ANALYSIS AND NORMALIZATION OF GNSS ONBOARD CLOCKS

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ABSTRACT. Nowadays determination of precise coordinates using GNSS (Global Navigation Satellite System) observations can be made with the differential method or with an absolute solution (PPP method - Precise Point Positioning). The precision of navigational data, such as satellite ephemerides and satellite clock biases, is very important when using the PPP method. Usually, satellite orbits are approximated with smooth functions, currently, their accuracy is about 2-3 cm. Unlike ephemerides satellite clock biases are not approximated with any function, also clock series are being processed not as a continuous time series but as daily fragments, which leads to jumps at 00:00 UTC. Processing methods that are currently used can also lead to clock jumps inside a day. Different studies propose a variety of satellite clock improvement methods but clock jump removal is performed manually. An automatic jump correction algorithm is proposed. About two years of satellite clock biases were processed. Usage of the algorithm allows removal of clock jumps on time intervals of any length..

1. INTRODUCTION

Nowadays determination of precise coordinates using GNSS (Global Navigation Satellite System) observations can be made with differential method or with absolute solution (PPP method Precise Point Positioning). Precision of navigational data is very important when using PPP method.

Currently GPS and GLONASS satellites are using rubidium (Rb) and cesium (Cs) clocks. GPS satellites use 10.23 MHz frequency sources [GPS-IS, 2019], GLONASS - 5 MHz [GLONASS-ICD, 2008]. Satellite clock biases are transmitted in navigational messages with ephemerides.

GNSS analysis centers provide satellite clock biases in form of unapproximated time series. This leads to clock biases having random jumps up to several ns.

Analysis of the aforementioned jumps shows that clock biases from different analysis centers have different jumps and a lot of these jumps are at 00:00 UTC.

This shows that most of the jumps are processing artifacts, as confirmed by other researchers [Prange, 2017].

Different methods of improving satellite clock biases are proposed [Shi, 2019, Hauschild, 2010, Hauschild, 2009], but they require manual correction of aforementioned jumps [Huang, 2012].

2. ALGORITHM DESCRIPTION

2.1 Global change detection

To get a more correct estimation of the quadratic trend of the clock bias series outliers need to be corrected. They are searched for and corrected by using the formula

$$b_j = \frac{b_{j+1} + b_{j-1}}{2}; \tag{1}$$

where b_j is a point of the series with number j.

If a trend change is present, the series is split and its parts are processed separately. Trend change algorithm contains the following steps:

1. The second derivative of the series is computed.
2. If the second derivative of the clock bias series is at least 500 times larger or smaller than its average, then we consider that a trend change has been detected.

2.2 Jump correction

The quadratic trend of the clock bias series is computed with the least squares method and removed. Then a search for significant (more than 0.55 ns for 30-second clock file) differences between neighbouring points is performed. When such difference is found (point with number k), search for next difference that is not further from point k than 3 days is performed. If the next difference is not found then the jump is absent. However if such difference is found (point n or the series ends before that, the right border of correction interval is the last point in the series (point n).

Jumps are being corrected by adding a linear trend on the correction interval. Difference between borders of correction interval is computed ($\Delta b = b_k - b_n$). Correction on the interval from point k to point n is performed using formula (**??**)

$$b_{k+i} = b_{k+i} - \Delta b \cdot \frac{i}{n-k}, \quad 0 < i \le n-k \tag{2}$$

2.3 Clock bias filtering

After jump correction filtering was performed. Kalman filter was used. Clock bias series were modelled as wiener process $\dot{b} = w$, where w is random function. The following Kalman filter model was used:

$$P = \begin{cases} \sigma^2 & \text{, if error is present in clk file} \\ 10^{-24}\ \mathrm{s}^2 & \text{, if error is absent in clk file;} \end{cases}$$

where P is error covariance. Predicted state estimate:

$$b^-_{k+1} = b_k$$

Predicted error covariance:

$$P^-_{k+1} = P_k$$

Updated state estimate:

