Experimental Assessment of a PPP-based P2-C2 bias estimation

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1. Introduction

This poster makes use of observations from IGS stations to determine a set of P2-C2 bias b_{P2-C2}, which are evaluated in the estimation of the coordinates of a station using C2 observations processed in PPP mode.

2. P2-C2 Computation

2.1 – Directly from the observations

A very simple way to obtain a set of differential P2-C2 code bias is by computing the mean of the difference between time series of P2 and C2 observations collected by the same receiver. Today, there are already receivers that report both P2 and C2 so this task is simple. For example, all Trimble NETR5 receivers whose locations are shown in Figure 1 observe both P2 and C2 pseudoranges.

Mathematically, the P2-C2 obtained directly from the observations is like a geometry-free combination, resulting in:

$$P2 - C2 = b_{P2-C2} + (M_{P2} - M_{C2}) + (E_{P2} - E_{C2}) \qquad (1)$$

This equation shows that differential multipath and differential noise are still present in the time series. For that reason, the P2-C2 differential code bias should be the result of a mean over several days and stations, given by:

$$\hat{b}_{P2-C2} = \frac{1}{N}\sum_{k=1}^{N}(P2 - C2)_k \qquad (2)$$

where N is the number of stations and days.

Figure 2 shows the time series of P2-C2 for station COCO, DOY 109, satellite PRN 17. This time series is "relatively stable", but other P2-C2 time series show a few oscillations.

2.2 – Using residuals from PPP processing

The approach summarized here was first presented in Leandro et al. (2007). Unlike the previous method, it can be used for any receiver type, including receivers that do not track both P2 and C2 for the same satellite. The differential code bias can be estimated directly from the residuals of a PPP processing, by using the information that is inherent to it: estimated station coordinates, neutral-atmospheric parameters T and receiver clock dT, plus the input orbits and satellite clocks dt_{IF} (realizing the later as being IF clocks). Considering a C1&C2 IF observation equation:

$$P_{IF(C1\&C2)} = \rho + cdT + T - cdt_{IF} + M_{IF(C1\&C2)} + E_{IF(C1\&C2)} + \alpha cb_{P1-C1} - \beta cb_{P2-C2} \qquad (3)$$

where ρ is the geometric range and α and β are the frequency-based coefficients.

The residuals can be computed as:

$$\tilde{P}_{IF(C1\&C2)} = P_{IF(C1\&C2)} - \hat{\rho} - cd\hat{T} - \hat{T} + cdt_{IF} \qquad (4)$$

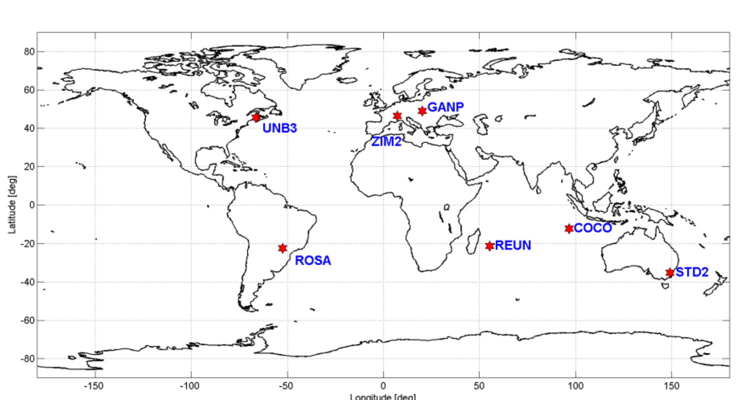
where the symbol '^' indicates a quantity estimated by the PPP. This yields the mathematical model:

$$\tilde{P}_{IF(C1\&C2)} = \alpha cb_{P1-C1} - \beta cb_{P2-C2} + M_{IF(C1\&C2)} + E_{IF(C1\&C2)} \qquad (5)$$

Considering that P1-C1 is known, the problem is simply to estimate by least-squares the differential bias from a network of C1, C2 receivers, whose observations are first processed by PPP. The covariance matrix is built weighing the pseudo-observations as a function of elevation angle, to minimize any remaining low-elevation angle effect.

An important consideration in this approach is that the receiver bias is usually absorbed by the receiver clock. But as there are only 7 satellites broadcasting C2 observations, the PPP solution is generated using other satellites (using C1&P2 combination), therefore, receiver clock is absorbing the receiver P1-C1 differential code bias. A *zero-mean* assumption for each station solution is used to isolate the parameter or interest.

