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HOW STABLE ARE INSTRUMENTAL BIASES P2-C2?

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Abstract. *This paper presented results of investigations about estimation DCB P2-C2 for satellites and receiver in GPS system. The data from LAMA station in Poland were used to determination of stability instrumental biases P2-C2, using least square method. Author proposed new strategy to solution of DCB P2-C2 (biases were calculated with temporal resolution 2 hours). The test results were compared with CODE's product. Difference between proposed method and CODE's values for Satellite DCB is less than ± 1 ns and for Receiver DCB less than ± 0.2 ns. Standard deviation of presented method is about 0.4 ns.*

Keywords: GPS, CODE, DCB

JAK STAŁE SĄ OPÓŹNIENIA SPRZĘTOWE P2-C2?

Streszczenie. *Artykuł przedstawia wyniki badań dotyczących wyznaczenia opóźnień sprzętowych DCB P2-C2 dla satelitów i odbiornika w systemie GPS. Dane ze stacji referencyjnej LAMA w Polsce zostały użyte do wyznaczenia stałości opóźnień sprzętowych P2-C2, przy wykorzystaniu metody najmniejszych kwadratów. Autor zaproponował nową strategię do rozwiązania opóźnień sprzętowych P2-C2 (opóźnienia zostały policzone w rozdzielczości czasowej 2 godzin). Wyniki przeprowadzonego testu zostały porównane z produktami z Centrum Analizy CODE. Różnica pomiędzy proponowaną metodą a wynikami z CODE jest mniejsza niż 1 ns dla opóźnień sprzętowych satelitów oraz mniejsza niż 0.2 ns dla opóźnienia sprzętowego odbiornika. Odchylenie standardowe prezentowanej metody wynosi około 0,4 ns.*

Słowa kluczowe: GPS, CODE, DCB

Introduction

Starting from 2005, when USA launched satellite PRN17, users on the all world could received new civil signal C2 at the 2nd frequency in GPS system. At first only three satellites: PRN12, PRN17, PRN31 and currently twelve satellites: PRN1, PRN5, PRN7, PRN12, PRN15, PRN17, PRN24, PRN25, PRN27, PRN29, PRN30 and PRN31, are able to transmitted new signal L2C. These group of satellites is called Block IIR-M, where „R" means replenishment and „M" means modernized [5].

New signal L2C was the reason to create special applications, which can determine relation between code P2 and code C2. In GPS system, this relation is called Differential Code Biases P2-C2, but in numerical computations many users separate DCB P2-C2 on two types: Satellite DCB P2-C2 and Receiver DCB P2-C2. Instrumental biases SDCB P2-C2 are called difference of transmission time between observations P2 and C2 from each satellite to receiver. Instrumental biases RDCB P2-C2 are called difference of travel time between observations P2 and C2 from antenna to hardware of receiver [2]. Magnitude of values DCB P2-C2 is about ± 1 ns (nearly ± 30 cm).

Only few organizations or scientific institutions from all over the world estimate instrumental biases P2-C2, for example: the Center for Orbit Determination in Europe (CODE), the Natural Resources Canada (NRCan), the University of New Brunswick (UNB). CODE and NRCan determinate DCB P2-C2 using Geometry Free combination based on collections data from global network from all day [1, 4, 6]. UNB calibrate Satellites DCB P2-C2 in GAPS software using Ionosphere-Free linear combination (also based on collections data from global network from all day) [3, 5].

Author in article presents new strategy to estimation DCB P2-C2 using observations data from single station. Code source of program „SciTEC" was written in Scilab 5.4.1 language. Description of mathematical model is located in section „Estimation DCB P2-C2". Results of calculations will be found in section „Experiment and Result", and last part of article has got some conclusions.

