Handling and Estimation of GNSS Code Biases- Latest Developments at CODE

IGSWS2016
International GNSS Service Workshop 2016
8 - 12 February 2016, Sydney, Australia

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GNSS Code Biases

The emitted code signals from the Global Navigation Satellite Systems (GNSS) are used for various applications, such as satellite and receiver clock estimation, carrier phase ambiguity resolution, and ionosphere analysis. However, they are affected by non-negligible systematic biases. The GNSS code biases are time delays within the satellite and receiver caused by their hardware. This implies that the given time from the satellite clock is not equal to the signal emission time. The same is valid for the receivers. The given reception time adopted by the receiver is the time when the signal was demodulated and linked to the internal receiver clock. However, there is a time delay between the reception time in the antenna and the time linking within the hardware. This delay is commonly known as bias and has to be taken into account when processing GNSS data.

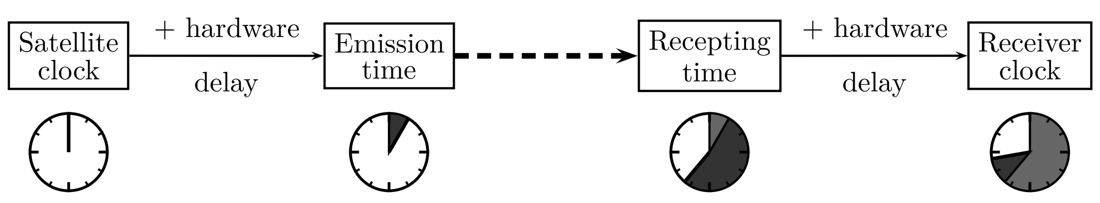

Figure 1: Simplified diagram illustrating the origin of satellite and receiver code biases.

Code Bias Estimation Workflow

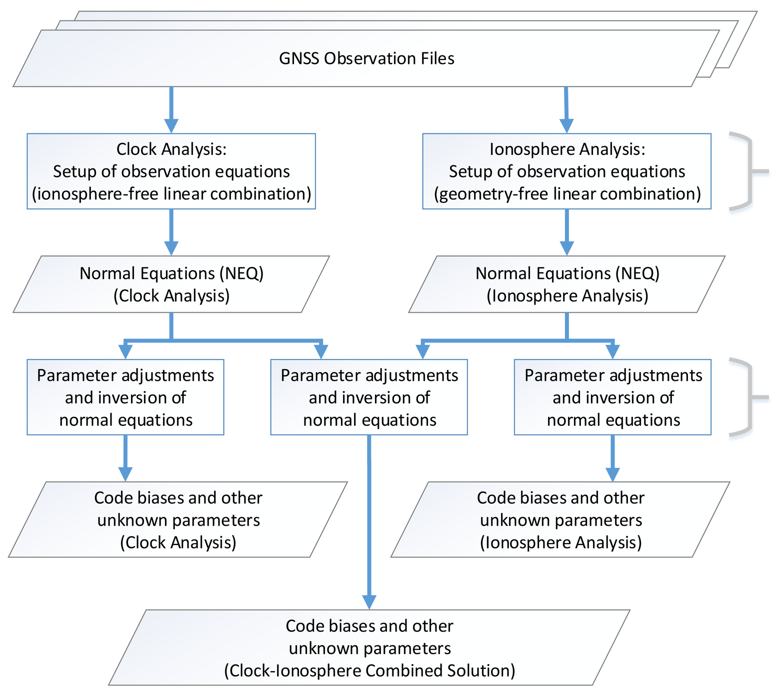

Figure 2: Recently developed workflow for bias estimation at CODE.

