Biases in GNSS Data Processing

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1. INTRODUCTION

Since May 2003, CODE (Center for Orbit Determination in Europe serving as one of the global analysis centers of the International GNSS Service) has been providing orbits, station coordinates, Earth rotation parameters (ERP), troposphere and ionosphere products from a rigorously combined processing of GPS and GLONASS observations.
In 2005, CODE has started an initiative to provide also clock corrections for the GLONASS satellites. Due to the sparse GLONASS tracking network at that time, the estimation of the inter-system and inter-frequency biases were very unreliable and the time series of clock corrections revealed many interrupts. For that reason, regular generation of such a clock product was postponed.
Nowadays, a global coverage of GLONASS tracking sites is available. We decided to develop a new, refined GPS/GLONASS clock product generation system (on the basis of the old one mentioned above).
The considerably increased tracking data redundancy allows a profounded interpretation of the biases. They are of particular interest when comparing and combining GPS/GLONASS clock products from different analysis centers. They may also be studied to be prepared for the upcoming new GNSS signals and systems.

2 CODE MULTI-GNSS CLOCK ESTIMATION

GNSS orbits, ERPs, and station coordinates are introduced as known from the double-difference solution. **Figure 1** illustrates the processing flow to generate the GPS/GLONASS rapid clock corrections.

