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PROGRESSION OF CLOCK DBD CHANGES OVER TIME

Kamil Maciuk[1], Inese Varna[2], Jacek Kudrys[1]

1) Department of Integrated Geodesy and Cartography, AGH University, Mickiewicza Av. 30, 30-059 Krakow, Poland (maciuk@agh.edu.pl, ✉ jkudrys@agh.edu.pl)
2) Institute of Geodesy and Geoinformatics, University of Latvia, Jelgavas St. 3, LV-1004, Riga, Latvia (inese.varna@lu.lv)

Abstract
Day-boundary discontinuity (DBD) is an effect present in precise GNSS satellite orbit and clock products originating from the method used for orbit and clock determination. The non-Gaussian measurement noise and data processing in 24 h batches are responsible for DBDs. In the case of the clock product, DBD is a time jump in the boundary epochs of two adjacent batches of processed data and its magnitude might reach a couple of ns. This article presents the four GNSS (Global Navigation Satellite System) systems DBD analysis in terms of change over an 8 year period. For each of 118 satellites available in this period, the yearly value of DBD was subject to analysis including standard deviation and frequency of outliers. Results show that the smallest DBDs appear in the GPS system, the biggest – for the BeiDou space segment. Moreover, the phenomenon of changes in DBDs over time is clearly seen at the beginning of the analysed period when the magnitude and number of the DBDs were larger than for current, newest clock products.

Keywords: GPS, satellite, clock, jump, outlier, DBD, reference clock.

1. Introduction

Daily clock and orbit products are crucial in many GNSS (*Global Navigation Satellite System*) systems applications, *e.g.*, RTK (*Real-Time Kinematic*), time transfer, PPP (Precise Point Positioning) applications [1–3, 5]. The *Multi-GNSS Experiment* (MGEX) was set-up in 2012 by the IGS (*International GNSS Service*) to track, collate and analyse all available GNSS signals [6, 7]. Currently, apart from GPS and GLONASS, it also includes BeiDou, Galileo, QZSS, and NAVIC systems, as well as other *space-based augmentation systems* (SBASs) [8–11]. First clock products cover data with a 300 s sampling interval and since 2017 with a 30 s one. GNSS products are usually computed in 24 h batches, thus consecutive days solutions are independent of each other. It may lead to a day-boundary discontinuity of magnitude of 1 ns [12]. It might be reduced just by adopting the 30 s sampling interval instead of the 300 s, then DBD is reduced by 10 to 30% [13]. Similar research has been conducted so far but it was limited in terms of the covered time interval

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or number of analysed GNSS systems. For example, *e.g.*, Rovira-Garcia *et al.* analysed GNSS clocks DBD but on an intra-annual basis [14] and [15], Qing et. al analysed BeiDou and Galileo DBDs for a several dozen of days in one year [16] and Zhang analysed time transfer [17].

In this paper the authors analysed DBDs for the whole GNSS satellite constellations available in MGEX clock products since its establishment in 2012. The analysis included a dataset for 2017–2021 using the 300 s sampling interval for data, based on the CODE (*Center for Orbit Determination in Europe*) AC (*Analysis Center*) [18]. First clock products contained only GPS and GLONASS data, but since 2014 clocks have become available for the five satellite systems GPS, GLONASS, Galileo, BDS2, and QZSS [19]. The presented DBD analysis includes magnitude and its changes over time for 4 GNSS systems – GPS, GLONASS, Galileo and BeiDou (BDS-2 only) during the analysed period together with DBDs standard deviation and this is the first time such analysis has been prepared.

2. DBDs' magnitude and its changes over 2017–2021

Data for satellite clock correction determination are processed in daily batches. Such a method of processing results in clock product discontinuities between two adjacent batches of data. The magnitude of day-boundary jumps is usually larger than intra-day between epochs discontinuities. Discontinuities in the clock products may be caused by ground control adjustment of the clock but such effects are much larger in amplitude [20]. They were not analysed in the present work but treated as outliers in the frequency data. Satellite clock DBDs were analysed after their isolation from CODE clock products at yearly intervals (Fig. 1).