RINEX 3 Datapool at CODE

With the new satellite systems and modernization of the older GNSS satellites, the variety of the emitted signals is increasing. Figures 3 and 4 give an overview of the tracked signals of the receiver types as the RINEX 3 standard describes explicitly which observation types are used compared to the RINEX 2 standard. It shows the variety of signals available in the CODE IGS RINEX 3 datapools. RINEX 3 observation codes ending with X are marked red in Figure 3. The clearly high number of corresponding observations could indicate that this observation code (X) might be used not accordingly to RINEX 3 standard (at least in some cases). Because of the drastically increasing number of available signals, we decided to switch from a differential to a observable-specific (pseudo-absolute) bias treatment in the Bernese GNSS software.

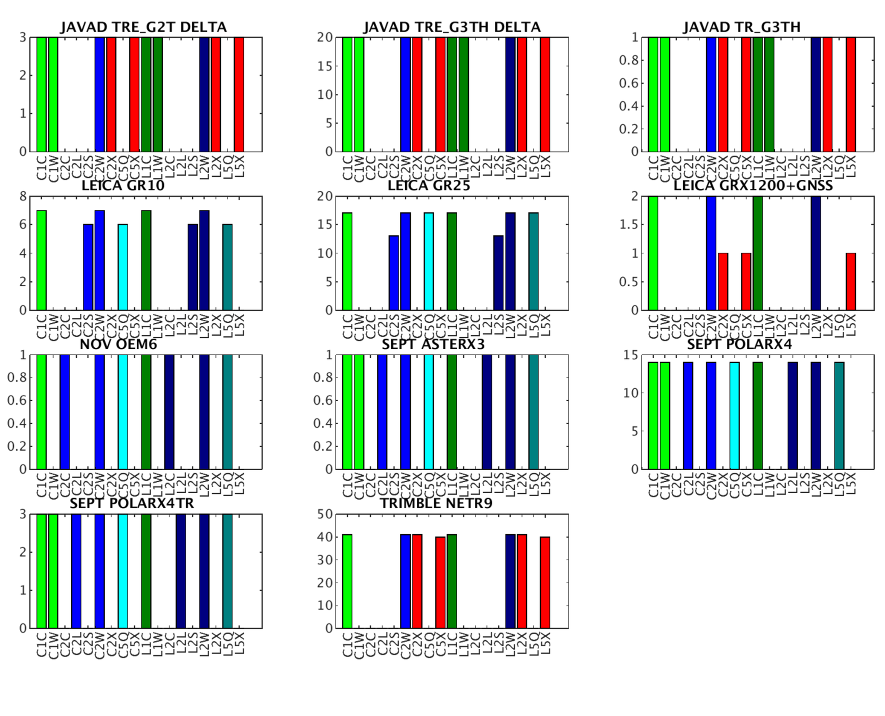

Figure 3: Tracked signals for day 244 in 2015 for GPS as found in the IGS RINEX 3 datapools collected at CODE.

