

# Compatibility of the data processing system combined with Global Positioning System and Global Navigation Satellite System

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This paper reports on the compatibility of combined with GPS and GLONASS data processing system. The conditions for the compatibility and comprehensive correction methods of deviation were proposed. Through the using of schemes and algorithms, the objective existence GLONASS deviation can be reduced, and the capacity of GPS+GLONASS complex system can be improved. It was also demonstrated that if the base station receiver and rover were from different manufactures, the deviation from GLONASS pseudo range and carrier phase could lead to the failure of achieving cm level. With the algorithms, in all the applications and in any base stations or networked systems, the GPS+GLONASS complex system could exhibit the advantages over just GPS applied system both positioning accuracy and positioning speed and other RTK positioning performance.

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## 1. Introduction

GPS+GLONASS complex system appeared in 1996 [1]. Three kinds of satellite multiplex system appeared in 2005 [2]. At present, 4 kinds of satellite multiplex system including CNSS appears. GPS is given priority to in these multiplex systems or multiplex receiver data processing methods and other system are used to add correction. For RTK, other multiplex systems are still mainly to help determine the initial whole weeks to improve the initial speed [3]. The contribution of multiplex systems to RTK precision and other performance remains to be further research. Taking GLONASS as an example, the present work investigates the influences of correcting multiplex receiver system deviation for improving the multiplex receiver precision and other deviation solutions.

GLONASS can not only result in the additional positioning satellites for the GNSS field but also cause a series of tough questions for the manufacturers of GPS + GLONASS complex system receivers. No matter from subjective (GLONASS space and the control part) or objective (receiver processing), GLONASS data has a lot of uncertainty no matter in appearance or behavior, for example, incomplete and instability constellation, some satellites' orbit and clock. Therefore, large numbers of factors must be taken into consideration in the design of GNSS receiver.

There are many awkward problems for the compatibility of receivers from different manufactures. GLONASS RTK compatibility problems generally affect the below two major applications [4]:

Level network difference correct from different manufactures' base station receivers.

RTK rover station worked in the 3rd part.

If involving network difference correct, one of the four ways usually refers to: VRS, FKP, MAC and the CBI. GPS system is able to support the four ways. For GLONASS, there are still no proper solutions. The three most common difference protocols, RTCM 2.X, RTCM 3.X and CMR/CMR+, they all can produce GPS+GLONASS complex data. Each agreement support GPS network solutions properly. For example, RTCM 2.X supports FKP and RTCM 3.X supports MAC and non-physical base station.

Each network technology mentioned above is based on the following assumptions: the first is the so called general carrier ambiguity. It usually requires that reliable fixed double difference (DD) ambiguity among a few main base stations and some auxiliary stations. Obviously, if network solutions are needed, whole week double difference problem of each single baseline must be solved firstly. In other words, a good network solution is actual derive from methods of classical single baseline solution. This is why we should first consider the basic problems.

## 2. The main issues

### 2.1 Half week ambiguity

Early launched GLONASS satellites (Numbers # 1, 4, 8, take up the channel 6 and 7) only transit L2 and P code [5]. The recent launched GLONASS-M satellite (number 13 satellite currently occupies channel -2 to 5) can simultaneously transmit L2 carrier C/A code and L2 carrier P code. Signal specific summed up as follows: L2 C/A signal is modulated by known structure. So it's very easy to restore polarity and provide carrier phase

observation with ambiguity of whole cycles. L2 P signal used in GLONASS-M is modulated by unknown data structure. So it is usually can't restore correct polarity and provide carrier phase observation with ambiguity of whole cycles. There's no any data modulation in L2 P signal of early launched GLONASS satellite. So it can restore correct polarity and provide carrier phase observation with ambiguity of whole cycles.

RTCM protocol recommended GLONASS receiver which support L2 and it can: Tracking the L2 C/A signal of latest launched GLONASS-M satellites. Tracking the L2 P signal of early launched GLONASS satellites.

Early factory's GLONASS receiver didn't support the two points above [6]. Even if the latest receiver may have accepted the proposal, we cannot assure all receivers properly set the mark CA/P of GLONASS L2. For example when we do the experiment test of a third party OEM board, we find that all GLONASS code marked as C/A code. Even when this OEM board tracked early launched GLONASS satellite, L2 actually haven't transmitted the code.

Therefore, rover station receiver can't 100% assure that the data from third party reference does not contain half week integer deviation of GLONASS L2.

