GPS-BEIDOU time transfer comparisons

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INTRODUCTION

The use of Global Navigation Satellite Systems(GNSS) data for time and frequency transfer(TFT) began with the US Global Positioning System(GPS) in the 1980s, when Allan and Weiss at the National Institute of Standards and Technology(NIST) have proposed a system using common view observations of GPS satellites [1, 2]. Three decades later, the Russian GLONASS constellation was also considered to TFT[15]. The ionosphere model was introduced in these early days of TFT. Later, in 2003, P. Defraigne and G. Petit[13], in a procedure similar to the All-in-View method[2], adapted the Common View to take advantage of dual-frequency receivers by measuring the observation codes in two different frequencies and performing a linear combination of the GPS *P*1 and *P*2 code pseudoranges to remove first-order ionospheric propagation. The CGGTTS files have information about the clock offsets, which represent the differences between the ground reference clock and a specific GNSS timescale. These clock offsets are obtained from the pseudorange measurements, corrected for the signal travel time (satellite-station), for the troposphere and ionosphere delays, and for the relativistic effects. The clock comparison, then, is obtained as a weighted average of the differences between the two stations CGGTTS results for each satellite separately. With the new GNSS constellations, such as GALILEO and BeiDou, a generalization of the R2CGGTTS software[13]can be done considering not only the most recent version of the Rinex Files (3.02), but also the new codes broadcasted by all GNSS constellations. In this work, our interest was to analyze the free ionosphere combinations of the new GPS observation codes (*C1C*,*C1W*,*C2W*,*C2L*,*C5Q*) and BeiDou codes(*C1I*, *C7I*) tracked by PolarRx4TR PRO-Septentrio receiver.

METHOD

To use the newest observation codes provided by the GNSS constellations, C++ software to read and write any RINEX version file and to combine observation codes to generate regular CGGTTS and modCGGTTS files were implemented using the Ubuntu SDK(Software Development Kit). The Rinex observation and navigation data for analysis were collected from two time-frequency geodetic receivers in our laboratory, which we call RJEP01 (PolaRx2eTR) and RJEP05 (PolarRx4TR PRO). Rinex data generated by RJEP01 are in version 2.11 whereas Rinex data generated by RJEP05 are in version 3.02. Rinex navigation files from the Multi-GNSS Experiment (MGEX) network[12],specifically for the BeiDou satellites, were also collected to evaluate the navigation files for the two receivers. Both receivers were connected to UTC(ONRJ).

ANALYSIS

RJEP01 Data and initial development:

The RJEP01 station tracks the satellites from GPS and SBAS systems. For this work we considered only the GPS satellites identified by *Gn* with *n* varying from 01 to 32 in the carrier frequencies L1(1575.42*MHz*) and L2(1227.60*MHz*). The observation codes tracked are the pseudoranges (C/A,P1,P2) and phases(L1,L2).

To achieve our goal, we first developed a C++ software to generate P3 codes from an free ionosphere combination of the *P*1 and *P*2 and compared our results with those obtained from Fortran R2CGGTTS software (P3 code) developed by Pascale Defraigne and available on BIPM ftp server. By definition, free ionosphere combination means that the ionosphere path delay is virtually eliminated. The ionosphere path delay is usually modelled as proportional to the Total Electron Content (TEC) over the signal path divided by the square of the transmitted frequency f, i.e., TEC/f^2 . The *P*3 code is calculated as follows:

$$P3 = \frac{f_1^2}{f_1^2 - f_2^2} P1 - \frac{f_2^2}{f_1^2 - f_2^2} P2 = aP1 - bP2,$$

where $f_1 = 1575.42MHz$, $f_2 = 1227.60MHz$, $a = \frac{f_1^2}{f_1^2 - f_2^2} = 2.545728$ and $b = \frac{f_2^2}{f_1^2 - f_2^2} =$ 1.545728.

The free ionosphere combination amplifies the pseudorange noise and multipath with respect to the individual code measurements *P*1 and *P*2 [15]. For time transfer, an important parameter is δtr (the receiver synchronization clock error with respect to the reference of satellite clocks). When an external clock drives or synchronize the receiver, δtr gives access to this external clock. This parameter can be obtained from a least-squares fitting of the *P*3 and *L*3 (a free ionosphere combination of *L*1 and *L*2).

We tested both programs (in C++ and in Fortran) and the results were identical (as should be, considering for this purpose, the multiple-precision of floating-point arithmetic in numerical calculations). We then proceeded to investigate the free ionosphere combinations of the new observation codes from Rinex version 3.02.

