CODE's New Combined GPS/GLONASS Clock Product

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INTRODUCTION

Since May 2003, CODE has been providing orbits, station coordinates, Earth rotation parameters, troposphere and ionosphere products from a rigorously combined processing of GPS and GLONASS observations.
In 2005 it has been 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 had many gaps. For that reason, the initiative for such a product has stopped.
With the global distribution of the GLONASS tracking sites available today it makes sense to solve for GLONASS satellite clock corrections. Starting from the old procedure a new combined GPS/GLONASS clock processing procedure has been developed at CODE.

PROCESSING CHART

GNSS orbit, 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.
The generation of the final product makes use of the GNSS satellite clock correction from the rapid product to perform the residual screening step by PPP. In addition, a further densification of the 30 to 5 seconds sampling runs at the end.

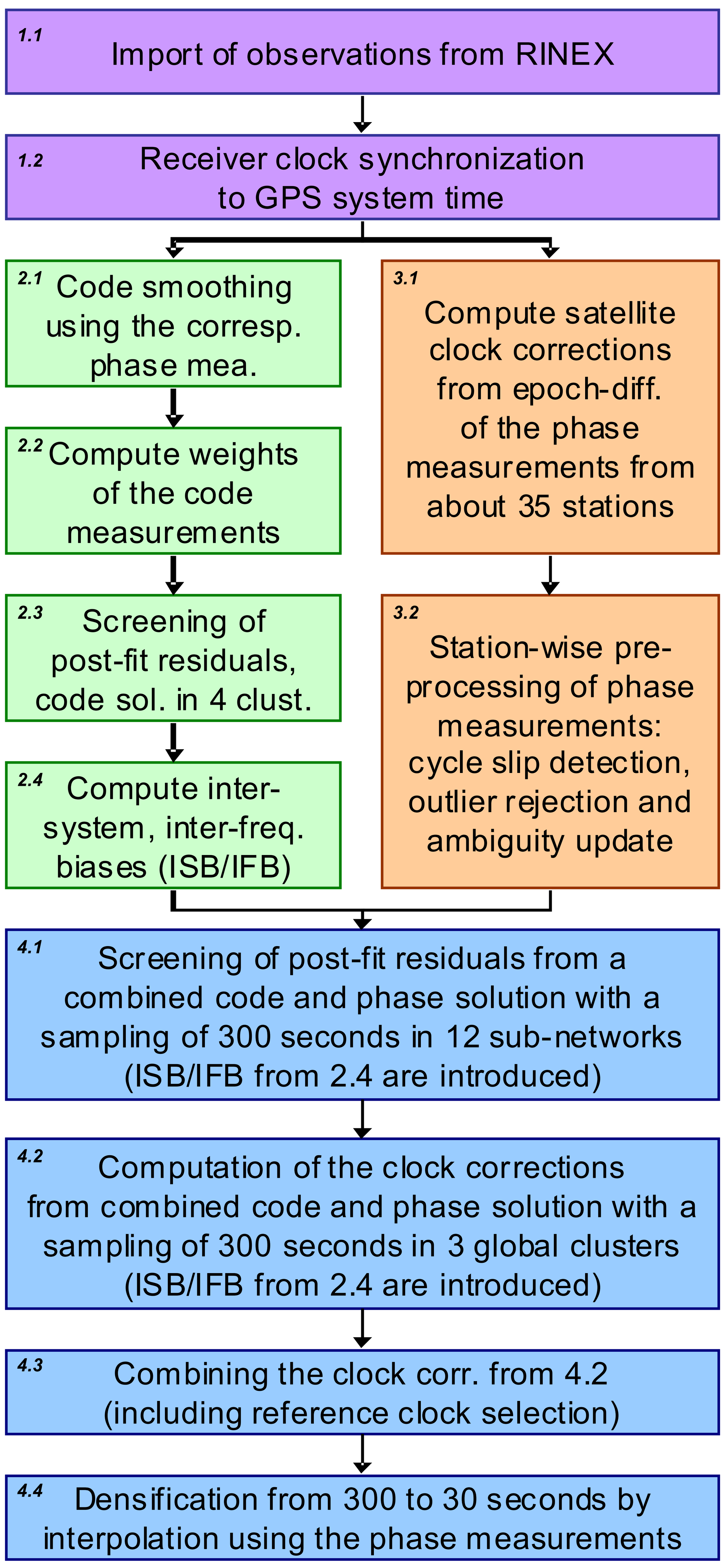

Fig. 1: Flow chart of the GPS/GLONASS rapid clock product generation .