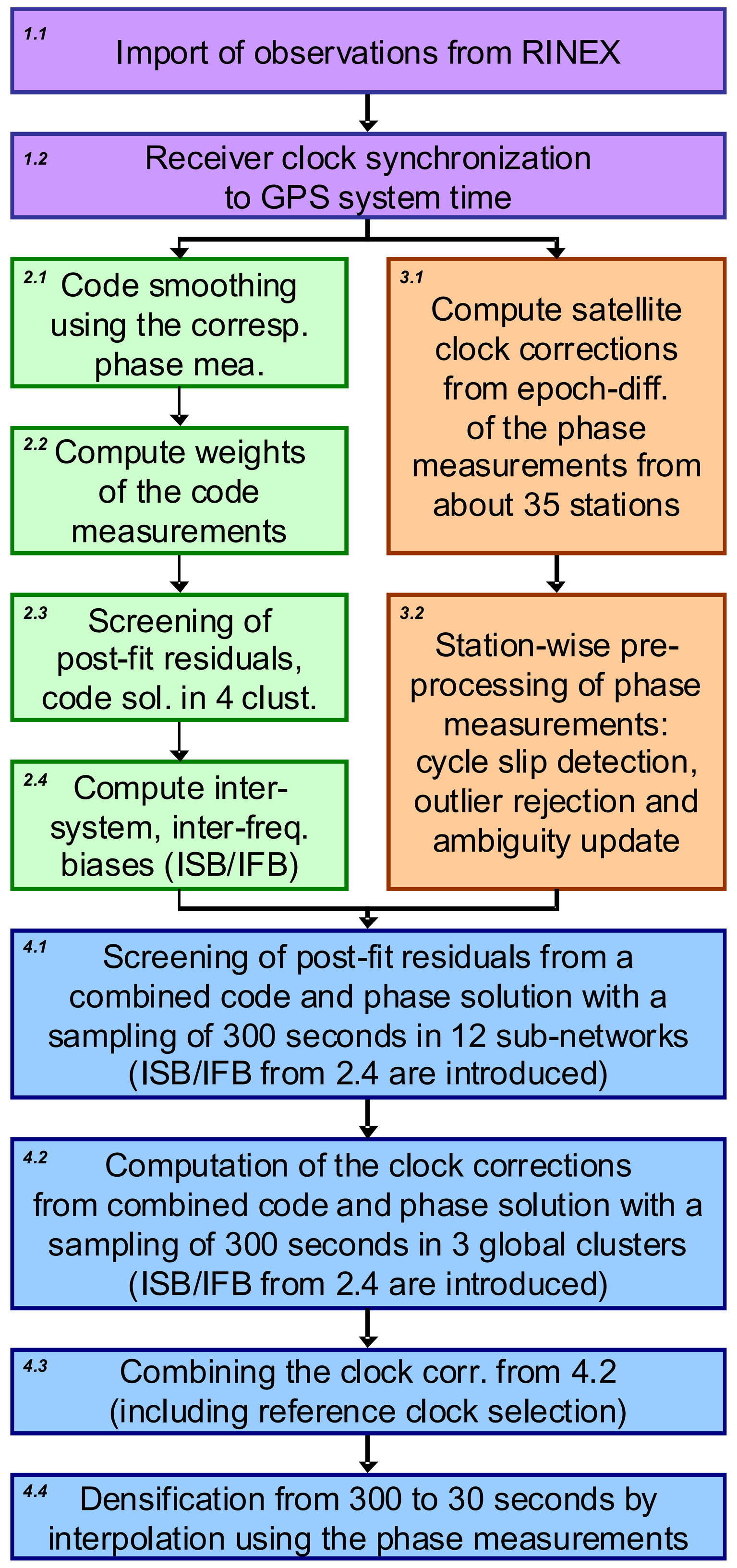

Figure 1

3. DISCUSSION OF THE GPS/GLONASS INTER-SYSTEM BIAS PARAMETERS

Types of Bias Parameters

In case of the GPS/GLONASS clock processing we have to consider the following types of code biases:

- Differential code bias (DCB: P1-C1/P2-C2) exist not only for GPS but also for GLONASS.
- Inter-system bias (ISB) responds to the difference between the GPS and GLONASS receiver time frame.
- Inter-frequency bias (IFB) appears for GLONASS because each satellite uses its own frequency for the signal transmitter. The antipodal satellites share the same frequencies.

In GNSS data processing, only the sum of these three biases can be assessed, e.g., by estimating one bias per GLONASS satellite with respect to all GPS satellites for each GPS/GLONASS tracking station.

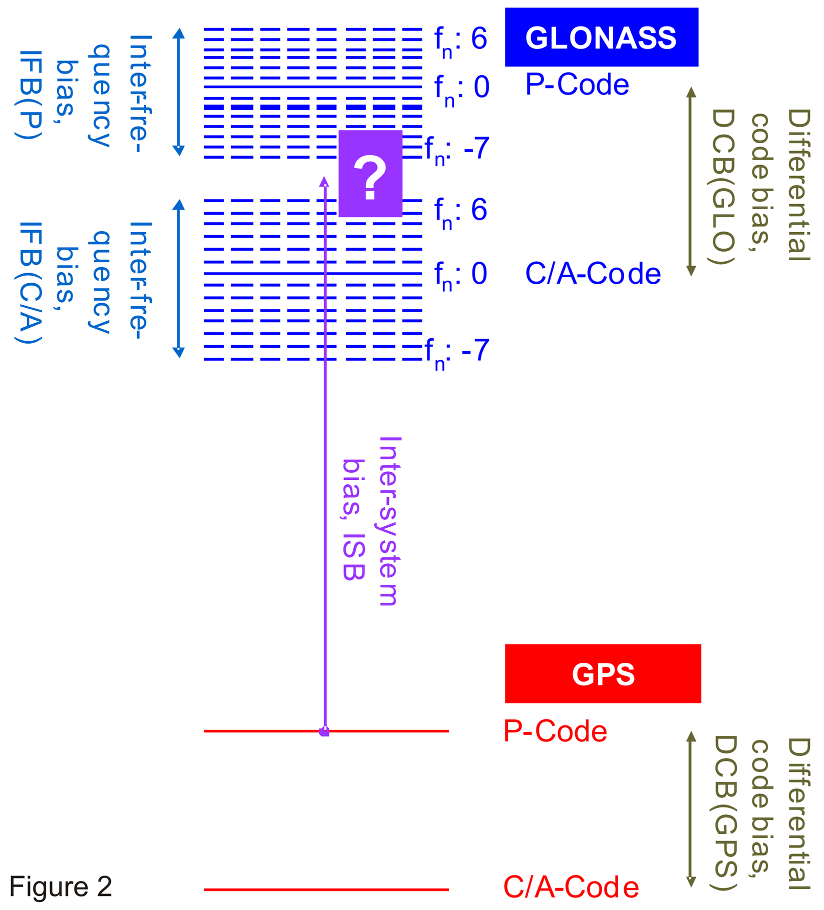

Figure 2

Inter-Frequency Biases (IFB)

IFB need to be considered as soon as code measurements from GLONASS are involved. **Figure 3** shows that they are not only specific for a receiver type but they are typical for each individual receiver (or at least groups of receivers). The daily IFB estimated from 4 weeks (September 2010) are plotted for five stations (all equipped with TPS E_GGD receivers). The repeatability of these values for a single station is much smaller than the differences between the individual receivers. Other receiver types give similar results.