## 2.2 A quarter of a week ambiguity

RTCM/RINEX organization had argued about that about the same frequency signal measurement of different carrier may have 0.25 week deviation ambiguity and the conclusion is certain [3]. If a receiver for some GLONASS satellite produce L2 CA data, and for other GLONASS satellite produce L2 P data, then 0.25 week deviation ambiguity problem may appear. Some firms have used 0.25 week to correct, but some of them are still fuzzy. The some situation occurs in GLONASS L1 C/A and L1 P.

## 2.3 Hardware deviation

Because of the FDMA access technology adopted by GLONASS system, deviation from hardware is existed. When different signal via different head port of RF the delay caused by frequency will be inserted to the pseudorange and carrier phase measurements. The main factors lead to these deviations are as follows: Unperfected design of the head of RF lead group delay (GD); The change of the part of device lead group delay of each receiver; The environmental conditions (temperature is the main factor) lead the GD change of each receiver; Relevant tracking algorithms main lead the change of observation deviations and the algorithms provide very similar GD.

Below we discuss the deviation from different hardware between base station and rover station (RTK mode). Any deviation change (according to temperature speaking) may be caused by both rover station and base station. If base station and rover station have the same design of hardware and they use the same tracking algorithms, factors 1 and 2 will not lead the deviation. The only sources of deviation are from factors 3 and 4. The

preliminary experience is 2 and 3 factors can cause pseudorange deviation, however carrier phase offset even exists, it will be difficult to clearly observed. If base station and rover station receivers are different or use different tracking algorithm, then factors 2 and factor 3 will also be the main causes of pseudorange and carrier. In reference [7] and [8], example of the pseudorange and carrier deviation caused by different receiver can be found.

Fig. 1 shows the example of carrier phase bias model between different manufacture's receivers of single difference (SD, between receivers). Although in many cases, the relative bias frequency is linear, the assumption is not 100% be set up.

## 3. Solutions

### 3.1 GLONASS carrier bias model

Simplified SD model of L1 or L2 GLONASS carrier phase on short base line can be said as the following formula [9]:

$$L(j)=R(j)/\lambda(j)+B(j)+n(j)$$

Here,  $j$  represents GLONASS satellite number;  $L(j)$  is measured carrier(unit: week);  $\lambda(j)$  is wavelength (unit: m);  $B(j)$  is whole carrier deviation(unit: week);  $n(j)$  is noise path error(unit: week); Different satellites have different values of  $L, R, B$  and the values changes with time goes on. By deduction, whole carrier deviation can be expressed as:

$$B(j,t)=N(j)+b(j)+\text{clock}(t)/\lambda(j)$$

Here,  $t$  is time (unit: second);  $N(j)$  is SD carrier phase ambiguity(unit: week);  $b(j)$  is SD carrier phase hardware deviation(unit: week);  $\text{Clock}(j)$  is SD's clock error.

Each satellite has different  $N$  and  $b$  value. When the number of satellite is given,  $N$  value is a constant until the satellite loses lock. The given satellite  $b$  value is a constant (at least when the temperature is stability). Regardless of whether the satellite is out of lock, it is relative to hardware itself. The differences of  $N$  value and  $b$  value on carrier losing lock or not are the first principles to follow in GLONASS hardware deviation correction.  $\text{Clock}(t)$  value changes over time, but it is always the same for all satellites. Hardware deviation  $b$  changes indirectly with satellite number  $J$ . Because the majority of "relative" GLONASS satellites use the same frequency number, the "relative" satellite has the same  $B$  value.

In this case, GLONASS carrier and GPS carrier is similar (even though there are some differences). It shows that, in RTK mode, GLONASS DD whole ambiguity can be safely calculated without considering any hardware deviation correction. If the base station and rover station are from different manufactures and rover station don't know the algorithms of base station firmware then: ① Value  $N$  on L2 of GLONASS satellite at some time may

be half integer. ② Rover station corresponding to the GLONASS satellite N value may exist 0.25 week deviation and that depends on whether the base station has adjust the 0.25 week ambiguity. ③ All b values are usually not zero. In this case, hardware deviation correction is needed when using GLONASS and give the attached half week hypothesis. If there's no initial calibration, GLONASS DD ambiguity can not get the fixed solution of whole week or half week. Once correction goes on, either unlocked or restart deviation b can apply to the corresponding GLONASS carrier.

