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# RESULTS FROM TIME TRANSFER EXPERIMENTS BASED ON GLONASS P-CODE MEASUREMENTS FROM RINEX FILES

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## Abstract

***The time transfer procedure presently used for the realization of TAI is based on the common view approach, using the CGGTTS data computed by an internal software of the time receivers. We choose here another approach and analyze the raw data available in the RINEX files produced by GPS/GLONASS geodetic receivers. We concentrate our analysis on the use of GLONASS P-code measurements. Because the frequency emitted by each GLONASS satellite is different, the measurements must be corrected for their frequency-dependent receiver hardware delays. These delays can be computed either from the CGGTTS files or directly from the raw P-code data. We show that the first approach is better than the second one. After this correction, time transfer (using the GLONASS P-codes) is realized with a rms of about 2 nanoseconds for a 1-day session between two receivers distant of a few hundred of kilometers.***

## INTRODUCTION

The use of the GLONASS P-codes for time transfer is very promising, as already shown by different studies ([2] [3] [4] [6] [7]). In all the mentioned studies, the time transfer results were obtained using CGGTTS (GPS/GLONASS Time Transfer Standard) data files provided by receivers designed for time transfer applications. The CGGTTS files ([1]) contain the clock differences between the GLONASS/GPS system time and the local clock of the time laboratory. These differences are computed by the receiver software for the satellites given in the international tracking schedules distributed by the BIPM (Bureau International des Poids et Mesures) and are used for the computation of TAI. On the other hand, the International GLONASS EXperiment (IGEX) ([10]) gave access to RINEX files from about 25 receivers in the world. Part of these combined GPS/GLONASS receivers are driven by precise frequency standards, and some of them contribute also to the realization of TAI. We have, therefore, investigated the possibility of performing time transfer using the GLONASS P-code data given in these RINEX data files.

Using a common view method, we determine the receiver clock offsets and consequently the time transfer between the external frequency standards driving these receivers. Compared to the method based on CGGTTS files, this method allows to work with a higher number of data points (about 3000 per day) and allows to control each aspect of the correction terms from the raw data to the final product.

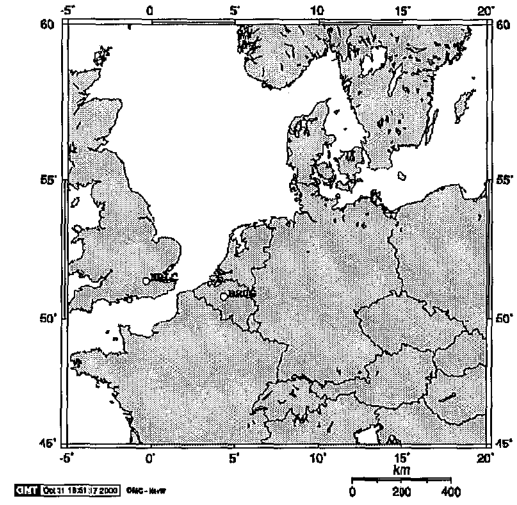

Figure 1: GPS/GLONASS sites used in this study.

In ([8]), the final precision of the time transfer between two 3S-Navigation R100 receivers distant of a few hundred of kilometers, obtained using the precise ephemerides, was about 10 *ns*. The main limitation was the receiver hardware delays which are different for each satellite because of the satellite dependency of $L_1$ and $L_2$ frequencies. Due to the fact that calibration values are not available, a first approach consisted in estimating the corrections of each satellite directly from the time transfer results produced by each satellite separately. However, this adjustment was not perfect due to the fact that we estimated the offset between the results of the different satellites on a time span of only 1 day. In ([9]), we used the CGGTTS delays determined on a time span of two weeks and showed that the final precision of the time transfer improves to 1.8 *ns* for a typical 1-day session between 2 receivers distant of a few hundred of kilometers. The disadvantage of this approach was that it could only be applied for time receivers.

In order to overcome this limitation, we try in this paper to determine these differential receiver hardware delays directly from the raw P-code measurements, but now using several days of measurements and we compare the results with those obtained from the CGGTTS data.

# DATA SET DESCRIPTION

We have used the RINEX data of GPS/GLONASS receivers belonging to IGEX network, and operating at the same time as time laboratories participating in the realization of the international atomic time scale (TAI) (see Figure 1):

- BRUG, located at the Royal Observatory of Belgium, equipped with a combined GPS/GLONASS multi-channel receiver R100-30T from 3S-Navigation, connected to a H-maser for the geodetic part, and to a cesium clock HP5071A (=UTC(ORB)) for the participation to TAI;
- NPLC, located at Teddington (Greater London, UK), 336 km far from Brussels, equipped with a combined GPS/GLONASS multi-channel receiver R100-40T from 3S-Navigation, connected to a H-maser (=UTC(NPL)) for both the geodetic part and the participation to TAI.