Fig. 1 – Geographical location of the IGS stations used. ➔



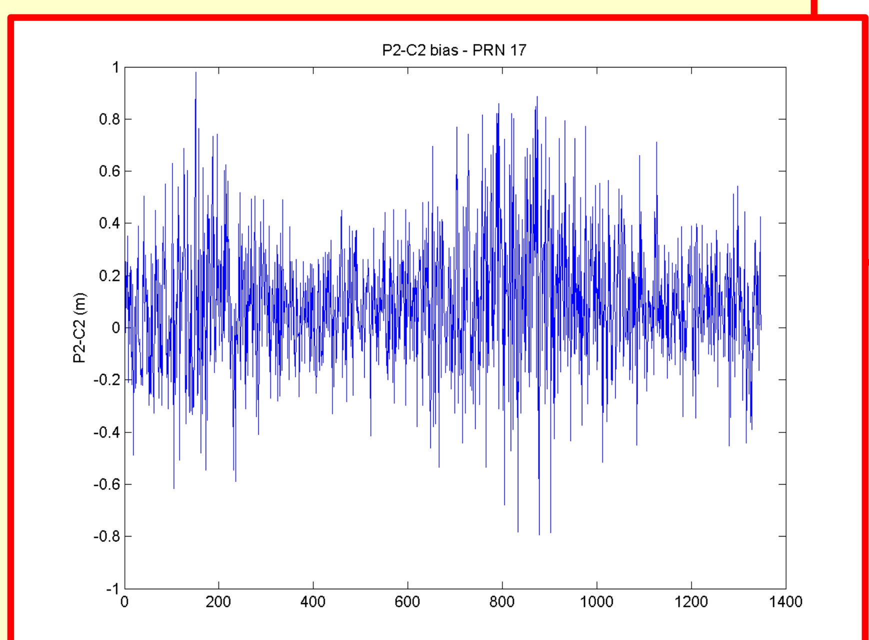


Fig. 2 – Time series of P2-C2, station COCO, DOY 109, PRN 17. 🡐

2.3 – P2-C2 differential code bias values

We computed two sets of P2-C2 differential code bias. Table 1presents the values computed directly from the observations (as mentioned in Section 2.1). The values estimated from the PPP residuals are slightly larger and we are already investigating possible solutions. The daily repeatability shown in Table 1 indicates the spread of the daily P2-C2 biases.

PRN	P2-C2 bias (m)	Daily Repeatability (m)	PRN	P2-C2 bias (m)	Daily Repeatability (m)
1	0.145	±0.006	15	2×10^{-5}	±0.008
5	−0.056	±0.014	17	0.093	±0.008
7	0.107	±0.008	29	−0.006	±0.010
12	−0.122	±0.008	31	−0.199	±0.009

Table 1 – Mean P2-C2 differential code values for DOY 105 to DOY 112

3. Data sets and processing

Data for over 8 days (DOY 105 to DOY 112 – 2010) were collected by a (C-2 capable) Trimble R7 receiver located on the roof of the Netherlands Meteorology Institute (NMi) building on TU Delft Campus. This data set was used to determine the coordinates of the point using C2 observations over the two hours when four C2 satellites were visible (5, 12, 29, 31). The pseudorange observations on C2 were corrected by the P2-C2 bias values presented in Table 1. Satellite PRN 1 had neither orbit nor clocks therefore was not used. The data was processed in a phase-adjusted C2 single-frequency PPP mode, using orbits and clocks from RETICLE, ultra-rapid GIM maps and P1-C1 differential code bias from CODE (van Bree et al., 2009).

4. Results

The results are presented in Figures 3 and 4 and explained as follows. Each figure shows results for each individual day put together and compared to the know coordinates of the site, for the three components (North, East and Up). The statistics were generated based on that. Figure 3 shows the results without any bias being added, whereas Figure 4 depicts the results coming after the biases were added. Comparing the figures, we can see a somehow disappointing increase in the difference between the estimated solution and the known coordinates for the North component (-42%) but an improvement for both East and Up components (76% and 26%, respectively), being that the improvement for the East component is considerable. As far as the spread of the solutions, the addition of the differential code biases brought no improvement for the North component but decreased the spread of the East and Up components (by 16% and 12% respectively).