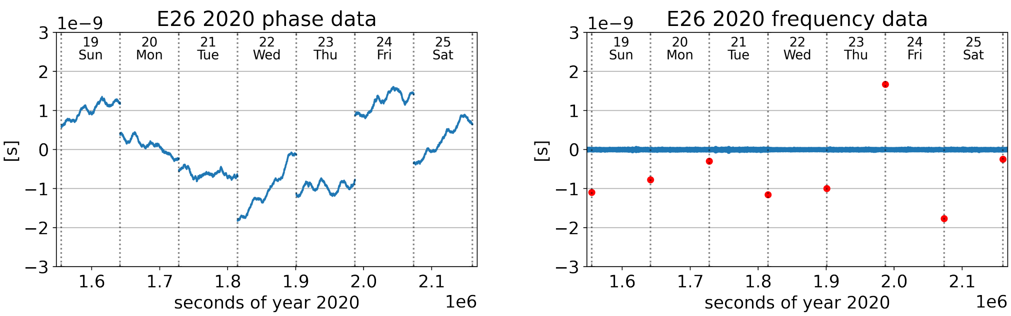

Fig. 1. One week of the E26 satellite clock data with visible DBDs (left) and isolated magnitudes of DBDs marked with red dots for the same time span (right).

Figure 2 shows a magnitude of a yearly DBDs for selected representative satellites for each GNSS system analysed. For a better comparison, the y-axis scale on each graph is the same.

Once the satellites are compared, there is a visible repeatability of the magnitudes during the analysed year, which strictly characterizes a trend for each satellite. A comparison of the magnitude between the satellites leads to the conclusion that the smallest DBD at a level not exceeding ±1 ns represents the GPS satellite, Galileo ±2 ns, GLONASS, and BDS-2 slightly over ±2 ns with a couple of jumps larger than this value.

Figure 3 shows a magnitude of the mean DBDs for the whole segments for selected years before (Fig. 3a for GPS, Fig. 3c for GLONASS, Fig. 3e for BeiDou, Fig. 3g for Galileo) and after cutting DBDs (Figures 3b, 3d, 3f and 3h respectively) as outliers at 1.5e-8 s (15 ns). In the figures below, the decrease of the magnitude of DBDs over time can be clearly observed. The

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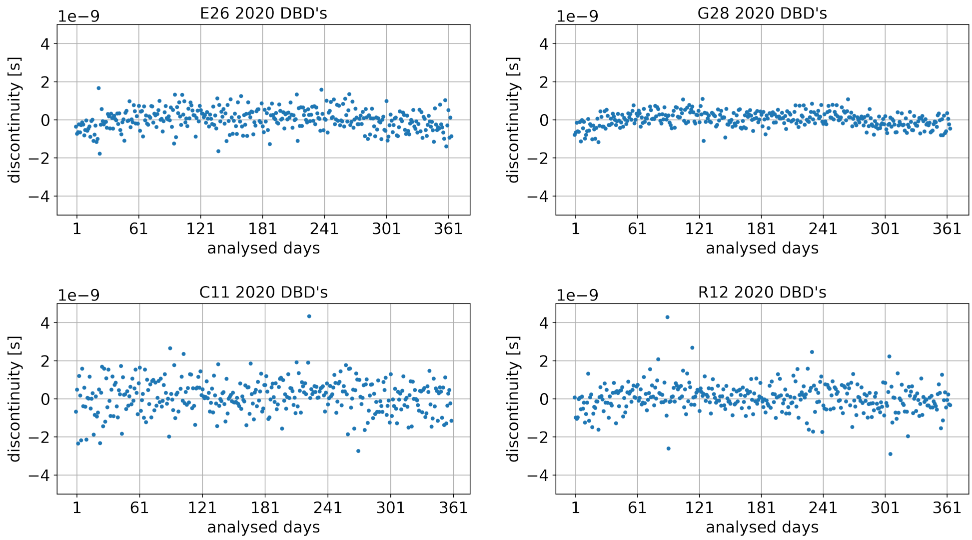
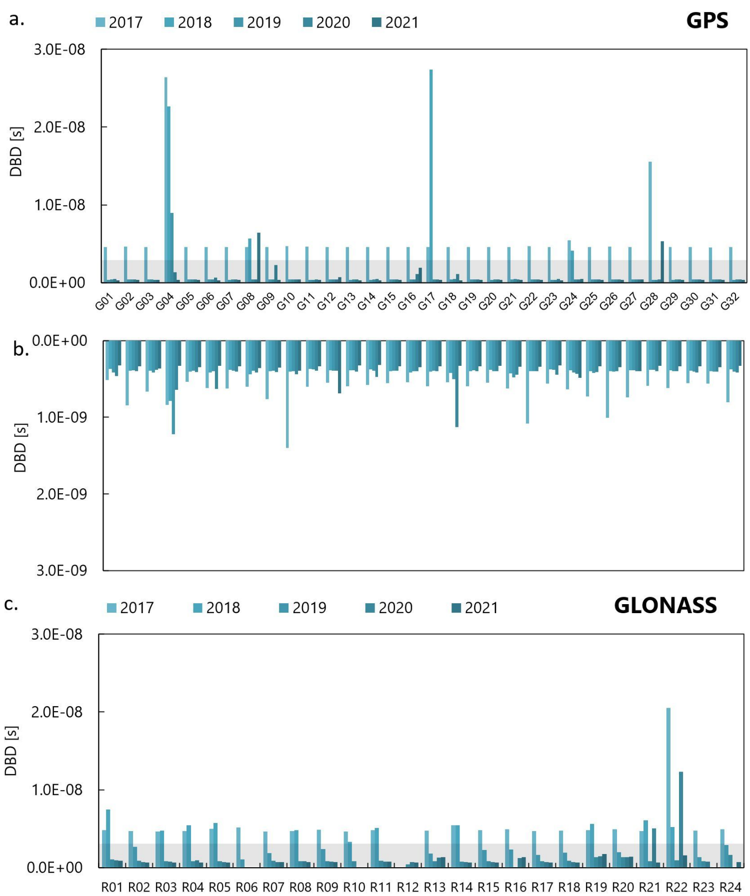