As shown in ([8]), the R100 receivers exhibit regular artificial discontinuities in the computed receiver clock synchronization errors, which make it impossible to perform RINEX-based precise time transfer for more than 1 day. This is a typical situation for all receivers from this manufacturer.

# RECEIVER HARDWARE DELAYS

Figure 2a shows that the time transfer signal obtained using a single day of observations with precise ephemerides still presents some small jumps or curvatures not attributable to the H-maser. These are due to changes in satellite configuration and to the uncorrected receiver hardware delays associated with the different satellites observed.

We have used two different methods for determining the hardware delays. The first one, already presented in ([9]), is based on the fact that the receivers used in our experiment (BRUG, NPLC) also provide CGGTTS files to the BIPM, so we used the time transfer results provided by these CGGTTS files to estimate the differential receiver hardware delays. When using CGGTTS files, there are no jumps because these results give the offset between GPS time and the 1 *pps* (1 pulse per second) signal provided by the laboratory clock. Using the CGGTTS files, the calibration delays can now be determined using a longer time span containing more simultaneous observations. Note that we cannot assert that the hardware delays are the same for both geodetic data and the CGGTTS data; this depends on the receiver architecture and will be tested here by comparing with the hardware delays obtained directly from the raw data given in the RINEX files. Clock resets are not problematic because they do not alter the differential hardware delays computed from the RINEX files. This means that we can determine the calibration delays using RINEX data over a time span longer than 1 day.

| Satellite number | hardware delays CGGTTS (ns) | hardware delays RINEX (ns) | Differences |
|---|---|---|---|
| 1 | -0.4 | 3.6 | 4 |
| 3 | -2.9 | -2.3 | 0.6 |
| 4 | -0.4 | -1.4 | 1 |
| 6 | -0.9 | -2.1 | 1.2 |
| 7 | 0.0 | 0.0 | 0 |
| 8 | -0.5 | 1.4 | 1.9 |
| 9 | 7.2 | 7.9 | 0.7 |
| 10 | 1.4 | 5.3 | 3.9 |
| 11 | -2.7 | 1.8 | 4.5 |
| 13 | 6.9 | 7.7 | 0.8 |
| 15 | -2.1 | -4.4 | 2.3 |
| 16 | -3.8 | -4.7 | 0.9 |
| 17 | 4.0 | 8.5 | 4.5 |
| 22 | 6.0 | 6.2 | 0.2 |

Table 1: Hardware delays. Satellite 7 is chosen arbitrary as the reference one.

We test both methods on the baseline BRUG – NPLC. A period of 14 days (51351-51365 MJD (Modified Julian Date) corresponding to GPS weeks 1015 and 1016) has been used to determine the calibration delays from the CGGTTS files (see ([9]) for details) as well as from the RINEX files. Table 1 lists the hardware delays determined by both methods.

In Figure 2, we have plotted the time transfer results between BRUG and NPLC for the first day of the GPS week 1016 (corresponding to MJD 51357). The first part of the graph shows results which are not corrected for the frequency dependent receiver hardware delays. In this case, the rms of the differences is equal to 2.6 *ns*. The second part is corrected for the receiver hardware delays using CGGTTS files and the corresponding rms is equal to 1.8 *ns*. The last part is corrected for receiver hardware delays obtained from the RINEX files and the corresponding rms is equal to 2.0 *ns*. We can say that this correction removes the curve variations induced by the variable 'mean' hardware delay, corresponding to the mean of the delays of the observed satellites at each time. But, as seen from the graphs, although our correction sometimes reduces the jumps and variations, it leaves some variations at other times. This is due to the limited accuracy of the computed receiver hardware delays: the computed receiver calibration errors between the different satellites are of the same order of magnitude (from 0 to 10 *ns*) as the noise level of the clock differences computed with any satellite (2.5 *ns*). We see also that the results using the CGGTTS files for calibration are better than the ones using RINEX files (rms of 1.8 *ns* vs 2.0 *ns*). Indeed, even if the RINEX files provide a larger number of observation points, the noise level is higher than with the CGGTTS files (standard deviation of 5 *ns* instead of 2 *ns*). This is due to the data smoothing, which is part of the procedure applied to compute the CGGTTS files.

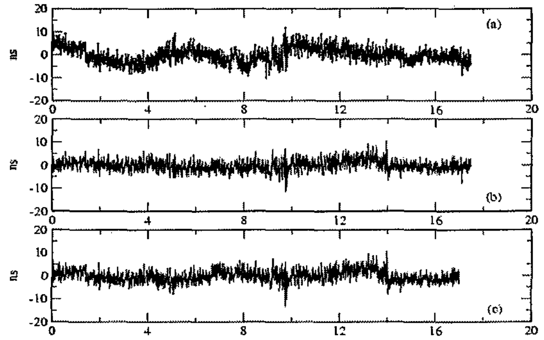

Figure 2: Time transfer (BRUG-NPLC). (a) Hardware delays not corrected, rms =2.6 *ns* (b) Hardware delays corrected by CGGTTS files, rms =1.8 *ns* (b) Hardware delays corrected by RINEX files, rms =2.0 *ns*.

