GLONASS and GPS PPP for Time and Frequency Transfer

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Abstract— **The software Atomium has been developed by the ROB to perform GPS-based time and frequency transfer in Precise Point Positioning (PPP) mode. This software has been adapted in order to produce a PPP solution for the Russian GLONASS constellation. The least square analysis of GLONASS dual-frequency carrier phase and pseudorange measurements is used to find the receiver clock solution for a specific station. This paper describes the implementation of the GLONASS constellation in the existing PPP analysis procedure and presents some preliminary results**.

I. Introduction

The software *Atomium* was initially developed by the ROB to provide a tool mainly dedicated to precise GPS time and frequency transfer. It is based on a least square analysis of code and carrier phase GPS measurements to determine the receiver clock synchronization error, the position and the tropospheric zenith path delay [1]. This software uses the satellite orbits and clocks taken from the IGS products, and absolute phase center variations provided by the IGS (igs05.atx) for receiver and satellite antennas. *Atomium* therefore provides the clock solutions at a 5-minute sampling rate. The present study consists in adapting *Atomium* in order to provide a clock solution based on GLONASS code and carrier phase measurements. GLONASS was already used for several time transfer experiments. GLONASS P code was first tested [2,3]. The conclusion drawn by these studies is that the main limitation for time transfer using GLONASS P-code is the existence of frequency-dependent receiver hardware delays. A first experiment of using both GPS and GLONASS P-code measurements for common-view time-transfer is also proposed in [3].

A combined analysis of GLONASS code and carrier-phase measurements was described in [4], based on the Bernese software. This study computed time links in a network analysis either using the combination of GPS+GLONASS data, or using GPS-only and GLONASS-only data. The expected improvement of the results using the complete constellation GPS+GLONASS rather than GPS-only, i.e. a factor of 1.2 on the short term Allan deviation, was not reached due to the lost of efficiency of the method caused by the necessity to estimate the receiver inter-frequency biases.

The future income of the European navigation system Galileo and its joint use with GPS, will offer a big potential to improve the time transfer precision thanks to the enhanced number of satellites and available signals. GLONASS is presently an incomplete constellation, but its use for time transfer provides an opportunity for combining different satellite navigation systems for time transfer applications. This study therefore is a first step in that direction : it consist in performing time and frequency transfer in PPP mode [5] using the GLONASS code and phase measurements, and to compare the solutions with the GPS based solutions in order to estimate the possible improvement of the combination of both systems.

The first section of this paper will present the differences between the two constellations and the associated modifications needed in *Atomium* for the processing of GLONASS data. In the second section, we compare some time transfer solutions obtained for different IGS stations using from GLONASS PPP and the corresponding solutions obtained using GPS PPP.

II. PPP using GLONASS data

The implementation of GLONASS constellation in a GPS-based tool like *Atomium* requires to account for all the differences between both systems. Table 1 summarizes the main differences between GLONASS and GPS, focusing on the reference frames and signals of each system.

TABLE I. COMPARAISON OF THE TWO CONSTELLATIONS

	GLONASS	**GPS**
Carrier L1 Carrier L2 C/A-code (L1) P-code (L1, L2)	1602.562 to 1615.5 Mhz 1246.437 to 1256.5 Mhz 0.511 Mhz 5.110 MHz	1575.42 Mhz 1227.60 Mhz 1.023 Mhz 10.23 MHz
Reference system Time reference	PZ-90 GLONASS time	WGS-84 GPS time

While GPS signals are modulations of the same carriers L1 and L2 for all the satellites, GLONASS carrier frequencies depend on the emitting channel. There are 12 channels for the 24 satellites, and the carrier frequency for a given channel is given by

$$\begin{aligned} f_{L_1} &= (1602 + 0.5625n)\text{MHz for } L_1 \\ f_{L_2} &= (1246 + 0.4375n)\text{MHz for } L_2 \end{aligned}$$

where n is an integer corresponding to the frequency channel. As different L1 and L2 frequencies are used by the different GLONASS satellites, the receiver hardware delays are different for the different satellites or, more precisely, for the different frequency channels. This presents a major issue for time transfer when looking for an accurate synchronization error between two clocks connected to GLONASS receivers.

