ionosphere-free P3 combination) and IGS precise ephemerides. Expressing results as 1 point per day, the mean is generally < 0.5 ns with a few exceptions (up to 1.5 ns). The standard deviation is between 0.4 ns and 0.9 ns. A few sets have time-varying systematic effects at a level of up to 2 ns peak to peak, as shown for one example in Figure 8. TDEV shows evidence of some residual flicker PM processes at 100 ps from 3 - 10 d.

As each closure is the sum of three long-distance links, which are independently computed with the CV technique (i.e. the measurements used in each link are independent from one another), we can draw from the closure analysis some conclusions on long-distance CV links. For an averaging time of 1 d, using dual frequency P code and IGS ephemerides we find a white PM level below 0.5 ns, perhaps a flicker floor of 100 ps after 3 d, and systematic effects at a level of up to 1 ns (2 ns for the sum of 3 links). The likely source of such effects is low elevation observations such as tropospheric estimation errors and multi-path interference. AV reduces such systematic effects because it uses all available data, not only measurements with lower elevation satellites. In addition, the measurements taken at different elevations can be used with appropriate weighting in the AV technique, whereas in common-view for long-distance links, all measurements are low elevation anyway. We thus expect AV to improve the accuracy of links with respect to common-view. However, other systematic effects, linked to the equipment, may affect both CV and AV.
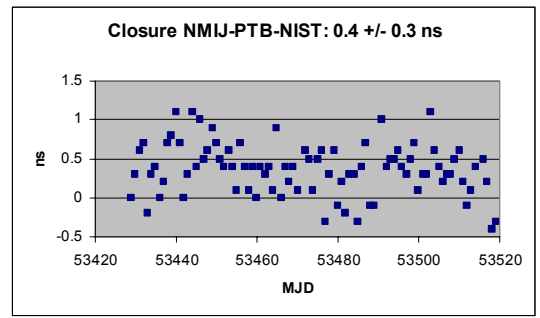


Figure 7. CV transfer across three stations back to the first. Non-zero values indicate error levels.
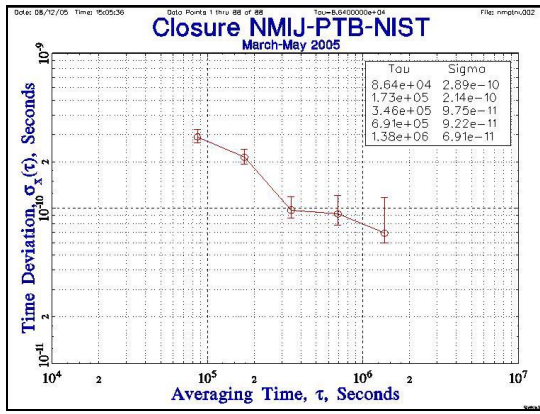
Figure 8.    TDEV of the data in Figure 7.  There appears to be a flicker PM process from 3-10 d.
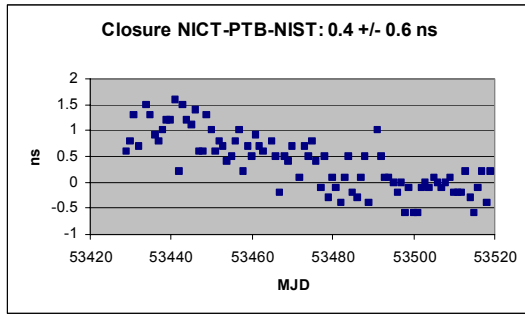


Figure 9.    A CV closure using a different set of stations.  There is evidence of a systematic change in the residuals.
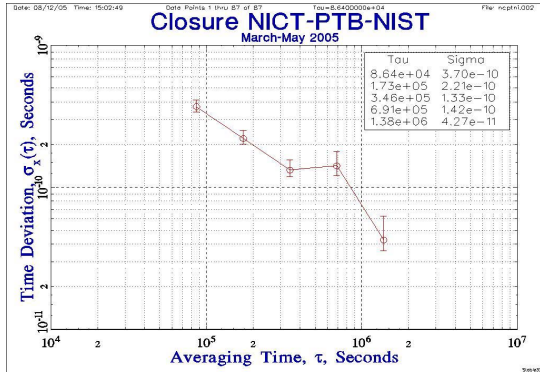


Figure 10.  TDEV of the data in Figure 9.  Due to the uncertainty in the last point, we cannot rule out a flicker PM process after 3 d.

## V.  CONCLUSIONS

All-in-view adds data with high elevation angles, an advantage over common-view, whereas All-in-View contains IGS corrections not used in common-view, a disadvantage. We have shown that these IGS corrections should average appropriately to well below 100 ps for averaging 1 day and longer, hence contribute no new instabilities to TAI. Common-view may, particularly over baselines of 2000 km and less, be as stable as all-in-view. For long-distance links, the around-the-world closures with CV indicate a white PM level below 0.5 ns with an averaging time of 1 d, perhaps a flicker floor of 100 ps after 3 d, and systematic effects at a level of up to 1 ns.  Differential ionospheric corrections and multi-path interference can contribute long-term instabilities and use of P3 ionosphere-free data is always recommended to drop instabilities below 100 ps at 5 d.

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