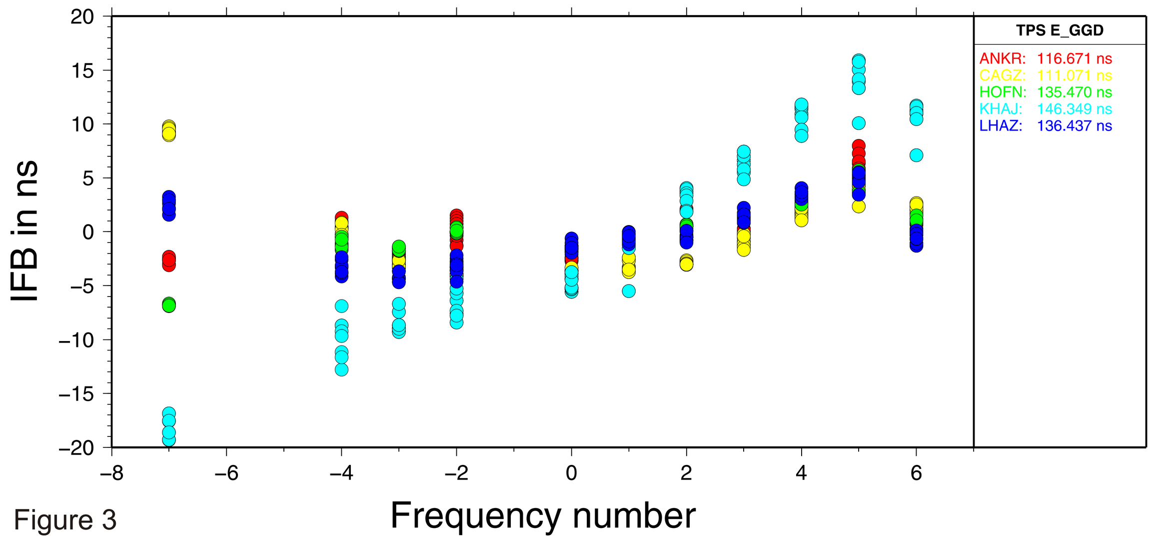

Figure 3

A zero-mean condition for all IFB parameters of a station and day has been applied. Consequently, the result depends on the frequency channels used by the currently observed satellite constellation.
Alternatively, the IFB for one particular satellite (frequency channel) may be set to zero (or any other value) for all stations. If this particular satellite is not available, the reference changes as well.

Differential Code Bias (DCB)

DCB occur at the satellites as well as in the receivers. As far as receivers provide P- and C/A-code measurements, the P1-C1 and/or P2-C2 DCB can directly be extracted from the (RINEX) observation files.

- In case of GPS, they can be determined as part of the clock estimation procedure.
- For GLONASS we have the IFB, which need to be assumed as different for the P- and C/A-code. For that reason the definition of the P1-C1 (or P2-C2) DCB for GLONASS is related to the assumptions introduced for the IFB.

Figure 4 shows the DCB as they are computed for individual GPS and GLONASS satellites directly from the RINEX observation file. The big variations of the results for the individual GLONASS satellites (top right panel) confirms that the IFB are different for the P- and C/A code measurements.