$$b_{k+1} = b^-_{k+1} + K_{k+1} v_{k+1}$$

$$v_{k+1} = b_{k+1} - b^-_{k+1}$$

Updated estimate covariance:

$$P_{k+1} = (1 - K_{k+1}) P^-_{k+1}$$

Optimal Kalman gain:

$$K_{k+1} = \frac{P^-_{k+1} H^\top}{H^\top P^-_{k+1} H + R}$$

$$H = 1, \quad R = 9 \cdot 10^{-23}\ \mathrm{s}^2$$

H is the observation model; R is the covariance of the observation noise; v_{k+1} is measurement pre-fit residual.

3. RESULTS

Analysis was performed on 2017 satellite clock biases from IAC. Figure **??** shows the beginning of a correction interval highlighted by the red vertical line. Figure **??** shows the end of the same correction interval as on the Figure **??**. It is noticeable that the processed time series does not have a jump on 17.02.2017 at 11:39.

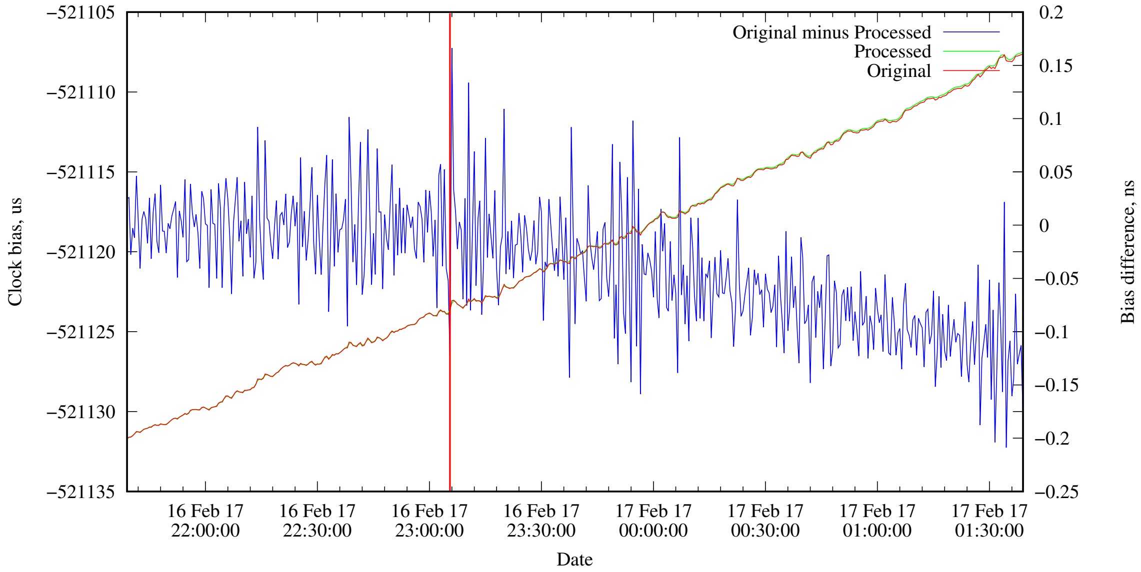

Figure 1: Start of correction interval for G21

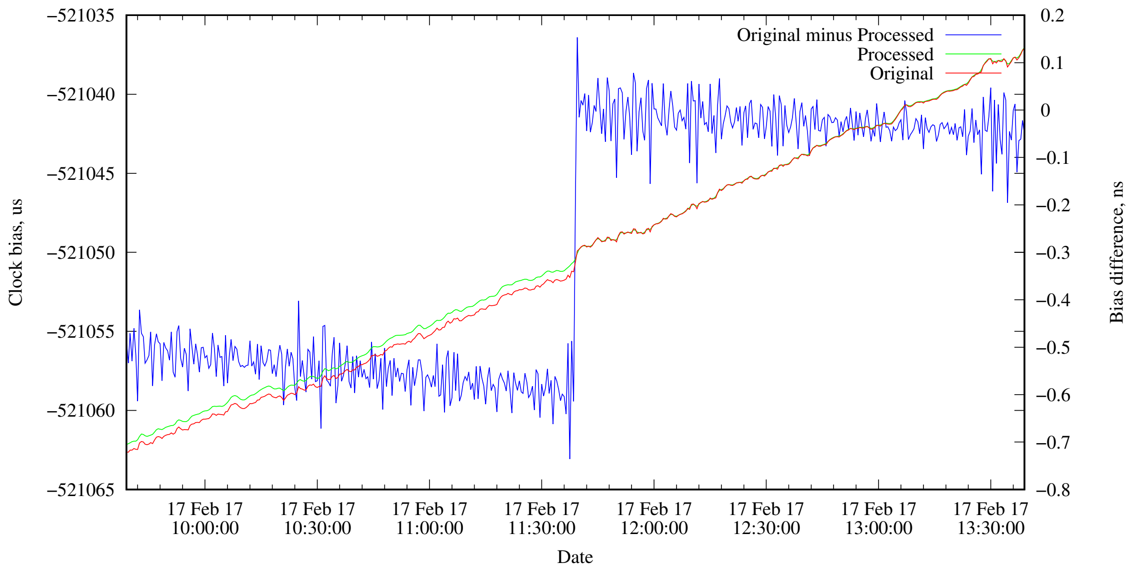

Figure 2: G21 clock bias

Absense of jumps on the processed biases can be seen on Figure **??**. Original biases show multiple jumps on the same figure. It should be noted that differences are not accumulated.

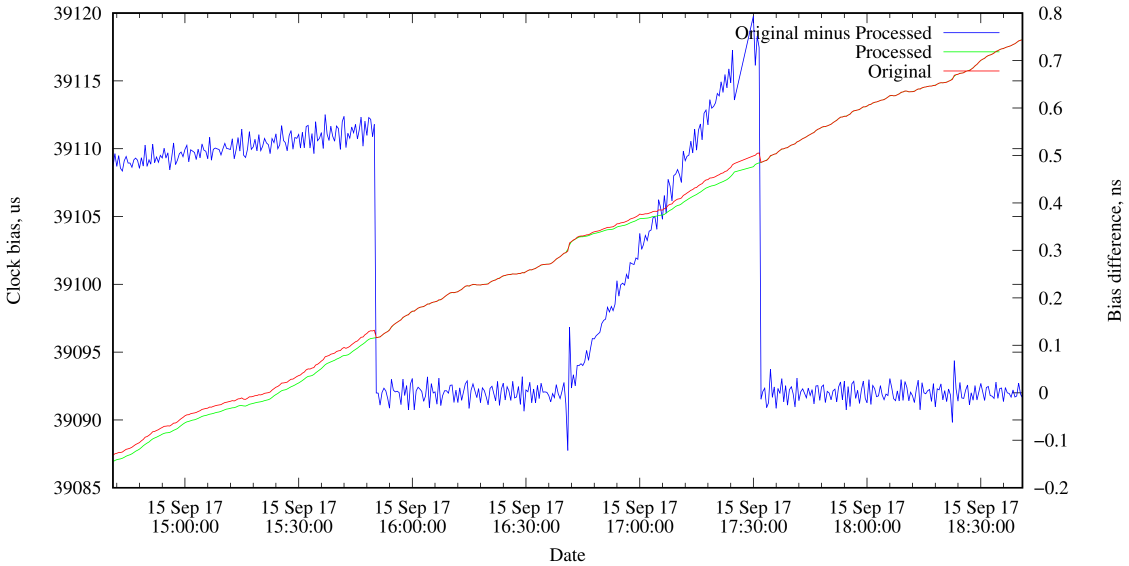

Figure 3: R09 correction

4. CONCLUSION

- Current processing methods for estimating satellite clock biases lead to jumps.
- The proposed correction algorithm allows to remove jumps in clock biases automatically.
- Applying this algorithm to processing of GNSS measurements leads to more precise results.

5. REFERENCES

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