DISCUSSION OF (CODE) BIASES

Three types of biases are relevant for the combined GPS/GLONASS clock processing:
- P1-C1/P2-C2 DCBs exist not only for GPS but also for GLONASS.
- Inter-system bias (ISB) between GPS and GLONASS system time.
- Inter-frequency bias (IFB) appears in GLONASS because each satellite uses its own frequency for the signal. The antipodal satellites share the same frequencies.

Some of these biases are correlated and may not be separated by a parameter estimation procedure — but they are **relevant for the comparison of results, e.g., between different ACs**.

DCB / ISB:
Differential code bias and inter-system bias

For GPS the convention exists that the satellite clock corrections must be referring to the ionosphere-free linear combination from P-Code mea-sure-ments. Observations providing other types of code measurements are corrected to this reference using defined satellite DCBs (P1-C1 and/or P2-C2).
The corresponding bias for GLONASS is estimated as a part of the ISB. The DCBs (P1-C1 and P2-C2) for GLONASS can only be derived from data files containing both types at the same time (see **Figure 2** for an example).
Without any convention here the obtained ISB depends on the processed code-type.

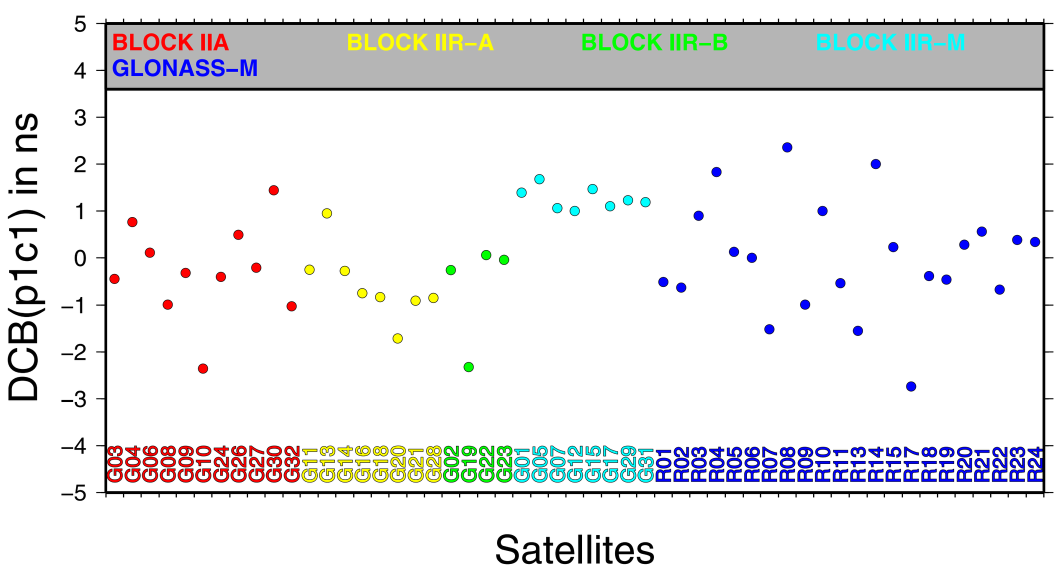

Fig. 2: P1-C1 DCB values for GPS and GLONASS satellites derived from a monthly set of daily RINEX files (May 2010) performing a least squares adjustment (combination all daily contributions considering also receiver-specific DCBs).

ISB / IFB: Inter-system/frequency bias

The ISB refers to the GPS derived receiver clock on one hand. On the GLONASS side the situation is not so clear because in addition IFBs need to be considered for each station for each satellite or at least for each GLONASS frequency.
As long as no convention exists the estimated **ISB will depend on the current GLONASS satellite constellation** (e.g., in case of the convention that the sum of all IFBs is zero) or it cannot directly be accessed (e.g., there is no active satellite using the defined reference frequency at a certain time).

