CHAMP Clock Characterization Revisited

Rolf König, Grzegorz Michalak, Ludwig Grunwaldt and Christoph Reigber

GeoForschungsZentrum Potsdam (GFZ), Dept. 1 'Geodesy and Remote Sensing', Telegrafenberg, 14473 Potsdam, Germany, *koenigr@gfz-potsdam.de*

Summary. The behaviour of the space-borne CHAMP GPS receiver clock over nearly three years is inspected by the results of the Rapid Science Orbit (RSO) determination and the on-board navigation solution (NAV). The analysis completes and enhances the results of the clock characterization study carried out earlier on a limited number of data. It is shown, that CHAMP on-board events like software uploads and hardware reboots frequently lead to large clock offsets, which are reduced on-board within a few hours. Comparisons of RSO and NAV solutions show, that the RSO clock offset estimates are additionally affected by bias and drift of the reference clocks chosen in the processing. The two independent solutions, RSO and NAV, indicate, that the CHAMP clock is free of a drift in the long term. In the short term, the clock parameters show a standard deviation of 0.4 μs and a small negative bias of 0.3 to 0.4 μs.

Key words: CHAMP, BlackJack GPS receiver, clock offset

1 Introduction and Data

The CHAMP on-board GPS receiver "BlackJack" is equipped with a steered quartz clock. The behaviour of the clock over the period 2001/04/17 - 2003/08/18 is analyzed based on two independent solutions for the clock offsets. One solution is generated by the GFZ Rapid Science Orbit (RSO) processing system [1].The second one is the real-time CHAMP on-board navigation solution (NAV). The CHAMP clock behaviour was already studied [2] based partially on Post-processed Science Orbits (PSO), RSO and NAV solutions. There however, the data covered a few small segments in the time frame 2000/07/30 to 2002/02/23. In this paper we present a study based on a continuous time series of RSO clock estimates since the beginning of the CHAMP RSO processing. Because the PSO solutions are rather incomplete over the chosen analysis period and because they are anyway rather similar to the RSO results, the PSO solutions are not considered here.

2 Clock Offset Time Series Analysis

A general view of the clock offset estimates is given in Fig. 1 (RSO solution) and Fig. 2 (NAV solution). Both figures are dominated by singular large clock