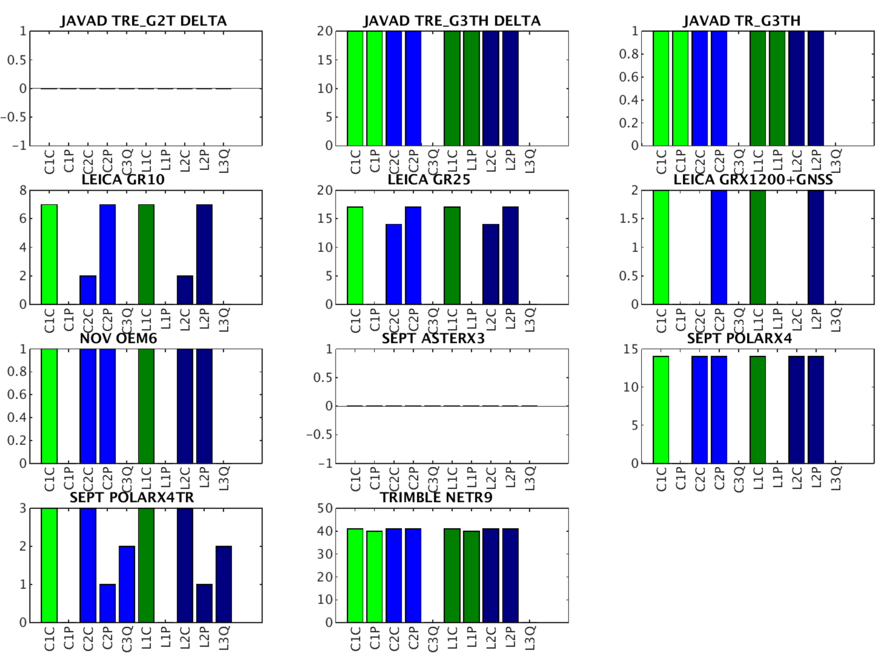

Figure 4: Tracked signals for day 244 in 2015 for GLONASS as found in the IGS RINEX 3 datapools collected at CODE.

Observable-Type-Specific Code Biases

When processing code measurements the estimation of the corresponding biases is crucial. This is in particular valid for clock estimation or ambiguity resolution strategies relying on code measurements. In comparison to a relative bias setup, using differential code biases (DSB), the pseudo-absolute code biases (OSB) is a step towards a flexible, expandable GNSS bias handling. The constrains, depending on the input data and processed data, can be evaluated after the full observation equations have been set up and can therefore be exactly determined prior to the normal equation (NEQ) inversion.
The current convention by the International GNSS Service (IGS) defines that clock parameters have to refer to the ionosphere-free linear combination of P1 and P2 signals. To fulfill this criterion, corresponding conditions are introduced to define the reference observables (e.g., C1W and C2W). The datum definition is realized using a zero-mean condition. Because the GNSS signals tracked by the receivers can not be adequately described by the RINEX 2 naming convention, our implementation consequently uses the RINEX 3 naming convention. This means that data from RINEX 2 files is translated into the new naming convention. The reference biases for satellite constellations are selected according to the user specification (commonly the IGS clock convention, i.e. P1/P2 for GPS). The reference biases of the individual receivers are selected automatically, following a (user-defined) priority list. This implies that the user is able realize every possible bias reference for the GNSS analysis.

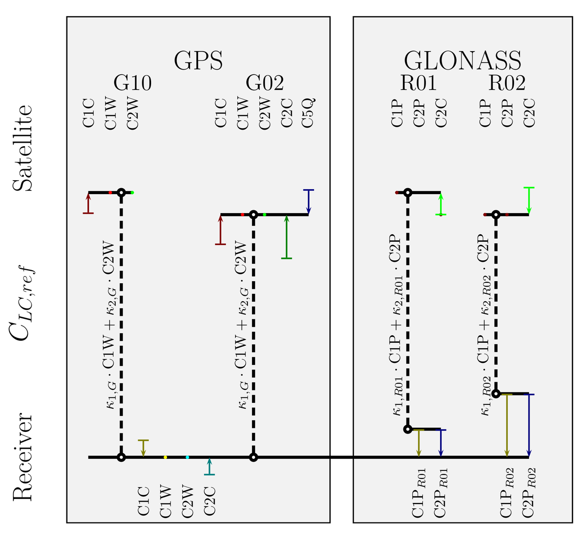

Figure 5: Illustration of the resulting code biases for clock analyses relying on the ionosphere-free linear combination of GNSS observations.

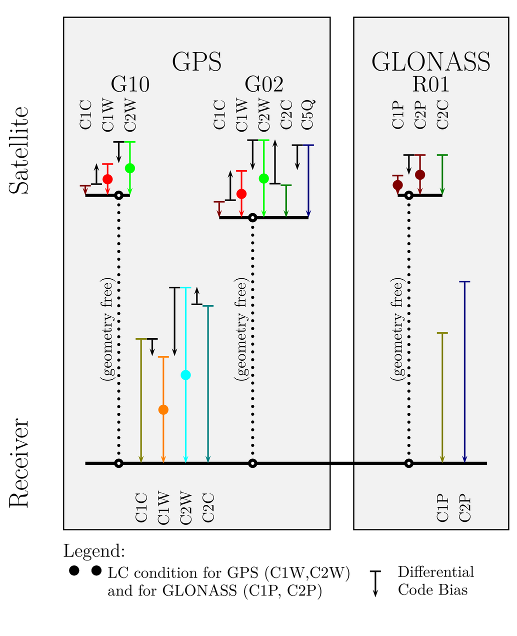

Figure 6: Illustration of the resulting code biases for ionosphere analysis relying on the geometry-free linear combination of GNSS observations. The black arrows indicate the differential code biases (e.g. C1C-C1W) whereas the dots mark the used reference observables to which the ionosphere-free linear combination condition is applied.