### 3.2 GLONASS problem solutions

Pseudorange and carrier phase hardware deviation is the same as half or 1/4 ambiguity and is the main problem affects GPS+GLONASS complex receiver. We put forward some solutions, these solutions include: ① OTF correction of pseudorange deviation. ② The provision and processing receiver name. ③ The support for whole week and half week ambiguity hypothesis. ④ The optional 1/4 week correction. ⑤ Support receiver name database. ⑥ OTF correction of carrier deviation.

Figure 2 shows the schematic structure of GLONASS carrier phase correction process. The following is the explanation of these solutions:

First of all, pseudorange hardware deviation is meter to km magnitude and will be relatively stable over time, so proper random model can be used for modeling. Deviation estimation is actually OTF correction and it's described in detail in the literature [7]. GLONASS pseudorange deviation correction does not require the receiver specially enter the correction mode. Instead the receiver provides high quality floating or fixed ambiguity solution even if it is in the correction process. The pseudorange deviation correction will restart when base ID or base receiver's name changes. Correction process includes different protection program in order to prevent wrongly frozen the pre-correction deviation. As the pseudorange hardware deviation may exist in the same design of receivers, pseudorange correction algorithm can be used the same base station and also can be used for third party base station.

To ensure the efficient of GLONASS data processing, RTK rover receiver need to know the name of the base station receiver. So we need to establish the receiver name database. Once the GNSS organization provide carrier deviation model clearly, our receiver will allow to adopt the receiver name database. Receiver is better to adopt the recommendation, tracking GLONASS L2 signal, of RTCM. This can provide whole week carrier ambiguity. By default, we believe that third party base station can support the carrier integer ambiguity on L1 and L2. In this way, all the rover receivers can work under the assumption

of integer ambiguity. In addition, if prior knowledge of third-party base station can only provide half of the week on L2 ambiguity, then, the rover receiver can be set to L2 on the half week ambiguity model, that is, half of L2 is still able to get a fixed integer ambiguity solution.

Rover station receiver can also correct the 1/4 week ambiguity in order to match GLONASS L2 C/A and L2 P data. At here, the rover station receiver will take advantage of almost completely linear relationship of L2 carrier deviation model with third party receiver (Fig. 1). Without this correction, for the GLONASS satellites launched earlier before which frequency's number is 6 and 7, 1/4 week problem will occur. Users will turn on or off 1/4 week correct function according to the type of base station receiver.

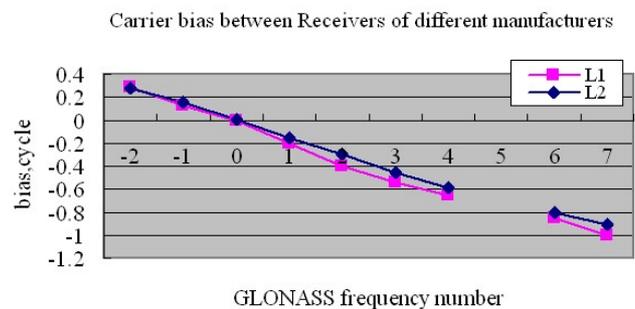


Fig. 1. The example of carrier phase bias model between different manufacture's receivers of single difference (SD, between receivers). Rectangle line represents L1 bias in different cycle whereas rhombus line is the bias of L2.

If reliable information about hardware deviation can be obtained, receiver should apply the same type GLONASS carrier data compensation before RTK solution and store in memory in the receiver the information of each name known receiver. This principle is similar to the antenna center offset correct principle used by most current RTK receiver. However, there are official table of antenna correct and for GLONASS hardware deviation there is no similar data. Therefore, it limits the receiver on the market to implement deviation compensation for third party reference data. In addition, we carried out the following test. When the working condition is in third party receiver, we estimate the first GLONASS deviation model (Fig. 1). A few days later, when a same receiver work in the same third party base station in the same condition, we applied this model. The results showed that application of this model can compensate for third party base station data and eliminate the DD carrier deviation. And, for different third party receivers, similar correction is able to be given. Through this operation, all the correction values can be inserted into the database of receiver name and compensate the base station data of receiver name database listed.

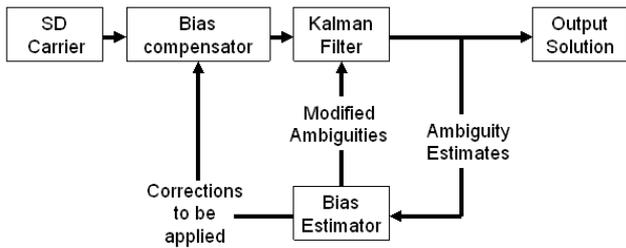


Fig. 2. Schematic structure of GLONASS carrier phase correction process. In order to make the search go with integer search, ambiguity itself as deviation needs correction and compensation.