Taking into account these satellite-dependent receiver hardware delays, the measurement equation for GLONASS data becomes

$$\begin{aligned} L_i &= R + c(-\tau_s + \tau_r + \tau_t) - c\tau_{i,L_i} \\ &+ \frac{\lambda_{L_i}}{2\pi}\phi_{d,L_i} + N_{L_i}\lambda_{L_i} + n_{\phi_{L_i}} \\ P_i &= R + c(-\tau_s + \tau_r + \tau_t) + c\tau_{i,L_i} \\ &+ c\tau_{d,Li}(n) + n_{P_{L_i}} \end{aligned}$$

with R the geometric distance receiver-satellite, τ_s the satellite clock error, τ_r the receiver clock error, τ_t the tropospheric delay, τ_i the ionospheric delay, λ the carrier wavelength, N the phase ambiguity, $\phi_{d,Li}$ the instrumental phase shift on the carrier (receiver + satellite), $\tau_{d(n)}$ the receiver hardware delay for the frequency channel n and n_ϕ and n_p the noise on the carrier phase and on the code measurements respectively.

For the carrier phases, the instrumental phase shifts ϕ_d will be absorbed in the ambiguities. For the codes, the hardware delays $\tau_{d(n)}$ can be either estimated through receiver calibration, and hence introduced in the analysis as fixed values, or estimated by the least square inversion as a new set of unknowns. As there are presently no calibration values available for the existing dual-frequency GLONASS receivers, we have to estimate the corresponding frequency-dependent biases together with the receiver clock, and possibly the station position and tropospheric zenith path delay. One channel is therefore chosen as reference, its hardware delay is fixed to zero. The other frequency hardware delays are determined as biases with the respect to fixed channel. We choose as reference the channel number having the largest amount of observations.

Atomium is based on the analysis of the ionosphere free combination the pseudoranges (named P3) and of the carrier phases (named L3); the coefficients of the linear combination being determined by the L1 and L2 frequencies, they are also frequency-dependent.

A further adaptation of *Atomium* to the GLONASS data concerns the satellite orbits and clocks. For the GLONASS satellites, as for GPS, the IGS provides satellite orbits expressed in the ITRF (International Terrestrial Reference Frame). However, no precise clock product is computed at a 5 minute interval by the IGS for the GLONASS constellation, we therefore use the satellite clock synchronization errors provided by MCC in daily files at a 5-minute sampling rate [6] and expressed with respect to the GLONASS time scale. As we are using post-processed obits provided by the IGS, all expressed in the ITRF, the difference between the reference systems PZ-90 and WGS84 must not be considered here.

One further major difference between GLONASS and GPS is presently the number of available satellites in each constellation : 11 for GLONASS and 29 for GPS. As a consequence, the number of visible satellites is often reduced; over one day, the mean number of available satellites per epoch is 8 for GPS and 3 for GLONASS, as shown in Figure 1. Furthermore, we have frequent tracking interruptions inducing a larger proportion of ambiguities to determine than for GPS data. It is consequently not possible to estimate all the parameters (position, clock, troposphere, frequency-dependent biases and phase ambiguities) from GLONASS observations. We therefore fix the position and tropospheric zenith path delay to their values estimated from GPS PPP on the same RINEX observation files (mixed GPS-GLONASS files), and solve only for clock, frequency-dependent biases and phase ambiguities GLONASS PPP analysis.

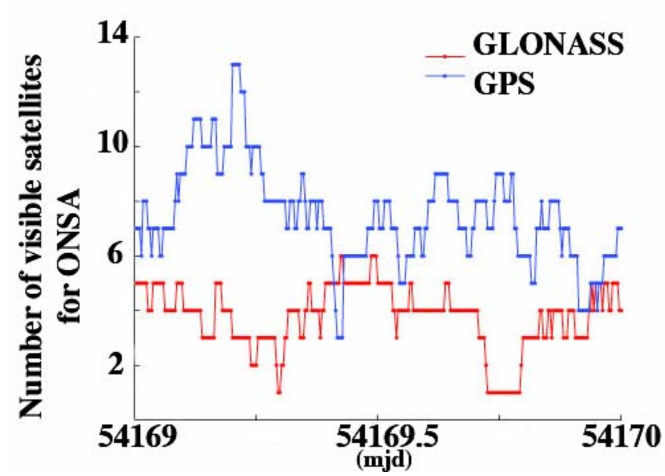

Figure 1.Number of available satellites for ONSA on day 54169

In order to maximize the number of available satellites, the elevation cutoff has been reduced down to 5 degrees. This does not increase the noise significantly and has the advantage of reducing the number of epochs with no observations, and hence the number of discontinuities and jumps in the clock solution. These jumps are due to the pseudorange noise: the clock evolution in each continuous track is determined by the carrier phase measurement, while the clock value is only determined by the pseudoranges as carrier phase are ambiguous. When there is no observation at a given epoch, the carrier phase observation are all discontinued, new ambiguities have to be determined as well as new absolute clock value. Similarly to geodetic GPS time and frequency transfer, the GLONASS time and frequency transfer suffers of jumps at each tracking interruption and each boundary between (daily) data batches analyzed.