Reference Observable Definition

One of the major tasks is to steer the reference observable selection depending on the availability of the observation types. In order to allow user specific reference observable selection, the definition is given by a priority list defining the order for satellite and receiver code biases.

```
Bias convention       S/S  O/F  OBS
*******************   ***  ***  ***
GPS                   G    C1   C1W
                      G    C2   C2W

GLONASS               R    C1   C1W
                      R    C2   C2W

Receiver type         S/S  O/F  RINEX observation codes and their priority
*******************   ***  ***  *** *** *** *** *** *** *** *** *** *** *** ***
DEFAULT               G    L1   L1P L1C L1X
                      G    L2   L2P L2C L2D L2W L2X
                      G    C1   C1P C1C C1X
                      G    C2   C2P C2C C2D C2W C2X
                      R    L1   L1P L1C L1X
                      R    L2   L2P L2C L2X
                      R    C1   C1P C1C C1X
                      R    C2   C2P C2C C2X
```

The section in the bias convention is used to define the satellite reference observable used for the bias convention. The receiver reference observable selection is based on the RINEX 3 priority list used to select the to be processed observables.

Repeatability of OSB over a 30 day period

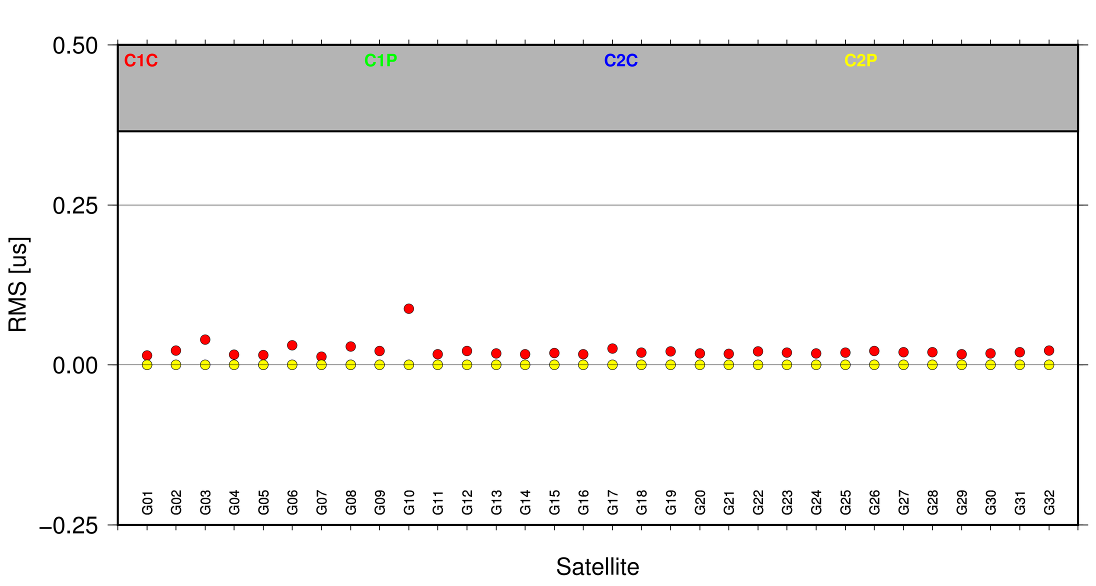

Figure 9: RMS over a 30 day period for satellite biases (from clock analysis)