Fig. 2. Sample yearly DBDs for a representative satellite from each GNSS system.



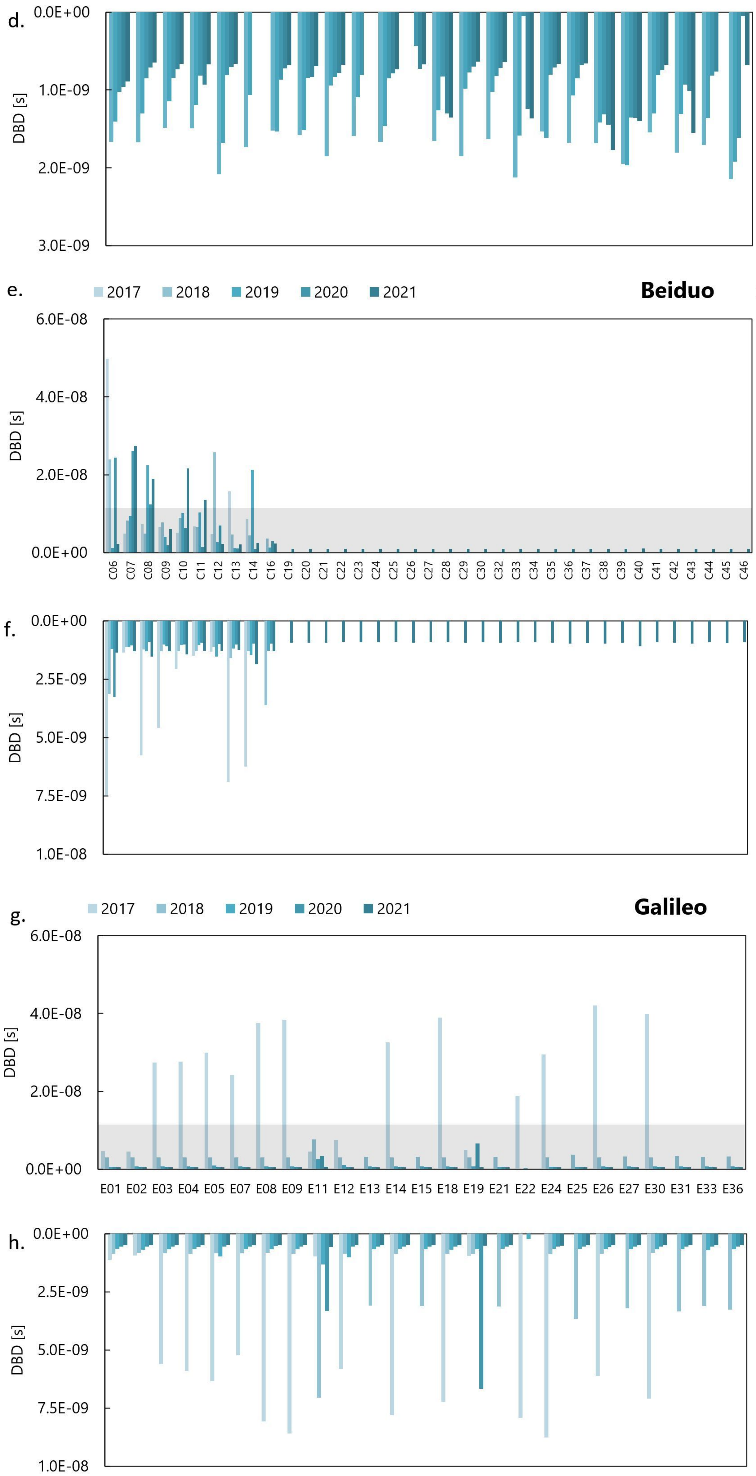


Fig. 3. Sample yearly DBDs for GPS and GLONASS systems before (top) and after the cleaning (bottom).