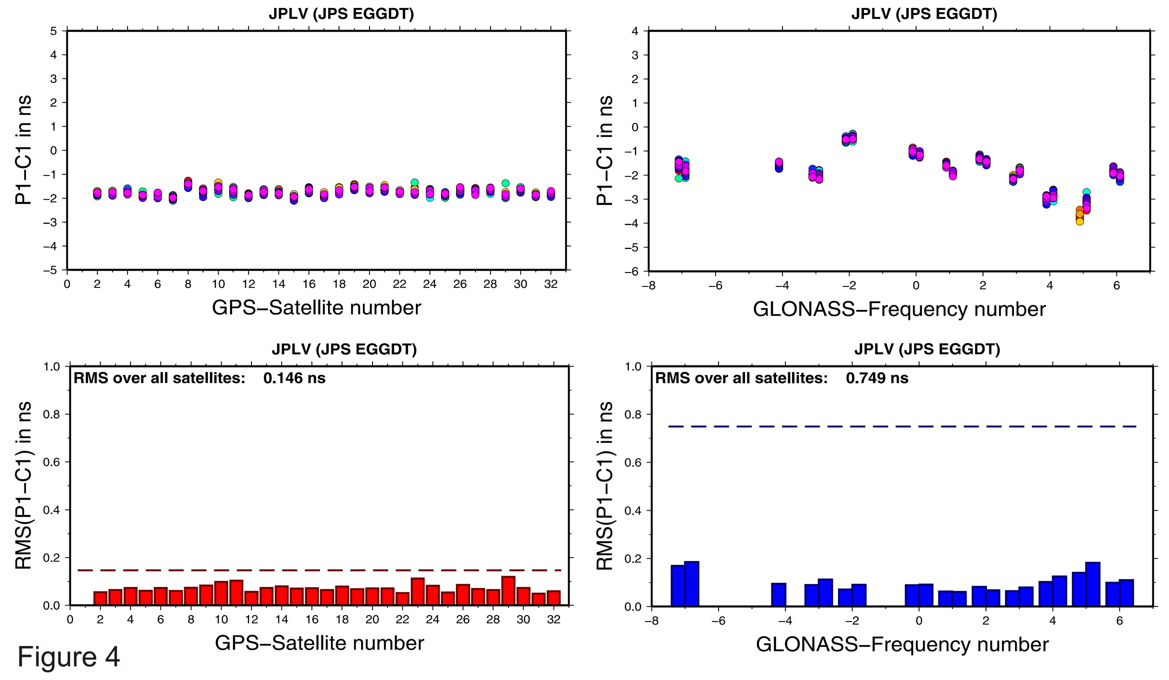

Figure 4

The two bottom panels show the RMS of the DCB values for each individual satellite estimated from 30 days in September 2010 based on the RINEX data. It is compared to the overall value obtained from one single receiver DCB values for all satellites (dashed line).
Note that the RMS of the DCBs per satellite become nearly equal for GPS and GLONASS, if no correction for the satellite DCBs is applied.

Inter-System Biases (ISB)

The reference for the ISB estimates is not fixed because it depends on the assumptions for the IFB and DCB on the GLONASS side.
Nevertheless, the results in **Figure 5** show that the ISB dominate the biases. One bias per satellite and station has been computed from 30 days in September 2010. The variation between the satellites is much smaller than the differences between the ISB of different receiver types. It is also worth mentioning, that the six "exceptional" values for TRIMBLE NETR5 type are related to latest receiver firmware version (4.15 or higher).