1. Estimation DCB P2-C2

To determine instrumental biases P2-C2 Geometry Free linear combination is used, free from geometric errors, troposphere and ionosphere delay, satellite and receiver clock errors. Basic equation for P2 and C2 observation is given by:

$$P2 = \rho + c \cdot (t_o - t_s) + I_2 + T + SDCB_{P2} + RDCB_{P2} \tag{1}$$

$$C2 = \rho + c \cdot (t_o - t_s) + I_2 + T + SDCB_{C2} + RDCB_{C2} \tag{2}$$

where:
ρ – geometric distance between satellite and receiver,
c – speed of light,
t_o, t_s – receiver and satellite clock error,
I_2 – ionosphere delay at the 2nd frequency,
T – troposphere delay,
$SDCB, RDCB$ – instrumental biases for satellites and receivers.

Subtracting equation (2) from (1), geometric errors and systematic errors are eliminated, as follows:

$$P2 - C2 = SDCB_{P2-C2} + RDCB_{P2-C2} \tag{3}$$

DCB P2-C2 from equation (3) are estimated using least square method:

$$x = \left(A^T \cdot A\right)^{-1} \cdot A^T \cdot l \tag{4}$$

where:
x – vector with unknown biases;
A – matrix with dimension (n, m); matrix has got rank deficient, which equals one;
l – vector of observations.

Rank deficient is reduced if one constraint is added to matrix A. Typical constraint- reference sum of Satellite DCB P2-C2 equals zero, is applied as follows:

$$\sum_{1}^{n} SDCB_{P2-C2} = 0 \tag{5}$$

where n – number of satellites.

Based on equation (5), satellites biases are stable relative to centre of gravity frame of all SDCB P2-C2. Another constraint can be also utilized, e. g. one bias of SDCB P2-C2 is known as a prori value. In this procedure all unknown biases are obtained in relation to reference bias, so very major is determinated mean error of reference bias.

Mean errors for unknown biases are estimated using equation (6) [7]:

$$mx = m0 \cdot \sqrt{\left(A^T \cdot A\right)^{-1}} \tag{6}$$

where: $m0$ – standard deviation of unit weight, $m0 = \sqrt{\frac{[vv]}{r-k}}$, v – vector of residuals, r – number of observations, k – number of unknown parameters.

The mx term in equation (6) expresses accuracy for unknown biases and typical results of these values should be less than 1 ns.

2. Experiment and Results

In analysis were used 24 hours (with interval 30 seconds) GPS data from LAMA station in RINEX format 2.11. LAMA reference station is located in north-eastern Poland (coordinate: 53.71 N, 20.67 E). Station has got dual frequency receiver LEICA GRX1200+GNSS, which can register code observations: C1, P2, C2 and phase observations: L1, L2. Collections of RINEX data were downloaded from BKG server: [8]. Calculations were executed in „SciTEC" software in temporal resolution 2 hours. „SciTEC" is open source toolbox, which code source was written in Scilab 5.4.1 numerical platform. After 24 hours, results from each sessions were saved and next mean value and standard deviation were calculated. Final results were compared with CODE's DCB P2-C2 monthly product (from website [9]). In Table 1 is presented results from day 083 to 086, 2014 year, as a examples of proposed strategy.

In adjustment processing of GPS observations were obtained eleven SDCB P2-C2 (no available data for satellite PRN30) and one RDCB P2-C2. For each day, differences between proposed method and CODE's values are maximum for satellites PRN1, PRN5, PRN7, PRN15, PRN25, PRN31 (about $\pm\ 0.4 \div 0.8$ ns) and minimum for satellites PRN12, PRN17, PRN24, PRN27 and PRN29 (about $\pm\ 0 \div 0.2$ ns). Magnitude of standard deviation, for SDCB P2-C2, is between $0.25 \div 0.42$ ns. In case of RDCB P2-C2, differences between CODE's values and presented method, are very small (less than 0.2 ns, respectively for each day). Standard deviation of RDCB P2-C2 is about 0.3 ns.

Aspect of stability instrumental biases is very important in submitted paper. After 4 days of investigations, for individual satellite and receiver, were computed daily repeatability of DCB P2-C2 (see Table 2).