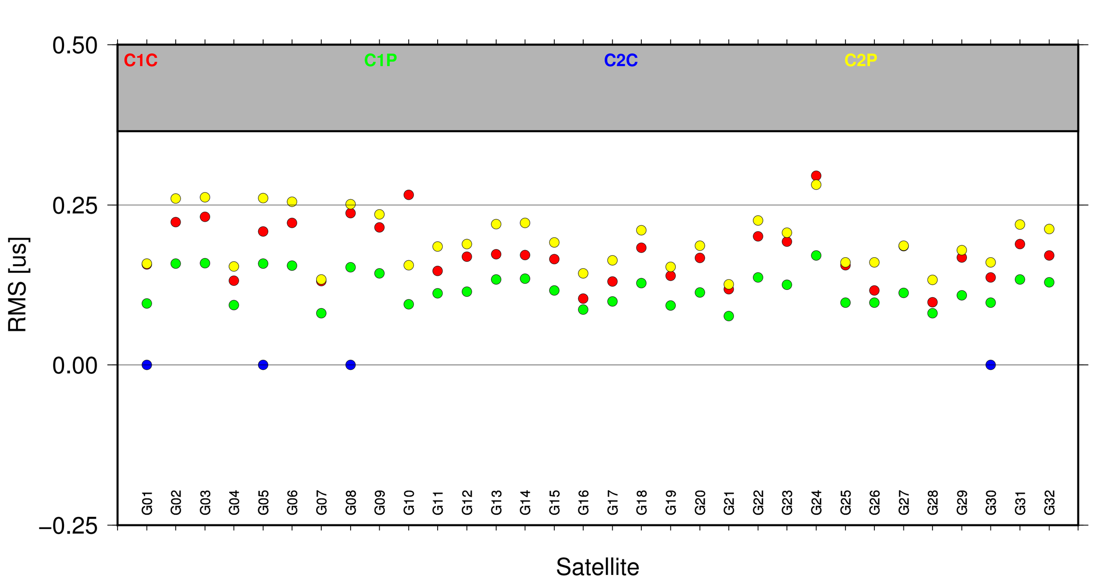

Figure 10: RMS over a 30 day period for satellite biases (from ionosphere analysis)

Implementation

With the switch from differential to observable specific code biases we introduced a flexible and expandable way to handle GNSS.
The generalized bias handling enables the combination at normal equation level, e.g., to combine bias results from clock and ionosphere analysis. The ultimate goal is to get at the end one common GNSS bias product (either delivered as differential or observable-specific product).
The comparison between results produced with the old DSB implementation and the new pseudo-absolute observable bias approach, shown in Figure 7, is consistent. As the presented bias implementation now allows to consider (GPS/GLONASS) C2C code observations, the results may be slightly different (compared to previous results produced without the consideration of any C2C code data). Figure 8 shows the resulting observable-specific code biases from a combined clock and ionosphere analysis estimation.