In most cases the rover station database is not complete and cannot apply the compensation technology. Therefore, when the receiver database cannot obtain the correction receiver name, receiver will automatically apply the OTF carrier deviation correction technique. OTF correction thinking is very simple: take the SD carrier hardware deviation as a stochastic model's priori unknown parameter. The method is simple, but its implementation process is not simple.

Carrier ambiguity based on integer ambiguity searching and makes DD ambiguity convergence for integer solution. Therefore, in order to make the search go with integer search, ambiguity itself as deviation needs correction and compensation. Compared with pseudorange deviation correction, its structure is somewhat complex. After RTK Kalman filter updated the current ambiguity estimation, GLONASS carrier deviation estimation was entered. Not only used to estimate the SD carrier measurement correction, but also modified ambiguity to ensure DD as integer. In consideration of the quasi linear deviation model, which actually is a generally purpose deviation estimation. Through the feedback of SD ambiguity estimation, actually corrected DD and they are stable with time. No matter whether half week hypothesis is existed or not, estimation of deviation is able to be made. Of course, when given half week hypothesis brings better effect. In short baseline (less than 10 km) cases, ionosphere, troposphere and the track error can be ignored. Deviation estimate has good stability. We had gotten good repeatability when working in the third party receiver.

When the user works in the network environment, the short baseline situation is rare. We usually get a baseline for 30-70 kilometers beyond. When the distance changes, ionosphere, troposphere, orbit error and carrier deviation is not easy to distinguish. Linear hypothesis can handle this situation, but half and 1/4 week problem mentioned before lead to no application of linear hypothesis. So for any RF design deviation correction must be taken.

For carrier deviation correction, long baseline is the real challenge. Using appropriate stochastic model can give better accuracy of deviation estimation. Although these estimates may be a bit "deviation" of their original

values because of the ionosphere, troposphere and the track error, they can still get better ambiguity results when the sky condition is poor and lose lock.

For a selected satellite, extra precautions for capturing suspected deviation is designed to stop the satellite for ambiguity search and correction. In addition, these measures also take the deviation drift caused by temperature into consideration and allow small deviation correction without reduction correction.

## 4. Some specifications

### 4.1 Specific Detection Method

All the description about illustration of capability is from PC and RTK engine. The engine is with complete real-time working way and the work is the same to the receiver. All the description about illustration of capability are statistically processed; with enough data to support high reliability estimation.

Compared with GPS, GLONASS usually can not improve fixation solution RTK precision, but does not deteriorate. In RTK engine, the primary task of GLONASS is to obtain fixed solution of ambiguity faster and more reliable. What's more, in some condition, the fixed solution can be maintained. The coming of so called "time to first fix" (TTFF) statistic is explained.

In each case, the process of capability estimation include automatically restart RTK engine every 600 seconds (not reset the GLONASS carrier phase correction) to obtain enough independent length fixed RTK test data. And then integrate each result of the tests to build cumulative TTFF distribution. In order to demonstrate the system, we selected 50%, 90% and 99% TTFF distribution of scattered points. In fact in any case, we can provide TTFF distribution chart which is similar to single GPS system. It is noteworthy that, in many cases when take 50% scatter of TTFF distribution, the difference is not significant between conventional techniques and latest technology. However, when take 90% and 99% scatter distribution, the difference changes significantly. This anomaly is the worst case (usually the most users worry), new technology show its strong performance here.

### 4.2 Base Station of the Same Equipment in RTK Mode

Fig. 3 is the 3 different kind of short base line 99% fixed solution ambiguity.

In short baseline case:

1) Comparing with using GPS signal only, adding GLONASS can improve the positioning capability preferably.

2) Taking OTF GLONASS carrier phase deviation correction makes the system have the same capability with taking the same base station assumption.

3) RTK works in third party network.

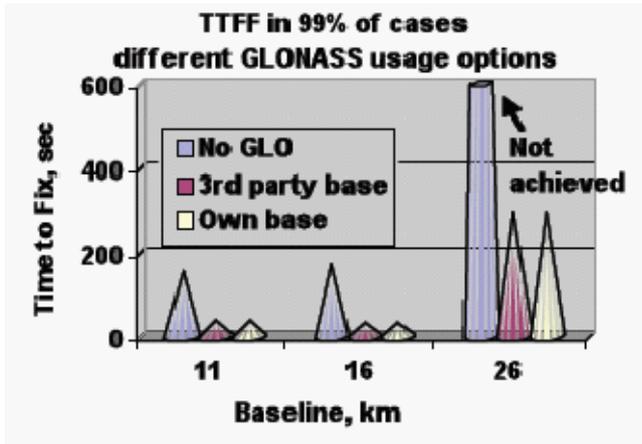


Fig. 3. The Same Types of Base Station" TTF Distribution. Horizontal axis represents baseline length and longitudinal axis represents time to fix. 3 cases, no GLONASS signal, working in third party base station and working in own base station, are shown in the figure.