Table 2. Daily repeatability of DCB P2-C2 from 24-27 March 2014

Satellites	Mean SDCB P2-C2 [ns]	Daily repeatability [ns]
1	0.706	0.069
5	-0.769	0.110
7	0.822	0.044
12	-0.488	0.182
15	-0.681	0.052
17	0.329	0.136
24	0.309	0.064
25	-0.225	0.106
27	-0.072	0.068
29	-0.189	0.069
30	No data	No data
31	0.256	0.065
Receiver	Mean RDCB P2-C2 [ns]	Daily repeatability [ns]
Leica GRX1200+GNSS	-1.051	0.057

Magnitude of daily repeatability, for SDCB P2-C2, is between $0.04 \div 0.19$ ns. More than 0.1 ns have got four satellites: PRN5, PRN12, PRN17, PRN25, but for rest satellites daily repeatability is below 0.07 ns. In case of RDCB P2-C2, daily repeatability is less than 0.06 ns (about 2 cm), and it can be concluded that instrumental biases P2-C2 are very stable. Average value of SDCB P2-C2 over 4 days can reach up to 0.822 ns (maximum result) and -0.769 ns (minimum result). Difference between maximum and minimum value is more than 1.5 ns (about 45 cm). Among all results of SDCB P2-C2, more than 54% are negative and only 5 values are positive.

Table 1. Comparison daily solution DCB P2-C2 and monthly CODE's values, using single station

Satellites	CODE [ns]	24 March 2014		25 March 2014		26 March 2014		27 March 2014	
		Day 083 [ns]	Standard deviation [ns]	Day 084 [ns]	Standard deviation [ns]	Day 085 [ns]	Standard deviation [ns]	Day 086 [ns]	Standard deviation [ns]
1	1.499	0.755	0.369	0.697	0.400	0.759	0.402	0.612	0.414
5	-0.264	-0.928	0.330	-0.753	0.336	-0.705	0.344	-0.689	0.324
7	0.410	0.843	0.377	0.872	0.386	0.773	0.404	0.801	0.378
12	-0.307	-0.306	0.258	-0.737	0.303	-0.491	0.291	-0.419	0.286
15	-0.073	-0.756	0.353	-0.647	0.342	-0.679	0.373	-0.643	0.374
17	0.331	0.271	0.314	0.518	0.348	0.325	0.346	0.202	0.345
24	0.131	0.297	0.301	0.317	0.302	0.234	0.316	0.391	0.316
25	-0.674	-0.125	0.275	-0.158	0.294	-0.359	0.288	-0.256	0.292
27	-0.100	-0.113	0.371	-0.146	0.342	-0.028	0.396	-0.001	0.374
29	-0.015	-0.124	0.336	-0.186	0.341	-0.159	0.364	-0.285	0.344
30	-0.389	No data	No data	No data	No data	No data	No data	No data	No data
31	-0.499	0.186	0.301	0.222	0.327	0.333	0.324	0.285	0.322
Receiver	CODE [ns]	Day 083 [ns]	Standard deviation [ns]	Day 084 [ns]	Standard deviation [ns]	Day 085 [ns]	Standard deviation [ns]	Day 086 [ns]	Standard deviation [ns]
Leica GRX1200 +GNSS	-0.918	-0.992	0.311	-1.027	0.312	-1.058	0.330	-1.127	0.318

3. Conclusions

In this paper, new strategy of estimation instrumental biases P2-C2, were showed. The test results of proposed method were compared with monthly CODE's product. Difference between presented method and global solution is less than ± 1 ns, with standard deviation about 0.4 ns. Additionally, aspect of stability DCB P2-C2, were described in article. Daily repeatability of SDCB P2-C2 is less than 0.19 ns and for RDCB P2-C2 about 0.06 ns. In future, code source of program will be usable in determination IFB P2-C2 in GLONASS system.

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