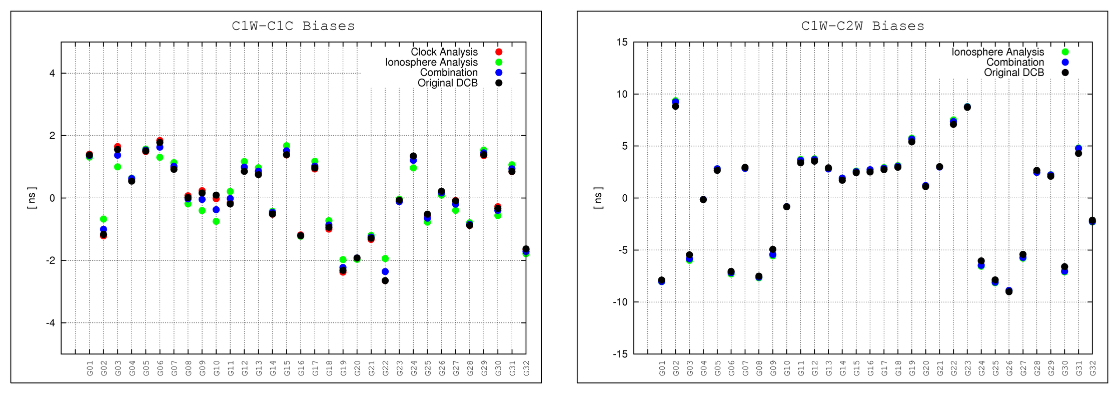

Figure 7: Comparison of differential code biases, C1W-C1C (left) and C1W-C2W (right), from clock analysis, ionosphere analysis, combination and current DSB (C1W-C1C from clock, C1W-C2W from ionosphere) estimation.

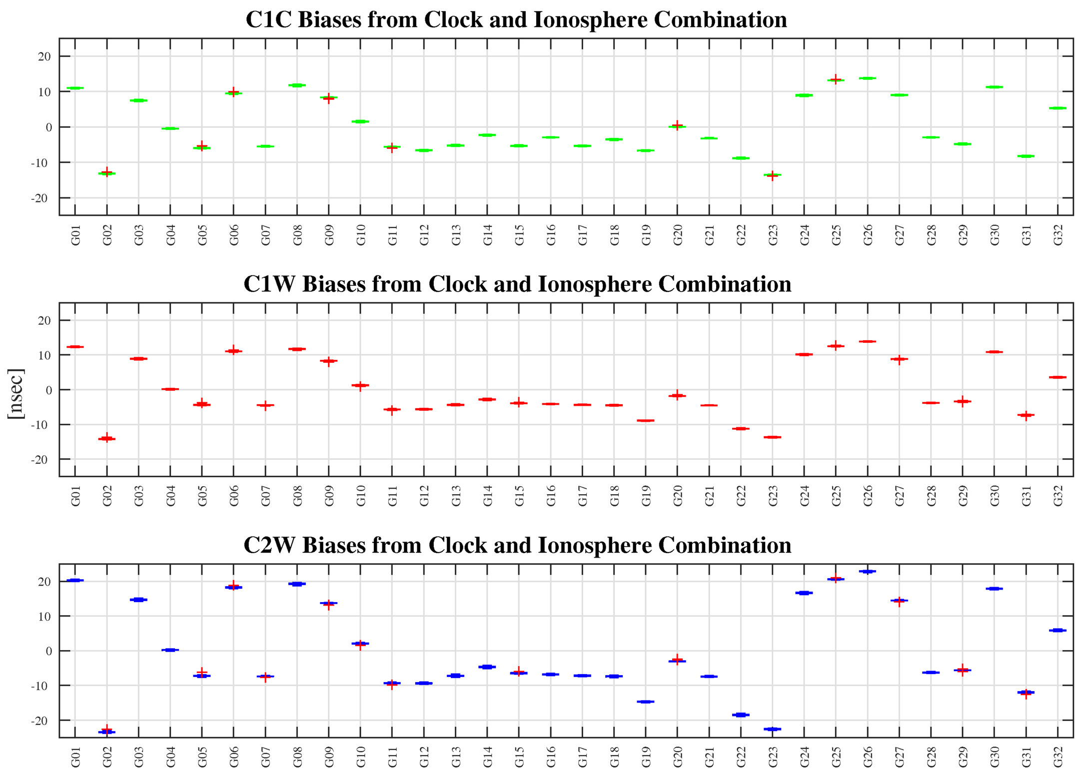

Figure 8: Boxplot of pseudo-absolute code biases from the combined clock and ionosphere solution of 30 days (2015 260-289).

Summary

The main features of our new bias handling may be summarized as follows:

- Code bias parameters are treated specific to each observable (instead of the difference of a pair of observations).
- RINEX 3 naming convention is used in any case to describe the GNSS observables.
- Combination of bias results at the normal equation level.
- Selection (scheme) of the reference observables (for all involved GNSS systems) controlled by the users.

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Poster compiled by Arturo Villiger, February 2016
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