Take third party equipment as base station, but the device manufacturer's condition is unknown. The RTK system performance is shown in Fig. 4. It can be seen that GLONASS data from third party base station can significantly improve TTF performance. When the elevation mask value was set to 20 degree, it can be more clearly seen that 99% of the points cannot achieve TTF in 600 second interval.

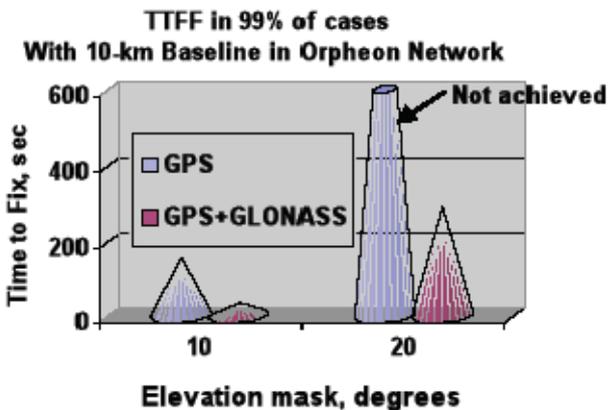


Fig. 4. TTF of Orpheon Network TTF (Short Baseline). Horizontal axis represents elevation mask degrees and longitudinal axis represents time to fix. 2 cases, only GPS signal and GPS+GLONASS signal, are shown in the figure.

Differential use of the network, the 10 km baseline is not a typical situation. Usually in the inside or outside the area of network, the rover station works in the 30-90 km baseline. For long baselines, effective OTF GLONASS carrier deviation is not as easy as short baseline described above. However, it can be seen from Fig. 5 that even in the 58 km baseline case, compared with the GPS single

system, through the solution of third party base station GLONASS data, TTF improved significantly.

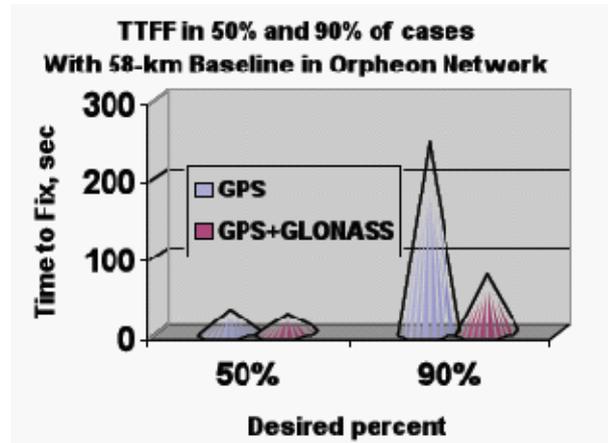


Fig. 5. TTF of Orpheon Network TTF (Long Baseline). Horizontal axis represents desired percent and longitudinal axis represents time to fix. 2 cases, only GPS signal and GPS+GLONASS signal, are shown in the figure.

It can be seen from Fig. 5 that when taking 50% points, two kinds of circumstances TTF are almost the same; But when taking 90% points, TTF of GPS+GLONASS complex style increased significantly. In other words, when GPS signal is strong, GLONASS is not important, but when the fixed solution cannot be obtained quickly due to the poor GPS signal, the adding of GLONASS becomes useful.

### 5. Conclusions

Taking the new algorithms with GLONASS added will bring the improving of positioning performance; though in suitable working condition is not significant, it can dramatically improve the observation data quality and capacity of complex receiver for poor working condition. Application value is powerful.

By using latest correction scheme of GNSS receiver's GLONASS deviation correction compensation algorithm, objective existence GLONASS deviation can be reduced. The problem that by adding GLONASS signal can only improve RTK initialization speed but multiplex receiver data processing precision cannot be improved can be solved.

Application of the latest GLONASS data processing algorithm provides references for the research and development of multiplex receiver. It is very significant for speeding up the standard development process of multiplex satellite navigation and positioning receiver.

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