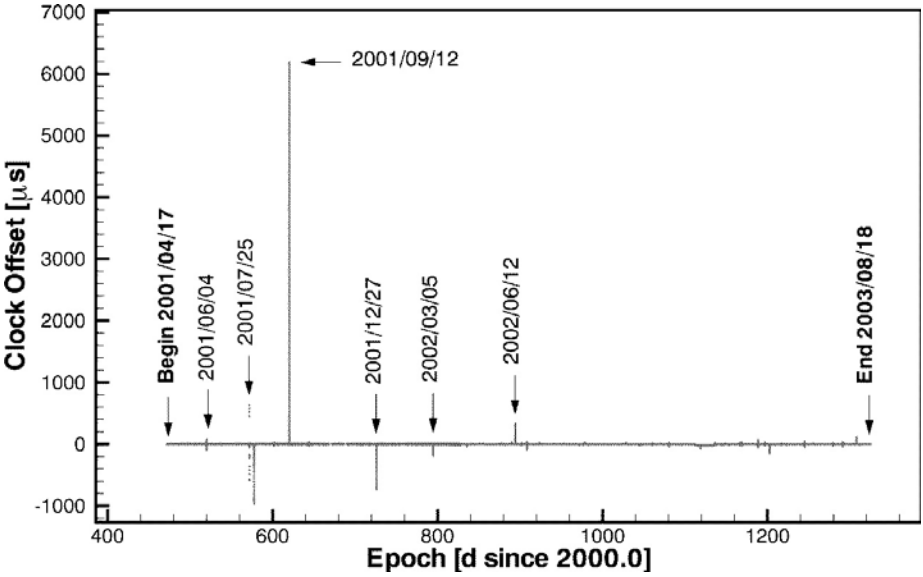

Fig. 1. CHAMP clock offset estimates of the RSO solution - overview

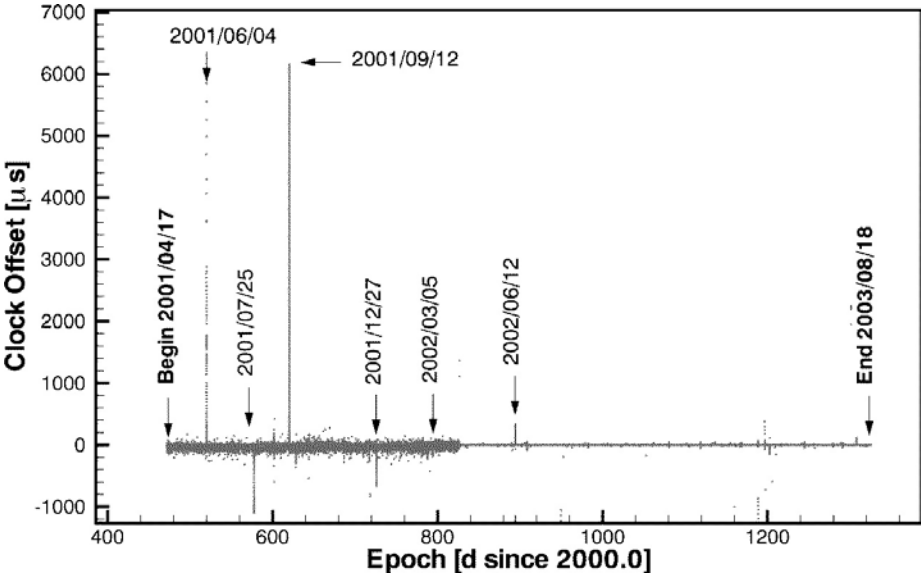

Fig. 2. CHAMP clock offset estimates of the Navigation solution - overview

offsets being congruently visible in both approaches. These clock offsets result from on-board events like software uploads and updates and receiver reboots.

In Fig. 3 and Fig. 4 a more detailed view of the clock offsets for both solution is given. A significant improvement of the clock behaviour after