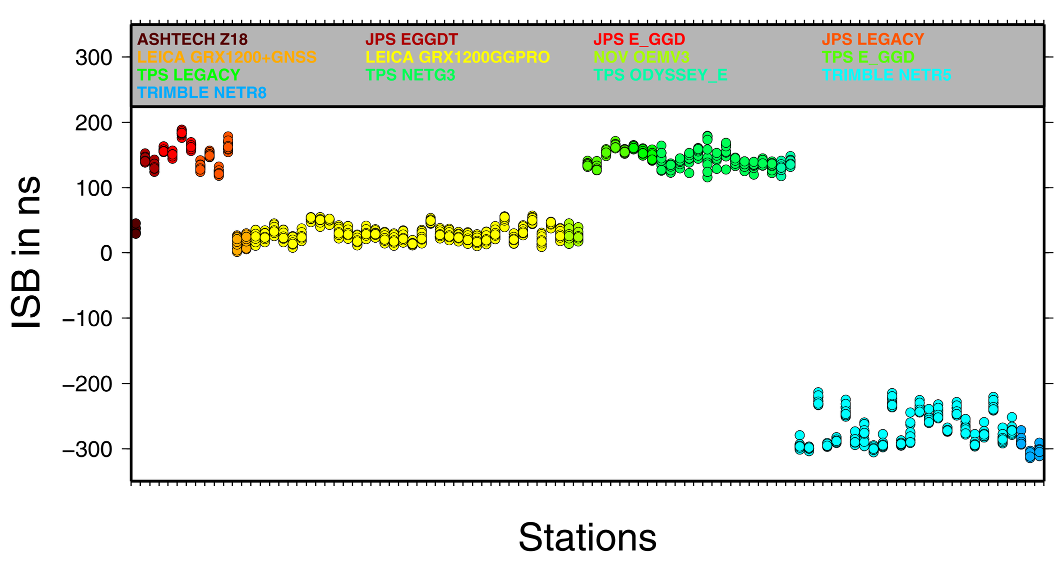

Fig. 3: Mean inter-system bias per satellite plotted for each station. The scatter of the dots for each station indicates the dependency of the bias from the satellite/frequency of the signal. Stations with the same receiver type are plotted with the same colour. Nevertheless, the variations of the ISB of the receivers of one type is so significant that it is indispensible to consider individual ISBs for each station involved.

INTER-SYSTEM/FREQUENCY BIAS:
one parameter per frequency or per satellite?

In the general case, the (ISB+IFB)-parameter may be setup as one bias between the GPS derived receiver clock and each GLONASS satellite tracked by the receiver. Assuming that all GLONASS satellites with the same frequency number (i.e., the two antipodal satellites) have the same IFB, the number of parameters reduces by a factor of two.
Figure 4 shows the time series of IFB estimated for each satellite (coloured dots) or only for each frequency (gray diamonds). The day-to-day variations of the IFB are on the same level as the differences between the bias of the two satellites using the same frequency. In conclusion, **one IFB per frequency and station seems to be sufficient**.