III. RESULTS AND DISCUSSION

Time transfer solutions were computed between IGS stations equipped with a GPS+GLONASS receiver. We computed separately a clock solution for each station either with GPS measurements or with GLONASS measurements, both in the PPP mode. As the GPS satellite clocks are referred to the IGS time scale (IGST) and GLONASS satellite clocks are referred to the GLONASS time scale, we therefore got the solutions as *Station clock - IGST* and *Station clock - GLONASS time*. We then computed the differences between the results obtained for 2 stations, and compared the time link so-obtained from either GLONASS or GPS. The results obtained for the time link ONSA-SPT0 are presented in Figure 2.

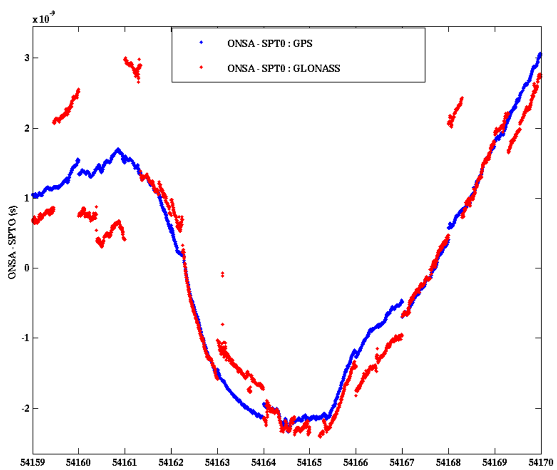

Figure 2. Time transfer solution between ONSA and SPT0 from GPS PPP (in blue) and GLONASS PPP (in red) after removing the drift.

We can observe that while the GPS solution presents the only classical day-boundary discontinuities, the GLONASS solution contains additionally intra-day discontinuities of large amplitudes, due to the existence of epochs without any visible satellite and to epochs where no satellite of the reference frequency channel is visible.

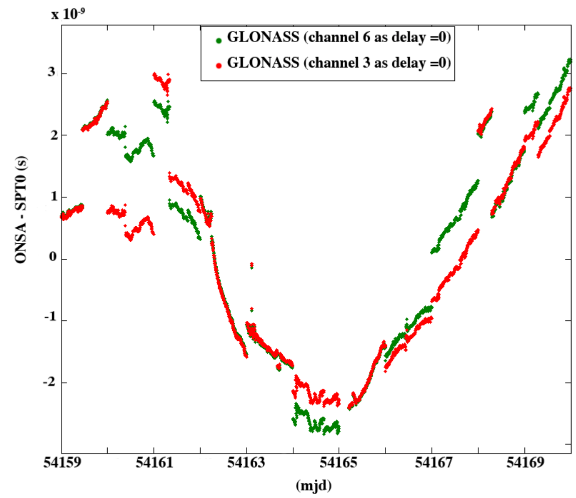

Figure 3. GLONASS solution for ONSA-SPT0 on 11 days. In red, the solution is computed with the channel 6 taken as reference. In green, the solution is computed with the channel 3 taken as reference.

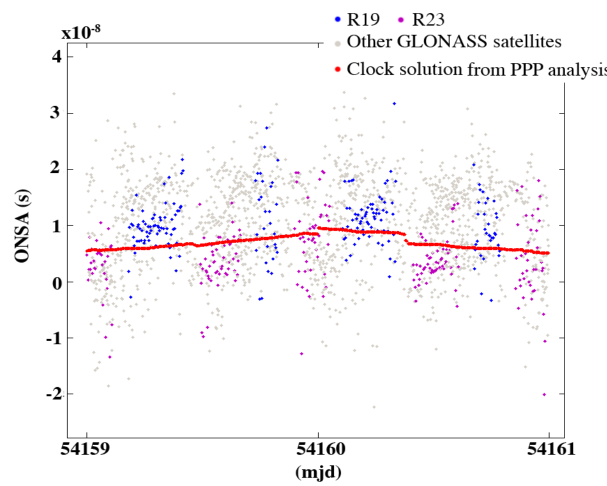

Figure 4. Clock solution deduced from the PPP analysis for ONSA, plotted on the P3 measurements corrected for all geophysical effects, satellite clock errors, geometric distance and antenna phase center variations.