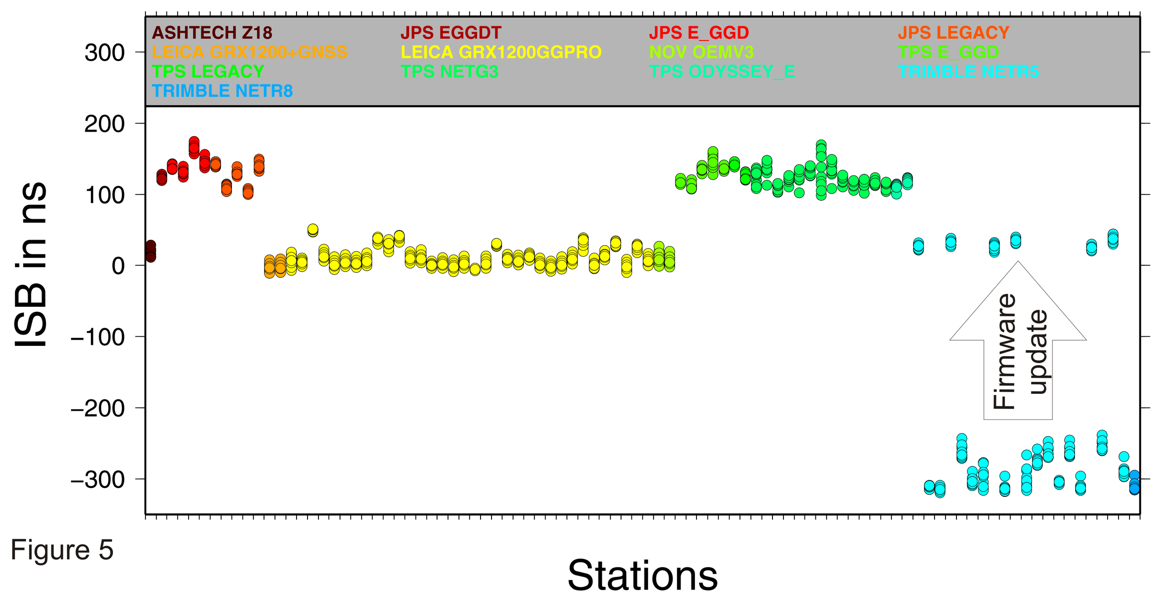

Figure 5

4. CONCLUSIONS AND CONSEQUENCES

In the combined GPS/GLONASS clock estimation process, one bias parameter per station and frequency/satellite needs to be computed.

- The reference for the bias parameter is individually defined for each solution because it includes the ISB, IFB, and DCB. For that reason, the reference is realized either by a zero-mean condition or by the definition of a "perfect" receiver without any bias.
- The GPS/GLONASS PPP procedure is not affected by the assumptions of these biases as long as one bias per station and frequency/satellite is estimated.
- The inter-system bias parameter depends not only on the receiver type but also on the firmware version (as seen in Figure 5).
- To make independent solutions comparable and prepare them for a combination (e.g., in the frame of the IGS), the estimated biases and the types of used code measurements for GLONASS is needed. This information may, e.g., be provided together with the clock results in the header of the clock RINEX format:

```
AVAILABLE RECORD TYPE                                           COMMENT
G    7 C1P C1C L1P C2P C2C L2P L2C                              SYS / # / OBS TYPES
E    4 C1C L1C C5Q L5Q                                          SYS / # / OBS TYPES
R    8 C1P C1C L1P L1C C2P C2C L2P L2C                          SYS / # / OBS TYPES
NEEDS TO BE EXTENDED TO REPORT WHICH "OBS. TYPE" WAS USED       COMMENT
AT WHICH STATION, RECORD TO BE EXTENDED (REDEFINED):            COMMENT
G    ZIM2 14001M008      4 C1P L1P C2P L2P                      SYS / STA / OBS TYPES
E    ZIM2 14001M008      4 C1C L1C C5Q L5Q                      SYS / STA / OBS TYPES
R    ZIM2 14001M008      4 C1C L1C C2C L2C                      SYS / STA / OBS TYPES
RECORD TYPE TO BE DEFINED                                       COMMENT
G    ZIM2 14001M008           0.000      0.000                  STATION / BIAS / RMS
E    ZIM2 14001M006          -4.461      0.033                  STATION / BIAS / RMS
R02  ZIM2 14001M008         -12.556      0.033                  STATION / BIAS / RMS
R03  ZIM2 14001M008         -11.556      0.033                  STATION / BIAS / RMS
...
```

- Consequently, the ISB of an individual (independent) daily solution depends on the station selection and satellite constellation considered in the processing.

This last point is illustrated in **Figure 6**, showing the series of satellite clock estimates for one GLONASS satellite (red curve) referring to the IGS time scale. The blue curve is the same result, but after re-aligning the daily estimated bias parameter to a monthly solution.