*RJEP05 Data and the generalization of P*3:

The PolarRx4TR PRO is a high precision receiver with 264 hardware channels and supports all GNSS constelations. For the GPS satellites, the RJEP05 station tracks the 32 satellites identified by *Gn* with *n* varying from 01 to 32 in the carrier frequencies L1(1575.42*MHz*), L2(1227.60*MHz*) and L5(1176.45*MHz*). The observation codes tracked are the pseudoranges (*C1C*,*C1W*,*C2W*,*C2L*,*C5Q*) and phases (*L1C*,*L2W*,*L2L*,*L5Q*). For the BeiDou satellites, the RJEP05 station could track the global ones identified by C11,C12, C13 and C14 in the carrier frequencies B1(1561.098*MHz*) and B3(1268.52*MHz*), as defined by Rinex v3.02. For now, the only observation codes tracked are the pseudoranges (*C1I*,*C7I*) and the phases (*L1I*,*L7I*).

GPS

In the case of the new GPS observation codes, free ionosphere combination for time-transfer using Rinex 3.02 data, namely, *C1W - C2W*, *C1W - C2L*, *C1W - C5Q*, *C1C - C2W*, *C1C - C2L* and *C1C - C5Q*, were done in a procedure similar to the *P*3 to generate modCGGTTS data. Let X_ξ be a generic GPS ionosphere-free combination of Rinex 3.02 pseudoranges X_k and X_l. We can write:

$$X_\xi = \frac{f_i^2}{f_i^2 - f_j^2} X_k - \frac{f_i^2}{f_i^2 - f_j^2} X_l = a_{ij} X_k - b_{ij} X_l$$

where *fi* and *fj* can assume the values f_1(1575.42*MHz*), f_2(1227.60*MHz*) and f_5(1176.45*MHz*) depending on the pseudoranges X_k and X_l considered, which can be *C1C*,*C1W*,*C2W*,*C2L* or *C5Q* implying that a_{ij} and b_{ij} can assume the values for each GPS free ionosphere pseudorange combination as shown in table 1.

Table 1. Values of a_{ij} and b_{ij} for each combination used for GPS in this work.

Combination	f_i(MHz)	f_j(MHz)	a_{ij}	b_{ij}
C1C-C2W	1575.42	1227.60	2.545728	1.545728
C1C-C2L	1575.42	1227.60	2.545728	1.545728
C1C-C5Q	1575.42	1268.52	2.843645	1.843645
C1W-C2W	1575.42	1227.60	2.545728	1.545728
C1W-C2L	1575.42	1227.60	2.545728	1.545728
C1W-C5Q	1575.42	1268.52	2.843645	1.843645

BEIDOU

For the BeiDou constellation, some coefficients used in the calculations are defined differently for each GNSS constellation. As pointed out by O. Montenbruck and P. Steigenberger[16], the Earth gravitational coefficient is defined as 398600.4418 x 10^9 m^3/s^2 in the BeiDou ephemeris model and as 398600.5 x10^9 m^3/s^2 in GPS ephemeris model. The value of Earth rotation rate has also different values for different GNSS constellations. For BeiDou, the Earth rotation rate is 7.2921150 x 10^{-5}*rad/s* and for GPS is 7.2921151467 x 10^{-5}*rad/s*.

There is also a difference in how the clock reference is chosen in different GNSS constellations. In the case of BeiDou, the provided clock offsets are referred to a single frequency B3 signal. Then, it must be applied a differential code bias (DCB) in B1 single-frequency navigation and in B1/B3 dual-frequency navigation. In this work, we obtained a free ionosphere combination of *C1I* (B1 channel - 1561.098*MHz*) and *C7I* (B3 channel - 1268.52*MHz*):