Choosing a different reference frequency channel affects the GLONASS PPP clock solution, as illustrated in Figure 3. While this should cause just a constant offset, it appears that the offset is not constant, due to the fact that the satellites on a same channel still have an offset between their P3 measurements. This is confirmed in the Figure 4, where the P3

measurements made on the PRNs 19 and 23 (both satellites are on channel 3) are show a discrepancy of about 8 ns. The origin of this difference was not yet understood at the time of writing.
Due to the jumps in the solution, the Allan deviation of the GLONASS time link is degraded at short time scales as shown in Figure 5, where the GPS and GLONASS Allan deviation converge for averaging times larger than 3 days. The Allan deviation of the GLONASS P-code time transfer taken from [2] has been plotted in parallel for comparison, shows that adding dual-frequency carrier phase measurements improves the stability at 1hr by a factor of 2.

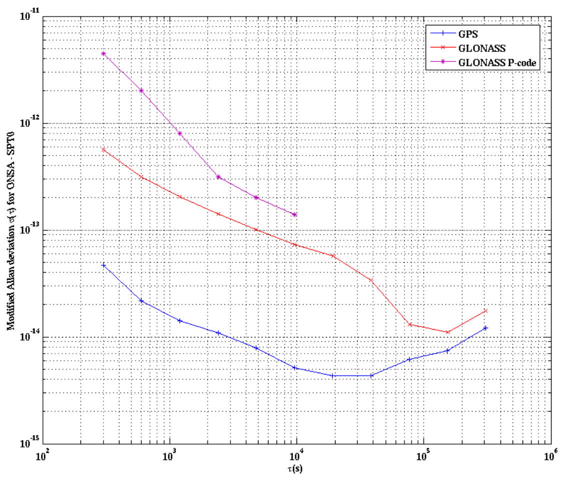

Figure 5. Allan deviation of the time transfer between ONSA and SPT0 computed by GPS PPP and GLONASS PPP. For comparison, the Allan deviation obtained using GLONASS P-code, taken from [2], is also plotted.

As explained before, the satellites of a given frequency channel should have the same bias in their P3 measurements, while it is not the case presently. In order to better quantify the possibility of our approach, the biases for each satellite separately have been determined, while still choosing a reference frequency channel for which the two satellites have similar P3 biases (channel 6). This reduces significantly the jumps in the final clock solution, as shown in Figure 6.

IV. Conclusion

This study aimed at testing the ability of GLONASS to perform time transfer in PPP mode. We therefore adapted the *Atomium* software initially dedicated to GPS, taking into account the the necessity to estimate inter-frequency biases, as no calibration data exist at present. We have shown that it is presently not possible to determine from GLONASS data only the position, the tropospheric zenith path delay, the clock, the phase ambiguities and the inter-frequency biases. We therefore fixed the position and the tropospheric path delay to their solutions deduced from GPS PPP analysis. Our preliminary results for time transfer show that GLONASS solutions still shows large discontinuities at day boundaries and at tracking interruptions and provides a stability smaller than GPS results for averaging times up to about 3.5 days.

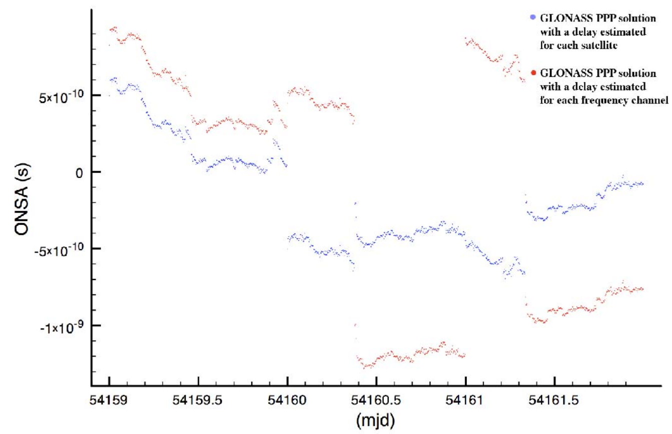

Figure 6. In blue, GLONASS clock solution for ONSA computed with the estimation of one delay for each satellite. In red, same solution, but computed with the estimation of one delay for each frequency channel (both choosing the channel 6 as reference).

These discontinuities are probably due to the conjunction of two phenomena : some epochs where there is no visible satellite of the frequency channel taken as reference, and some epochs without any visible satellite. We however could show that these jumps can be reduced to a maximum of 0.5 ns when estimating one bias for each satellite rather than for each frequency channel.
This problem of jumps will disappear in a combined analysis of GPS and GLONASS data, either in a PPP mode (only if GLONASS satellite clocks corrections are referred to the same time scale as for GPS) or in a differential mode. Indeed, in such a combined analysis, the continuous GPS measurements can be used as the reference to determine the GLONASS inter-frequency biases.

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