Fig. 3 – Results without applying P2-C2 biases

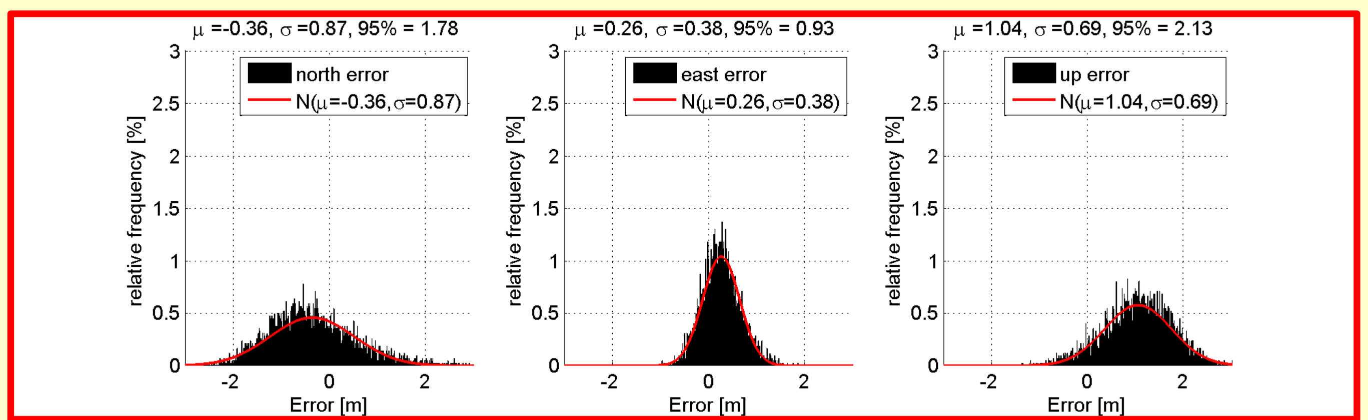
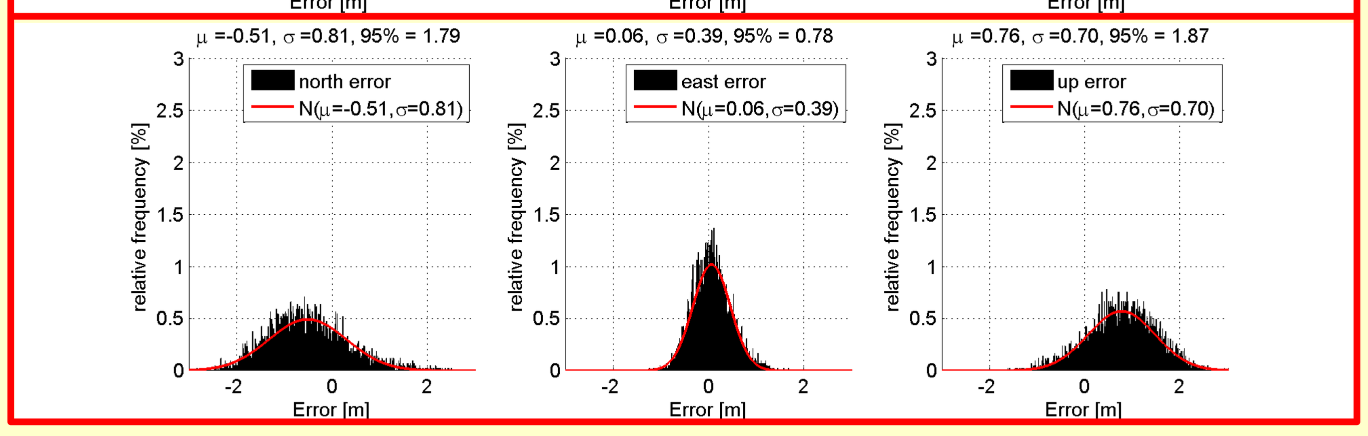


Fig. 4 – Results after applying P2-C2 biases



5. Concluding Remarks

(1) The application of the P2-C2 differential code bias improved the 3D position and their spread by 10% and 4%, respectively.

(2) The computation of P2-C2 biases directly from the observations may be improved if elevation angle effects are taken into account and if time series is smoothed out.

(3) Results obtained for the PPP-based estimation (not shown) were a bit larger. The theory seems right. More effort to be placed to investigate what may be causing that.

(4) The ideal differential code biases are the ones that would bring the mean coordinate differences to be equal to zero. But then, there are also other error sources that can be playing a role in the final estimation.

Acknowledgements

The first author acknowledges support by a grant from the Netherlands Organization for Scientific Research (NWO) during his stay at Delft University of Technology. He also acknowledges support from the Natural Sciences and Engineering Research Council of Canada (NSERC).

IGS Workshop, Newcastle upon Tyne, England, 28 June – 2 July, 2010