$$DCB_{IF(C1I,C7I)} \approx 2.943681770145979 DCB_{B1-B3}.$$

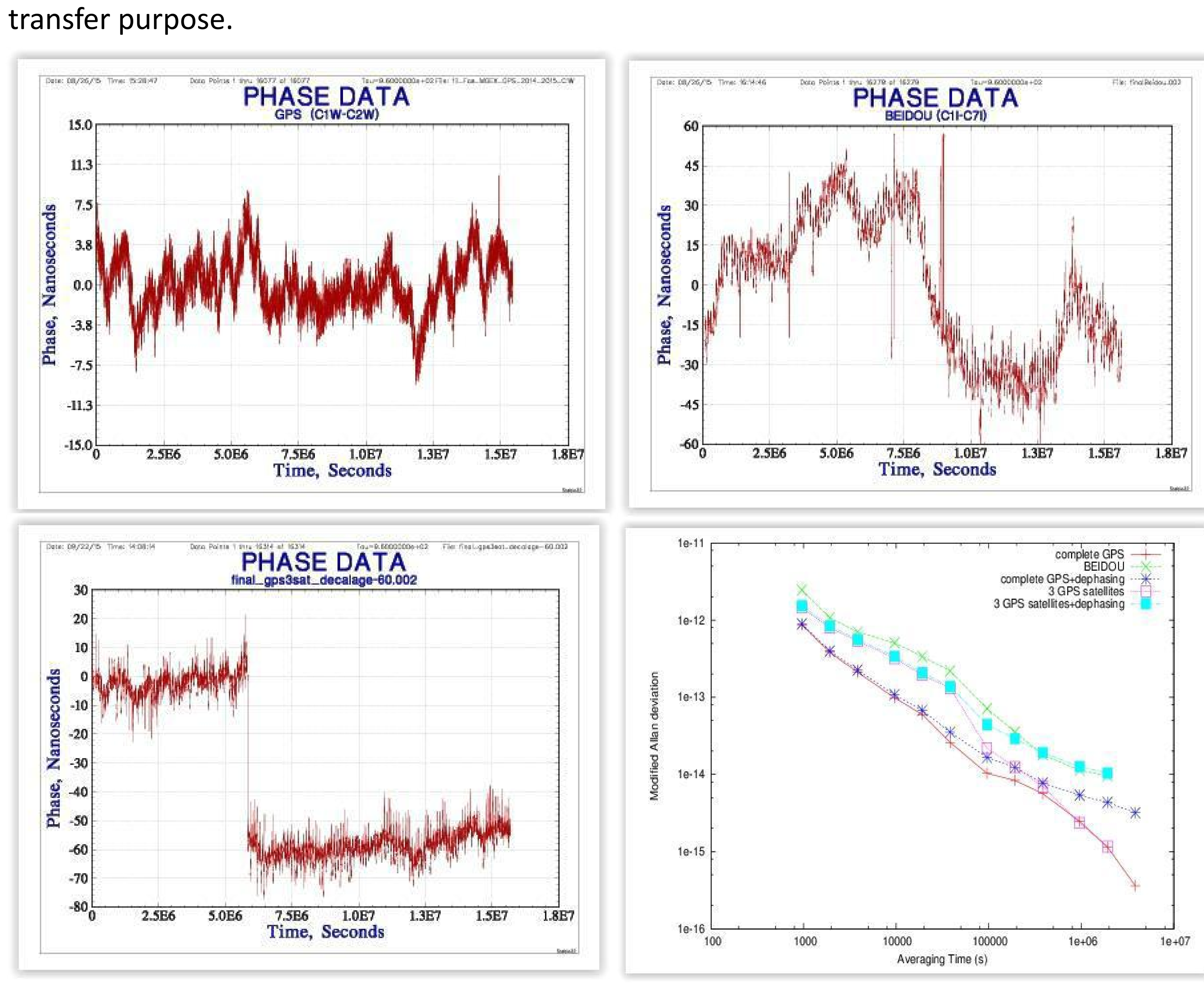
A time correction must be introduced since the data provided by BeiDou satellites are dated in BDT (BeiDou time). The relation between GPS time and BDT is:

$$GPS = BDT + \Delta t_{LS}(2006),$$

where Δt_{LS} (2006) = 14*s* is the difference between GPS and UTC due to leap-seconds in 2006

RESULTS AND DISCUSSIONS

Many changes occurred on satellite data available to GNSS receivers in recent years: the upcoming of the Chinese Navigation Satellite System BeiDou, the European Navigation Satellite System Galileo and the Japanese System QZSS. Also in recent years the GPS and GLONASS got improvements with the new frequencies (L5-1176.45MHz for GPS and G3-1202.025MHz for GLONASS). The possibility to track frequencies on different channels and the more detailed definition of the observation codes stimulated the GNSS community to change significantly the record structure of data present in RINEX files. All these changes implied that was necessary to improve the existing software and to develop new software to analyze GNSS data and become up to date with the technology. To treat the RINEX 3.xx data and to generate a file in a format similar to CGGTTS (modCGGTTS) we had to go deeply in RINEX 3.xx format version and in the R2CGGTTS software to investigate the new possibilities of algorithms and combination codes for time transfer. We also started to combine the newest GPS codes tracked by RJEP05 (using a free ionosphere combination as explained in the previous section) and a free ionosphere combination of BeiDou (C1I,C7I) codes for time transfer purpose.



Figures showing GPS and Beidou phase difference in ns and Mod Allan Deviation