Metrol. Meas. Syst., Vol. 30 (2023), No. 3, pp. 499–505
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shaded area in Figs. 3a, 3c, 3e and 3g shows a scale of DBDs after the cleaning (vertical scale in Figs. 3b, 3d, 3f and 3h respectively). For a GPS system mean DBD is at 2e-9 s (2 ns) level over the given years, and 5e-10 s after outlier removal. In the case of the GLONASS system it is 2.5e9 s (5 ns) and 1e-9 s (1 ns), respectively, for BeiDou it is 1e-8 s and 2e-9 s and, finally, 4.8e-9 s and 1.7e-9 s for Galileo.

In the case of the two other GNSS systems, the changes are even at a higher level, but in the initial period the satellite segment was incomplete, and the analysis would include only a part of the satellites.

3. DBDs' standard deviation analysis

Analysis of the DBDs standard deviation by type of GNSS system is shown in Figure 4. It shows a trend of the decreasing values of standard deviation over time. DBD standard deviation for GPS changes from 0.6 ns in 2017 to 0.3 ns in 2021, Galileo – from 1 ns to 0.5 ns, GLONASS – from 1.5 ns to 0.7 ns, and for BDS-2 is at level 1–1.5 ns. The lowest value of the standard deviation for the GPS system compared to other GNSS systems analysed may indicate the nature of the noise in GPS observations that is closest to white noise.

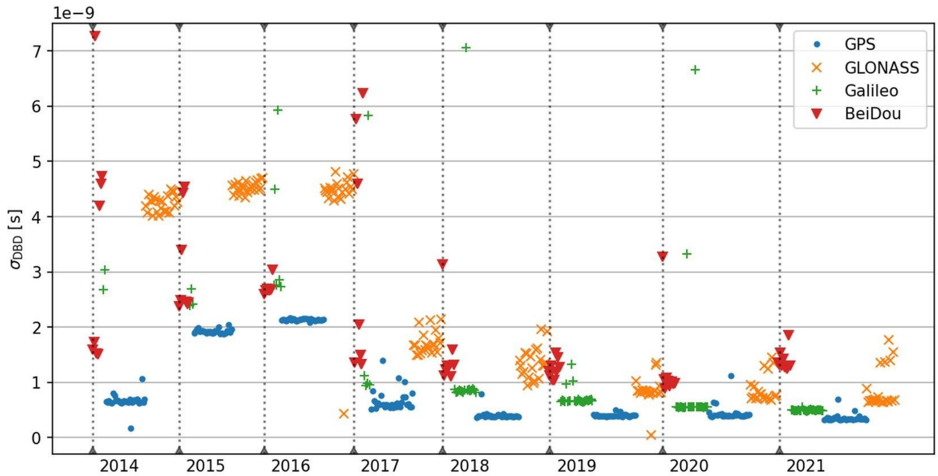

Fig. 4. DBDs standard deviation. Successive satellites are presented along the horizontal axis.

Comparing GNSS systems, the GPS system has the smallest DBD standard deviation – smaller than 0.5 ns, GLONASS and Galileo 0.5-1 ns and BeiDou BDS-2 system at 1-2 ns level.

4. Conclusions

This paper presents a comprehensive analysis of day-boundary discontinuities for 4 GNSS system clock products covering the years 2017–2021 as provided by the MGEX. The DBDs in final clock products are caused mainly because of the long-term pseudo range noise while estimating the clock offset. Analysis shows that for the GPS system which was fully operational at the beginning of the analysed time span, the DBD magnitudes are at significantly lower levels (±1 ns) than for the other three GNSS systems – Galileo (±2 ns), GLONASS and BeiDou (slightly over ±2 ns). Also, GPS DBD standard deviations are lower than for the other analysed GNSS systems. Therefore, GPS satellites are the most stable and safest to use as reference satellites in positioning applications or time transfer. Moreover, for the whole analysed period, a decreasing trend in DBD amplitudes and DBD standard deviations over time is clearly visible.

The increase of the clock rate in MGEX products 2017 from 300 s to 30 s in 2017 is the main reason for the reduction of DBDs at that and time and in subsequent years. Further reduction could have been caused by the decrease of inaccuracies in the estimation process, increasing number of satellites and GNSS clock stability. It can be predicted that further improvements in clock offset estimation computational algorithms will aim to minimize the DBD at a level close to intra-day deviations.

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Metrol. Meas. Syst., Vol. 30 (2023), No. 3, pp. 499–505
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