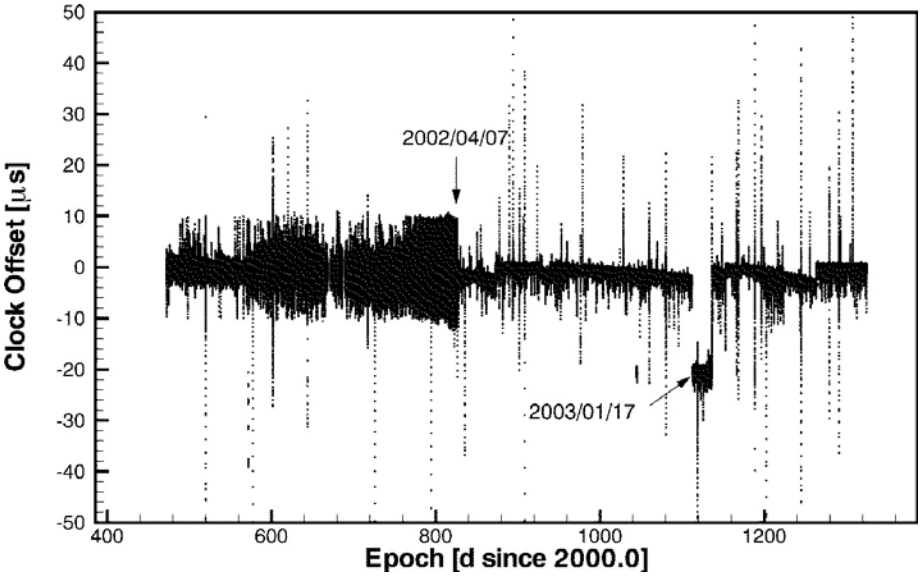

Fig. 3. CHAMP clock offset estimates of the RSO solution - detailed view

2002/04/07 can be noticed. This is due to an update of the receiver parameters (mainly causing a higher frequency of the NAV solution generation) that resulted in a more efficient correction of the clock drift. When comparing Fig. 3 to Fig. 4 it can also be seen, that the RSO solution is affected by biases and trends. These biases and trends are dependent on the characteristics of the ground reference clock being fixed in the generation of the GPS ephemerides in our two-step CHAMP RSO processing [1]. This effect is outstandingly visible on 2003/01/17, when the usual reference clock, station ALGO, had to be changed due to a station downtime. A list of the most important events, labelled by dates in Fig. 1 to 4, affecting significantly the CHAMP clock performance follows:

- 2001/06/04 - BlackJack GPS data flow discontinuities due to firmware software problems
- 2001/07/25 - Software upload, BlackJack receiver reboots
- 2001/09/12 - Reboot of the receiver, large clock offset reduced subsequently by on-board software
- 2001/12/27 - Reboot of the receiver, clock offset reduced subsequently by on-board software

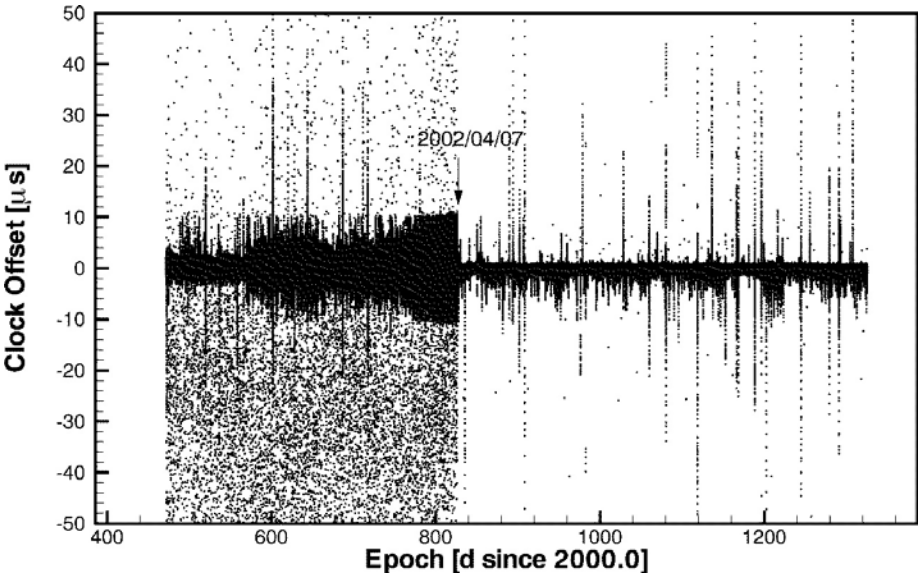

Fig. 4. CHAMP clock offset estimates of the NAV solution - detailed view

– 2002/03/05 - Receiver switch-off, major software upload
– 2002/04/07 - Reboot of the receiver, update of receiver parameters
– 2002/06/12 - Reboot of the receiver, switch of operation modes
– 2003/01/17 - Change of the GPS ground reference clock in the RSO solution due to down time of station ALGO

Looking at the most recent period of the CHAMP clock offsets time series, i.e. the last 30 days in Fig. 3 and Fig. 4, it can be seen, that the clock offsets obey values generally between -2 μs and +1 μs, the bias in the NAV solution equals -0.3 μs, for the RSO solution the bias is larger at -0.4 μs. The standard deviation, however, is the same for both solutions with 0.4 μs.