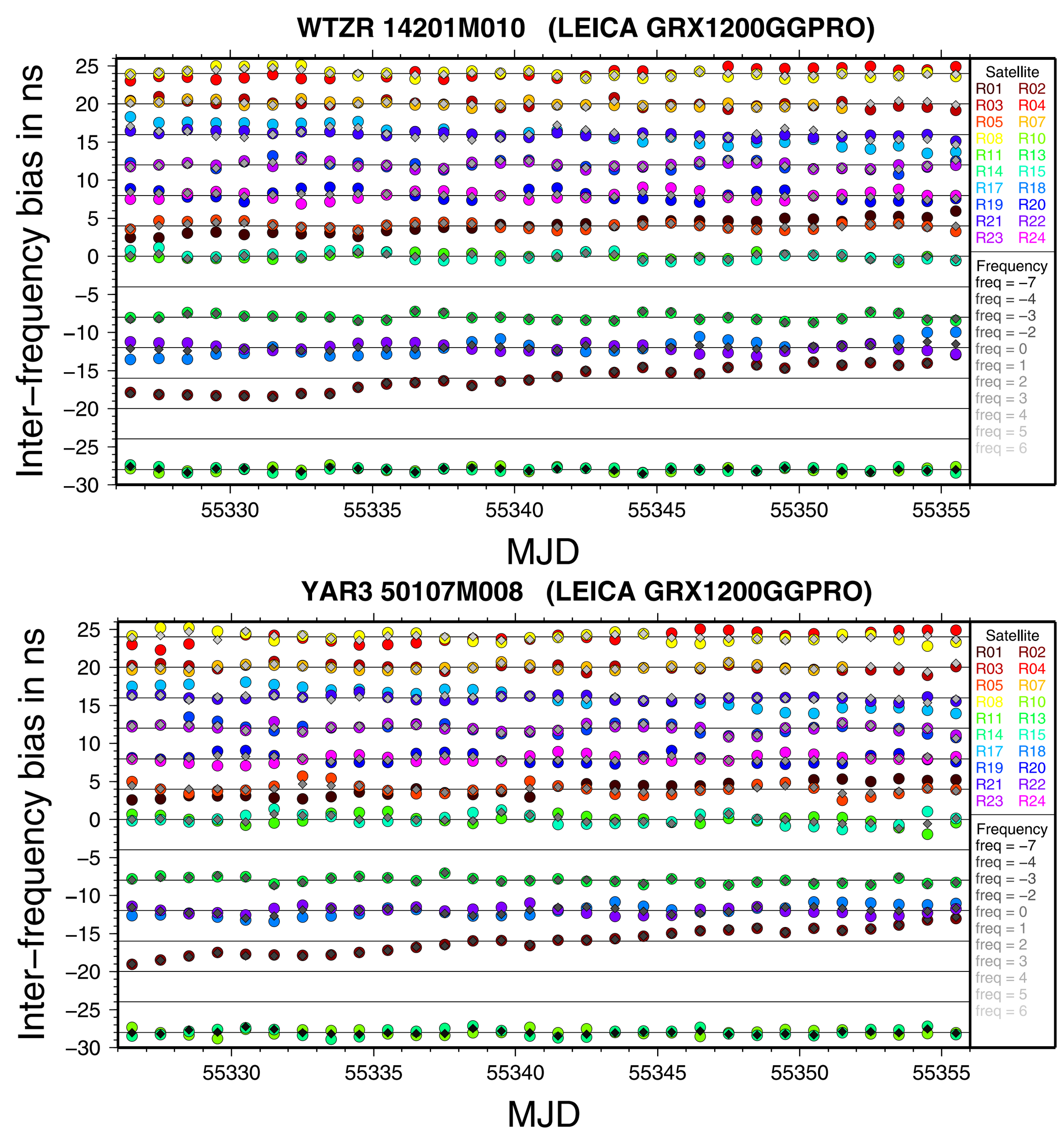

Fig. 4: Time series of IFB estimated per satellite (coloured dots) or per frequency (gray diamonds). The results are shifted by 4 ns according to the GLONASS frequency number for plotting.

COMPLETENESS OF CLOCK CORRECTIONS

For each satellite clock parameter at least three observing stations are requested to ensure a reliable satellite clock correction. Applying this requirement, a complete record of GLONASS satellite clock corrections per day can be achieved in about 90% of the cases with the current GLONASS tracking network.

EVALUATION USING KINEMATIC PPP

Since the kinematic PPP is very sensitive to the introduced products it was used to assess the quality of the new CODE multi-GNSS clock product, see **Figure 5**.

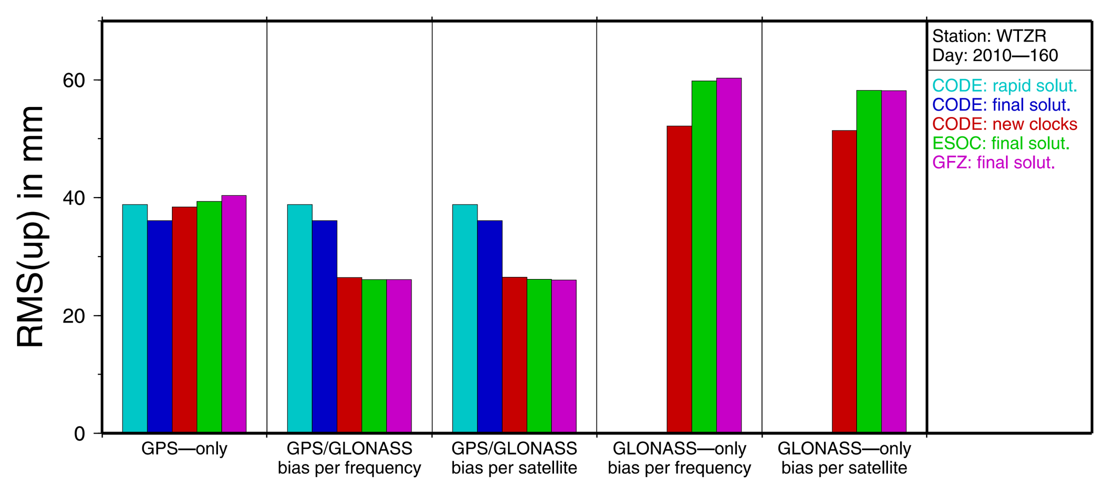

Fig. 5: RMS of the vertical component obtained from different kinematic PPP solutions.
Note, that the ESOC and GFZ solutions are generated with another software which nativly introduces modelling inconsistencies to which a PPP is sensitive.

CONCLUSIONS AND OUTLOOK

CODE has developed a new clock generation procedure providing not only GPS but also fully consistent multi-GNSS satellite clock corrections. It is planned to switch the IGS clock processing to this new procedure within the next weeks.
In the context of this development, many bias issues were identified that need a discussion and a convention to improve the comparability of GLONASS- and multi-GNSS clock products among the ACs.

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