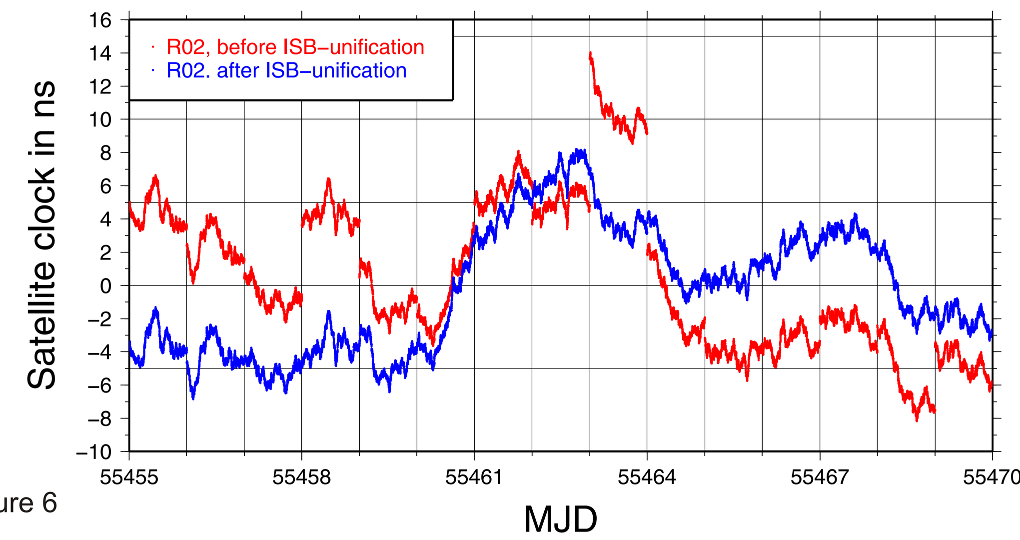

Figure 6

The unification of the daily estimated ISB is also important if the satellite clock results will be further analyzed (e.g., by Allan deviations computed from one week in September 2010). This is illustrated in **Figure 7** (left before and right panel after the unification).

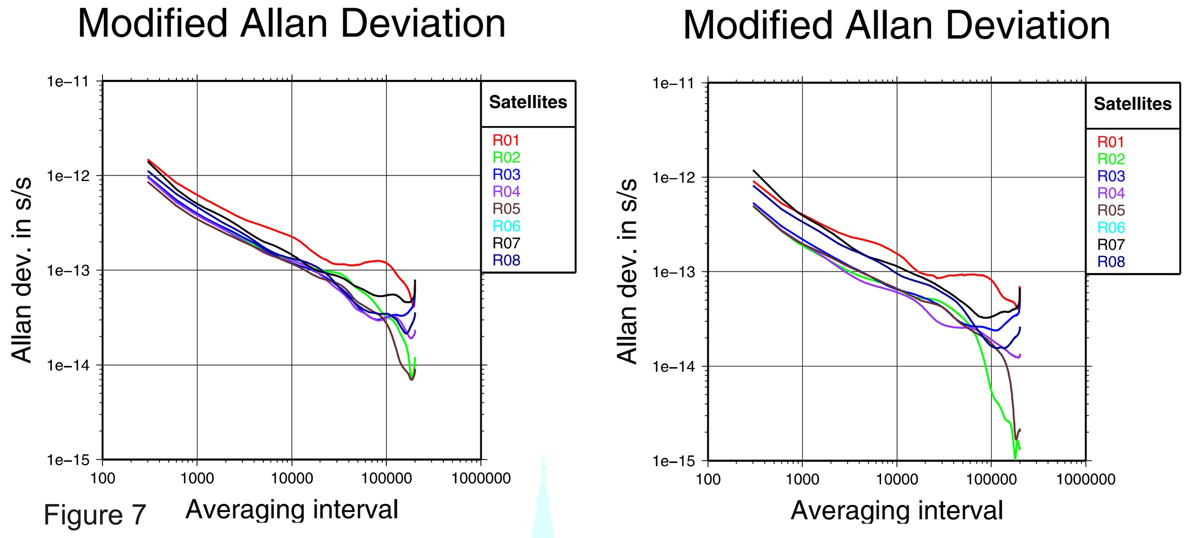

Figure 7

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