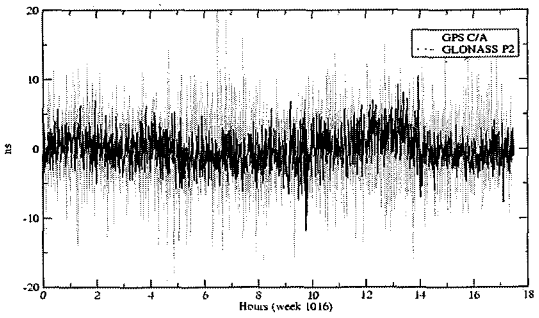

Figure 3: Time transfer (BRUG-NPLC).

# COMPARISON BETWEEN GLONASS AND GPS RESULTS

In Figure 3, we have plotted the time transfer between BRUG and NPLC for the first day of the GPS week 1016. We see that the use of the GLONASS P-code (rms of 1.8 *ns* and maximum difference of 11.8 *ns*) reduces the noise level with a factor between 2 to 3 with respect to the use of GPS C/A code (rms of 4.4 *ns* and maximum difference of 31.9 *ns*).

Figure 4 shows the frequency stabilities of the frequency transfer performed with GPS C/A-codes, GLONASS P-codes and GPS phases. The GLONASS P-code results show a better stability than GPS C/A-code results at short time scales (below 1 hour). This is a direct consequence of the lower noise level of the GLONASS P-code compared to the GPS C/A-code. At longer time scales (larger than 1 hour), we observe the opposite situation due to the imperfect correction of hardware delays in the GLONASS P-code results, inducing small undulations of the curve (as seen in Figure 3), which reduces the frequency stabilities. The results based on GPS carrier phases have frequency stability highly superior to the results based on codes (GPS or GLONASS). However, although carrier phases offer a huge potential for the frequency transfer applications, they still depend on the information in code data to determine the absolute synchronization offset (see ([5]) for more details).

# CONCLUSION

We have used RINEX data from combined GPS/GLONASS receivers involved in the IGEX campaign to investigate the performances of the GLONASS P-codes for time transfer applications. We pointed out that it is necessary to correct the P-codes for the receiver hardware delays which are, for the GLONASS data, different for each satellite. Receiver calibrations are unavailable at the present time; the determination of the receiver hardware delays for each satellite must be done during the computation of the synchronization errors. However, due to the noise of measurements and the variability of the hardware delays, this determination cannot be done precisely enough with only 1 day of data. Using several days of data would allow a more reliable determination of the satellite dependent hardware delays. The CGGTTS files made available by some IGEX receivers give a long time series of synchronization errors determined on individual satellites and allow easier determination of the differential biases between the satellites. Another approach is to use the RINEX files themselves in order to use geodetic receivers and not only time receivers: in this case, clock resets occur, but are not problematic because they do not alter the differential hardware delays between the satellites. More problematic is the fact that the RINEX raw data are more noisy than the smoothed CGGTTS data, even with a larger number of observation points for the RINEX files. This leads to a better determination of the hardware delays with the CGGTTS files than with the RINEX files (rms of 1.8 *ns* instead of 2 *ns* for a typical 1-day session between two stations distant of a few hundred of kilometers). However, even with the knowledge of these calibration delays, a precise frequency transfer with RINEX data will be restricted to 1 day due to the jumps at the day boundaries due to the daily resets of the 3S-Navigation receivers. If a time transfer is needed for a time span longer than 1 day, the receiver clock jumps must be monitored with an external time-interval counter.

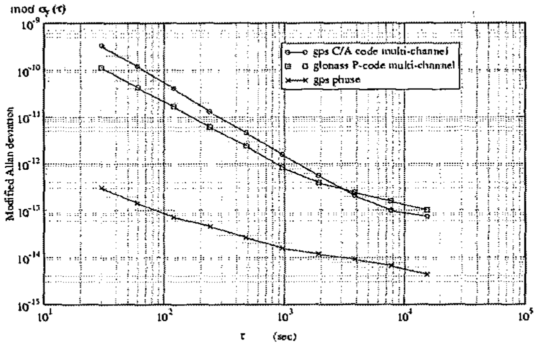

Figure 4: Frequency stabilities of the different time transfer results of Figure 3.

We can conclude that the present geodetic GLONASS receivers driven by a stable frequency standard can be used for time transfer applications only if (1) the satellite-dependent hardware delays are regularly monitored and, (2) the 1 pps output is monitored in order to measure the clock discontinuities.

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