A closer look into the time series indicates additionaly that the clock offset is not random around the mean value, but shows a periodic behaviour. The RSO solution is used to study these characteristics in more details. Since there is a significant improvement of the clock behaviour after 2002/04/07, the data were devided into 2 parts: before and after this date. All biases, trends and outliers are removed from these two data sets by means of iterative linear regression. The standard deviation of the clock offsets prior to 2002/04/07 is 1.7 μs, after 2002/04/07 it is 0.4 μs. Then the periodograms for the two data sets are calculated via a Fourier transformation and given in Fig. 5. Obviously strong periodicities show up in both periodograms, namely 1.37 h, 1.55 h and 1.77 h. They are close to the orbital period equal to 1.55 h or 93 minutes.

The amplitude of the periodic changes of the clock offset is approximately 1 μs (equivalent to 300 m in position). This is too large to be attributed

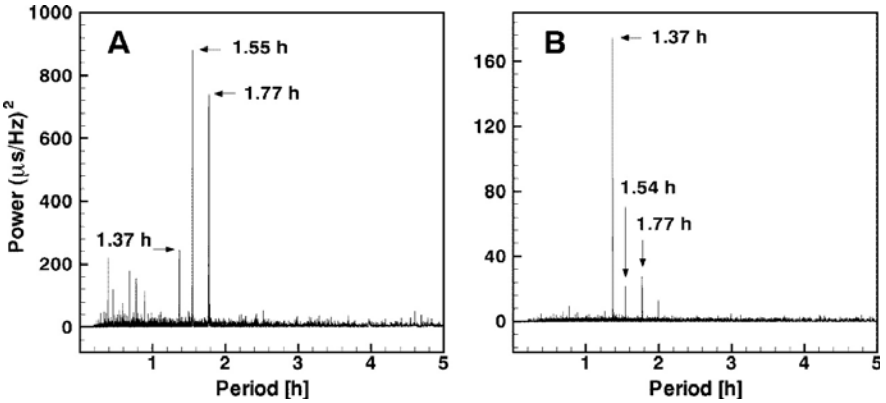

Fig. 5. Power spectra of the CHAMP clock estimates of the RSO solution. Plot A - prior to 2002/04/07, plot B - after 2002/04/07

to the orbit solution, neither in the RSO nor in the NAV case. The same periodicities are present in the RSO and in the NAV solution. The solutions are totally independent and follow distinct methodologies. The RSO is a dynamic batch solution, the NAV is a real-time filter approach. Therefore it could be suggested that the periodicities are not dependent on dynamics but rather on internal characteristics of the CHAMP clock parameter settings and steering algorithm. The BlackJack triggers its clock according to the GPS spacecraft clocks, after one revolution of CHAMP a similar GPS constellation is reached. Therefore the relation with the orbital frequency of CHAMP lies at hand. Exact explanations of the 1.37 h and 1.77 h periods however remain open.

3 Summary and Conclusions

The CHAMP clock characteristics can be summarized in the following way:

- The RSO clock parameter solution is less noisy than the real-time NAV solution.
- The RSO solution is affected by characteristics of the reference clock used in the processing.
- There is no long term drift of the CHAMP on-board clock. This is due to the clock steering loop, that updates the clock bias when it exceeds 1 μs.
- The clock offsets are in the range from -2 μs to +1 μs. After removing biases and trends from the RSO solution, periodicities close to the orbital period can be detected. The periodicities are also present in the NAV solution. There is evidence that they are independent from dynamics, but may stemm from the clock itself.
- The recent bias for the NAV solution equals -0.3 μs, for the RSO solution the bias equals -0.4 μs.

– The recent standard deviation of the clock offsets equals 0.4 μs.

The time series of CHAMP clock solutions shows effects of software uploads and on-board receiver reboots. These events cause large jumps which are quickly recovered by the receiver. The RSO solution for the CHAMP clock offsets is affected by bias and trend of the GPS ground station clock chosen as reference. This does not affect the quality of the CHAMP orbits.

References

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